I. C. ELECTRICIAN 2

NAVY TRAINING COURSES

I. C. ELECTRICIAN 2

PREPARED BY

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10556

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1955

PREFACE

This book is written for men of the U. S. Navy and Naval Reserve who are interested in qualifying for advancement to I. C. Electrician 2. Combined with the necessary practical experience, this training course will prepare the reader for the advancement-in-rating examination.

The qualifications for I. C. Electricians are listed in appendix II. This training course contains information on each examination factor of the qualifications for I. C. Electrician 2. Because examinations for advancement are based on these qualifications, interested personnel should refer to them frequently for guidance.

I. C. Electrician 2 was prepared by the U. S. Navy Training Publications Center, which is a field activity of the Bureau of Naval Personnel. Technical assistance was provided by the staff of the U. S. Naval School, I. C. Electricians, Class B, U. S. Naval Receiving Station, Washington, D. C. and by other Navy activities cognizant of I. C. equipment and the duties of I. C. Electricians.

READING LIST

NAVY TRAINING COURSES

I. C. Electrician 3, NavPers 10555
Gyro Compasses, NavPers 10606-A
Electricity, NavPers 10622-B
Basic Hand Tool Skills, NavPers 10085
Electricity for FC & FT Vol. 1, (Chapters 13–17), NavPers 10170

OTHER PUBLICATIONS

BuShips Manual, Chapters 43 ; 45 ; 61 ; 62 (Sec. I, II) ; 63 ; 69

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

SELF TEACHING

Number	Title
MA 784	*Electric Wiring*
MB 290	*Physics I (Mechanics)*
MB 785	*Electrical Measuring Instruments*
MB 858	*The Slide Rule*

CORRESPONDENCE

CB 290	*Physics I (Mechanics)*
CB 785	*Electrical Measuring Instruments*
CB 858	*The Slide Rule*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified on the active duty orders."

CONTENTS

CHAPTER 1

Page

Organization ---------- 1

CHAPTER 2

I. C. and A. C. O. switchboards ---------- 25

CHAPTER 3

Electronic power supplies ---------- 61

CHAPTER 4

Electron-tube amplifiers ---------- 94

CHAPTER 5

Oscillators ---------- 151

CHAPTER 6

Electronic test equipment ---------- 182

CHAPTER 7

Alarm and warning systems ---------- 237

CHAPTER 8

Sound and sound equipment ---------- 265

CHAPTER 9

Announcing and intercommunicating systems ---------- 298

CHAPTER 10

Sound recording and reproducing systems ---------- 346

CHAPTER 11

Sound motion picture system ---------- 368

CHAPTER 12

Page

Dial telephone system ---------- 403

CHAPTER 13

Gyrocompass errors ---------- 431

CHAPTER 14

Gyrocompasses ---------- 459

CHAPTER 15

Ship control order and indicating systems ---------- 496

APPENDIX I

Answers to quizzes ---------- 528

APPENDIX II

Qualifications for advancement in rating ---------- 548

Index ---------- 552

I. C. ELECTRICIAN 2

CHAPTER 1

ORGANIZATION

Navy ships are operated under standard administrative and battle organizations to facilitate quick expansion from peacetime to war status without major change. This organization divides the ship's personnel into the (1) Operations, (2) Navigation or Deck, (3) Gunnery, (4) Engineering, (5) Supply, (6) Medical, and (7) Dental Departments. Aircraft carriers and seaplane tenders have in addition an Air Department, and repair ships and tenders have a Repair Department.

ENGINEERING DEPARTMENT

The Engineering Department in large ships normally consists of five divisions, as illustrated by the organization chart in figure 1–1. The Machinery and Boiler Divisions are under the supervision of the Main Propulsion Assistant; the Electrical Division is under the Electrical Officer; and the Repair and Auxiliary Divisions are under the Damage Control Assistant. These officers are charged primarily with the operation, maintenance, and repair of the machinery and equipment allotted to their divisions, and they also act as assistants to the Engineer Officer in the performance of his duties. The office of the Engineering Department is called the LOG ROOM.

The maintenance and repair of all electronics equipment of the ship, except as assigned to another department, is now the responsibility of the Operations Officer.

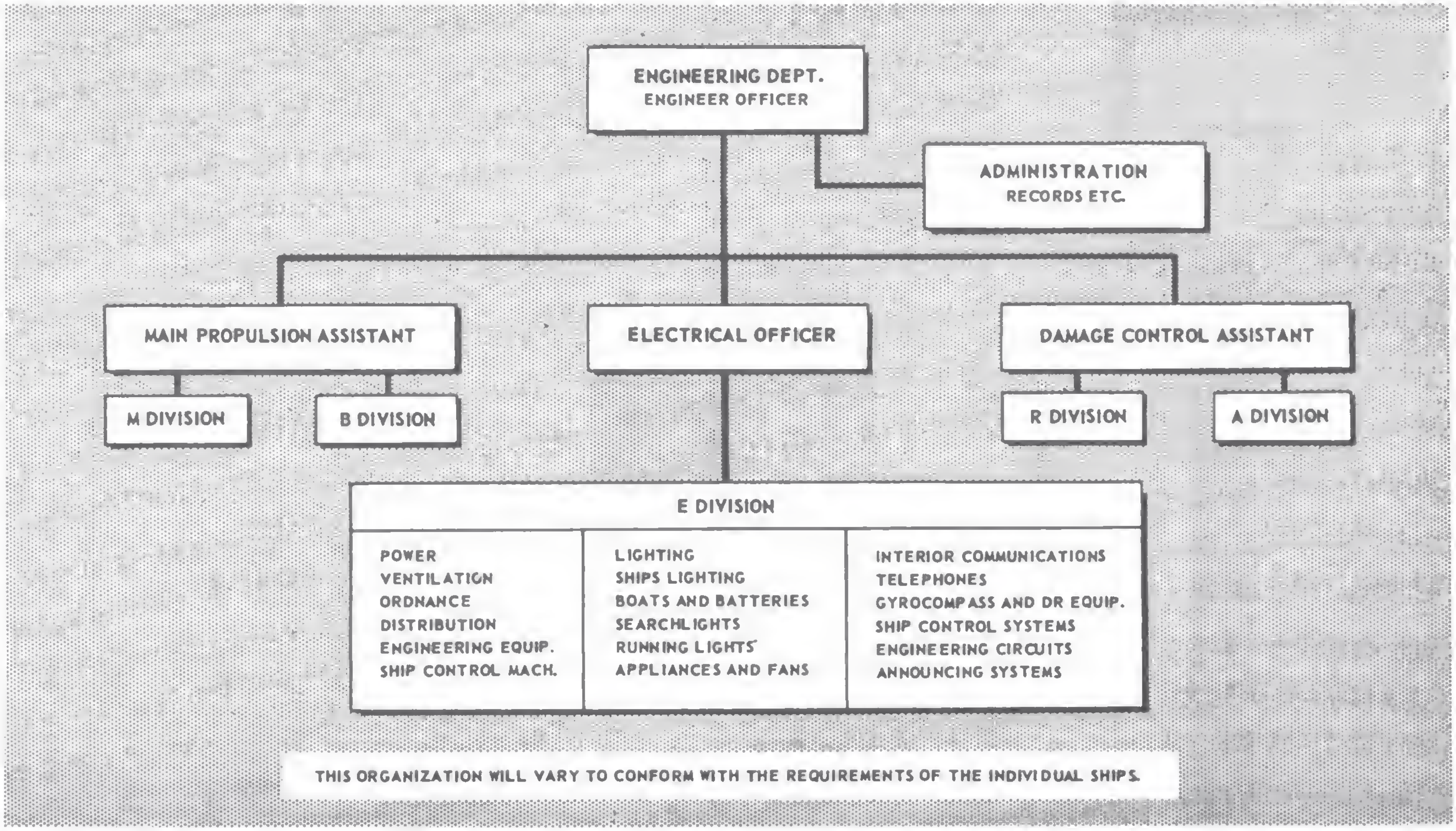


Figure 1-1.—Organization of Engineering Department.

Electrical Division

The Electrical Division usually consists of the POWER, LIGHTING, and INTERIOR COMMUNICATIONS groups (fig. 1–1). The groups vary in number according to the size and type of ship but are basically similar in organization. In large ships these groups are often further subdivided. For example, the power group may have a turret gang and a distribution gang, and the interior communications group may have a telephone gang and a gyro gang, each with a chief petty officer or petty officer first class in charge.

Electrical Shops

The number of electrical and interior communications shops varies with the size and type of ship. For example, an aircraft carrier may have six electrical shops besides those in the Air Division; an attack cargo vessel may have two; and a tanker may have only one. A chief petty officer or petty officer first class is generally in charge of the electrical shop. He is responsible for a particular group of circuits and prepares a work schedule for his men so that they can maintain efficiently the equipment in their charge.

Rough record books on work completed each day, file cards on work pending, and reference books for replacement parts and technical information are kept in the shop. A telephone is provided to receive trouble calls. These calls are recorded on a trouble-call sheet (fig. 1–2) which is kept in a log. This record includes the time, name of the person making the call, trouble reported, and action taken.

A standard tool kit usually is issued to each man in the I. C. shop. On small ships special tools are stowed in a suitable locker. The petty officer in charge of the shop must sign for them on Equipage Custody Record (NavSandA form 306A) cards as shown in figure 1–3. On large ships and stations a central tool room is maintained for power tools, special tools, and instruments which are signed for or drawn on a chit system. The level of a mechanic's ability

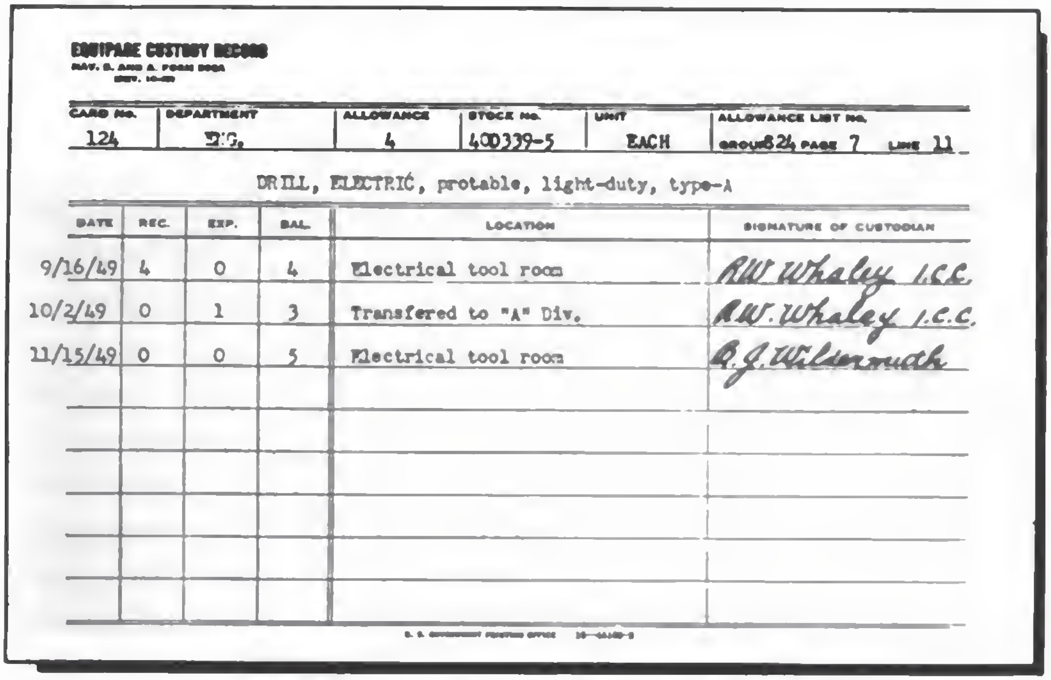
CL 83 Form 883 U. S. S. MANCHESTER (CL 83) CL 83 7/19/49 - 500

TROUBLE CALL RECORD

Use Back for Further Notes

Date	Time	Description of Trouble	Reported by	Remedy	Repaired by	Date	Time
May 1	0600	SHIFT CAPTAIN'S REPEATER TO STBD. SIDE	Quartermaster	SHIFTED REPEATER	Brooks	MAY 1	0610
	0830	PHONE 336 WILL NOT CALL OUT	Wilson Ak r	STICKY DIAL	Wildermuth	MAY 1	1100
	1015	TACHOMETER SHAFT #2 STICKY	O.O.D.	REMOVE + OIL AFTER ANCHORING	Sowers		
	1810	FORWARD GYRO COMPASS ALARM RINGING	Brooks	REPLACED C&A TUBE	Tarranova	MAY 1	1815
MAY 2	0915	5JP + JL CIRCUITS CROSS CONNECTED	COMBAT	OPENED TIE SWITCH	Simpson.	MAY 2	0930
	1012	2JV HAND SET OUT AFTER FIREROOM	Chief of water	REPLACED BROKEN CORD	Briggs	MAY 2	1115
	1045	BELLS ON PHONE #882 NEED ADJUSTING	Mr. Williams	ADJUSTED BELLS	Sanzpulla	MAY 2	1300
MAY 3	0115	CHECK PHONE IN W.O. PANTRY	Mr. Christopher	STICKY DIAL	Raulfans	MAY 3	0130
	0415	COMMUNICATION WEAK MOUNT 55	DIRECTOR 54	DEFECTIVE PHONE IN MOUNT	Kent	MAY 3	0435
	0445	CEASE FIRING HORN MOUNT 48 DOESN'T WORK	AIR AFT	HORN MOTOR BURNT OUT	Meadow	MAY 3	0830

Figure 1-2.—Trouble-call sheet.



EQUIPAGE CUSTODY RECORD

CARD No.	DEPARTMENT	ALLOWANCE	STOCK No.	UNIT	ALLOWANCE LIST No.
124	[illegible]	4	400339-5	EACH	GROUP 824 PAGE 7 LINE 11

DRILL, ELECTRIĆ, protable, light-duty, type-A

DATE	REC.	EXP.	BAL.	LOCATION	SIGNATURE OF CUSTODIAN
9/16/49	4	0	4	Electrical tool room	R.W. Whaley I.C.C.
10/2/49	0	1	3	Transfered to "A" Div.	R.W. Whaley I.C.C.
11/15/49	0	0	5	Electrical tool room	[illegible]

Figure 1–3.—Equipage Custody Record.

is shown in his use of tools. A skilled mechanic uses his tools with a minimum of effort to accomplish a maximum of results. He uses the right tool for the right job and does not abuse his tools or damage the equipment on which he works. Instruments are issued to the shops on custody cards and their use is restricted to qualified electricians. Good instruments are expensive and the care with which they must be used cannot be overemphasized.

Duties

As an I. C. Electrician 2, you must perform both military and specialist duties. Your military duties are the same as those of other petty officers regardless of their specialty ratings. These military duties are explained in the *General Training Course for Petty Officers*, NavPers 10055; *The Bluejackets' Manual*; and certain articles of *Navy Regulations*. The most important of your specialist duties are those assigned to you on the Division Watch Quarter and Station Bill. You may be assigned to a damage control party at the interior communications or action cutout switchboard, as a telephone talker, or any one of several other equally important stations.

Your routine duties, which are assigned by the division officer, will be the operation and maintenance of specific interior communications circuits and equipment. The term "interior communications" when used with reference to naval vessels includes all methods of transmitting and receiving orders and information between stations within a ship. These methods include a large number of diversified circuits, systems of circuits, and mechanical devices concerning the transmission or indication of orders, signals, and information that is essential to the operation of the ship. A complete descriptive list of all I. C. circuits and their classifications, as well as a description of many of the circuits and equipment, is contained in chapter 65 of the *Bureau of Ships Manual*. Chapter 65 should be studied thoroughly and used as a final authority concerning interior communications.

Your advancement in rating depends to a great extent on the the instruction you receive from senior petty officers and on their recommendations concerning your quarterly marks.

I. C. systems are grouped under the following classifications according to their functions:

1. UNAMPLIFIED VOICE COMMUNICATION SYSTEMS consist of all types of telephones and voice tubes used to transmit unamplified voice signals.

2. VISUAL INTELLIGENCE SYSTEMS include character transmission systems, facsimile systems, and intraship television systems.

3. SHIP'S METERING AND INDICATING SYSTEMS include underwater log, dummy log, shaft revolution indicator, wind indicator, and profile draft indicator and transmitter systems. These circuits provide a means of transmitting meter readings from central locations to remote indicators.

4. AMPLIFIED VOICE AND PROJECTION SYSTEMS consist of the various announcing systems, voice recorders, record players, motion picture projection equipment, electric megaphones, and portable announcing systems. These systems transmit, amplify, and reproduce the voice.

5. Alarm and warning systems include high-temperature alarms, lubricating-oil low-pressure alarms, general and chemical-attack alarm, diving alarm, rocket-warning alarm, and similar systems. The purpose of these systems is to protect equipment and to warn personnel of impending trouble or damage.

6. Signal systems consist of various call-bell and annunciator circuits, boiler-feed signal systems, catapult signal system, and others. These systems provide a means of sounding signals from remote stations.

7. Ship control systems include steering-gear control, engine-order and propeller revolution order circuits. These systems provide means for controlling the ship from remote stations and for transmitting orders to the various control stations.

SUPPLIES

Each naval vessel has an allowance of equipage and supplies on board. The various items and the amount of each, depending on the type of ship, are contained in an itemized list known as the allowance list.

Allowance List

The allowance list is a compilation of the equipage, maintenance repair parts, and consumable supplies essential for the efficient operation and maintenance of the ship.

The material contained in the allowance list is subdivided into three parts—(1) installed and semi-installed equipments, machinery, and components; (2) equipage; and (3) consumable supplies. In each part, the items are listed in groups. Material group numbers S60 through S69 include most electric equipment. An electrically driven pump, however, is listed under S47, which is the file number for pumps. The Bureau of Ships controls the allowance of technical equipment by directives which amend the allowance list.

A quarterly allowance of money is allotted to each vessel for operation and maintenance. Each department and division is required to keep within its assigned allotments.

The allowance list for consumable supplies provides a guide to the range and quantities of material that will be required to operate the ship. Allowance lists are used to prepare custody and stock records; to prepare requisitions for replacement material; and to indicate proper identification of technical maintenance repair parts aboard. An individual allowance list is prepared for an individual ship and is the specific and final allowance list for that ship.

General Stores

A limited amount of cleaning gear, tools, and miscellaneous supplies are stowed in the electrical shops. When replacement of this material, or when new material for a specific job is required, this material is drawn from the Supply Department by a STUB REQUISITION. The stub requisition which is a standard form for requesting the various items is made out in duplicate, initialed by the chief petty officer in charge of the shop, and signed by the division officer or department head. Most supply officers require that each stub requisition list only one class of items. In the *Catalog of Navy Material* the items are divided by stock classes and listed in groups by standard Navy stock number (SNSN). For example, the stock number 17–B–11573 is in class 17, which is "electrical equipment; wire communication apparatus." The letter "B" denotes the first letter of the material group (in this case, bells); the serial number 11573 identifies the specific item, which is listed according to the type, voltage, and physical characteristics.

The General Stores Section of the catalog contains (1) brief description; (2) specifications; (3) illustrations; (4) measurement equivalents; (5) usage data; (6) sources of supply; (7) requisitioning procedures; (8) stowage notes; (9) indexing; and (10) standard prices. The quantity, the stock number, and a brief description are generally all that is required on the stub requisition. When the stub requisition is properly signed it is presented to the storekeeper who issues the material. The person who actually receives the material must also sign the requisition. The duplicate is retained by the department requesting the material. The replacement of material in the storeroom is a function of the supply section. I. C. Electricians will most likely use the following classes of material:

Class 15—Electric cable and wire (insulated).

Class 17—Electric equipment; wire communication apparatus.

Class 38—Brooms, brushes, mops.

Class 40—Plant and shop equipment (excluding hand tools).

Class 41—Hand tools.

Class 43—Bolts, nuts, rivets, screws, washers.

Class 77—Bearings.

Repair Parts

Repair parts for each piece of equipment are provided aboard ship. For ready identification and accessibility, the trend is to stow most repair parts in metal drawers and bins that are marked with standard Navy stock numbers. Some parts may be stowed in individual repair parts boxes.

Aboard some ships the supply officer retains custody of all repair parts until they are issued for use. Most of these parts are stowed in storerooms under the cognizance of the supply department. Repair parts are drawn from the supply department on Stub Requisitions (NavSandA form 307) by the department requiring the parts. A replacement for these parts is then requisitioned by the supply department, which uses its own material lists for necessary procurement information.

Aboard other ships each division has custody of its repair parts. These repair parts are stowed in division storerooms or near the associated equipment. The division officer is responsible for maintaining the full allowance of repair parts.

Regardless of whether the supply officer or the division officer has custody of repair parts, replacement for these parts must be requested from the supply officer through the log room. It is your responsibility to furnish the log room with the information necessary to identify the part.

Complete identification, including the SNSN, will expedite the delivery of repair parts. The primary source of identification data is the allowance list, which is available in the log room. If the allowance list contains the SNSN for the repair part, a Stub Requisition listing this number and other available data is submitted to the supply office via the log room. However, if the SNSN is not available, complete identification of the part must be entered on the Stub Requisition. This identification should include such information as nameplate data and the manufacturer's drawing, part, and piece numbers. If the nameplate on the associated equipment is not readable, these data may be obtained from the machinery history files in the log room or from the applicable manufacturer's instruction book.

Aboard ships in which each division has custody of its repair parts, if the standard Navy stock number cannot be found, a Request for Repair Parts (NavSandA form 302) in addition to a Stub Requisition must be submitted to the supply office by the log room.

Stowage

Stowage of materials, instruments, batteries, and repair parts is a problem aboard ship. To prevent damage that might be caused by the roll or pitch of the ship, electrical storerooms are provided with bins, lockers, and brackets that are used for the safe stowage of this equipment.

RECORDS AND REPORTS

Naval vessels are required to maintain certain records and to submit certain reports. These records and reports are a very important part of your job. They provide data for (1) keeping the ship's company advised concerning changes and alterations to equipment, (2) surveying old equipment, (3) informing boards of inspection and survey, (4) keeping the Bureau of Ships informed as to the material status of the ship, and (5) comparing the operational characteristics of each vessel with those of other vessels of the same type for recommended improvements. These records and reports comprise the (1) MACHINERY INDEX, (2) MATERIAL HISTORY RECORD, and (C) MAINTENANCE RECORDS.

Machinery Index

The MACHINERY INDEX is a comprehensive listing of all machinery and equipment, exclusive of electronic equipment, installed in each vessel. The index for each item of equipage includes the (1) material group number; (2) complete nameplate data; (3) manufacturer's instruction book number; and (4) location in the ship. This information is required by the Bureau of Ships to provide adequate repair parts, battle damage components, and replacement equipment of the forces afloat.

The ELECTRONIC INVENTORY serves the same purpose for electronic equipment as the Machinery Index serves for all other units.

Material History Record

The MATERIAL HISTORY RECORD consists of cards filed in looseleaf binders. These cards list all items of machinery by group numbers with descriptive data and history of repairs and alterations for each item. The following four types of cards form the basis of the ship's material history:

1. Machinery History Card (NavShips 527)
2. Electrical History Card (NavShips 527A)
3. Electronic History Card (NavShips 536)
4. Hull History Card (NavShips 539)

The spaces provided on these cards for identification data should be completely filled in. These data include such information as machinery index number, model designation, nameplate data, and plan numbers. An appropriate card is used for each item in the machinery index and in the electronic inventory. Entries are made on the cards which describe repairs effected, derangements experienced, alterations, field changes, tests conducted, and other data necessary

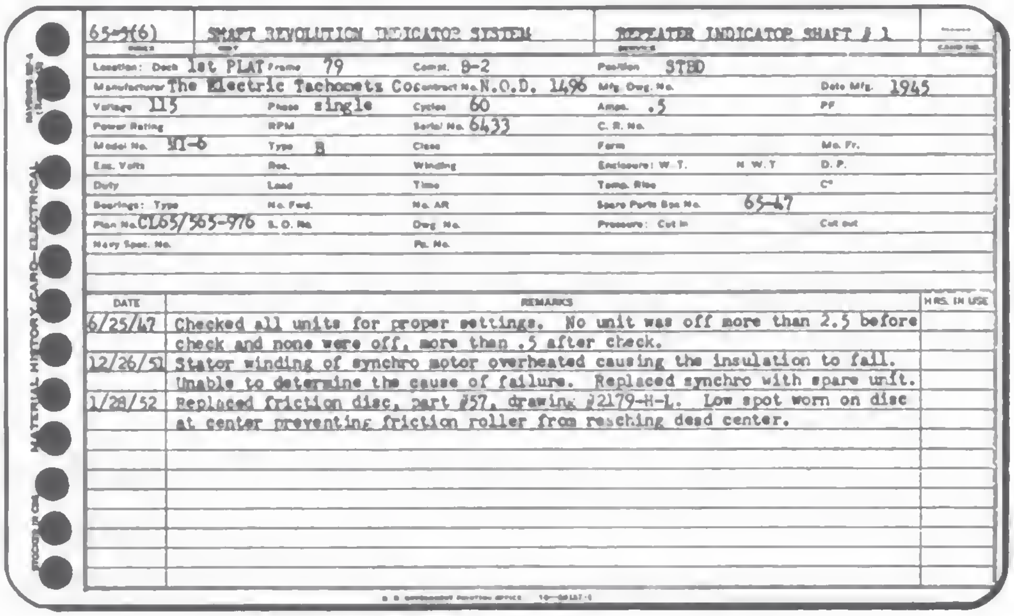


Figure 1–4.—Electrical History Card.

to provide a comprehensive material history of the items concerned. A typical Electrical History Card is illustrated in figure 1–4.

Megger Test Record Cards (NavShips 531), shown in figure 1–5, are provided to record the periodic insulation

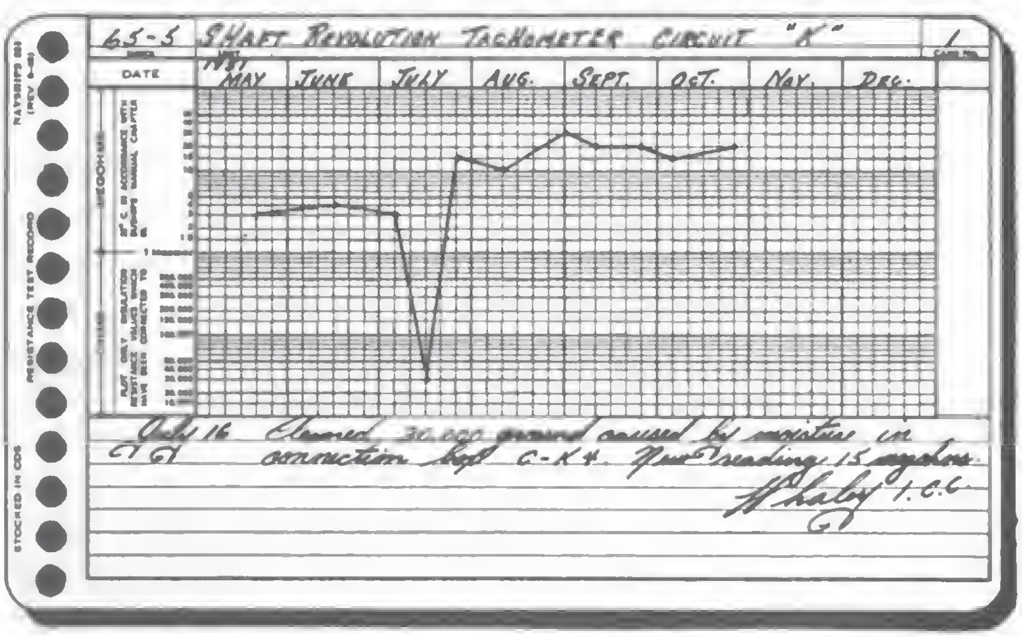


Figure 1–5.—Megger Test Record.

resistance readings of a unit or circuit. These cards are inserted in the binder adjacent to the applicable history card for the unit or circuit.

CURRENT SHIP'S MAINTENANCE PROJECT.—The Current Ship's Maintenance Project (CSMP) provides a means of keeping a running record of all work that is to be performed. The following three types of cards comprise the CSMP:

1. Repair Record Card (NavShips 529, blue)
2. Alteration Record Card (NavShips 530, pink)
3. Record of Field Changes Card (NavShips 537, white)

As a repair is required or an alteration is authorized, an applicable card is filled in and placed in the Material History Binder adjacent to the proper history card.

The REPAIR RECORD CARD and the ALTERATION RECORD CARD, which are colored blue and pink respectively, provide a quick reference to current and pending work. When the item of work has been completed and the proper notation has been entered on the material history card, these cards are removed from the binder and placed in a "completed work" file.

The RECORD OF FIELD CHANGES CARD is used for each model or type of electronic equipment for which field changes are authorized. As field changes are authorized, the number, title, and authorization are entered on the card. The remaining spaces provided on the card are filled in when the field change is completed. The Record of Field Changes Card is filed in the material history binder adjacent to the history card for the equipment to which the field changes apply.

Maintenance Records

As an I. C. Electrician 2, you are required to maintain a number of records, check-off lists, and reports at your assigned station. Maintenance records are of two types—(1) official NavShips forms prepared by the Bureau of Ships and (2) ship's forms prepared by the engineering department. The number of these latter forms and the method of recording test, inspection, and maintenance data are prepared for a particular installation and class of vessel. The following forms are typical of those which you may be required to keep aboard your ship.

STORAGE BATTERY TRAY RECORD.—The Storage Battery Tray Record (NavShips 151) is a complete history of each lead-acid battery in the ship (fig. 1–6). It lists the (1) battery number, (2) nameplate data, and (3) record of service, repairs, charges, and test discharges. The information contained in this record shows the true condition of a battery and often indicates trouble in advance of battery failure.

NAVSHIPS (NBS) 151
(Rev. 9-46)

Page 8

(USE SEPARATE SHEET FOR EACH TRAY)

STORAGE BATTERY TRAY RECORD

U. S. S. MANCHESTER Service for which used S.S. TELEPHONE Tray No. S62-3-11
(See art. 62-285, BuShips Manual)

CHARGES

Date of each charge	Specific gravity and number of lowest cell at start of charge	Starting rate (amps.)	Finishing rate (amps.)	Specific gravity and number of lowest cell at finish of charge	Was battery watered	Type of charge (if equalizing, state total time at finishing rate)	Service tray has performed since previous charge	Approval of engineer officer or electrical officer
9/12/51	1210	2			YES	TRICKLE	S.S.TELEPHONE	
9/19/51	1210	2			NO	"		WHALEY
10/15/51	1220	2			NO	"		
10/25/51	1210	2			YES	"		SNOWDEN
11/8/51	1200	2			YES	"		
11/19/51	1210	2			NO	"		
11/28/51	1200	2			YES	"		SNOWDEN
12/8/51	1200	2			NO	"		
12/17/51	1200	2			YES	"		
12/27/51	1210	3			NO	"		SNOWDEN
1/4/52	1210	3			YES	"		
1/12/52	1210	3			NO	"		
1/18/52	1210	3			YES	"		
1/26/52	1210	3			NO	"		WHALEY
2/5/52	1200	2			YES	"		
2/14/52	1210	2			YES	"		
2/22/52	1210	2			YES	"		
2/29/52	1200	2			YES	"		WHALEY
3/6/52	1210	3			NO	"		
3/12/52	1210	3			YES	"		
3/22/52	1210	2			NO	"		
3/30/52	1200	3			NO	"		SNOWDEN
4/10/52	1210	2			YES	"		
4/21/52	1220	2			YES	"		
5/2/52	1220	2			YES	"		SNOWDEN

NOTE.—All specific gravity readings to be corrected to 80° F. (art. 62-274, BuShips Manual).

The following information is to be copied from the tray name plate: Contract No. NX-4128
Navy class 6V-SAM-202AH Manufacturer EXIDE Manufacturer type 3-MVAL-15
Date initial charge 8-20-46

Figure 1–6.—Storage Battery Tray Record.

Weekly ground sheet.—A complete set of ground (insulation resistance) test records is maintained for all interior communications and fire control circuits and switchboards. Insulation resistance tests are made weekly with the use of a 500-volt megger. The ground test sheets (fig. 1–7) are examined and signed daily by the leading petty officer of the station and the electrical officer.

Circuit work sheet.—Circuit work sheets are shop records maintained on cards that are kept in a looseleaf binder. A separate card is filled in for each circuit. These cards are similar to the Electrical History Card (fig. 1–4). They are records for routine inspections and tests, lubrication and cleaning, as well as major overhauls. When any repair, test, or overhaul (exclusive of routine ground tests) is completed, a notation is entered in the history column of the proper (card) circuit work sheet. Applicable data are transferred from these cards to the material history record cards.

CDP E-327 (Rev. 12-40) U.S.S. Piedmont—1-9-51—48,500.

CIRCUIT NO. K — FOR Shaft Revolution tachometer — PANEL NO. IC swbd — FEEDER NO. C-K1 — LOCATION I C room

DATE	PHASE POS A	PHASE NEG B	C	DATE	PHASE POS A	PHASE NEG B	C
May 17	3	3					
June 14	4	4					
July 3	3	3					
July 16	30?	30?					
July 28	15	15					
Aug 10	15	15					
Aug 30	10	10					
Sept. 10	30	30					
Sept. 27	20	20					
Oct. 5	15	15					
Oct. 25	20	20					

CIRCUIT NO. M — FOR Engine Revolution telegraph — PANEL NO. I C swbd — FEEDER NO. C-M1 — LOCATION I C room

DATE	PHASE POS A	PHASE NEG B	C	DATE	PHASE POS A	PHASE NEG B	C
May 17	12	12					
June 14	12	12					
July 3	10	10					
July 16	10	10					
July 28	10	10					
Aug. 10	14	14					
Aug 30	14	14					
Sept. 10	12	12					
Sept. 27	14	14					
Oct. 5	14	14					
Oct. 25	14	14					

Figure 1–7.—Weekly Ground Sheet.

CDP E-333 (5 of 16)

B. WEEKLY

1. Test electrical circuits in such a manner that all circuits will be covered once during each quarter. 65-120(2)

MONTH OF	INITIALS 1st WEEK	2nd WEEK	3rd WEEK	4th WEEK
JAN.	UNDERWAY	R.W.W.	UNDERWAY	
FEB	ALL CIRCUITS OPERATE CONTINUOUSLY			
MARCH	RWW	UNDERWAY	ALL CIRCUITS	
APRIL	IN OPERATION CONTINUOUSLY			
MAY	R.W.W.			

2. Conduct insulation resistance test on all I. C. and F. C. circuits and switchboards. 65-120(4)

MONTH OF	INITIALS 1st Week	2nd Week	3rd Week	4th Week
JAN.	UNDERWAY		RWW	UNDERWAY
FEB	UNDERWAY		UNDERWAY	
MARCH	RWW	UNDERWAY		
APRIL	UNDERWAY			
MAY	R.W.W.			

3. Test high temperature alarm. 65-825

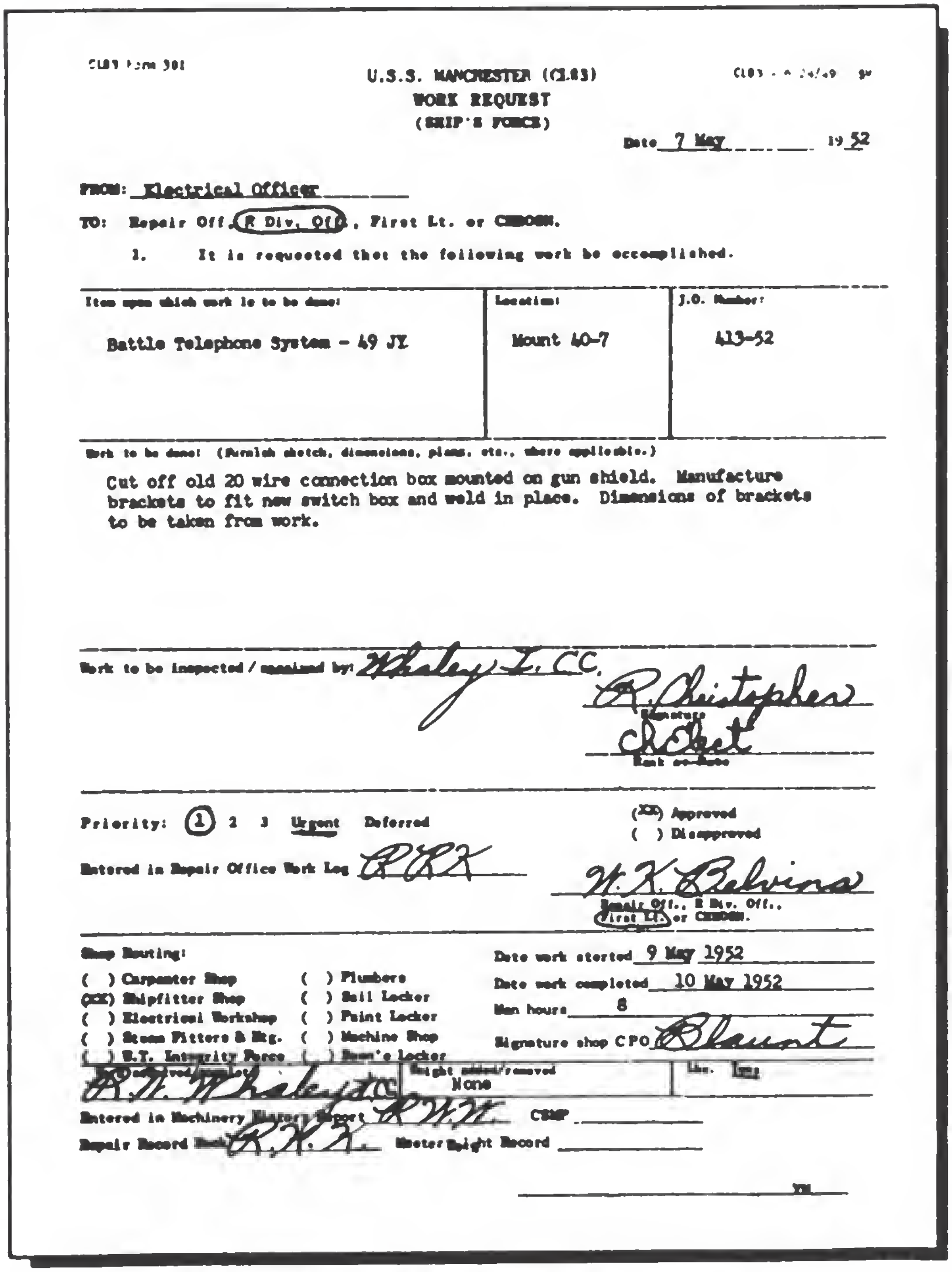
MONTH OF	INITIALS 1st Week	2nd Week	3rd Week	4th Week
JAN.	RWW	RWW	JCS	JCS
FEB	JCS	JCS	JKT	RWW
MARCH	JKT	RWW	RWW	J.C.S.
APRIL	B.B.	RWW	JKB	JKB
MAY	JKB	JKB		

4. Test sound powered circuit for cable ground and insulation continuity. 65-222

MONTH OF	INITIAL 1st Week	2nd Week	3rd Week	4th Week
JAN.	UNDERWAY	RWW	UNDERWAY	
FEB	UNDERWAY			
MARCH	RWW	UNDERWAY		

Figure 1–8.—Test record of a high-temperature alarm circuit.

High-temperature alarm circuit test.—The operation of each high-temperature alarm circuit and alarm bells is checked weekly by operating the test twitches on the high-temperature alarm switchboard. The results of these tests are recorded in the test record book, a page of which is shown in figure 1–8.



U.S.S. MANCHESTER (CL83)
WORK REQUEST
(SHIP'S FORCE)

Date 7 May 19 52

FROM: Electrical Officer

TO: Repair Off., R Div. Off., First Lt. or CHBOSN.

1. It is requested that the following work be accomplished.

Item upon which work is to be done:	Location:	J.O. Number:
Battle Telephone System - 49 JY	Mount 40-7	413-52

Work to be done: (Furnish sketch, dimensions, plans, etc., where applicable.)

Cut off old 20 wire connection box mounted on gun shield. Manufacture brackets to fit new switch box and weld in place. Dimensions of brackets to be taken from work.

Work to be inspected / approved by:

Signature

Rank or Rate

Priority: (1) 2 3 Urgent Deferred

(XX) Approved
( ) Disapproved

Entered in Repair Office Work Log

Repair Off., R Div. Off., First Lt. or CHBOSN.

Shop Routing:

( ) Carpenter Shop ( ) Plumbers
(XX) Shipfitter Shop ( ) Sail Locker
( ) Electrical Workshop ( ) Paint Locker
( ) Steam Fitters & Mtg. ( ) Machine Shop
( ) W.T. Integrity Force ( ) Bosn's Locker

Date work started 9 May 1952
Date work completed 10 May 1952
Man hours 8
Signature shop CPO

Weight added/removed: None — lbs.

Entered in Machinery History Report

CSMP

Repair Record Book

Master Weight Record

Figure 1–9.—Ship's Memorandum Work Request.

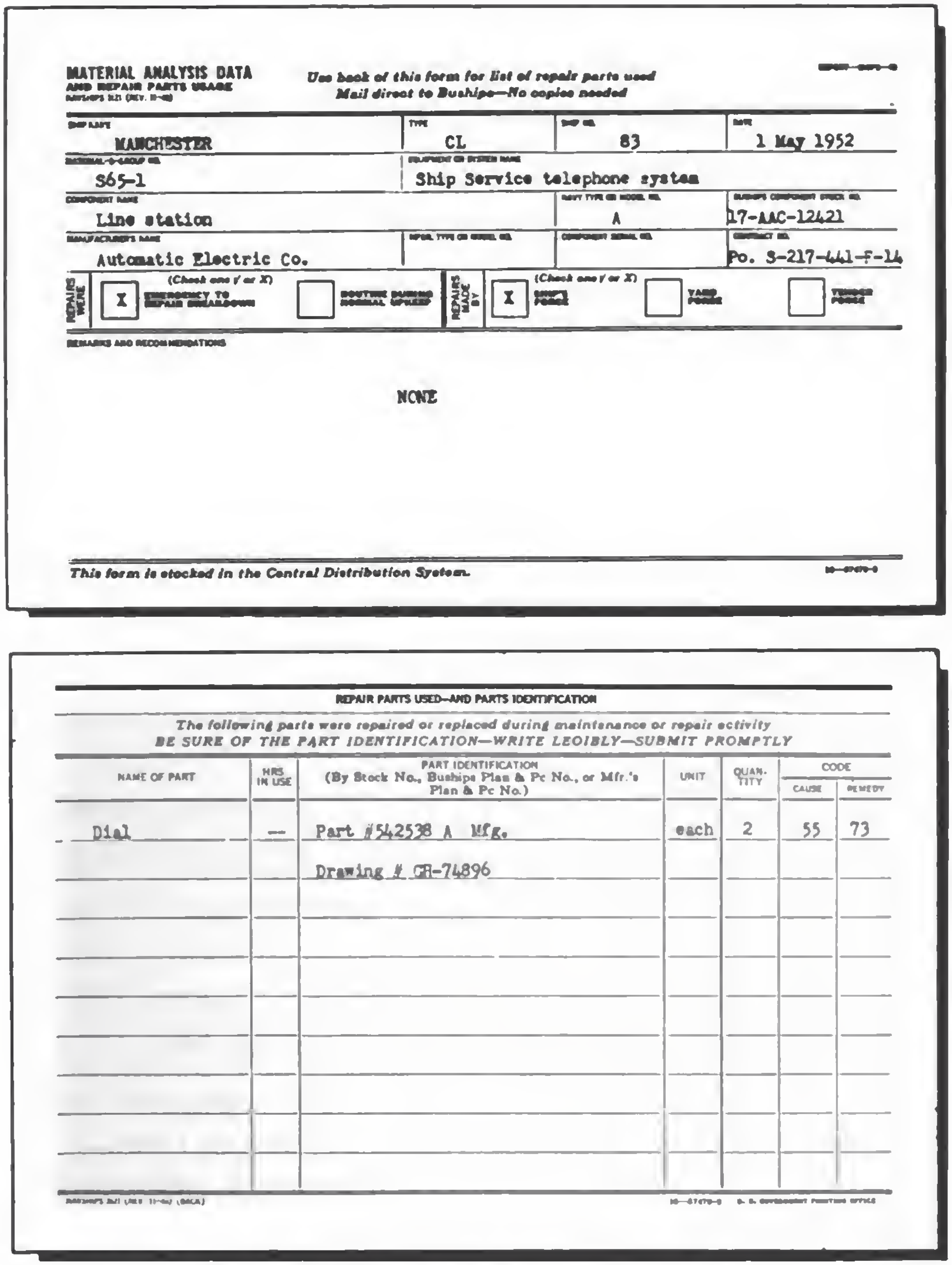
Ship's memorandum work request.—Ship's memorandum work requests are interdepartmental forms used by any department requiring work to be performed by another shipboard department. This memorandum ensures the proper routing of work requests between heads of departments. These work requests, or job orders (fig. 1-9), list the work to be done and include an estimate of the man hours and material required to complete the job. Space is provided also for the shop that performs the work to list the material used, man hours expended, date of completion, and the approximate cost. Similar forms are filled in when a ship requires work to be done by a shipyard or tender.

Compass record book.—The compass record book is a history of inspections, repairs, and alterations of a gyrocompass. All routine inspections are listed in this book and signed by the person making the inspection. The compass record book belongs with the gyrocompass and goes with it when the compass is removed.

Material analysis data form.—Material analysis data forms provide a means of informing the Bureau of Ships of all electrical and mechanical troubles encountered aboard ship. These forms (fig. 1-10) enable the Bureau of Ships to determine the performance of various types of equipment installed aboard ship. Space is provided on these forms to identify completely the equipment concerned and to list the work done and the parts used. A simple numbering system is provided to describe the reason for a failure and its remedy. Material analysis data forms (1) may be filled in by hand if necessary, (2) require no signature, and (3) are turned in to the log room for mailing.

Inspections and Tests

The establishment of a periodic schedule of inspections and tests for all I. C. systems and equipment is one of the most important factors in a good maintenance program. Time spent in a preventive maintenance program is time saved in overhauls and repairs.



MATERIAL ANALYSIS DATA
AND REPAIR PARTS USAGE

Use back of this form for list of repair parts used
Mail direct to Buships—No copies needed

MANCHESTER | CL | 83 | 1 May 1952

S65-1 | Ship Service telephone system

Line station | A | 17-AAC-12421

Automatic Electric Co. | Po. S-217-441-F-14

REPAIRS WERE: (Check one ✓ or X) [X] EMERGENCY TO REPAIR BREAKDOWN [ ] ROUTINE DURING NORMAL UPKEEP

REPAIRS MADE BY: (Check one ✓ or X) [X] SHIP'S FORCE [ ] YARD FORCE [ ] TENDER FORCE

REMARKS AND RECOMMENDATIONS

NONE

This form is stocked in the Central Distribution System.

REPAIR PARTS USED—AND PARTS IDENTIFICATION

The following parts were repaired or replaced during maintenance or repair activity
BE SURE OF THE PART IDENTIFICATION—WRITE LEGIBLY—SUBMIT PROMPTLY

NAME OF PART	HRS IN USE	PART IDENTIFICATION (By Stock No., Buships Plan & Pc No., or Mfr.'s Plan & Pc No.)	UNIT	QUANTITY	CODE CAUSE	CODE REMEDY
Dial	—	Part #542538 A Mfg.	each	2	55	73
		Drawing # GR-74896				

Figure 1—10.—Material Analysis Data Form.

All I. C. circuits must be inspected and tested once during each quarter. To assure this coverage, the circuits are usually divided into weekly overhaul groups. Maintenance personnel may determine if more frequent intervals are necessary. Some circuits are scheduled for in-port availability because they cannot be checked and maintained adequately while underway. For example, the general announcing system is best maintained at night in port.

In the overhaul of I. C. circuits the general procedures to be followed are:

1. Study the wiring diagram of the complete system and note the instruments, panels, and fixtures that should be checked.
2. Study the instruction books and lubricating charts applicable to the system.
3. Take insulation resistance readings prior to maintenance work.
4. Clean the appliances that are normally subject to dust, dirt, and moisture.
5. Oil the working parts of the appliances as necessary in accordance with the instruction books and lubricating charts.
6. Test the complete circuit and adjust relays, contacts, and controllers as necessary for satisfactory operation.
7. Check the fuses for the proper type and capacity shown on the finished plans.
8. Take insulation-resistance readings and compare them with those taken prior to the maintenance work.
9. Record this test in the CIRCUIT WORK SHEET and make the required entries on the MATERIAL HISTORY CARD. Also enter insulation resistance readings on the proper INSULATION RESISTANCE TEST RECORD (NavShips 531).

When practicable, weekly insulation-resistance tests must be made on all I. C. and F. C. circuits and switchboards. Any change in the condition of insulation is indicated by comparing the test results with those of previous tests. A radical change in insulation resistance readings indicates a faulty condition that must be cleared immediately. A comparison of these readings taken over a period of time shows the differences in readings due to (1) normal slow deterioration of the cable or apparatus; (2) weather conditions; (3) accumulation of moisture, dirt, or oil; and (4) sudden grounds.

PUBLICATIONS

Publications pertinent to the operation and maintenance of I. C. equipment and systems are kept in the log room. Refer to the applicable publications before working on any equipment or circuits with which you are not thoroughly familiar.

Publications of primary interest to the I. C. Electrician are: (1) Manufacturers' instruction books, (2) *Bureau of Ships Manual*, (3) *Bureau of Ships Bulletin of Information*, (4) Bureau of Ships Technical Bulletins, (5) Record of Electrical Installations and Electrically Operated Auxiliaries with Performance Data, and (6) Ship's Plans.

Instruction Books

Manufacturers' instruction books contain technical information and instructions for the operation and maintenance of specific apparatus. This information usually includes a general description, principles of operation, installation instructions, operating data, maintenance checks, lubricating schedules, safety precautions, and plans.

On most ships instruction books are issued to responsible personnel on custody receipts. This procedure is necessary because the number of copies allotted to each ship is small, and the replacement of missing copies is very costly.

Bureau of Ships Manual

The most important Bureau of Ships publication is the *Bureau of Ships Manual*. This manual is the "Bible" of the engineer department. It describes methods of conducting inspections and tests, procedures for making repairs, and many helpful maintenance hints. It is the official authority on operating procedures.

As an I. C. Electrician, you should be familiar with the following chapters of the *Bureau of Ships Manual:*

Chapter	*Title*
4	Allowance, Surveys, and Requests for Material
5	Cognizance
6	Inspections, Records, and Reports
22	Steering Gear
24	Ship Control Equipment
31	Spare Parts
45	Lubricants and Lubrication Systems
60	Electric Plant—General
61	Electric Generators and Voltage Regulators
62	Electric Power Distribution
63	Electric Motors and Controllers
64	Lighting
65	Interior Communications Installations
66	Searchlights
69	Electric Measuring and Test Instruments
71	Fire Control Installations
85	Motion Picture Equipment
88	Damage Control

Bureau of Ships Bulletin of Information

The *Bureau of Ships Bulletin of Information* contains data concerning the maintenance and operation of naval vessels. This information includes analysis of casualties, research developments, and reports concerning tests on materials, equipment, and apparatus.

Bureau of Ships Technical Bulletins

Bureau of Ships Technical Bulletins and similar publications are for the dissemination of information concerning (1) the design and construction of ships' machinery and equipment; (2) technical developments; and (3) accomplishments in the field of research.

Record of Electrical Installations and Electrically Operated Auxiliaries with Performance Data

The Record of Electrical Installations and Electrically Operated Auxiliaries with Performance Data, which is furnished by the shipbuilder, consists of two volumes. The first volume contains a description of operation and reference drawings of each electrical auxiliary and equipment including the I. C. systems. The second volume contains the manufacturer's and shipbuilder's test data. This volume is particularly valuable as a basis for comparison of test results obtained after the equipment has operated over a period of time.

Ship's Plans

A complete file of standard plans and blueprints is available in the log room for reference and study. At the time a vessel is delivered, the shipbuilder furnishes a set of blueprints to the commanding officer via the supervisor of shipbuilding. These blueprints are in accordance with a list of working plans corrected to show the equipment as installed. Two copies of the Ship's Plan Index are also furnished to the ship. This index lists all plans under the cognizance of the Bureau of Ships which apply to the vessel concerned.

The plans furnished to the ship include elementary and isometric wiring diagrams of all circuits; lists of telephones, loudspeakers, microphone control station, voice tubes, calls, message-passing facilities, assembly plans, and wiring diagrams of interior communication and action cutout switchboards and panels; arrangement of electrical equipment in ship control, command, and plotting stations; and a summary of interior communication and fire control equipment.

Each time an alteration is completed, the yard accomplishing the work furnishes the ship a copy of the plans that show the alteration. A revised copy of the Ship's Plan Index also is furnished, which shows all plans including the latest alteration numbers that apply to the ship. Copies of the latest alterations of Bureau of Ships standard plans applicable to the equipment installed in the ship must be carefully safeguarded. If these plans are lost, replacement plans might be for a later alteration that is not applicable to the equipment actually installed.

The items of principal interest concerning I. C. systems are the electrical standard plans which have plan numbers prefixed by 9–S or 9000.

QUIZ

1. Name the five divisions comprising the engineering department aboard a large ship.
2. What is the log room?
3. What major groups comprise the electrical division?
4. When special tools are drawn aboard small ships, what forms must be signed by the petty officer in charge of the I. C. shop?
5. What bill lists the stations or duties of each man aboard ship?
6. Advancement in rating depends largely upon what two factors?
7. What list is used to compile equipage, repair parts, and consumable supplies required to operate and maintain a ship?
8. What form is used to draw general stores?
9. What is a Machinery Index?
10. What four basic cards comprise the Material History Record?
11. What three cards comprise the Current Ship's Maintenance Project (CSMP)?
12. What two types of maintenance records are used aboard ship?
13. What does the Storage Battery Tray Record generally indicate?
14. What are Circuit Work Sheets?
15. What forms are used to ensure the proper routing of work requests between heads of departments?
16. What is the purpose of the Material Analysis Data form?
17. How often must I. C. circuits be inspected?
18. What is the best source of technical information and instructions for the operation and maintenance of specific apparatus aboard ship?
19. What publication should be referred to for a description of the methods used to conduct inspections and tests aboard ship?
20. Where are complete files of ship's standard plans and blueprints kept?

CHAPTER 2

I. C. AND A. C. O. SWITCHBOARDS

I. C. SWITCHBOARDS

The I. C. switchboard is the nerve center of the interior communications system. Its function in large ships is to energize all interior communications and fire control circuits including fire control electronic systems, and in small ships to supply power to other electronic equipment.

The I. C. switchboard is installed behind the armor belt and below the waterline to obtain maximum protection. It is energized from a normal, an alternate, and an emergency power supply to ensure continuous service.

In large combatant ships two main I. C. switchboards are provided. One switchboard is located in the forward I. C. room and the other switchboard is located in the after gyro compartment. Thus, each system or equipment receives its normal supply from the nearer I. C. switchboard and receives its alternate supply from the more remote I. C. switchboard. The after main I. C. switchboard is usually arranged similarly to the forward main board except that in the after board some of the special buses such as the controlled-frenquency bus may be omitted.

Live-Front I. C. Switchboard

I. C. Switchboards installed in naval vessels are of the (1) live-front, (2) semidead-front, (3) dead-front, and (4) dead-front front-service types.

The live-front I. C. switchboard (fig. 2–1) is the oldest type of board and is found only in older ships. All switches are of the live-front lever type with fuses in exposed clips, which are mounted on insulating panels. Blown-fuse indicators are installed over the fuses. The ship's cables are

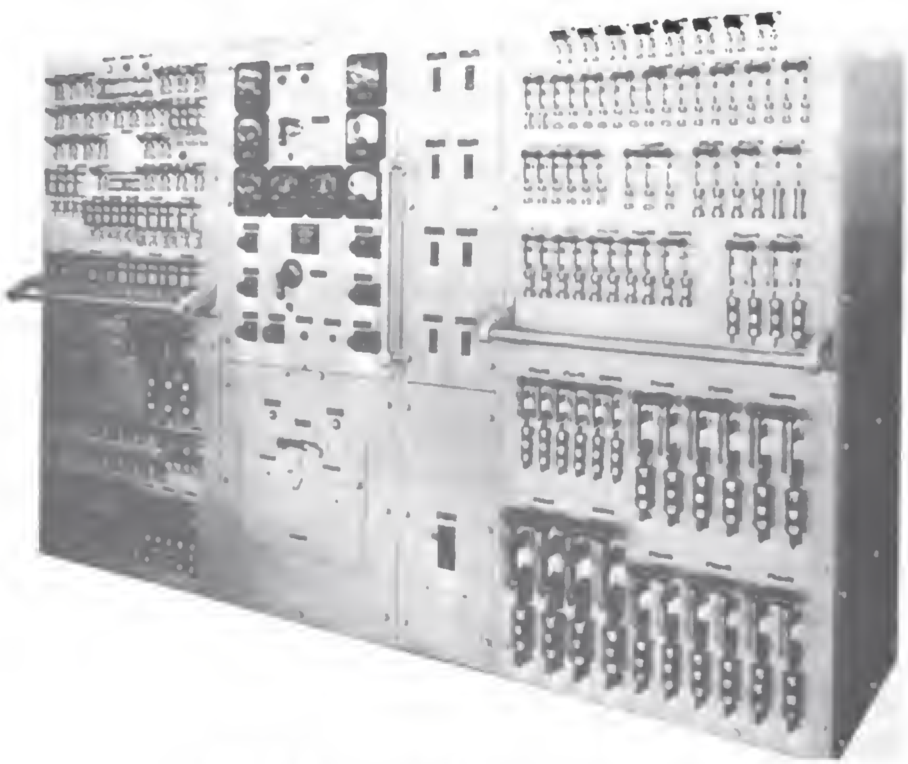


Figure 2–1.—Live-front I. C. switchboard.

connected to the switch and fuse terminals in the rear of the switchboard.

Semidead-Front I. C. Switchboard

The semidead-front I. C. switchboard is seldom used but may be encountered in some ships. All switches are of the dead-front type, either snap switches or enclosed type-K switches, and are mounted on metal panels. The fuses associated with the snap switches are mounted in open clips on slightly recessed insulating strips beneath the associated switches. A hinged metal door with peep holes is mounted in front of each fuse strip to permit viewing the blown-fuse indicators. Fuses are replaced by removing the metal panel and pulling the fuses from their clips with a fuse puller. The ship's cables are connected to the switches and fuses from the rear of the switchboard.

Dead-Front I. C. Switchboard

The dead-front I. C. switchboard (fig. 2–2) utilizes dead-front-type switches. The fuses, except those mounted in type-K enclosed switches, are mounted in plug-type combination fuse holders and blown-fuse indicators. This type of switchboard is the most commonly used as it has many advantages over the other types. The principal advantages are: (1) all switches and fuses are mounted behind the panel, affording complete protection to operating personnel against electric shock; (2) fuses are placed in plug-type holders and mounted perpendicular to the panel, resulting in a more

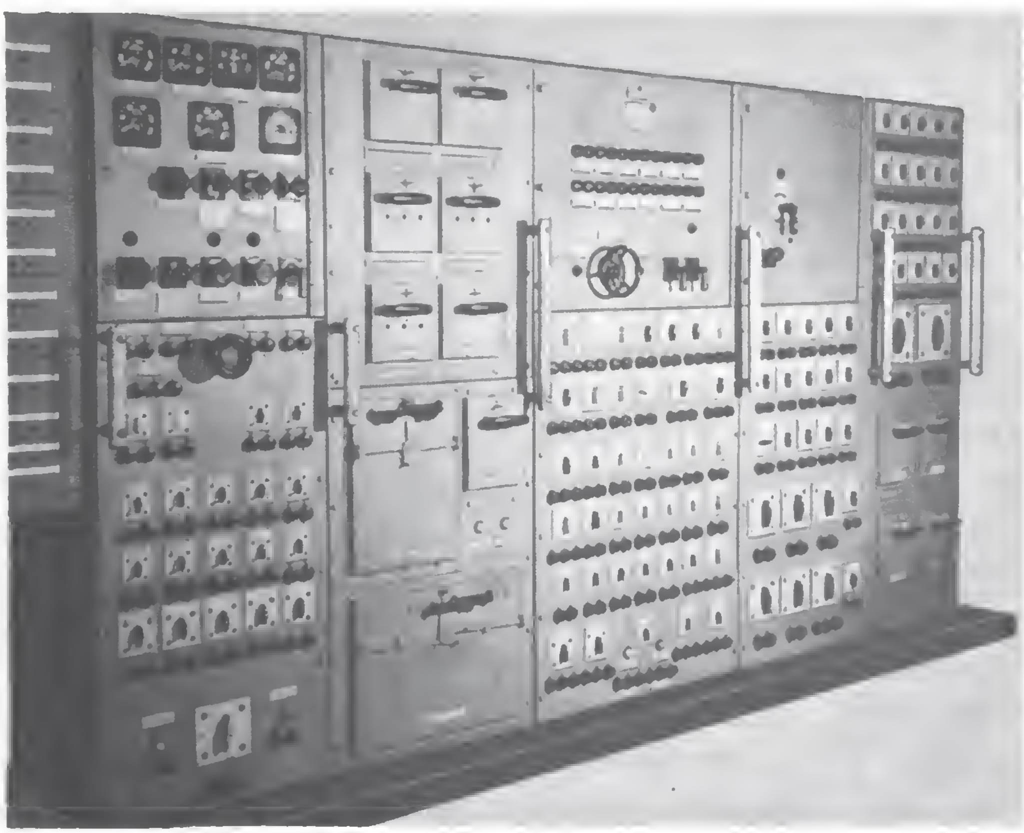


Figure 2–2.—Dead-front I. C. switchboard.

compact and efficient board; and (3) meters, circuit breakers, and bus-tie switches are behind hinged panels, simplifying the maintenance of the board.

Dead-Front Front-Service I. C. Switchboard

The latest type of I. C. switchboard is the dead-front front-service I. C. board. This board is constructed similarly to the dead-front type except that it is designed so that installation, operation, and maintenance can be accomplished entirely from the front of the switchboard. The front-service design utilizes a box-type construction with hinged front panels. Switches and fuse holders up to 60-ampere capacity and other relatively light items are mounted on the hinged panels while heavier items are mounted on stationary panels. Access to the rear of the stationary panels is gained by opening an adjacent hinged panel.

Terminal boards are provided within the switchboard enclosure for termination of all ship's cables except for a few of the larger cables, which run directly to their associated switches and fuse holders. All wiring between the terminal boards and the equipment mounted on the hinged and stationary panels is installed by the switchboard manufacturer to permit free swinging of the panels without interference from, or damage to, the wiring.

In order to reduce the rigidity of the switchboard, and to permit separate movement of panels during shock, cables are used instead of horizontal buses for connection between or among switchboard sections. Some vertical buses may be used, however, to supply sections of the individual panel.

The principal advantage of this type of switchboard is that it can be mounted against a bulkhead because no access space is required in the rear of the board. This feature results in a saving of space, which is most important aboard ship.

A. C. O. SWITCHBOARDS

The function of the action cutout (A. C. O.) switchboard is to permit isolation of various portions of I. C. systems and to transfer control of certain systems from one station to another. Separate switchboards are usually provided for specialized systems such as the sound-powered telephone system.

In older combatant vessels the A. C. O. switchboard is located in the central station, which also functions as damage control central. In recent vessels damage control central is combined with engineering central and is located nearer to the engineering plant and farther from the I. C. room. The A. C. O. switchboard, therefore, is located in the I. C. room and is usually adjacent to the I. C. switchboard. In smaller combatant vessels the I. C. and A. C. O. switchboards are combined into one unit.

Live-Front A. C. O. Switchboard

A. C. O. switchboards installed in naval vessels are similar in construction to the several types of I. C. switchboards.

The live-front A. C. O. switchboard is found only in the older ships. This switchboard utilizes (1) type–J switches mounted on insulating panels to control synchro circuits and (2) open-type knife switches, with fuses in open clips, to disconnect contact makers and audible signals.

Dead-Front A. C. O. Switchboard

The dead-front A. C. O. switchboard (fig. 2–3) utilizes dead-front steel panels. On these panels are mounted type–J or type–JR rotary switches, snap switches, and fuse holders.

Dead-Front Front-Service A. C. O. Switchboard

The dead-front front-service A. C. O. switchboard is shown in figure 2–4, A and B. All self-synchronous circuits are controlled by type–JR switches and have individual fuses for synchro primary excitation wires and overload indicators for synchro secondaries. Draw-out switch units are utilized, each unit incorporating the associated fuse holders and overload indicators. Rotary selector switches are always used on the A. C. O. board to permit the selection of several different stations or supplies.

The inherent design of the equipment on most I. C. synchro circuits is such that if all receivers and indicators are in parallel, a casualty to any station on the circuit or to corresponding cables would incapacitate the entire circuit. The

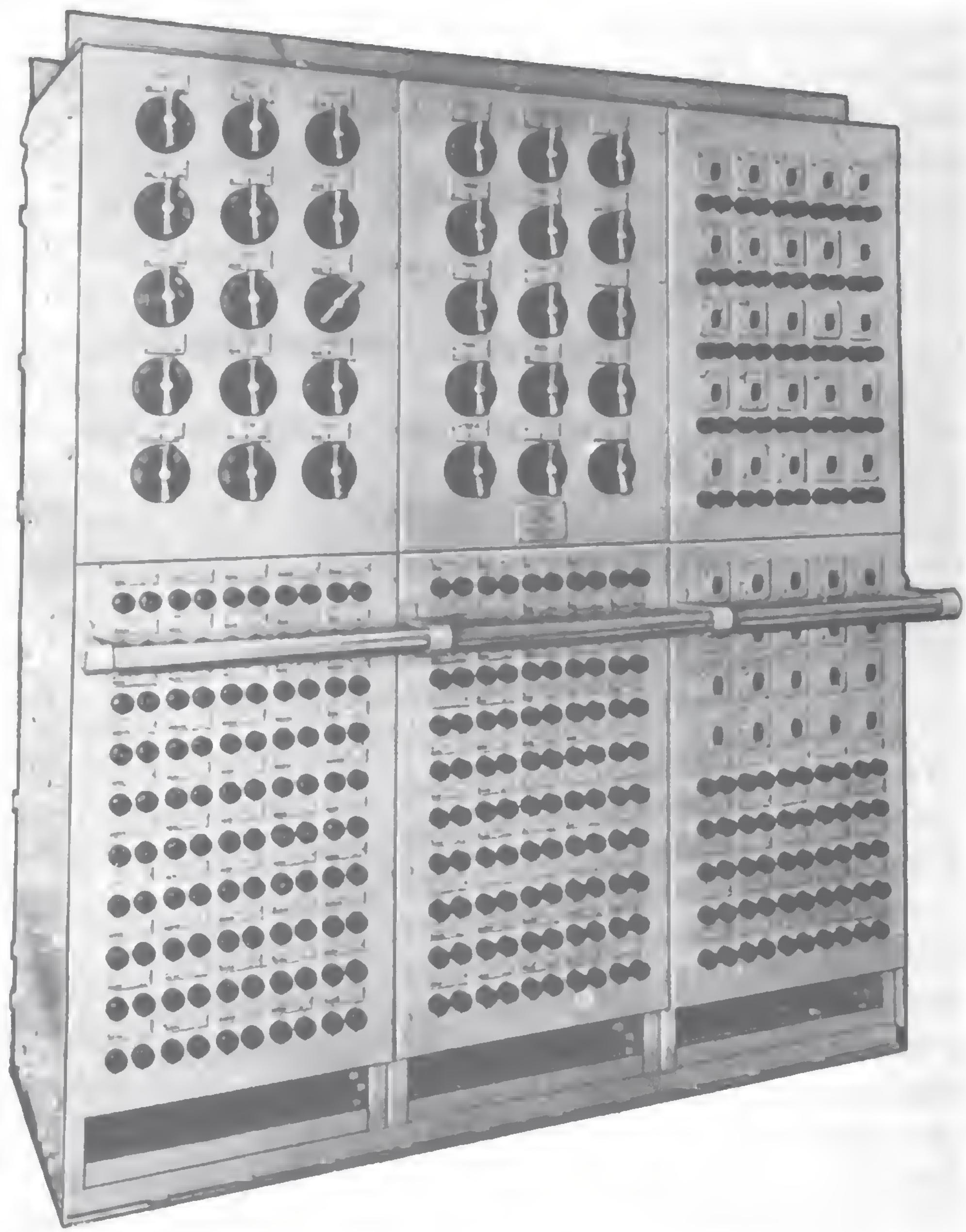


Figure 2–3.—Dead-front A. C. O. switchboard.

only means of overcoming this condition is to provide action cutout switching; individual fuses; and, in some cases, automatic disconnect relays in one or more central points to disconnect damaged instruments and cables. The use of action cutout switching is limited to the most important circuits, the loss of which might endanger the vessel.

In order to reduce the number of switches on A. C. O. switchboards, two synchro indicators are usually grouped

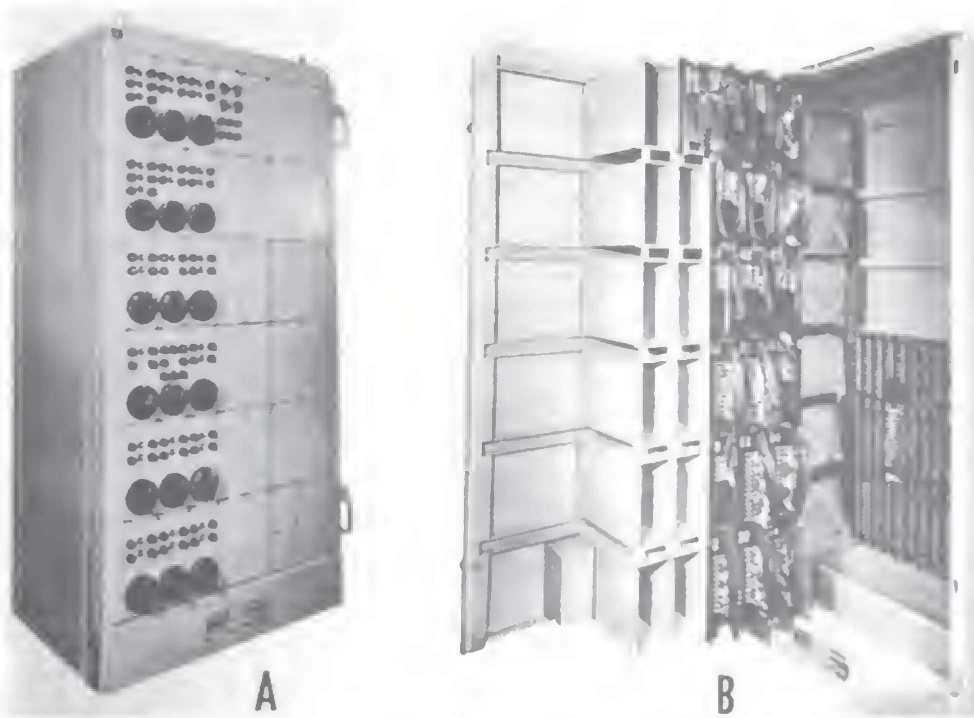


Figure 2–4.—Dead-front front-service A. C. O. switchboard, A, External view; B, internal view.

on each multipole rotary switch. These switches are of the 4JR type and usually provide "either or both" selection. By "either or both" is meant that the synchro signal as connected to the switch can be connected to either of two instruments singly or to both instruments together. Such a switching arrangement might be used to connect the underwater log transmitter to the pilot house, the open bridge, or to both the pilot house and the open bridge.

If several switches receive parallel inputs from the same transmitter, separate connections are provided from the terminal boards to the input terminals of the first and last switches of a series. Jumper connections are then provided from these switches to the switches between. Thus, any switch can be removed without disrupting the input connections to any other switches. If practicable, all switches of the same circuit are grouped together and all switches that control instruments in the same station are located on the same horizontal or vertical line.

Another switch arrangement on the A. C. O. switchboard may provide for selecting a transmitter at one of several stations. For example, the engine-order system may be controlled from the pilot house, the open bridge, or the secondary conn. The A. C. O. switchboard may also provide for isolating damaged circuits. For example, the output from the general-announcing amplifier may be connected to, or disconnected from, the various subgroups of speakers.

Many instruments on important circuits have individual disconnect switches on the A. C. O. switchboard so that the instruments can be energized as needed or disconnected from the circuit in the event of trouble.

LOCAL I. C. AND A. C. O. SWITCHBOARDS

An I. C. and A. C. O. switchboard or panel is usually provided in each engineroom (motor or maneuvering room in electric-drive vessels) to energize local I. C. circuits. The normal supply for each panel is from the nearer I. C. switchboard (automatic in more recent vessels). The emergency supply for each panel is from a local lighting circuit. This arrangement provides the panel with the same power backup as that of the I. C. switchboard. However, in case of loss of power at the I. C. board or damage to the connecting cable, the panel can still be energized from a local source. Action cutout switches are provided to disconnect instruments connected to local transmitters.

A combined I. C. and A. C. O. switchboard or panel (fig. 2–5) is usually installed in each steering gear room to ener-

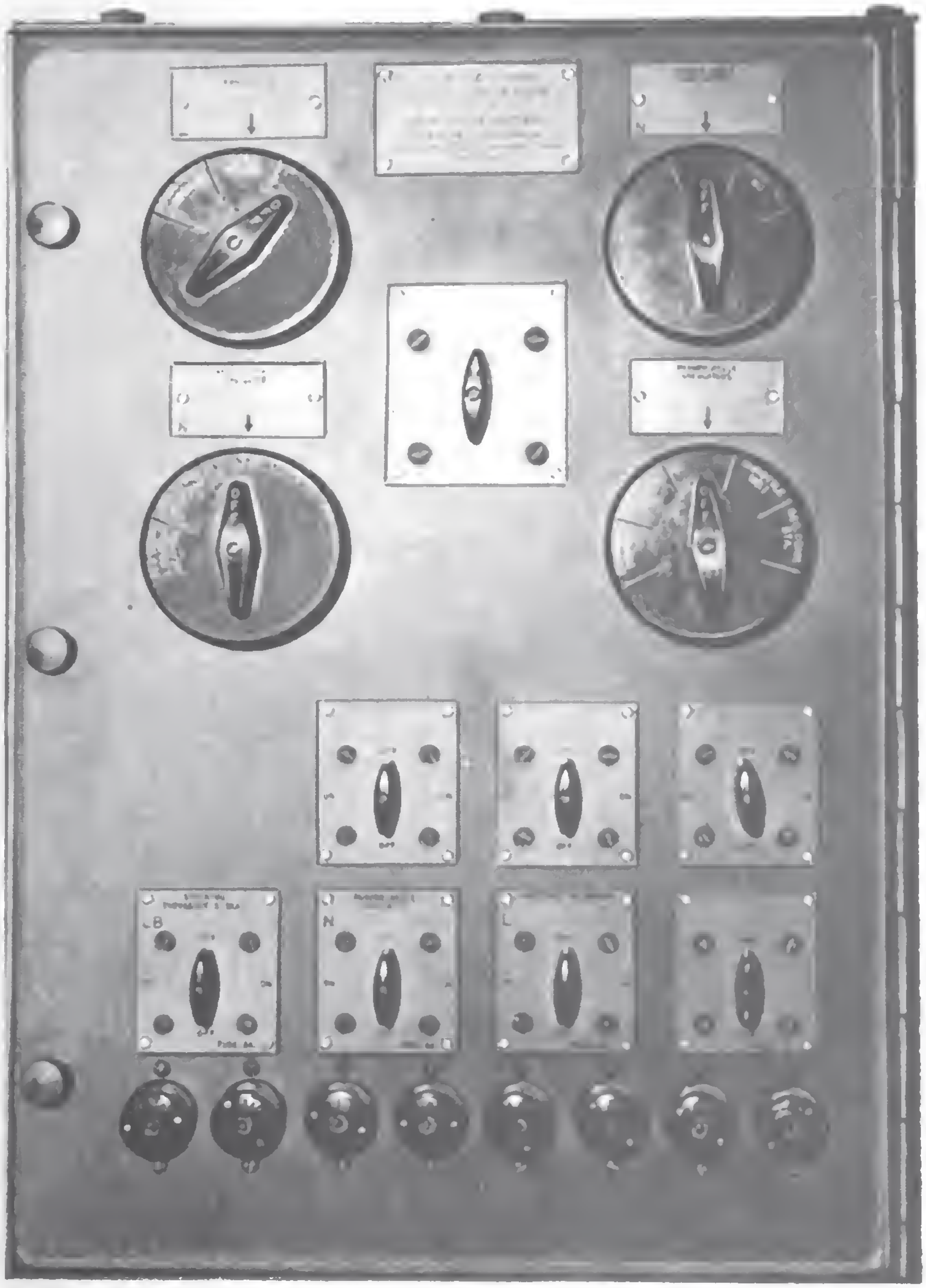


Figure 2–5.—Combined I. C. and A. C. O. switchboard.

gize all circuits associated with steering such as the steering-order and rudder-angle-indicator systems. The normal supply for this panel is from the steering-power transfer switchboard through a local transformer. The alternate supply is from a local lighting circuit to provide for the contingency of casualty to the transformer, because manual or emergency steering gear is provided in case of power failure to the steering power board.

A turret-type combined I. C. and A. C. O. switchboard (fig. 2–6) is also installed in each turret. This panel is

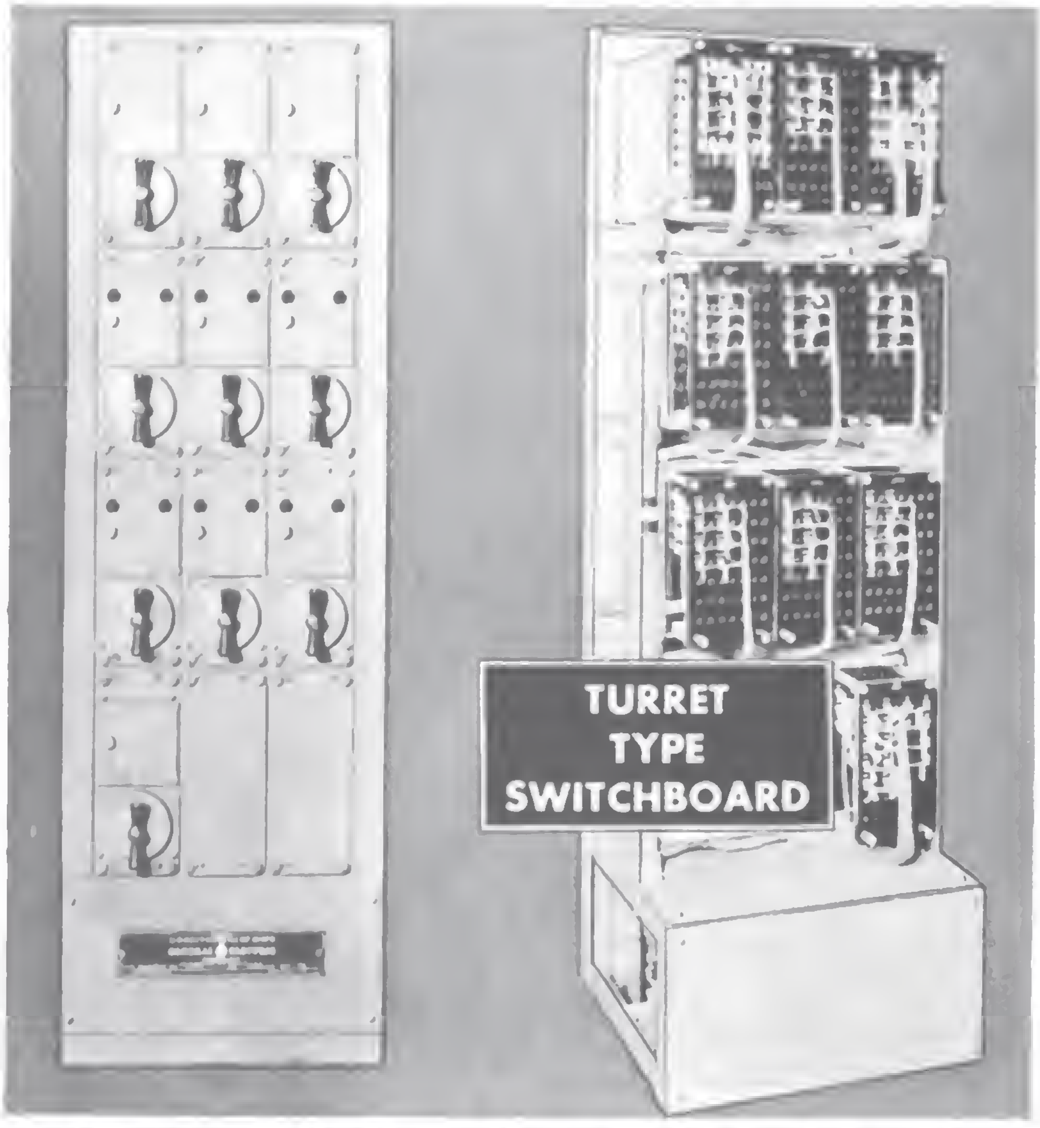


Figure 2–6.—Turret-type combined I. C. and A. C. O. switchboard.

energized through a double-throw switch from the normal and alternate 450-volt power feeders to the turret via a local 450/120-volt transformer. A supply from the I. C. switchboard is not provided because, with modern highspeed turrets, the turret is relatively useless if the power to it fails.

SWITCHBOARD DEVICES AND COMPONENTS

The following devices and components are used on I. C. and A. C. O. switchboards and panels:

1. Meters and meter transformers
2. Meter switches
3. Indicator lamps
4. Snap switches
5. Multipole rotary switches
6. Disconnect switches
7. Automatic bus-transfer equipment
8. Fuses
9. Fuse holders
10. Blown-fuse indicators
11. Overload indicators
12. Indicator lights
13. Relays and control switches

The rheostats and starting push switches for the associated I. C. motor-generator sets are usually mounted on the I. C. switchboard.

Detailed descriptions of many of the preceding items are included in the training course, *I. C. Electrician 3*, NavPers 10555.

Multipole Rotary Switches

All new I. C. and A. C. O. Switchboards are provided with the type–JR switch (fig. 2–7). This switch consists of a series of PANCAKE sections (fig. 2–7, A). Each section has eight stationary contacts (fig. 2–7, B). The sections are stacked in multiples of 5 up to a total of 25 sections. Externally the stationary sections of all JR switches appear to be the same.

Electrical circuits are completed by means of a rotor with movable contacts that, depending upon the rotor arrangement, bridge adjacent stationary contacts or connect a common contact to any of the other contacts. The rotor is driven by a shaft and handle. The nameplate is fastened to the shaft and rotates with the handle. The switch positions are

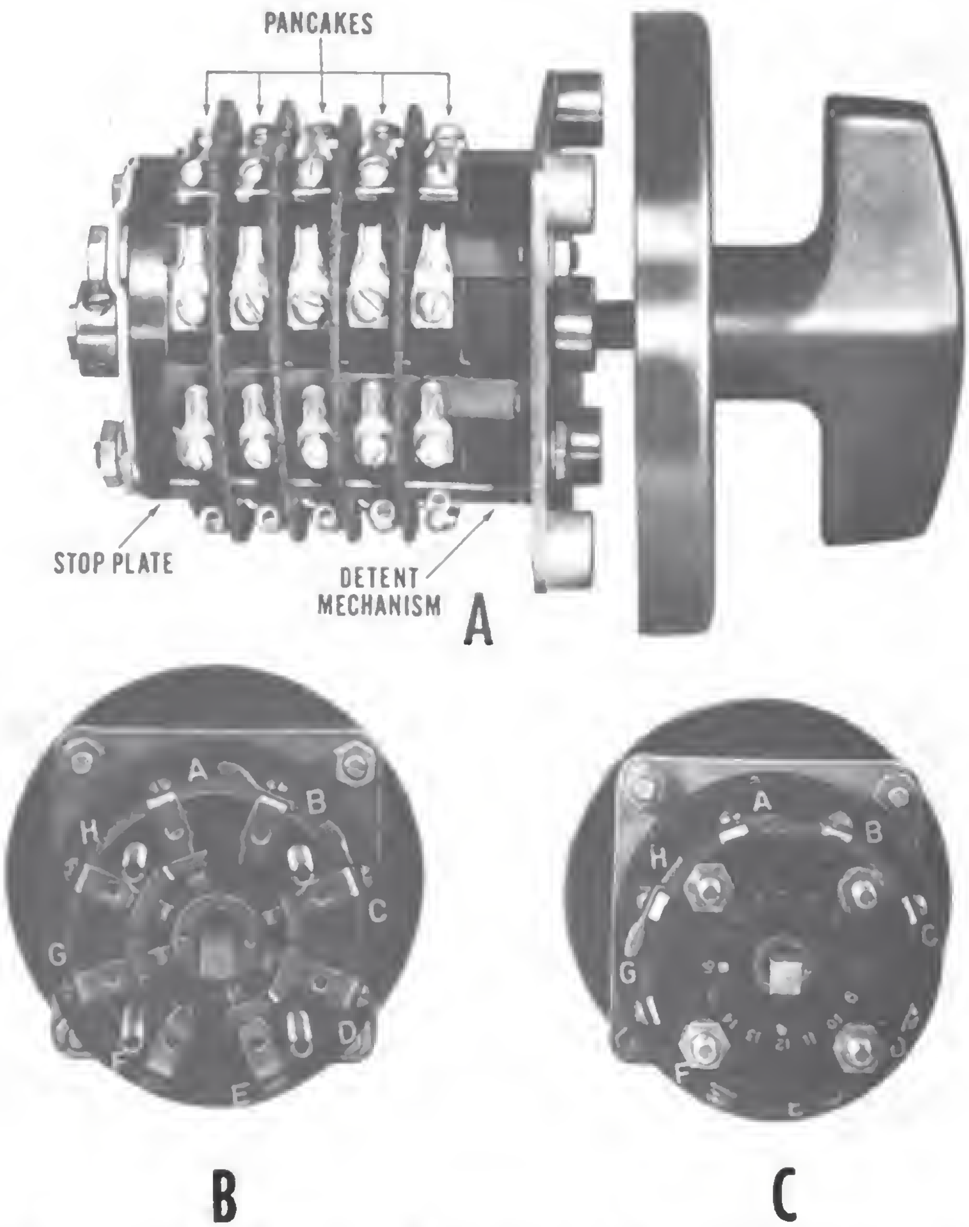


Figure 2–7.—Type–4JR switch. A, Internal view; B, contact assembly; C, stop mechanism.

indicated by a fixed index arrow mounted on the switchboard above the rotary-switch dial.

A detent mechanism is provided at the panel end of the switch to position the movable contacts in any of eight positions. This detent mechanism is a sealed unit and does not come apart when the switch is disassembled. A star-wheel in the mechanism has a square hole through which the switch handle fits. Four ball bearings are forced into the notches of the starwheel by springs. These springs always tend to force the ball bearings to the bottom of the notches. This action causes the switch handle to stop at a position in which the rotor contacts make the desired contact with the stationary contacts. In switches of 15 sections or more, an additional detent is included at the opposite end of the switch.

Adjustable stops (fig. 2–7, C) are provided opposite the panel end of the switch. The stop plate at the end of the switch contains a stop arm that fits on the end of the switch shaft and rotates with it. Movable stop pins are inserted into holes in the stop pancake. As the switch shaft turns, the stop arm strikes one of the stop pins and prevents further movement of the switch in that direction. Turning the switch in the opposite direction turns the stop arm until it again strikes a stop pin and prevents further movement of the switch. The stop settings are easily changed by removing the plate and shifting the pins as necessary.

Phenolic barriers are provided between each pancake section. These barriers serve as insulating spacers to prevent short-circuiting of terminals in adjacent switch sections. The letters "A" through "H" are engraved on each barrier to identify the eight contacts.

The JR switch is designated by the type of rotor and by the number of sections in the switch. The rotor types are 1JR, 2JR, 3JR, and 4JR. Thus, a 4JR5 switch contains 5 type-4JR sections.

The 4JR switch (fig. 2–7) is the type most commonly used on A. C. O. switchboards. It has a rotor with two insulated contacts 180° apart. Each rotor contact bridges three stationary contacts at one time.

Bus-Transfer Equipment

A type-K, 3-position, manually operated switch is used on I. C. switchboards of older design to transfer between the normal and emergency sources of power. More recent I. C. switchboards are provided with an automatic rotary bus transfer switch (fig. 2–8, A) which is simpler and more compact than other types. This design of automatic bus transfer switch utilizes a pancake construction similar to that used in the manual rotary snap switch although the contact structure is different (fig. 2–8, B). The switch is operated by a magnetic coil (fig. 2–8, C) which is energized from the normal power supply through a voltage-sensitive

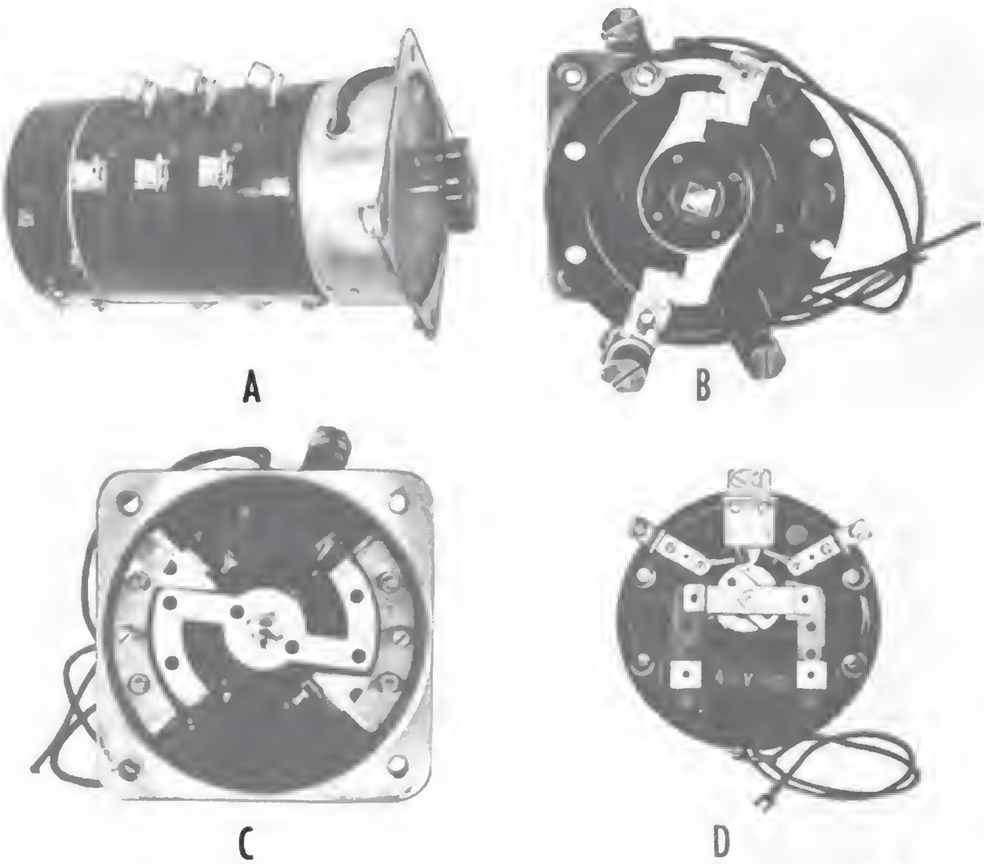


Figure 2–8.—Automatic rotary bus-transfer switch. A, External view; B, rotary contacts; C, magnetic coil; D, voltage-sensitive relay.

relay (fig. 2–8, D). This relay is mounted as an integral part in the back of the switch, but when the space behind the panel is limited, it can be mounted separately from the switch.

The coil operates the switch contacts to the normal position against the action of a spring. If the voltage on the normal supply feeder falls below 70 to 80 percent of its rated value, the sensitive relay operates to deenergize the coil and the spring moves the switch contacts to the emergency-power-supply position. When the voltage on the normal supply feeder rises above 85 to 90 percent of its rated value, the sensitive relay energizes the coil and thus restores the switch contacts to the normal power supply position.

The rotary bus-transfer equipment is adjusted by the manufacturer to transfer at the percentage values specified. Adjustments of these transfer values must not be made unless absolutely necessary because the sensitive relay is a precision device and should not be tampered with. Such adjustments can be made, however, by removing the sensitive relay and following the instructions contained in the plans furnished with the equipment.

In case of failure of the control circuit or the spring, emergency operation of the rotary transfer equipment provides for manually positioning the contacts. This positioning is accomplished by operating the indicating knob at the front of the switch. The indicating knob is connected directly to the main shaft which extends through the panel. A latch key, when engaged with the knob, holds the contacts in the desired positions.

An intermediate position is provided for the knob in which the movable load contacts are in between the stationary normal and emergency-supply contacts. When the contacts are in this intermediate position the load is deenergized.

The automatic bus transfer switch previously described is being replaced by a similar switch which corrects some of the difficulties encountered in the original type. The new switch is constructed so that when the blades of the switch are closed, they will remain closed under conditions of vibration and shock. An auxiliary switch is provided as an intergral part of the new design to deenergize the operating coils when the switch is in the manual OFF position.

The switch has three positions—(1) service, (2) off, and (3) emergency. It may be operated either electrically or manually. When necessary, the switch can be locked in any one of the three positions, as in the event of control-circuit failure or mechanical failure.

Whenever the switch is in the locked position it automatically disconnects the control circuits to protect the electrical components. Because the two contacting positions are located on the same shaft, no mechanical interlocking linkage is necessary as in the case of separate contactor mechanisms.

Twin dual-action plunger-type solenoids are employed with two parallel coils to initiate motion in either contact position. The movable cores of the solenoids are positioned one on each side of the shaft and are in static balance when deenergized. The neutral OFF position lies between the two energized positions. From the neutral off position either of the two sources (service or emergency) may energize its respective solenoid as conditions demand.

If both systems are energized, the service supply predominates and immediately neutralizes the EMERGENCY connections. With the switch in the SERVICE position, transfer to the EMERGENCY position takes place upon under voltage at a preselected percentage of full voltage or failure either in phase A or in phase B of the service supply. The preselected percentage of full voltage is obtained by adjusting the voltage-sensitive relay. When low voltage occurs across the service supply, the automatic bus transfer switch instantly responds to transfer the load to the emergency line. When normal voltage is restored, the switch again functions to transfer the load to the SERVICE supply.

Automatic rotary bus-transfer switches are available in two frame sizes based on current ratings of 50 and 100 amperes. For each current rating, separate switches are available for operation on 120-volt and 450-volt, 60-cycle a-c service and for 120-volt d-c service. The principal difference in the switches is in the design of the operating coils and the voltage-sensitive relays for the particular operating voltages.

A type-A automatic bus transfer switch is provided for attack aircraft carriers CVA59 and CVA60 to automatically select the source of power for the I. C. switchboard from any one of three sources. These sources are: (1) preferred, (2) alternate, and (3) emergency. The equipment consists of a 3-way, 450-volt, 600-ampere, drum-type switch with (1) pilot motor drive, (2) leading-supply selector switch, (3) test switch, and (4) automatic-manual selector switch, together with relays and control circuits.

In manual operation the drum-switch handwheel is turned to place the load in contact with any one of the three selected sources of supply.

In automatic operation the switch will select any one of the three supplies, depending on the position of the leading selector switch and the magnitude of the supply voltage. For example, if the leading selector switch is in the PREFERRED position and the magnitude of the preferred supply voltage is within the proper limits, the switch will connect the load to the preferred supply.

If the preferred supply voltage falls below the proper limits, the switch will automatically connect the load to the alternate supply and restore it to the preferred supply when the voltage returns to normal. If the load is connected to the alternate supply and low voltage occurs on both of these sources, the switch will automatically transfer the load to the emergency supply and restore it to the proper supply (depending upon the position of the leading selector switch) when voltage is restored to normal.

Fuses and Fuseholders

Table 1 lists the various types of fuses and fuseholders used in I. C. switchboards and equipment.

These fuses are nonremovable and nonindicating except as noted. In addition, several types of fuses similar to the miniature fuse but of varying lengths are used in some components. Special fuses are used in some specialized equipment

TABLE 1.—TYPES OF I. C. FUSES AND FUSEHOLDERS

Type	Fuses			Fuseholders
	Available current rating (amperes)	Maximum permissible voltage	Overload blowing characteristics on percentage of rated current	Application
MINIATURE 1¼″ × ¼″ Style FO3 Normal blowing	Up to 30	Less than 15 a (250 v) 15 a and more (120 v)	Within 1 hour on 135%	BuShips dwg 9000–S6202–74228 Type 10FH2. BuShips dwg 9000–S6202–74229 Type 10FH1.
MINIATURE 1¼″ × ¼″ Style FO3 Time lag	Up to 1	120 v	Within 1 hour on 135% 6 seconds minimum on 300%	Do.
MIDGET 1½″ × 13/32″ Style FO9 Normal blowing	Up to 30	250 v	Within 1 minute 150%	BuShips dwg 9000–S6202–73440 Type EL–1. BuShips dwg 9000–S6202–74230 Type 12FH1.

MIDGET 1½″ × 13/32″ Style FO9 Time lag	Up to 30	Less than 10 a (250 v) 10 a and more (120 v)	Within 1 minute on 150% 6 seconds minimum on 300%	Do.
TYPE CN 2″ × 9/16″ Style F15 Normal blowing	Up to 30	450 v (a-c) 250 v (d-c)	Within 1 hour on 135%	BuShips dwg 9–S–5530 Type EL–1.
TYPE TL 2″ × 9/16″ Style F15 Time lag	Up to 30	250 v	Within 1 hour on 135% 10–25 seconds on 500%	Do.
TYPE CN 3″ × 13/16″ Style F16 Normal blowing	31 to 60	450 v (a-c) 250 v (d-c)	Within 1 hour on 135%	BuShips dwg 9–S–5531 Type EL–1.

TABLE 1.—TYPES OF I. C. FUSES AND FUSEHOLDERS—Continued

Type	Fuses			Fuseholders
	Available current rating (amperes)	Maximum permissible voltage	Overload blowing characteristics on percentage of rated current	Application
TYPE TL 3″×1¾₁₆″ Style F16 Time lag	31 to 60	250 v	Within 1 hour on 135% 10–25 seconds on 500%	Do.
TYPE CN 5⅞″×1½″ (max) Knife blade Style F17 Normal blowing	61 to 100	450 v (a-c) 250 v (d-c)	Within 2 hours on 135%	BuShips dwg 9–S–5532 Type EL–1
TYPE TL 5⅞″×1½″ (max) Knife blade Style F17 Time lag	61 to 100	250 v	Within 2 hours on 135% 10–25 seconds on 500%	Do.

TYPE CN 7⅛″×2″ (max) Knife blade Style F20 Normal blowing	101 to 200	450 v (a-c) 250 v (d-c)	Within 2 hours on 135%	BuShips dwg 9000–S6202–73290 Type EL–1.
TYPE TL 7⅛″×2″ (max) Knife blade Style F20 Time lag	101 to 200	250 v	Within 2 hours on 135% 10–25 seconds on 500%	Do.
TYPE MI Midget	Up to 30	120 v	(Indicating)	Commercial fuseholder with transparent cap.

such as telephone indicating-type fuses in the ship's service telephone equipment.

The style FO3 fuse is electrically equivalent to the style FO9 fuse up to 14 amperes for 250-volt applications and from 15 to 20 amperes for 120-volt applications. The FO3 fuse will probably replace the 21-30 ampere FO9 fuse, also for all 120-volt applications. A new $1\frac{1}{2}'' \times \frac{13}{32}''$ fuse has been developed for 450-volt applications, and will replace the FO9 fuse for the higher voltages and the F15 fuse for new applications.

The type-MI fuse is used where the available voltage is too low to energize a lamp-type blown-fuse indicator.

The time lag fuses are used for fusing loads such as rotor supply circuits in which overloads and surges of short duration may occur.

Individual fuses are provided on the I. C. switchboards and panels for each associated circuit. A separate fuse is used in each line of each circuit as this arrangement has the effect of considerably increasing the maximum short-circuit current that the fuses can safely interrupt. Also, greater protection is provided to the remaining circuits that are energized from the same bus in case of a possible defect in one fuse.

Fuse ratings should generally be about 10 percent above the maximum continuous connected load. In circuits such as call-bell systems and alarm systems where only a small portion of the circuit is likely to be operated at any one time, the fuse rating should be 10 percent greater than the load of one associated group of signals operated, or 15 percent of the total connected load, whichever is greater.

When the circuit incorporates branch fuses, such as circuits associated with F. C. switchboards, the rating of the fuses on the I. C. switchboard should be 20 percent above the maximum connected load in order to provide sufficient margin so that branch fuses always blow before the main fuses.

The plug-type combination fuseholder and blown-fuse indicator provides for the mounting of fuses on a dead-front metal panel and permits ready replacement of the fuses.

This fuseholder, type EL-1, consists of a base and a plug. The base extends behind the panel. The plug containing the fuse is screwed into the base. A small neon lamp located behind a hole in the plug cap serves as a blown-fuse indicator. When a fuse blows, the energized circuit through the fuseholder is interrupted, causing the neon lamp to light. Series resistors of different values are used with a lamp on 125-volt circuits, except for the midget holder, which is rated for 125 volts only. A ground test hole is provided in the cap of the plug.

Fuse holders are made in different sizes for 250-volt fuses with maximum ratings of 30, 60, 100, and 200 amperes, and 125-volt midget fuses with maximum ratings of 30 amperes. The plugs have two voltage ratings determined by the indicator lamps and the series resistor.

The FH fuse holders are now used in many applications, and are replacing the EL-1 fuse holders of equivalent ratings. The present types are 10FH1, 12FH1, and 10FH2. This series is similar in design to the EL-1 series. In the FH series, however, the plug is secured to the base by a principle similar to that of the bayonet lamp-and-socket combination. This fuse holder is designed for dripproof applications. It is provided with a flat gasket between the panel and base, and an "O" ring gasket between the plug and base. The fuse holders are mounted with the ground testholes down or to the right (facing the switchboard).

Blown-Fuse Indicators

The circuits supplied by I. C. and A. C. O. switchboards and panels must be kept in continuous operation when energized. Therefore, the fuses installed on these boards are provided with blown-fuse indicators that are readily visible to the operating personnel. A blown-fuse indicator is simply a neon lamp connected in parallel with each fuse. When fuses are mounted in open clips, the neon lamp is mounted in a tube having projections that can be secured to the fuse clips so that the indicator can be mounted either on the side or on top of the fuse. Holes are provided in the doors of the enclosures over the neon-lamp indicators. When fuse holders are used, the neon lamp is mounted in the fuse-holder plug.

The neon lamps used in lamp-type blown-fuse indicators contain an inert gas such as neon or argon. The properties of these lamps are (1) reliability, (2) ruggedness, (3) high resistance, (4) low current consumption, (5) insignificant heat, and (6) long life. Neon lamps are very dependable. They do not fail suddenly, but gradually decrease in light output over a 3,000-hour period until the lamp is no longer useful.

A fuse is connected in each side of the line in all circuits supplied from the I. C. switchboard. A neon lamp and a series resistor are connected in parallel with the terminals of each fuse. Thus, when a fuse is good, the neon lamp is shorted out. If the fuse blows, the resistance of the neon lamp is so high that, provided the circuit remains closed, the greater portion of the applied circuit voltage appears across the neon lamp. Hence, the neon lamp lights and serves as a blown-fuse indicator, provided the voltage across it is sufficient.

Neon lamps have a definite breakdown voltage at which the inert gas becomes ionized and conducts current. The lamp does not pass current or glow below this breakdown voltage. The value of the breakdown voltage, which increases with the age of the lamp, is a function of the gas used and the spacing of the electrodes. The breakdown voltages of the lamps used in the fuse holders installed on I. C. switchboards and panels range from about 50 to 65 volts for 60-cycle a-c circuits and from about 75 to 90 volts for d-c circuits.

If one fuse blows in 120-volt a-c and 120-volt d-c circuits, nearly the entire voltage of the circuit is across the neon lamp. The lamp glows and serves as a blown-fuse indicator. If the fuses in both sides of the line blow in 120-volt a-c and 120-volt d-c circuits, about half the applied voltage is across each neon lamp and no indication is obtained. A blown-fuse indication for each fuse is obtained in most cases in a-c circuits, but no indication is obtained in d-c circuits.

Thus, a reliable blown-fuse indication cannot be obtained by this method in d-c circuits in which the applied voltage is 90 volts or below and in a-c circuits in which the applied voltage is 65 volts or below. In such cases mechanical type-MI indicating fuses with transparent plastic tops are used in plug-type fuse holders.

In the 30-ampere, 60-ampere, and midget fuseholders, the fuse ferrules complete the circuit to the fuse indicator. In the 100-ampere, 200-ampere, and FH-series fuseholders, the lamp is permanently connected to the fuseholder terminals. A blown-fuse indication is obtained if no fuse is inserted when the circuit is energized.

Overload Indicators

Recent designs of A. C. O. switchboards and panels are provided with overload transformers. These transformers are in series with the secondary connections of each synchro indicator to provide immediate information to operating personnel regarding a casualty so that the damaged instruments can be disconnected quickly by operating the associated switches. It is also necessary in each case to fuse the primary wires. Otherwise, a short in one indicator might blow the main fuses of the circuit and no power would be available to operate the overload indicators to show the faulty circuit.

The overload transformer (fig. 2–9) consists of two primary windings in series in two legs of the synchro stator wires. The secondary winding is connected to a small neon lamp, mounted on the face of the F. C. switchboard (fig. 2–9, A). The overload transformer is essentially a current-sensitive device. It is arranged so that when the sum of the currents in the stator circuits to a particular synchro exceeds a predetermined amount, a neon lamp glows.

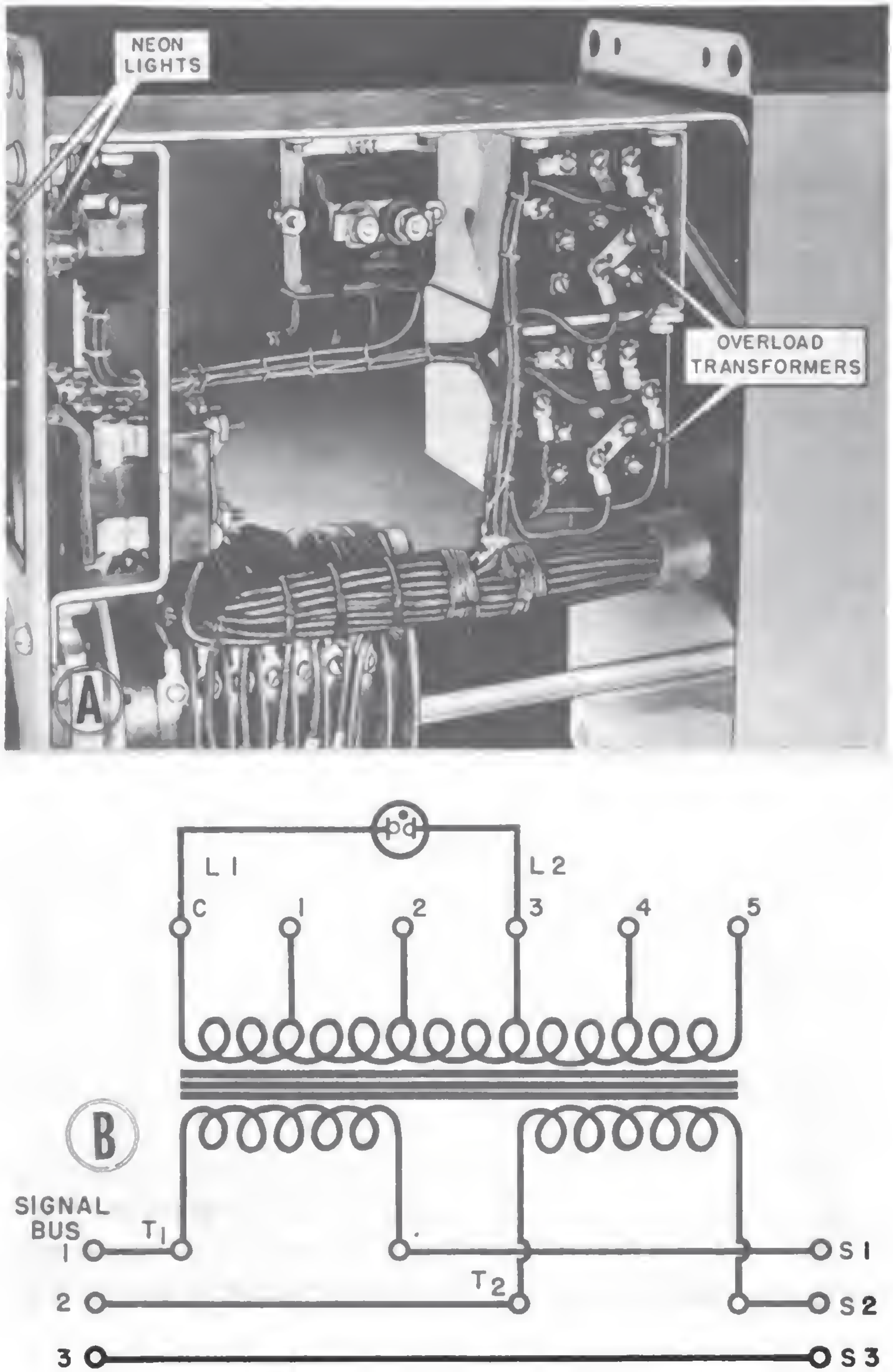


Figure 2-9.—Overload transformer. A, External view; B, schematic diagram.

The transformer has numerous taps (fig. 2–9, B) to provide adjustment for a wide range of currents above which the lamp can operate, depending upon the type of circuit in which it is used. The principal difference between the operation for I. C. synchro circuits and for F. C. circuits is that for I. C. synchro circuits the overload transformers are usually set to provide a much greater relative displacement between transmitter and indicator before the overload lamp lights. F. C. synchro circuits are usually precision systems in which a relatively slight displacement between a transmitter and indicator may involve a serious error. I. C. circuits are generally used for the transmission of a relatively small number of orders and a displacement between transmitter and indicator is not serious until sufficiently great to cause an incorrect order to appear at the indicator.

Operating personnel of A. C. O. switchboards should be very cautious when operating switches to disconnect indicators, particularly on vital circuits such as the engine order system. When practicable, operating personnel should investigate before operating the switch as the overload indication may be a result of too low a setting on the overload transformer.

Operation of a transformer switch generally results in a flash on the associated overload light, which is caused by the momentary displacement between the transmitter and receiver or by transients. Such indications are normal and show that the system is operating properly. Continual flashing, however, should be investigated.

The overload transformers are designed to operate with neon lamps for which the breakdown voltage is 52.5 alternating volts and 74 direct volts. As previously stated, the breakdown voltage of neon lamps varies over a wide range. Any variation in this breakdown voltage is equivalent to changing a transformer tap. Replacement lamps therefore, should be selected by measuring the breakdown voltages until a lamp is found that conforms approximately to the values given.

The indicator lights on I. C. switchboards normally use two 6-volt lamps because 120-volt lamps are not suitable for the vibration and shock conditions encountered aboard ship. A-c applications require transformers, whereas d-c applications require resistors. The a-c indicator lights are provided with integral transformers for either 120-volt or 450-volt applications. D-c indicator lights are provided with separate resistors.

Globes of various colors are required for specific applications.

Relays and Control Switches

Undervoltage and auxiliary relays are used in automatic transfer switches and alarms associated with I. C. switchboards and panels.

Control switches are used principally on I. C. switchboards for starting I. C. motor-generator sets. Starting push switches are used in some installations and rotary switches in others.

I. C. SWITCHBOARD POWER SUPPLY

The generation and distribution of electric power aboard naval vessels is discussed in the training course for *I. C. Electrician 3*, NavPers 10555. The power distribution systems and arrangements of buses for I. C. switchboards vary widely in different ships and depend upon the size of the ship, the main power system, and the F. C. system. The following discussion describes the general principles of a typical I. C. switchboard power supply.

The forward main I. C. switchboard is supplied with power from as many sources as possible. This power supply usually consists of (1) a normal supply from a main power-distribution switchboard of the forward machinery group, (2) an alternate supply from a main power-distribution switchboard of the after machinery group, and (3) an emergency supply from the nearer emergency-distribution switchboard.

The normal 3-phase, 450-volt, 60-cycle power supply is obtained from the forward main ship's service distribution switchboard through a switch on that board. The 450-volt supply is connected to a 450-volt bus on the main I. C. switchboard through the bus-transfer switch, as shown in figure 2–10.

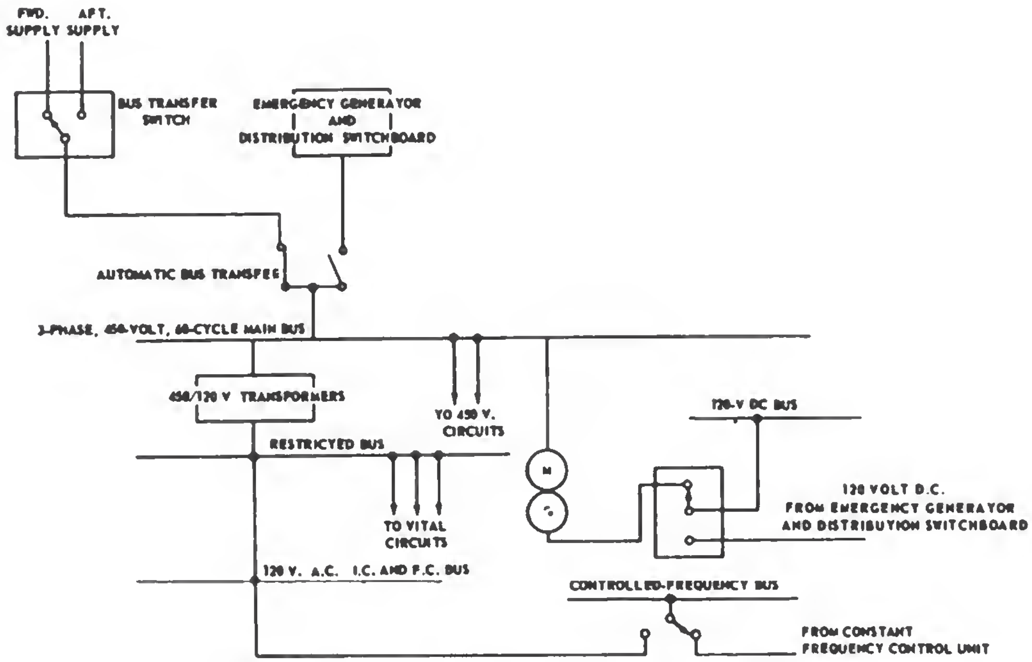


Figure 2–10.—I. C. switchboard power supply.

This bus energizes the various 450-volt circuits through individual switches and fuses. In some installations the main 450/120-volt I. C. transformer bank is energized directly from this bus through fuses, but in most cases the transformers are energized through both switches and fuses.

The I. C. transformer bank is connected delta-delta in order to operate open-delta in case of a casualty to one transformer. Fuses are provided on the I. C. switchboard in the delta circuit of the transformer primaries and disconnect switches are installed in the transformer secondaries. Fuses of sufficient rating to provide overload protection in the secondaries are considerably larger than the disconnect switches. Thus, casualty to a transformer primary or secondary, resulting in an overload, causes the primary fuses to blow. This condition is shown by blown-fuse indicators mounted on the switchboard. The damaged transformer can be isolated by removing the associated fuses and opening the associated disconnect switches. Load can be reduced as necessary by opening the switches of less essential circuits.

The main 3-phase, 120-volt, 60-cycle bus is energized from the output of the main I. C. transformer bank which is supplied from the 3-phase, 450-volt, 60-cycle ship's service power. The various I. C. and F. C. circuits are connected to this bus through individually fused switches.

In some ships in which the emergency power is extremely small, the main 120-volt a-c bus is divided into a restricted bus. This restricted bus supplies power to the most important circuits, and to the I. C. and F. C. buses which are connected to the restricted bus through manual switches or contactors. The contactors open automatically upon transfer to the emergency power supply. Thus, the normal 120-volt supply is disconnected from the I. C. and F. C. buses upon transfer to the emergency supply. After the switches for less essential circuits on the I. C. and F. C. buses have been opened to reduce the load, the contactors supplying these buses are closed again.

To insure continuity of power supply to the motor-generator sets for the gyrocompass and gyro stabilizer, two 3-phase, 120-volt, 60-cycle buses are provided. The normal supply is through a double-throw snap switch from the 3-phase, 450-volt, 60-cycle, motor-generator supply bus (not shown in figure 2–10). This bus is energized through an automatic bus-transfer equipment from a separate 3-phase, 450/120-volt, 60-cycle transformer bank. The emergency supply to this bus is from the 3-phase, 120-volt, 60-cycle gyrocompass motor-generator supply bus. This separate emergency bus provides for the contingency of a casualty to the gyrocompass motor-generator transformer bank.

Continuity of power supply is essential also for the d-c supply to the generator field of the gyro stabilizer motor-generator set. Otherwise the generator output would fall to zero even though the a-c supply kept the motor rotating.

To avoid the necessity of installing two automatic bus transfer equipments, the 450-volt motor-generator supply bus is provided. The normal power supply for this 450-volt bus is through an automatic bus transfer equipment from the 450-volt main bus. The emergency power supply is from the 450-volt emergency supply.

This 450-volt bus also energizes the a-c/d-c motor-generator set located in the I. C. room. The output of this motor-generator furnishes the normal power supply to the 120-volt d-c bus. This 120-volt d-c bus is energized through a double-throw snap switch. The emergency power supply is from the nearer main ship's service power-distribution switchboard. The provision of an I. C. motor-generator set that can be energized from three a-c sources provides the d-c bus with the backup equivalent to that of the a-c buses.

A special frequency bus is also provided on the I. C. switchboard (not shown in figure 2–10). This special frequency bus is energized from either of two motor-generator sets in the I. C. room and supplies those I. C. and F. C. circuits requiring 120-volt, 400-cycle power.

A 120-volt, 60-cycle, controlled-frequency bus (fig. 4–10) is provided to energize I. C. and F. C. components requiring extremely fine frequency regulation (within 0.1 percent). The normal power supply to this bus is through a double-throw switch from the output of the constant-frequency control unit. The emergency power supply is from the main 120-volt, 60-cycle bus.

A casualty power terminal is provided adjacent to the I. C. switchboard in vessels having a casualty power system. Risers are not usually provided in the I. C. room. It is necessary, therefore, to rig portable cables to the nearest riser outlet. All I. C. electricians must be familiar with the locations of these outlets.

Before connections are made to the casualty power system, the main power manual and automatic bus-transfer switches must be operated to the OFF position. This procedure prevents the possible paralleling of one of the power supplies to the switchboard with the casualty power system. The casualty power system is limited to the facilities necessary to keep the ship afloat and to get it out of a danger area as well as to supply power to a limited amount of armament.

Therefore, before connections are made to the casualty power system, all switches on the I. C. board except those energizing vital ship control circuits and F. C. circuits should be operated to the OFF positions.

Constant-Frequency Control Unit

A high degree of accuracy is necessary for the operation of some I. C. instruments such as the underwater log, shaft revolution indicator, and wind direction indicating systems. Therefore, the constant-speed synchronous motors used in these systems must be supplied with 120-volt, 60-cycle service having not more than ± 0.1 percent variation in frequency. A constant-frequency control unit is used to supply this power. However, in an emergency the constant frequency bus can be shifted over to the 120-volt ship's service supply. This supply has greater than 0.1 percent variation in frequency and produces corresponding changes in the motor speed that result in a proportional error in the system involved.

A typical constant-frequency control unit is illustrated in figure 2–11. The 120-volt, 60-cycle power is generated by a dynamotor. The armature of the dynamotor has two windings and a common set of field poles. One winding terminates in a commutator and receives 120-volt, d-c service to operate the machine as a compound motor. The other winding terminates in 2 slip rings and generates 120 volts at 60 cycles for the constant frequency bus. The speed of the d-c compound motor (9) is controlled automatically by the output of the tuning-fork amplifier so that the output of the a-c generator (10) remains constant at 60 cycles. This control is accomplished by varying the current in the shunt field by means of a field rheostat (8) that is positioned by the movement of the differential spider (6). The bottom face gear (5) of the differential is driven by the lower synchronous motor (3), the speed of which is directly proportional to the frequency of the a-c generator (10) which supplies power to this motor (3). The top face gear (4) is driven by the upper synchronous motor (2), the speed of which is directly proportional to the frequency of the tuning fork. The tuning-fork coils (1) generate a voltage that is amplified at this

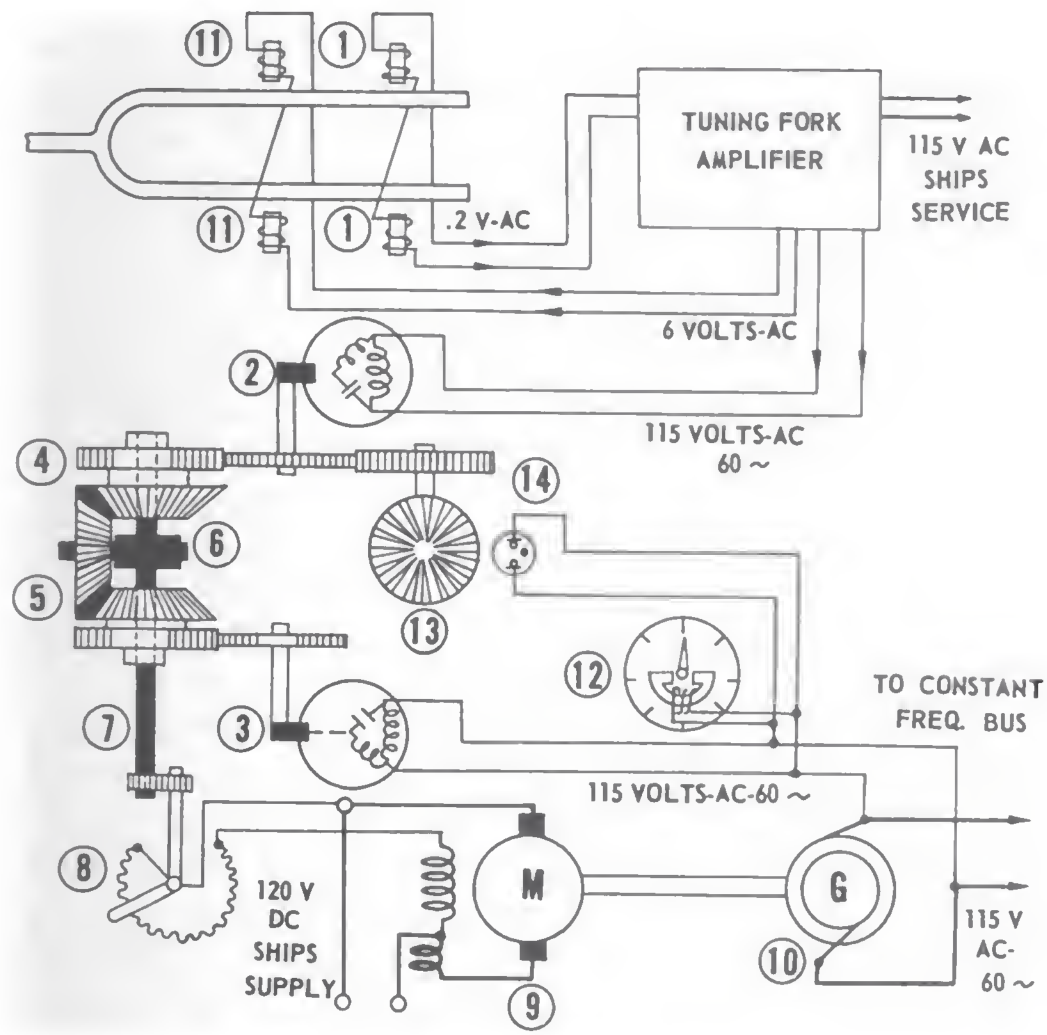


Figure 2–11.—Constant-frequency control unit.

frequency by the tuning-fork amplifier which supplies power to this motor (2). The differential spider rotates at a speed equal to the difference between the speeds of the two face gears.

If the converter frequency drops, the speed of the lower synchronous motor (3) driving the bottom differential face gear (5) decreases. The spider (6) then rotates because there is a difference in speed between the two face gears. The spider shaft (7), by turning in the direction of the faster moving gear, causes the arm of the rheostat (8) to move in a direction to cut more resistance into the shunt field. This action causes the converter to speed up, increasing the output frequency and, hence, the speed of the lower synchronous motor (3) and the bottom face gear (5). When the two face gears (4 and 5) of the differential are again moving at the same speed, the spider (6) and its shaft (7) stop turning. The rheostat arm then stops moving and remains stationary as long as the converter frequency remains constant.

A check clock (12), stroboscope (13), and lamp (14) are provided to check the frequency of the converter and the tuning fork. The clock and lamp are energized from the converter output, and the stroboscopic disk is driven by the upper synchronous motor (2) that is supplied by the tuning-fork amplifier. The stroboscopic disk and lamp arrangement is a relative check of the converter frequency and the tuning-fork frequency. When both are delivering 60 cycles, the lines on the disk appear to be stationary.

The hand of the check clock that operates from the rotary converter output makes exactly 1 rpm when the converter output is exactly 60 cycles. The tuning fork is kept vibrating by exciting the coils (11) from the 6-volt winding of the output transformer of the tuning-fork amplifier.

MAINTENANCE

The wiring and electrical connections of all I. C. and A. C. O. switchboards and panels should be cleaned and inspected at least once each quarter.

During each routine naval shipyard overhaul:

1. Deenergize each switchboard and panel.
2. Inspect individual leads for chafing.
3. Clean bus bars.

4. Check securing bolts.
5. Remove dust and lint.
6. Calibrate meters.
7. Check protective devices for proper operation.
8. Tighten all contacts.
9. Spot-check switches to determine the need for overhaul.

When the switchboard or I. C. room is secured, the temperature of the various switchboard parts is reduced. Consequently, moisture condensation may occur in the switchboards. Although the main I. C. switchboard is very seldom secured, the after I. C. board or the local I. C. panels are often deenergized. Always inspect switchboards and panels after they have been secured and remove any condensed moisture. Particularly inspect the underside of the drip shield for condensed moisture that may drip on live parts of the switchboard. If necessary deenergize the board and wipe off the condensed moisture in the vicinity of live parts with a clean dry cloth. Switchboards should be protected from sea water or spray that might be discharged from ventilation terminals. If possible these terminals should be relocated or suitable baffles should be installed to protect the I. C. and A. C. O. switchboards.

QUIZ

1. What is the function of the I. C. switchboard?
2. Where are I. C. switchboards installed aboard ship to afford maximum protection?
3. Name the three power sources that energize the I. C. switchboard.
4. Name the four types of I. C. switchboards.
5. What is the advantage of the dead-front front-service I. C. switchboard?
6. What is the function of the A. C. O. switchboard?
7. Where is the A. C. O. switchboard located aboard ship?
8. A. C. O. switching is limited to what class of circuits?

9. How are the number of switches on A. C. O. switchboards reduced?

10. What type of selection is provided by the 4 JR-type multiple rotary switches?

11. What is the purpose of I. C. and A. C. O. switchboards located in each engineroom?

12. Name two locations where combined I. C. and A. C. O. switchboards are installed.

13. How are the eight contact positions of the type-JR switch indicated on the phenolic barriers?

14. What does the designation 4JR5 indicate when applied to a rotary switch?

15. What unit energizes the magnetic coil of an automatic bus transfer switch?

16. What three sources of power can the type-A3 automatic bus transfer switch select for the I. C. switchboard?

17. Why are blown-fuse indicators provided on I. C. and A. C. O. switchboards?

18. What is the normal life of the neon lamps used in lamp-type blown-fuse indicators?

19. What three factors influence the value of the breakdown voltage of a neon lamp?

20. What condition is indicated by a continual flashing of the neon lamp in the secondary circuit of an overload transformer provided with an A. C. O. switchboard?

21. What is the purpose of the restricted bus?

22. When should I. C. and A. C. O. switchboards be cleaned and inspected?

CHAPTER 3

ELECTRONIC POWER SUPPLIES

A power supply provides various voltages for the filament, screen, plate, and control-grid circuits of electron tubes used in electronic equipment. The power for the filament, or heater, can be alternating current but direct current must be supplied for the screen and plate circuits and for grid biasing.

The power to heat the filaments of electron tubes is sometimes called the *A* supply. This supply is normally a low alternating voltage of about 6.3 volts. It is usually supplied through a step-down transformer from a single-phase source.

The power supply for the plate and screen circuits is called the *B* supply. This supply is generally a direct voltage of about 300 volts and is obtained from a rectifier-filter system.

The grid-bias voltage is called the *C* supply. The grid-bias voltage for a voltage amplifier may be taken from a part of the plate power supply by means of a voltage divider. A separate rectifier-filter system or d-c supply sometimes is used to supply the grid-bias voltage for large power amplifiers.

Power supplies may consist either of a (1) battery for small portable equipment, (2) rectified a-c power supply where a-c service is available, (3) rectified output of a vibrator, or (4) rotary device such as a motor-generator set.

A-C POWER SUPPLIES

The component parts of a regulated power supply are a (1) transformer, (2) rectifier circuit, (3) filter circuit, (4) voltage regulator, and (5) voltage-divider system. This power supply is energized with single-phase, 120-volt, 60-cycle power from the I. C. switchboard.

The alternating voltage from the I. C. switchboard is increased to the desired value by the transformer. The rectifier then converts the alternating voltage into pulsating direct voltage. The filter circuit smooths out the pulsating direct voltage, and the voltage regulator maintains the voltage constant. The voltage-divider system provides the various voltages for the plate and screen-grid circuits. Power supplies vary considerably as to use, rating, and the number and type of the component parts.

Transformers

A conventional power transformer is used in the power supplies of electronic equipment. The primary is connected to the a-c supply and the secondary usually consists of multiple windings to provide the different voltages required.

The high-potential secondary winding is connected through the rectifier which furnishes the pulsating direct voltage. When used with a full-wave rectifier, the secondary winding is tapped at the center. The low alternating voltages for the rectifier filaments and other tube filaments may be obtained from low-potential windings or from the secondary windings of a separate filament transformer.

Rectifiers

The rectifier converts the alternating current from the power transformer into a pulsating direct current. A few of the devices that rectify alternating current into pulsating direct current are (1) electron tubes, (2) metallic-oxide rectifiers, (3) crystal rectifiers, (4) electrolytic rectifiers, and (5) mechanical rectifiers.

Electron tubes and metallic-oxide rectifiers are used most widely for electronic a-c power supplies. The two general types of electron rectifier tubes are the high-vacuum tube and the gas-filled, or mercury-vapor tube. Ordinarily, the high-vacuum tube is used where high voltages are required and the gas-filled tube where large currents are needed. The operation of the high-vacuum and gas-filled rectifier tubes in half-wave and full-wave circuits is explained in the training course, *I. C. Electrician 3*, NavPers 10555.

HIGH-VACUUM RECTIFIER TUBE.—The most important characteristics of the high-vacuum rectifier tube are the (1) maximum peak plate current and (2) maximum peak inverse voltage.

The MAXIMUM PEAK PLATE CURRENT is the safe value of peak current that the tube can pass under continuous operating conditions. Normally the maximum peak plate current is governed by the permissible cathode emission for a given tube. Because the plate current flows in a rectifier tube for half the cycle, the average plate current which represents the average d-c load current should not exceed half of the maximum peak plate current rating of the tube.

The MAXIMUM PEAK INVERSE VOLTAGE is the largest negative voltage that may be applied to the plate of the tube with safety at a time in the cycle when the tube is nonconducting. No rectified a-c pulses result during these periods. The peak inverse voltage across a full-wave rectifier is practically the the peak voltage of the full transformer secondary neglecting the drop across the conducting portion of the tube.

The voltage drop across the high-vacum tube is an important factor during the operation of the tube. When the cathode is heated, the electrons are drawn toward the plate and a space-charge voltage drop is built up in the tube. This voltage drop depends upon the current drawn and the construction of the tube, and may vary from a few volts to several hundred volts. Hence, the output voltage of a circuit using this tube is relatively low at heavy loads and is influenced principally by the drop in the tube.

Gas-filled rectifier tube.—As previously stated, the regulation of the high-vacuum rectifier tube is poor because of the variable-drop characteristic. On the other hand the gas-filled, or mercury-vapor, rectifier tube has a constant tube drop of about 15 volts irrespective of load conditions.

As in the high-vacuum tube, the two most important characteristics of the mercury-vapor rectifier tube are the (1) maximum allowable peak plate current at which the tube can be operated without disintegrating the filament and (2) maximum safe peak inverse voltage at which the tube can be operated without flashing back.

The peak plate current depends on the circuit conditions. If a full-wave rectifier is connected in a single-phase circuit to a resistive load, the peak current is the maximum of the sine wave of the rectified pulses. If an inductance is in series with the load, the output current has the form of successive square blocks and the peak plate current is nearly equal to the output current. If a capacitor is connected across the rectifier output, the peak plate current may reach values of from three to five times the output current. This is true because when the capacitor initially charges, it draws a current that is limited only by the low resistance of the circuit elements. This increase in tube current is caused by the low effective resistance across the conducting portion of the rectifier tube and the accompanying large capacitive charging current. For this reason a capacitor is seldom connected directly across the output of a mercury-vapor rectifier tube.

The peak inverse voltage is practically the full voltage of the transformer secondary in a single-phase full-wave rectifier because the voltage drop in the tube is only 15 volts and can be neglected. Because of this low tube drop there is no excessive heating of the tube. Hence, the efficiency of this tube is much higher than that of the high-vacuum tube.

Metallic-oxide rectifier.—If two different metals make contact with each other, electrons flow more easily in one direction across the junction than in the other direction. The two combinations of metals that are most widely used in metallic-oxide rectifiers are a thin film of (1) copper oxide on copper and (2) selenium on iron or aluminum.

A diode rectifies because electrons flow more easily from the cathode to the plate than from the plate to the cathode. A COPPER-OXIDE rectifier rectifies in a similar manner because electrons pass from the copper to the copper oxide much more easily than in the opposite direction.

An individual metallic-oxide rectifier unit consists of two washers, each about 1½ inches in diameter. The washers are made of copper that is oxidized on one side. A washer of soft metal, usually lead, is placed between the individual units to provide uniform pressure between the copper and cuprous oxide. Although it is possible to assemble any number of units to give any practicable power rating, this type of rectifier is used only where low voltages and power are required. The breakdown alternating voltage per unit is about 11 volts and the breakdown temperature is about 160° F. The efficiency of this type of rectifier is from 60 to 70 percent under normal operating conditions.

A half-wave metallic-oxide rectifier circuit is shown in figure 3–1. The arrows point in the direction in which the electrons pass more easily through the rectifier.

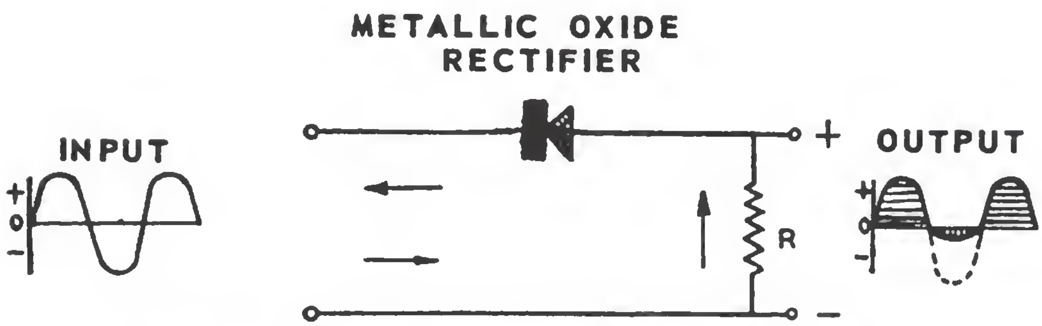


Figure 3–1.—Half-wave metallic-oxide rectifier circuit.

This rectifier acts like an electron-tube rectifier. On the positive half-cycles of the input voltage the cuprous oxide is more positive than the copper plate. Electrons flow freely from the copper plate to the cuprous oxide and the rectifier conducts as indicated by the arrows. On the negative half-cycles of the input voltage the copper plate is more positive than the cuprous oxide. Very few electrons flow from the cuprous oxide to the copper plate and the rectifier is non-conducting. The output is not a pure direct current because of a small amount of current that is passed on the negative half cycle, as indicated by the output waveform. Copper-oxide rectifier units are generally used in full-wave rectifier

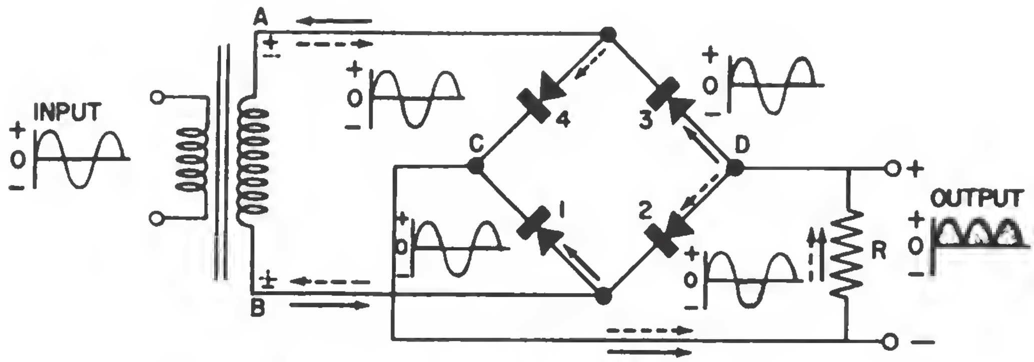


Figure 3–2.—Bridge-rectifier circuit.

circuits rather than half-wave, in order to limit the peak inverse voltage to that of the transformer supply when shunt input filter capacitors are used.

Rectifier Circuits

Bridge-rectifier circuit.—The bridge-rectifier circuit (fig. 3–2) is simply a method of connecting rectifiers. It is a single-phase, full-wave rectifier circuit that requires four rectifiers. Any kind of rectifier unit can be used in a bridge circuit. The input is applied to diagonally opposite corners of the circuit, and the output is taken from the remaining two corners.

During the positive half-cycle of the applied alternating voltage, point *A* is considered positive with respect to point *B* of the secondary. This voltage is impressed across unit 1, the load resistor *R*, and unit 3 in series. Units 1 and 3 conduct, as indicated by the solid arrows. A current flows from the bottom of the secondary, through unit 1, up through resistor *R*, through unit 3, and down through the secondary.

This flow of current up through the load resistor indicates the polarity of the voltage developed across it as positive at the top and negative at the bottom. At the same time the transformer voltage is impressed across rectifier units 4 and 2 in the inverse direction. Thus, units 4 and 2 are nonconducting.

On the next half-cycle, point *B* is positive with respect to point *A* of the secondary, and units 1 and 3 become nonconducting. The current now flows down through unit 4, up through the load resistor *R*, down through unit 2, and up through the secondary, as indicated by the broken arrows. The current through the load resistor is again accompanied by a voltage whose polarity is positive at the top and negative at the bottom of resistor *R*. Note that the current through the load resistor is in the same direction on both half-cycles. The bridge-rectifier circuit is a full-wave rectifier because current flows in the load resistor during both half-cycles of the applied alternating voltage.

Compared with the conventional two-unit full-wave rectifier using a center tapped transformer, the bridge-rectifier load circuit utilizes the entire transformer secondary voltage instead of half of it during each complete cycle. Hence, the output voltage available from the same transformer in the bridge-rectifier circuit is twice that of the two-unit rectifier. The peak inverse voltage in the bridge circuit is equal to the peak output voltage; whereas in the two-unit full-wave rectifier the peak inverse voltage is equal to twice the peak output voltage.

Filament type cathodes in a two-unit full-wave rectifier require only a single filament transformer winding to supply them either in series or in parallel. However, when tubes having filament type cathodes are used in a bridge-rectifier circuit, three separate filament transformer windings are required to supply the cathodes. This is because the difference in potential between the cathodes in two of the four arms of the bridge circuit is equal to the entire output voltage, and a single cathode filament supply winding would short-circuit this voltage. Thus a separate filament transformer winding is required for each of these two rectifier cathodes. A single third winding will suffice for the remaining two cathodes since there is no difference of potential between them. The need for three filament windings is eliminated when separate heater cathodes are used or when metallic oxide rectifier units make up the bridge circuit.

VOLTAGE-DOUBLER RECTIFIER CIRCUIT.—The voltage-doubler rectifier circuit (fig. 3–3) utilizes two capacitors. The capacitors are charged on alternate half-cycles and are arranged in the circuit so that the voltages on the two capacitors add in the output. The output of such a circuit is about twice the peak input voltage.

When point *A* on the transformer secondary is positive with respect to point *B*, the plate of *V*1 is more positive than its cathode. Electrons are attracted to the plate and flow from the cathode to the plate of *V*1, through the transformer, and up through the load resistor *R*1, as indicated by the solid arrows. At the same time, electrons leave the upper plate of *C*1, flow through *V*1, and accumulate on the lower plate of *C*1. Thus, the upper plate of *C*1 is positive with respect to the lower plate of *C*1 by a voltage equal to the peak voltage of the input wave.

During the next half cycle point *A* is negative with respect to point *B*, and *V*1 is nonconducting. Capacitor *C*1 discharges slightly through resistor *R*1. While *C*1 is discharging slightly, *C*2 is being charged by the electrons that flow through *V*2. The electron flow during this half cycle is indicated by the broken arrows. On this half cycle *C*2 is charged to the peak voltage of the input wave. The output voltage is taken between point *O* and ground and is equal to the sum of the voltages on *C*1 and *C*2, or nearly twice the peak voltage developed across the transformer secondary.

Note the waveforms of the input and output voltages. The current begins to flow in *V*1 when the input sine wave rises above the voltage on the capacitor and stops flowing as soon as the sine wave begins to decrease from its peak voltage. Similarly, *V*2 conducts during the half cycles in which *V*1 is nonconducting.

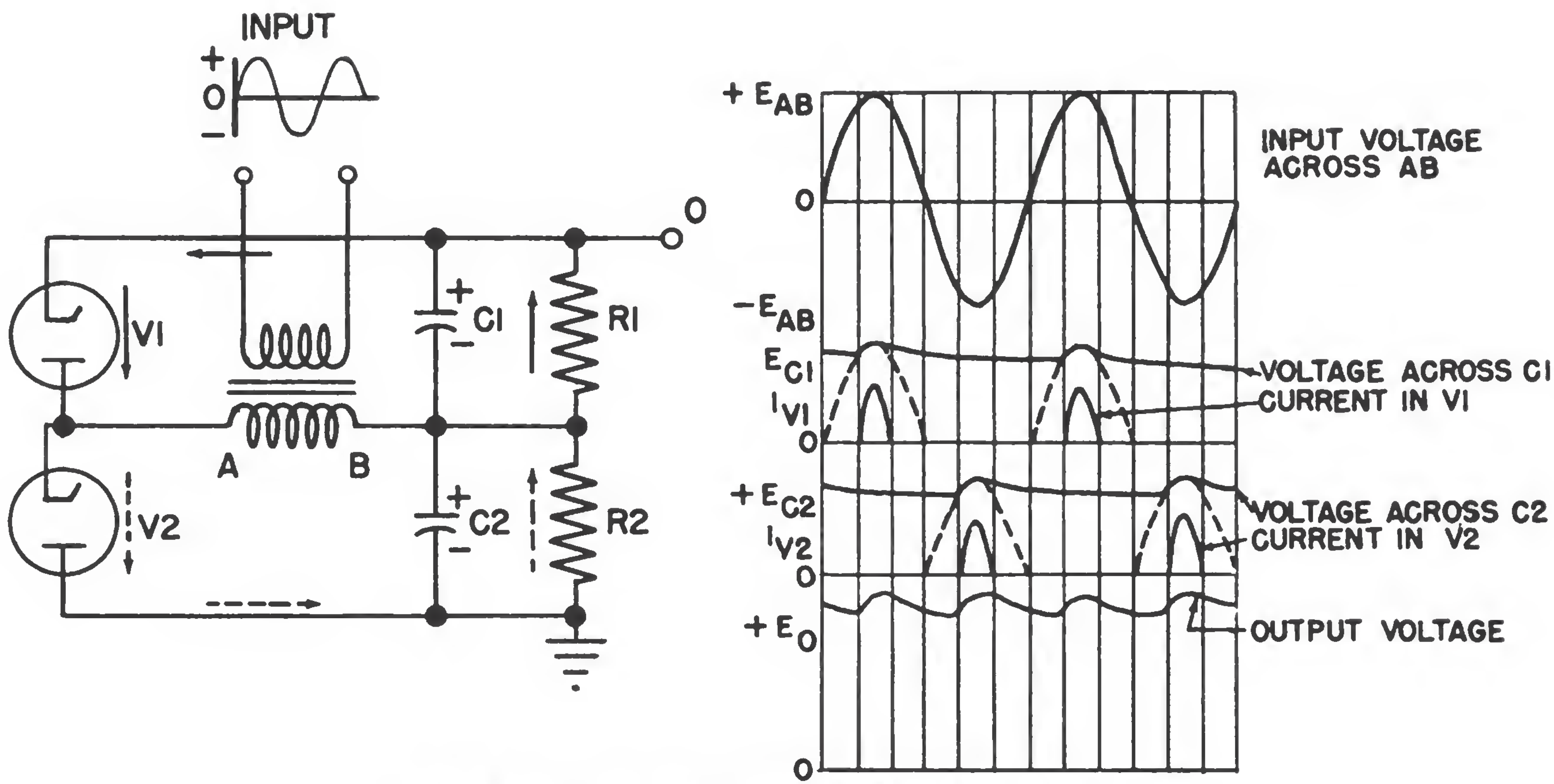


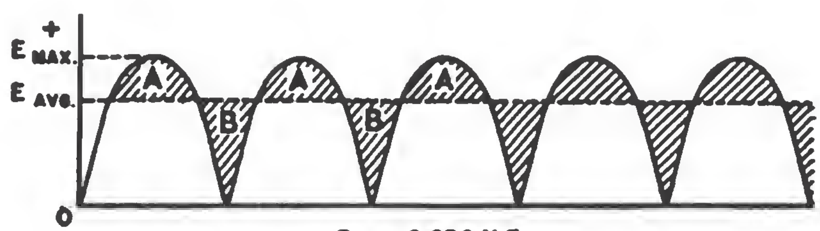
Figure 3–3.—Half-wave voltage-doubler rectifier circuit.

Resistors $R1$ and $R2$ have high resistance that permit the charge to leak off the capacitors when the transformer is de-energized. This is a safety measure to prevent injury to personnel from high voltage after the equipment has been secured. These resistors also equalize the voltage drops of the capacitors if a difference exists in their d-c leakage resistance. Thus, the working voltage of the capacitors is not exceeded.

The current delivered to the load comes from capacitors $C1$ and $C2$ in series. The application of this type of circuit therefore, is limited to loads requiring small currents. If a large current is drawn, the voltage across the capacitors drops greatly and the regulation is poor. If the capacitors are large the tubes can be protected from excessive peak current by placing limiting resistors in the cathode lead of $V1$ and in the plate lead of $V2$.

Filter Circuits

The output of any rectifier consists of a direct voltage and an alternating voltage. The output voltage has the same polarity, but its magnitude fluctuates about an average value as the pulses of energy are delivered to the load. The average voltage (fig. 3–4) is the line which divides the waveform



$E_{AVG.} = 0.636 \times E_{MAX.}$

Figure 3–4.—Average value of a full-wave rectifier output.

so that area *A* equals area *B*. The fluctuations of voltage above and below this average value are called RIPPLE VOLTAGE.

The frequency of the ripple of the output voltage from a full-wave rectifier is twice the input frequency to the rectifier. The frequency of the ripple from a half-wave rectifier is the same as the frequency of the input alternating voltage.

Thus, if the input voltage is obtained from a 60-cycle source, the main component of the ripple in the output of a half-wave rectifier is 60 cps, and the full-wave rectifier is 120 cps.

The rectified pulsating voltage must be smoothed out to a steady nonpulsating direct voltage before it can be applied to the plate or grid circuits. These pulsating voltages are

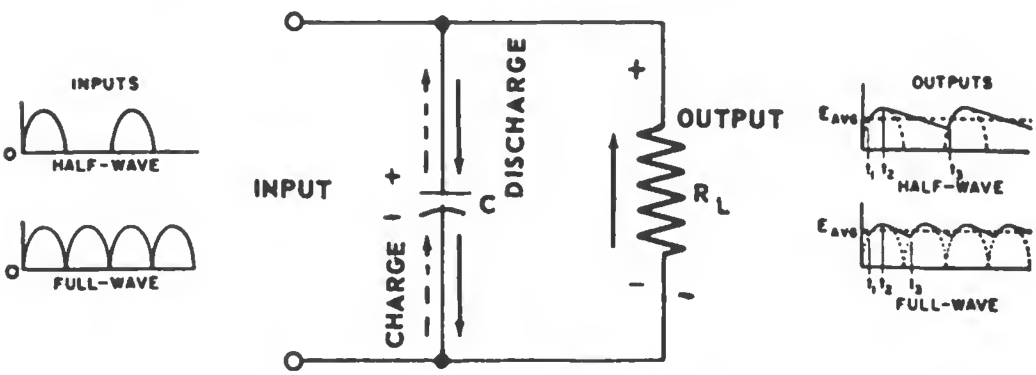


Figure 3–5.—Capacitive filter circuit.

smoothed out by means of filter circuits, which remove the peaks and fill in the valleys of the output waveform. Filter circuits consist of combinations of capacitors, inductors, and sometimes resistors.

Capacitive filter.—Ripple voltage exists because energy is supplied to the load through a rectifier in pulses. The ripple can be reduced if some of the input energy is stored in a capacitor and then used to supply the load between the pulses of energy through the rectifier. A capacitive filter circuit is shown in figure 3–5. The output voltage of a rectifier is applied across the filter capacitor, C, to supply the load resistor R_L. Capacitor C charges to the peak voltage of the rectifier within a few cycles after the circuit is energized.

Consider the output waveforms at three successive instants of time—t_1, t_2, and t_3. The action at these three instants shows how a capacitor filters out most of the d-c pulses. From instant t_1 to t_2 the pulsating voltage is increasing and the capacitor is charging, as indicated by the broken arrows. At instant t_2 the pulsating voltage is decreasing and the capacitor starts to discharge through the load resistor R_L as indicated by the solid arrows. The capacitor cannot discharge through the source because of the high resistance offered by the rectifier to the flow of current in a direction opposite to conduction. This discharge through the load continues as long as the pulsating input voltage is less than the voltage associated with the charge on the capacitor. At instant t_3 the charging and discharging cycle starts to repeat. Hence, the capacitor charges on the strong values of input voltage and discharges on the weak values of input voltage.

The output voltage can never fall to zero because the capacitor stores energy quickly during the pulse and delivers this energy slowly to the load between pulses because of the long time constant. This action produces higher average values for both the half-wave and the full-wave filtered outputs than those of the unfiltered inputs. If the resistance of the load is small, however, a large current is drawn by the load and the average output voltage falls. For this reason the simple capacitive filter is not used with rectifiers that supply large load currents.

RESISTIVE-CAPACITIVE (PI) FILTER.—A filter circuit consisting of a series resistor and two shunt capacitors is used for some applications. A resistive-capactive (*R-C* or pi) filter circuit is shown in figure 3–6. Shunt capacitor *C*1 offers an infinite impedance to the d-c component of input voltage between point *A* and ground. Hence any d-c leakage current through capacitor *C*1 is negligible. Series resistor *R*1 offers low impedance (about 50 k-ohms) to the d-c

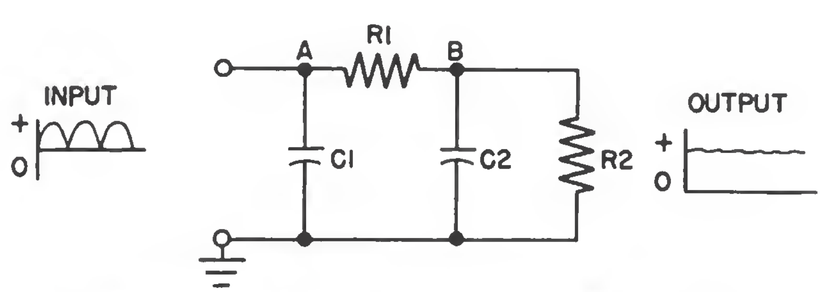


Figure 3–6.—Resistive-capacitive (pi) filter circuit.

component of load current flowing through the load $R2$. The direct voltage divides across $R1$ and $R2$ in proportion to the individual resistances. The d-c component of load current through $R1$ is limited by the desired load voltage since $R1$ is effectively in series with $R2$ and reduces the load voltage directly as load current increases. Hence the R-C filter is suitable for supplying constant potential to small current loads such as the screen grids of pentodes in order to keep the output voltage satisfactorily high.

The ripple component of the voltage is offered a very low impedance by $C1$ (about 500 ohms) and a relatively high impedance by $R1$ (about 50 k-ohms). Hence most of the current produced by the ripple voltage passes through $C1$. A small amount of this current passes through $R1$ and a small ripple voltage appears at point B. Capacitor $C2$, however, offers a lower impedance to the ripple frequency than does the load $R2$, and most of the ripple at B is shunted by $C2$.

INDUCTIVE FILTER.—An inductor in series with the rectifier output helps to prevent abrupt changes in the magnitude of the current. The smoothing action that results is caused by the reactance which opposes any change of current through the inductor. An inductive filter circuit is shown in figure 3–7. The broken waveforms show the type of load current supplied to a pure resistive load, R, with no filtering. If an inductance, L, is added in series with the load resistor, R, the output current to the load is modified as shown by the solid curves. The modification in the wave-

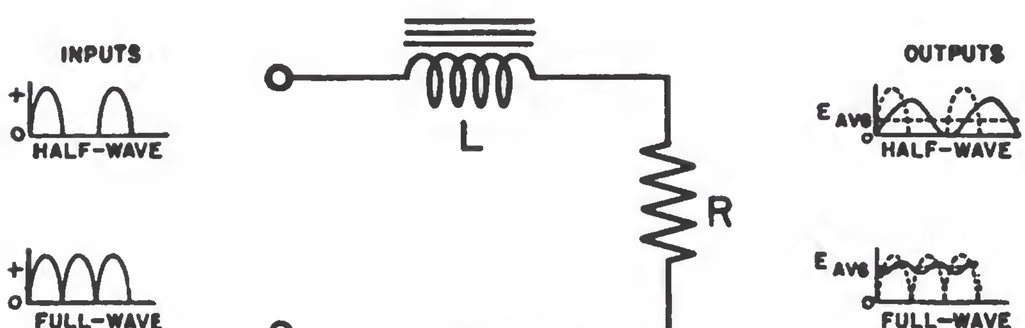


Figure 3–7.—Inductive filter circuit.

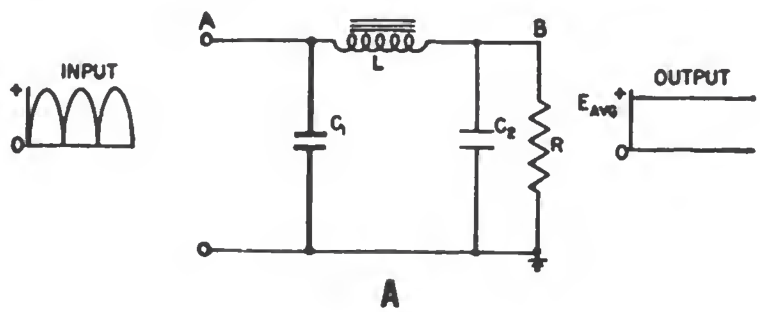
317993 O—55——6

form takes place because the reactance of the inductor opposes the build-up and the decrease of the d-c pulses. If the inductance is large enough the current becomes nearly constant.

The series input inductance prevents the current from ever reaching the peak value that it would reach with a shunt input capacitance. Also, a rectifier output that is filtered by a series input inductor cannot produce as high a voltage as one that is filtered by a shunt input capacitor. The inductive filter, however, permits a relatively large load current to flow without serious loss in output voltage. Inductors used in filter circuits are called CHOKES because they choke, or stop the passage of, the ripple current through the load.

INDUCTIVE-CAPACITIVE FILTER.—The ripple voltage in a rectifier output cannot be eliminated adequately for most electronic circuits by either the simple capacitive filter or the inductive filter. More effective filters can be made by using both inductors and capacitors. Two inductive-capacitive (*L-C*) filter circuits are shown in figure 3–8.

The inductive-capacitive filter circuit (fig. 3–8, A) is called a CAPACITOR-INPUT FILTER because the voltage input



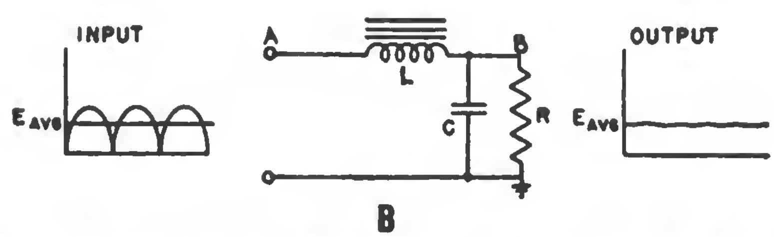


Figure 3–8.—Inductive-capacitive filter circuit. A, Capacitor input filter; B, choke input filter.

to the filter circuit is applied first across the capacitor. Because the output of a rectifier consists of a direct voltage on which is superimposed an alternating, or ripple, voltage, the function of the filter is to remove the alternating component from the output. Capacitor $C1$ (fig. 3–8, A) has an infinite impedance to the direct voltage, but a very low impedance to the ripple voltage. Hence, most of the ripple voltage is bypassed by capacitor $C1$. The remaining ripple voltage is offered a high impedance by inductor L.

The inductive reactance of inductor L constitutes the high impedance to the ripple voltage. The impedance offered to the d-c component of voltage is low because of the low effective resistance of the choke. In this respect the choke offers an advantage over a series resistance $R1$ (fig. 3–6). A higher load current through L than through $R1$ may be accompanied by less direct voltage drop in the former than in the latter. The small amount of ripple voltage that is not absorbed by inductor L is shunted to ground by the low impedance of capacitor $C2$. The result is that the output voltage has very little ripple.

At no load the output voltage of the capacitor-input filter is nearly equal to the peak value of the input alternating voltage. As the load current is increased, the output voltage drops because the lower effective resistance of the load prevents the capacitor from retaining its charge. Hence, the capacitor-input filter is not used for applications that require a large load current because of poor voltage regulation. Also if the input capacitor is very large the peak current that must flow in the rectifier to charge the input capacitor may damage the rectifier tubes. For these reasons moderate size input capacitors are used with light or constant loads.

The inductive-capacitive filter circuit (fig. 3–8, B) is called a CHOKE-INPUT FILTER because the voltage input to the filter circuit is applied first across the inductor in series with the load. The choke-input filter has a lower output voltage than the capacitor-input filter because the inductor, L, of the choke-input filter tends to maintain the output voltage at approximately the average value of the rectified alternating voltage.

At no load the output voltage of the choke-input filter is nearly equal to the peak value of the input alternating voltage. This voltage is obtained at no load because as the charge on capacitor C approaches its maximum value, the charging current through the series inductance approaches zero. Thus the impedance voltage across L approaches zero at the time the charging voltage across C becomes maximum However, if only a small load current is drawn, the output voltage drops sharply. This sharp drop occurs because the impedance of inductor L prevents a surge of current from charging capacitor C to the peak voltage. As the load further increases, there is very little change in the output voltage except for the drop that occurs in the effective resistance of inductor L. This type of filter has good regulation.

Effect of frequency.—Most power supplies are designed for operation on 60-cycle a-c service. If the frequency of the input voltage is increased, the components can be made smaller. The filters can be made smaller because, as the frequency increases, the reactance of a given capacitor decreases and the reactance of a given inductor increases. For a given shunting effect the capacitance of a filter capacitor varies inversely with the frequency. For a given series reactance the inductance of a series choke varies inversely with the frequency. Also, for a given exciting current the inductance of the power supply transformer varies inversely with the frequency. Hence, the size of these components becomes smaller when the frequency is increased.

However, adequate filtering can be obtained with less capacitance and inductance when the input frequency is higher. Under these conditions smaller and lighter capacitors and inductors can be used in the filter. Another important factor is that high-frequency power transformers are smaller and lighter than low-frequency transformers that have the same voltage and power rating. For example, aircraft power supplies are designed to operate on 400 or 800 cycles to save weight and space.

Voltage Regulators

A voltage regulator is a device that maintains the output voltage of a power supply constant irrespective of changes either in load current or in input voltage. Electronic voltage regulators ordinarily are used with rectifier power supplies. Other types of regulators generally are used with rotating machines.

The regulator that is used to stabilize the output voltage of a rectifier usually consists of a variable resistance, *R*, in series with the output, as shown in figure 3–9. This variable

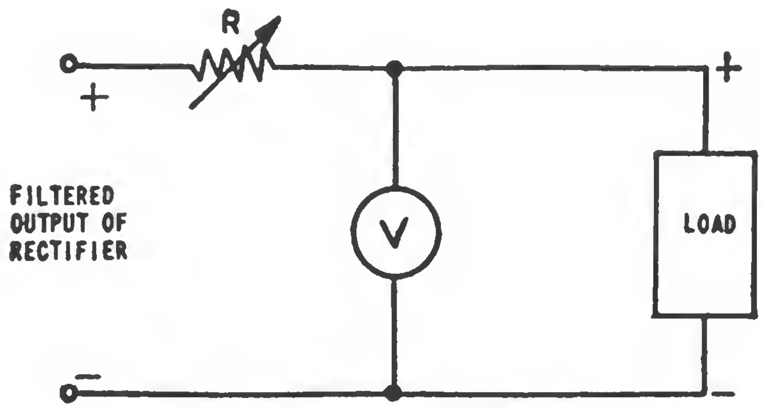


Figure 3–9.—Voltage-regulator circuit.

resistance and the load form a series voltage-divider circuit in which the variable resistance is adjusted when the load voltage tends to change so that the voltage across the load is held constant.

A voltage drop occurs across resistor *R* because all the load current passes through it. If the output voltage increases because of an increase either in the supply voltage or in the load resistance, the resistance of *R* must be increased so that a larger voltage drop occurs across the resistor. This action causes the voltage across the load to remain nearly constant.

In this simple regulator, resistor *R* must be varied manually according to the reading of voltmeter *V*. If the voltmeter reading increases, resistor *R* must be increased; and if the voltmeter reading decreases, resistor *R* must be decreased. This action takes place automatically in electronic voltage regulators. The variable voltage drop can be obtained in many ways, but the principle of operation is similar to that of the simple circuit shown in figure 3–9.

AMPERITE REGULATOR.—A simple device that can be used as a voltage regulator for constant loads is an amperite, or ballast, tube. It consists of an iron wire resistor enclosed in a glass envelope containing an inert gas. An elementary amperite regulator circuit is shown in figure 3–10.

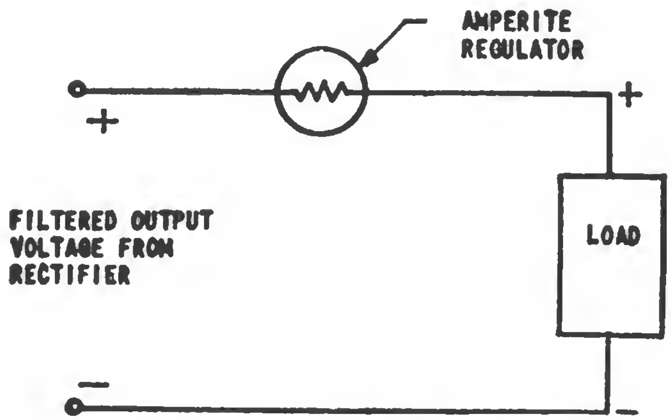


Figure 3–10.—Amperite regulator circuit.

The resistance of the iron wire in the ballast tube varies as the current through it changes. If the current tends to increase, the resistance of the wire increases and vice versa. Thus, the variable resistance of the amperite tube maintains the current flowing through it constant. This property can be used to compensate for changes in input voltage over a fairly wide range. If the input voltage increases, the current through the load increases. The resistance of the tube then increases and more of the voltage drop takes place across the tube. Thus the rise in current is checked and the load voltage maintained nearly constant.

The amperite regulator is not capable of holding the load voltage constant if the load changes—that is, if the load resistance decreases or increases. For example, decreasing the load resistance increases the current through the ballast tube and the voltage drop across it. Because the ballast tube is in series with the input, the increased drop subtracts a greater voltage from the input. Hence the voltage across the load is decreased a greater amount because of the ballast tube. However, when the load resistance is fixed the ballast tube is a good current regulator.

The ballast tube is often used in series with series-connected filaments which obtain their power supply from batteries. The ballast tube maintains a constant current through the filaments irrespective of variations in the battery voltage.

VACUUM-TUBE VOLTAGE REGULATOR.—A vacuum tube can be considered as a variable resistance. When the tube conducts, the effective resistance of the tube is the plate-to-cathode voltage divided by the current through the tube and is called the d-c plate resistance R_p. The plate resistance of the tube for any given plate voltage depends upon the current through the tube, which in turn depends upon the grid bias.

The variable resistor R in figure 3–9 can be replaced by a vacuum tube $V1$, as shown in figure 3–11. The effective re-

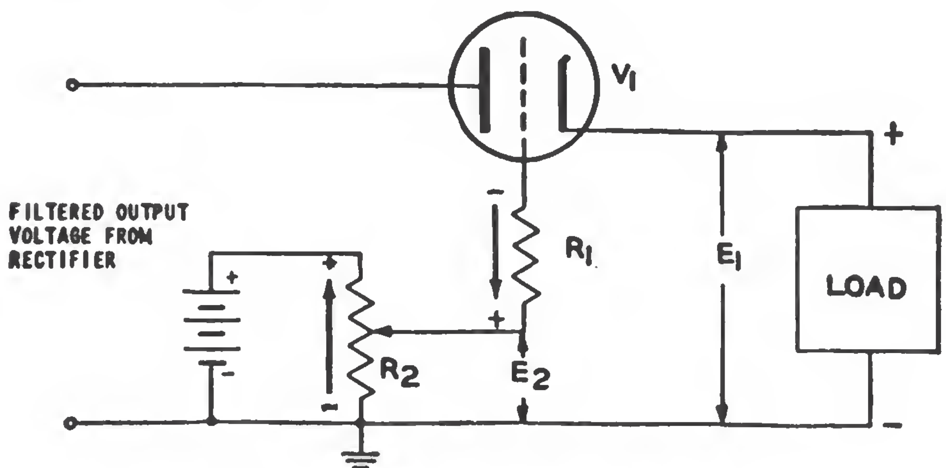


Figure 3–11.—Vacuum-tube voltage regulator circuit.

sistance of $V1$ in the circuit depends upon the grid bias.

When the voltage is applied to the load, the cathode of the tube is positive with respect to ground by some voltage, $E1$. The grid can be made positive relative to ground by a voltage, $E2$, which is less than $E1$. The potentiometer, $R2$, is adjusted until the bias ($E1-E2$) is sufficient to allow $V1$ to pass the full load current. With this bias, the resistance of $V1$ is kept at the proper value to reduce the rectifier output voltage to the desired load voltage. Because the cathode is at the positive output terminal and the drop across $V1$ is small, the grid must be at a positive potential slightly below that of the source.

If the rectifier output voltage increases, the voltage at the cathode of $V1$ tends to increase. As $E1$ increases the bias on the tube increases and the effective plate resistance of the tube becomes greater. Consequently, the voltage across $V1$ is greater. If the circuit is designed properly, the increased voltage drop across $V1$ compensates for the increase in voltage of the rectifier. Hence, the voltage across the load remains essentially constant.

The vacuum-tube regulator can compensate also for changes in load. If the load changes and draws more current, the output voltage begins to drop. This action decreases the cathode potential and thus decreases the bias. The effective resistance of the tube decreases, and the output voltage is held constant.

The load and battery voltages are in opposition in the grid-cathode circuit. The battery tends to make the grid positive, but the load makes it negative because its voltage exceeds that of the battery. In the absence of regulator input voltage, there is no load current or negative grid bias. Now the battery makes the grid positive and electrons flow from the cathode to the grid through series resistor $R1$ and back to the cathode. The accompanying voltage drop across $R1$ lowers the positive grid bias because it is opposed to the battery voltage. This action prevents excessive grid current.

Gas-tube voltage regulator.—When the gas in the simple gas-filled tube is ionized, the voltage across the tube remains constant over a fairly wide range of current through the tube. This property exists because the amount of ionization of the gas in the tube varies with the amount of current that the tube conducts. When a large current is passed, the gas is highly ionized and the internal impedance of the tube is low. When a small current is passed, the gas is lightly ionized and the internal impedance of the tube is high. The IR drop across the tube is practically constant over the operating range of the tube because as I increases R decreases and vice versa.

A gas-tube voltage regulator circuit is shown in figure 3–12. The load current and the current that flows through the gas tube both flow through the series resistor, R. If

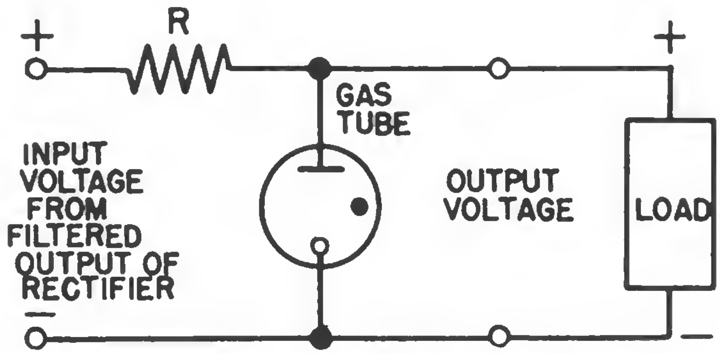


Figure 3–12.—Gas-tube voltage regulator circuit.

the supply voltage drops, the voltage across the gas tube tends to drop. However, the gas in the tube deionizes slightly, and less current passes through the tube. The current through R is decreased by the amount of this current decrease in the tube. Because the current through R is less, the voltage drop across R is less. If the resistor is of the proper value relative to the load and to the gas tube, the voltage across the load is kept nearly constant.

Now consider the regulator action when the load changes. If the input voltage is constant and the resistance of the load decreases, load current starts to increase and the increased voltage across R tends to lower the load voltage and that across the gas tube. This tendency is overcome by a reduction in the amount of ionization within the gas tube and a corresponding reduction in tube current. Thus less current flows through the tube and more through the load so that the total current through series resistor R remains constant. The load voltage therefore remains constant because the input voltage and the drop in voltage across the series resistor are not affected by the increase in load current and they remain the same as before the load resistance decreased. Hence, the gas-tube regulator compensates for both changes in load and changes in input voltage.

Gas tubes such as the VR75, the VR105, and the VR150 have different gases so that they operate at different voltages. The letters "VR" denote the function of the tube as a voltage regulator and the number following the letters denotes the terminal voltage of the tube.

The battery in the vacuum-tube regulator (fig. 3–11) can be eliminated from the circuit by using a gas tube and voltage divider to supply a fixed bias for the grid of the vacuum tube. In such a circuit, the grid voltage is kept constant by the gas tube. The operation of this regulator circuit is the same as that described for the vacuum-tube voltage regulator.

The conventional type of voltage regulator utilizes the pentode vacuum tube with its inherent advantage of high amplification. This voltage regulator (fig. 3–13) produces

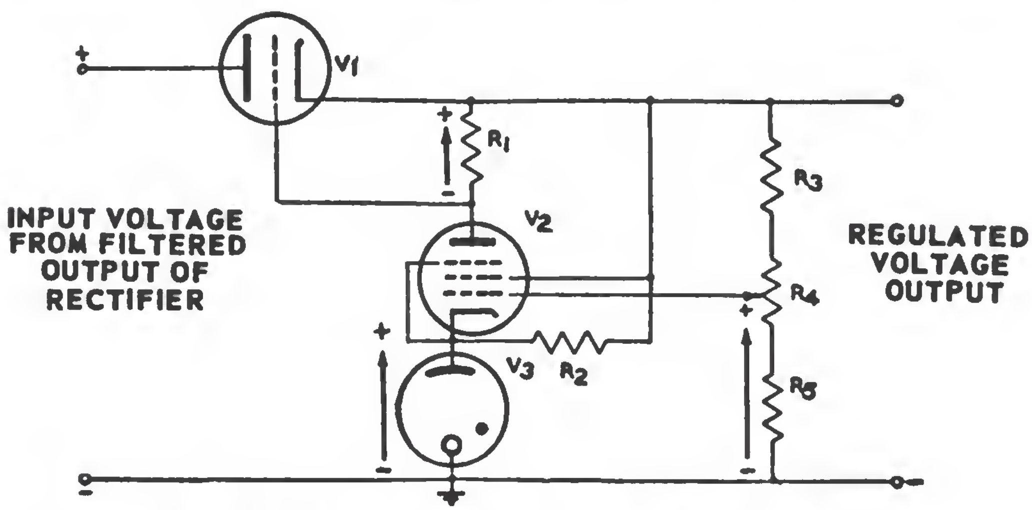


Figure 3–13.—Conventional voltage regulator circuit.

an output voltage that is independent of both the fluctuations in the a-c supply and the changes in the load.

The output voltage of this regulator is developed across the bleeder resistors *R*3, *R*4, and *R*5 in parallel with the resistance of the load. These resistances comprise the resistance of one part of the total voltage divider. The other resistance, through which all of the load current must flow, is the plate-to-cathode resistance of tube *V*1. The other elements in the circuit are used to control the effective resistance of $V1$ and thus maintain a constant voltage across the load.

The plate voltage of $V2$ is the regulated voltage output of the regulator minus the drop through $R1$. The potential of the cathode of $V2$ is kept at a constant positive value with respect to ground by the gas tube, $V3$. The control grid potential of $V2$ is a voltage selected by the potentiometer, $R4$. The potentiometer is adjusted so that the grid voltage is less positive with respect to ground than the cathode voltage by an amount (equal to the bias), that causes $V2$ to pass a certain plate current. This plate current flows through plate load resistor $R1$ and causes a voltage drop across it. The magnitude of the voltage across $R1$ is the bias on tube $V1$. Thus, the adjustment of potentiometer $R4$ establishes the normal effective resistance of $V1$. This adjustment is used to set the value of load voltage that the regulator is to maintain.

If the load voltage tends to rise, either from a decrease in load current or from an increase in the input voltage, the voltage on the control grid of $V2$, also tends to rise (become less negative), the cathode voltage remaining practically constant. Tube $V2$ then conducts more current because the bias is smaller. A larger current flows through $R1$, causing a greater voltage drop across it. This voltage drop, which is the bias voltage for $V1$, causes the effective resistance of $V1$ to increase. A larger portion of the available voltage appears across the higher effective resistance of $V1$, and the load voltage remains practically constant. The converse of this action occurs if the load voltage tends to fall.

This regulator is very effective in removing ripple from the output of rectifier power supplies because of its sensitivity to small changes of input voltages. Thus, it serves also to filter the output of a rectifier, although the usual filter systems are used with it. Hence, this type of regulator is used widely to stabilize the output voltage of rectifier power supplies.

Voltage Dividers

Frequently a resistor is placed across the output terminals of a rectifier power supply. The name applied to such a resistor depends upon its principal use. If the resistor is used to discharge filter capacitors when the rectifier is deenergized, or to draw additional current (not load current) to improve the voltage regulation of the power supply, it is called a BLEEDER RESISTOR. If leads are connected to the resistor at various points to provide a variety of voltages less than the terminal voltage, the resistor is called a VOLTAGE DIVIDER.

A resistor across the output terminals of a rectifier power supply may in general fulfill all of these functions. If the resistor is used as a bleeder resistor to discharge a filter capacitor, it usually has a very high resistance so that it draws a negligible current from the rectifier. If the resistor is used as a bleeder resistor to stabilize load voltage it should draw a minimum of 10 percent of the full-load current. Such a resistor should have a power rating sufficient to dissipate the heat produced by the current without excessive temperature rise.

A resistor connected in shunt with the load can be used as a voltage divider because the current flowing through the resistor produces a voltage drop across it that is proportional to the resistance. A voltage divider consisting of three identical resistors (*R*1, *R*2, and *R*3 of 50 k-ohms each) connected in series but grounded at different points is shown in figure 3–14. When no load is drawn from any terminal

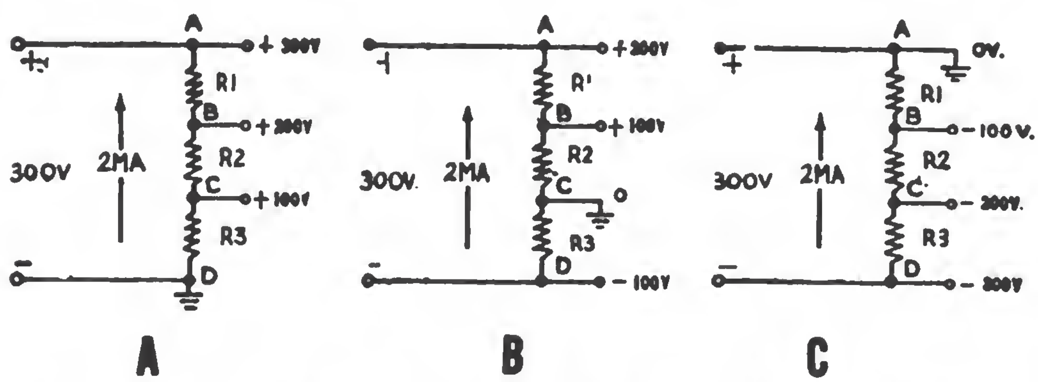


Figure 3–14.—Voltage divider. A, Point D grounded; B, point C grounded; C, point A grounded.

except the top or line terminal, the voltages across the resistors divide equally.

It is common practice to ground one side of most electronic circuits. Ground is normally used as a reference for measuring voltages as shown at point *D* (fig. 3–14, A). If a rectifier and its filter are connected so that no parts of the power supply are grounded, it is possible to ground the circuit at any point without affecting the operation of the rectifier. Thus, point *C* (fig. 3–14, B) is grounded and point *D* becomes 100 volts negative with respect to ground. Such a circuit is used to furnish both plate and bias voltages from the same power supply. Point *A* (fig. 3–14, C) is grounded and all voltages along the divider are negative with respect to ground. Point *A*, however, is always more positive than point *B* as long as the polarity of the power supply is maintained as shown in figure 3–14, A, B, and C.

When a load is attached to the voltage divider at any intermediate terminals, the voltage division shown in figure 3–14 is no longer correct. The resistance of the attached load forms a parallel circuit with the part across which the load is attached. Thus the resistance is changed between the terminals of the voltage divider across which the load is connected. Hence the total resistance, current, and voltage of the voltage divider are correspondingly changed.

In figure 3–15 a load, *R*4, of 150 k-ohms is placed across *BD* and a load, *R*5, of 50 k-ohms is placed across *CD*. Resistance R_{CD} is determined by Ohm's law for parallel resistors—

$$R_{CD}=\frac{50\times 50}{50+50}=25 \text{ k-ohms.}$$

Resistance R_{BD} (without *R*4) is *R*2 plus R_{CD} (50+25), or 75 k-ohms. Then by Ohm's law for parallel resistors,

$$R_{BD}=\frac{75\times 150}{75+150}=50 \text{ k-ohms.}$$

The total resistance, R_{AD} (without the main load), is *R*1 plus R_{BD} (50+50), or 100 k-ohms.

The total current taken by the divider and its two loads is

$$I_t=\frac{E_t}{R_{AD}}=\frac{300}{100}=3 \text{ milliamperes.}$$

This current of 3 milliamperes flowing in $R1$ produces a voltage drop of $I_t \times R1$ (3×50), or 150 volts. Hence when

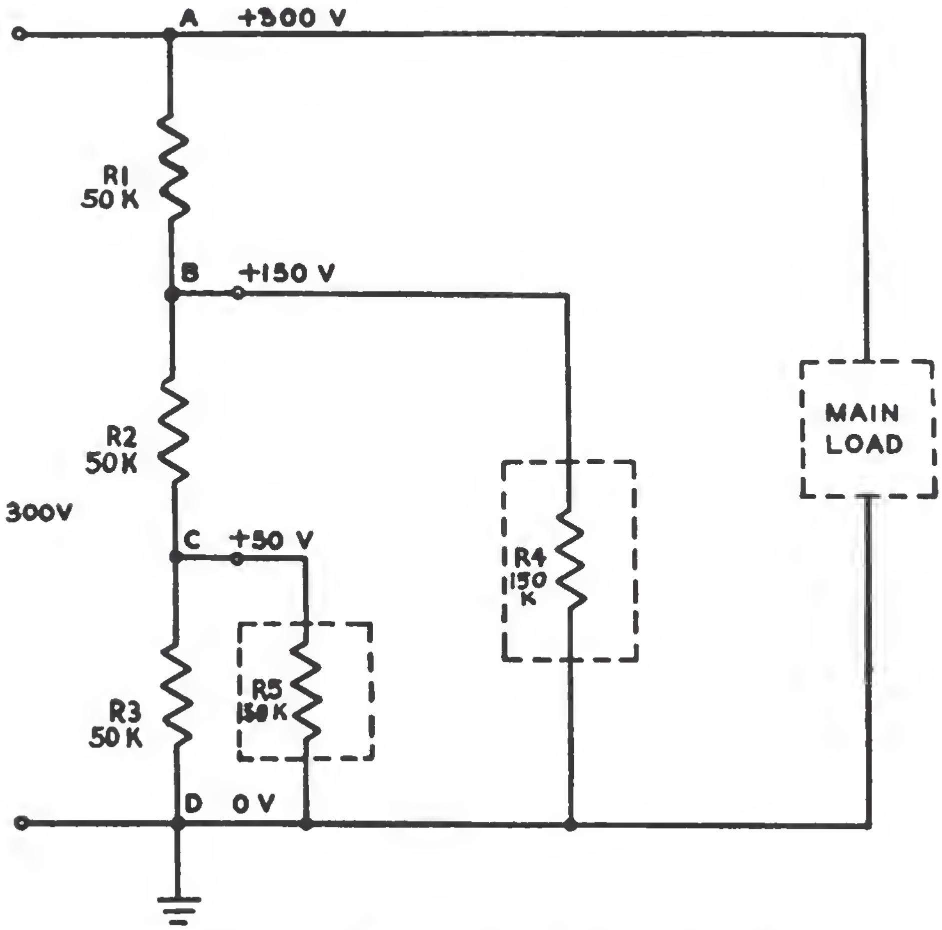


Figure 3–15.—Effect of loads on voltage division.

loads $R4$ and $R5$ have the values shown, $R1$ absorbs one-half of the available voltage instead of one-third as in the no-load condition (fig. 3–14, A).

The current of 3 milliamperes divides at B and flows through load $R4$ and resistor $R2$. The voltage across load $R4$ is $300-150$, or 150 volts. The current through load $R4$ is $150\div 150$, or 1 milliampere. The current in resistor $R2$ is $3-1$, or 2 milliamperes.

The current of 2 milliamperes flowing in resistor $R2$ produces a voltage drop of $0.002 \times 50{,}000$, or 100 volts. Thus, the voltage remaining to be applied across CD is $150-100$, or 50 volts. The current in load $R5$ is $50 \div 50$, or 1 milliampere. The current in resistor $R3$ is $2-1$, or 1 milliampere.

Other values of loads give correspondingly different values of voltage at B and C. Hence, the voltage across the intermediate terminals of a voltage divider divides proportionally to the values of the divider resistors only if no appreciable load is drawn from these terminals. Under loaded conditions the voltages at these terminals have various values depending upon the resistances of the loads. A voltage divider must therefore be designed for the particular load conditions under which it is to operate.

Full-Wave Voltage-Regulated Power Supply

A full-wave rectifier power supply circuit is shown in figure 3–16. The primary of the power transformer is connected to the 120-volt 60-cycle service from the I. C. switchboard. The low-voltage secondary of the power transformer supplies alternating current at 5 volts to the filament of the rectifier tube. Each end of the high-voltage secondary is connected to one of the plates of the duodiode rectifier tube. The high-voltage secondary is center-tapped. The center tap is connected to the negative, or ground, side of the voltage divider and to the external load. The rectifier cathodes are connected to the most positive terminal of the voltage divider through the low voltage secondary capacitor-input filter and voltage regulator.

When the power transformer energizes the plates of the rectifier tube, each plate becomes alternately positive and negative with respect to the cathode. The electrons emitted by the heated cathode are attracted by whichever plate is positive. From this plate the electrons flow through the half of the transformer that is connected to that plate and out the center tap of the winding to the load. Because one

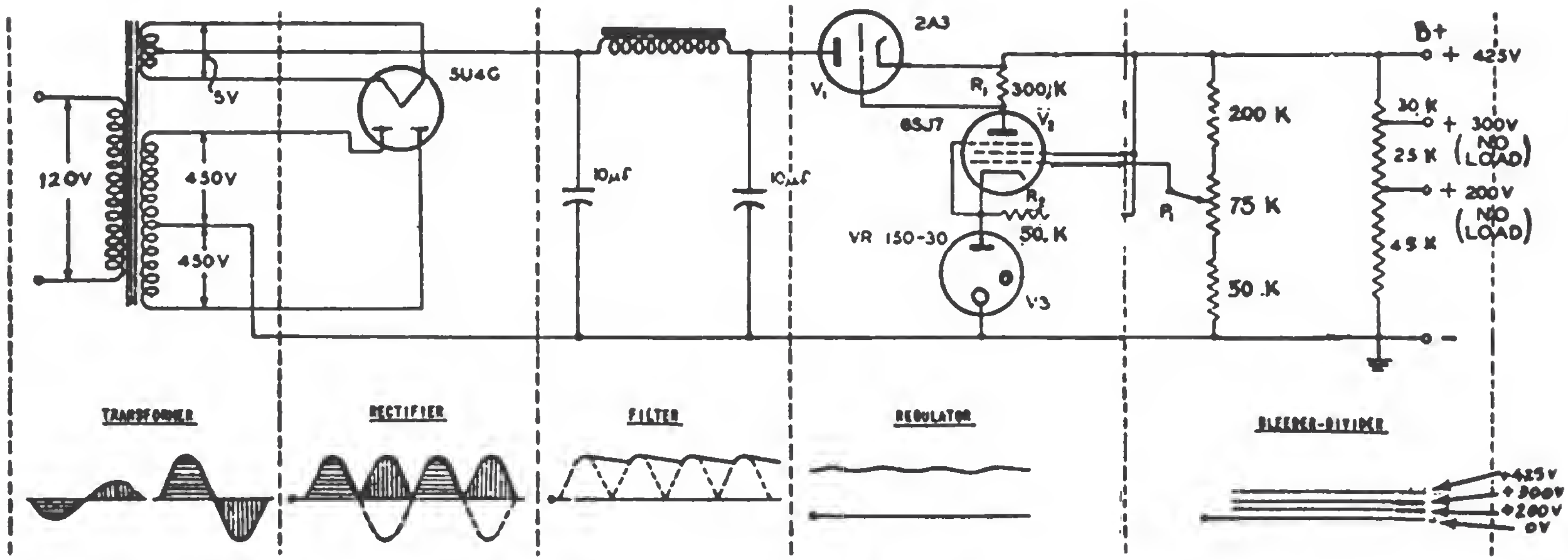


Figure 3–16.—Full-wave rectifier power supply circuit.

of the plates is always positive with respect to the cathode, current flows through the load on each half cycle.

The capacitor-input filter smooths the ripple voltage from the output of the rectifier tube. The voltage regulator maintains a constant output voltage. Pure direct current is available at the B+ output of the power supply circuit. The bleeder resistor with taps provides several lower d-c potentials for low-current applications.

D-C POWER SUPPLIES

D-c power supplies are divided into two groups depending upon the source of power. The first group receives its power from storage batteries, and the second group receives its power from the ship's service 120-volt d-c supply. Vibrators or motor-generator sets are used with batteries and other low-voltage sources to obtain the relatively high direct voltages necessary for electronic applications.

Vibrator

A nonsynchronous vibrator can be used in a power supply to change direct current from a low-voltage source (usually 6-volt or 32-volt batteries) to a higher direct voltage. Vibrators are very dependable when used within their rated limits. The life of the vibrator, however, is about half that of an electron tube. The only item that has to be replaced often is the vibrator itself, which is inexpensive and easily installed. Vibrators are available in sizes up to 100 watts. This maximum rating limits their use to applications that require very little power.

A vibrator power supply circuit is shown in figure 3–17. When power is applied to the unit, current flows through one half of the transformer primary and through the magnet coil of the vibrator. The magnetic field produced by the coil attracts the center contact, *C*, and closes contact *A*, shorting out the coil. This action causes a large current to flow through the transformer primary. The magnetic field of the vibrator magnet collapses because of the short across the coil and releases contact *C*. Contact *C* springs back to close contact *B*, and for a brief interval the other half of the transformer primary is connected to the d-c supply. The instant contact *A* opens, the magnet begins to attract center contact *C*. However, the field of the magnet builds up relatively

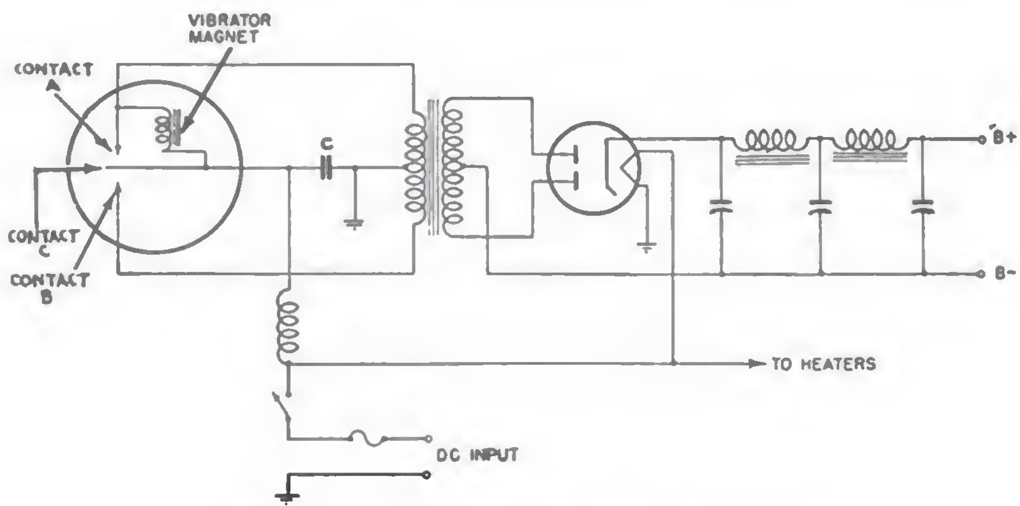


Figure 3–17.—Vibrator power supply circuit

slowly so that the full attraction is not produced immediately. Because center contact *C* is attached to an armature which has some inertia and because contact *C* is positioned normally nearer to contact *B* than to contact *A*, momentum carries it a short distance beyond its normal position to close contact *B*. The switching action of center contact *C* first causes current I_1 to flow in one half of the transformer primary and then current I_2 in the other half flows in the opposite direction. This action produces an alternating flux which induces an alternating voltage in the secondary. The secondary voltage causes first one plate and then the other of the twin diode rectifier tube to become positive on successive half cycles. By proper design of contact springs and center contact, a usable a-c waveform is produced.

Synchronous Vibrator

The synchronous, or self-rectifying, vibrator also is used in a power supply to change direct current from a low voltage to a higher voltage. A synchronous vibrator power supply circuit is shown in figure 3–18.

The action of this unit is similar to that of the conventional vibrator unit except that an additional set of contacts connected to the transformer secondary is used for rectifying. When the center vibrating contact is attracted to one

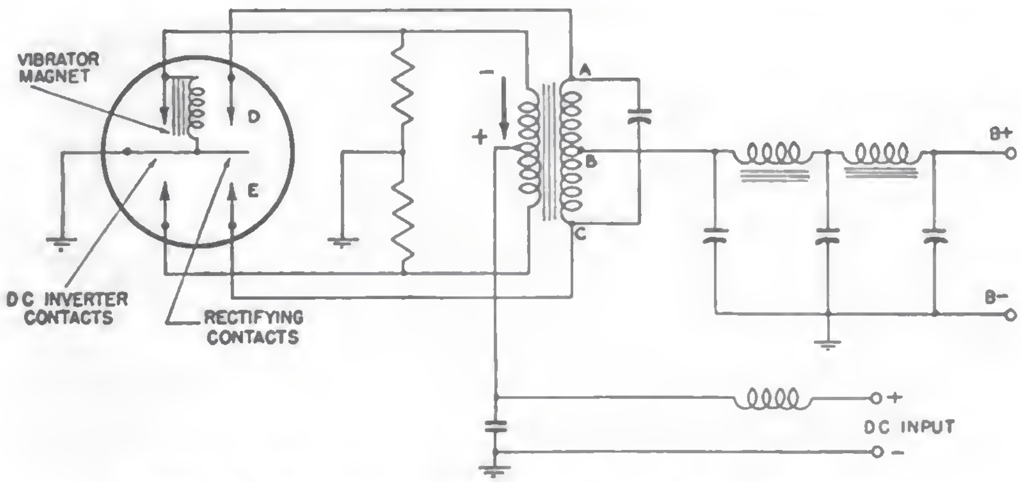


Figure 3–18.—Synchronous-vibrator power supply circuit.

side and closes contact *D*, current I_1 flows and terminal *A* of the transformer secondary is connected to ground. The polarity of the transformer during this half cycle is such that terminal *C* is positive.

During the next half cycle the vibrator closes contact *E* which connects the negative terminal *C* of the secondary to ground. Current I_2 flows and makes terminal *A* positive. Hence, terminal *B* of the center tap of the secondary receives a positive pulse on each half cycle. Terminal *B* is the positive side and ground is the negative side of the d-c output. The d-c inverter contacts are insulated from the rectifying contacts in order to prevent the low-voltage input from short-circuiting the relatively high-voltage output.

Dynamotor

Dynamotor is a d-c machine that is used to change a d-c source of power to a higher or lower value. It consists of a motor and a generator built into one unit with two or more windings on one armature and two or more commutators. The commutators are usually located on opposite ends of the shaft, and the windings are placed in the same armature slots. As both input and output windings are on the same armature, the field is common to both motor and generator windings. The relation between the voltages is fixed and depends on the ratio of turns in the various armature windings. It provides a means of changing voltage to a higher or lower value with relatively low loss as compared to the potentiometer but the first cost is much greater.

QUIZ

1. What type of voltage is supplied for the screen and plate circuits of electron tubes and for grid biasing?
2. Name four types of electronic power supplies.
3. Name five main components of a regulated power supply according to function.
4. What two devices are used most widely in a-c electronic power supplies to convert alternating current from the power transformer into pulsating direct current?
5. What is the approximate voltage drop across a conducting mercury-vapor rectifier tube and how does this voltage drop compare with that of a high-vacuum rectifier tube carrying the same load current?
6. What type of electron tube is used in a high-current electronic power supply?
7. What are the two most important characteristics of both the high-vacuum and gas-filled rectifier tubes?
8. Why is a capacitor seldom connected directly across the output of a mercury-vapor rectifier tube?
9. Why is the efficiency of the gas-filled tube higher than that of the high-vacuum tube?
10. In which direction does the electron current flow more easily through a copper-oxide rectifier?
11. Using the same transformer secondary, why is the output voltage higher from a bridge rectifier than from a conventional full-wave rectifier?
12. What are two reasons for connecting resistors across the capacitors in a voltage-doubler circuit?

13. For a given applied input voltage, which type has the higher output voltage with no load, a capacitor-input filter or a choke-input filter?

14. Which has the better regulation, a capacitor-input filter or a choke-input filter?

15. Why can physically smaller capacitors, inductors, and transformers be used on 800-cps power sources than can be used on 60-cps power sources?

16. Explain the principle of the ballast tube?

17. How can a vacuum tube be used as a voltage regulator?

18. What percentage of full-load current is usually allowed to flow through the bleeder resistor in the voltage divider of a power supply?

19. What is the function of a dynamotor?

CHAPTER 4

ELECTRON-TUBE AMPLIFIERS

An electron-tube amplifier is a device that is used to increase the voltage, current, or power of a signal. It consists of one or more tubes and the associated circuit elements necessary for its operation. Such an amplifier is able to function because a small change in grid voltage can cause a large change in plate current. Changes in grid voltage are μ (mu) times as effective in changing plate current as are changes in plate voltage, where μ is the AMPLIFICATION FACTOR of the tube.

In practical applications input and output coupling circuits must be used with the tube. If resistance-capacitance (R-C) coupling is used, the voltage gain of the stage is less than μ because of losses in the coupling circuit. If transformer coupling is used, the voltage gain may be greater or less than μ depending on whether the coupling transformer has a step-up or a step-down turns ratio.

In order to obtain certain waveform characteristics, amplifiers are sometimes purposely designed to distort the signal. When voltage or power is to be increased without appreciably changing the shape of the wave, as in high-fidelity amplifiers, it is generally necessary to sacrifice some of the gain that the stage would normally have if this condition were not imposed.

CLASSIFICATION OF AMPLIFIERS

Amplifiers are classified according to (1) frequency response, (2) use, (3) bias, and (4) resonant quality of load.

Frequency Response

Amplifiers are classified according to the frequency range over which they operate. Amplifiers classified according to frequency response are known as direct-current (d-c), audio-frequency (a-f), intermediate-frequency (i-f), radio-frequency (r-f), and video-frequency (v-f) amplifiers.

D-c amplifiers must be used when the current flow is in but one direction. To overcome certain problems inherent in such an amplifier, the circuits must be balanced and stabilized by means of resistors.

A-f amplifiers operating in the ranges from 30 to 15,000 cycles per second can be transformer-coupled, impedance-coupled, or resistance-coupled.

I-f and r-f amplifiers are ordinarily designed for tuned-circuit coupling, although in actual operation they may resemble either the transformer-coupled or the impedance-coupled circuit.

V-f amplifiers, which operate in a range extending from the lower audio frequencies to about 5,000,000 cps, commonly use *R-C* coupled amplifiers in which the coupling resistance is made low enough to produce the necessary high-frequency response. However, in actual television applications the *R-C* coupled amplifier must be modified to make the response essentially flat over a wide range of frequencies. In addition, the circuits must be modified to keep time-delay distortion within a certain minimum value at the high-frequency and low-frequency ends of the spectrum.

Use

Amplifiers are classified according to whether they are used to produce as much voltage or as much power as required in the load circuit. Amplifiers classified according to use are known as voltage amplifiers and power amplifiers.

Voltage amplifiers.—Voltage amplifiers are so designed that signals of relatively small amplitude applied between the grid and cathode of the tube produce large values of amplified signal voltage across the load in the plate circuit.

To produce the largest possible amplified signal voltage across the plate load (which may be a resistor or an inductor), the value of impedance must be as large as practicable.

The GAIN of a voltage amplifier is the ratio of the alternating component of output voltage to the alternating component of input voltage. This type of amplifier is commonly used in radio receivers to increase the r-f or i-f signal to the proper level to operate the detector. It is also used to amplify the a-f output of the detector stage. In transmitters, voltage amplifiers are used to increase the output of the microphone to the proper level to be applied to the modulator.

POWER AMPLIFIERS.—Power amplifiers are designed to deliver a relatively large amount of power to the load in the plate circuit. Because power, in general, is equal to the voltage times the current, a power amplifier must develop sufficient voltage across its load to cause rated current to flow. The POWER AMPLIFICATION of such a circuit is the ratio of the signal output power to the signal power supplied to the input circuit.

The load impedance of a power amplifier is selected to give either maximum plate efficiency or maximum power for a certain minimum level of distortion. PLATE EFFICIENCY is the ratio of useful output power to d-c input power to the plate (plate current times plate supply voltage).

Power amplifiers are commonly used as the output stage of radio receivers. They are used in transmitters to increase the power of the modulated carrier to the desired level before it is fed to the antennas.

Bias

Amplifiers are classified according to the conditions under which the tube operates—that is, according to the portion of the alternating signal voltage cycle during which plate current flows as controlled by the bias on the grid. Thus, voltage or power amplifiers are designated as class A, class B, class AB, or class C.

CLASS-A AMPLIFIERS.—Class-A amplifiers have their bias so adjusted that with normal input voltage, plate current flows throughout the entire electrical cycle. The operation of a class-A amplifier is illustrated by the characteristic I_p-E_g curve in figure 4–1.

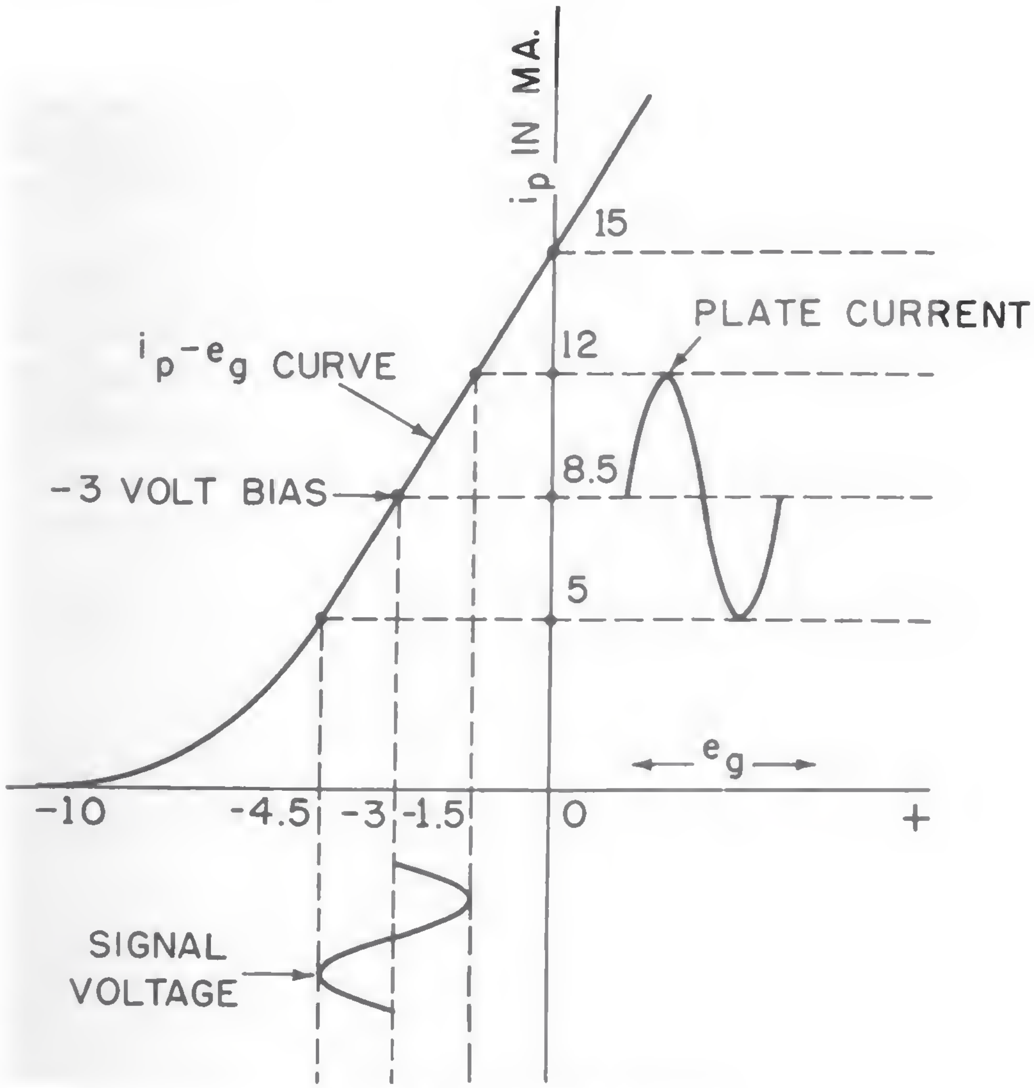


Figure 4–1.—Class-A operation.

The no-signal grid bias is −3 volts and the a-c signal swings the grid-to-cathode voltage from −1.5 to −4.5 volts. Plate current flows during both the positive and negative half cycles of the alternating signal voltage that is applied to the grid. If the tube is biased so that it operates on the linear portion of its I_p-E_g curve, the plate-current waveform is a reproduction of the alternating signal voltage waveform applied to the grid.

If the tube is biased so that no grid current flows, even on large signals, the tube is designated as a CLASS-A_1 AMPLIFIER.

The principle characteristics of class-A amplifiers are minimum distortion, low-power output for a given tube, high-power amplification ratio, and relatively low efficiency (20 to 35 percent). This type of amplifier is used commonly in various audio systems where low distortion is one of the prerequisites. Voltage amplifiers are usually operated as class-A amplifiers.

CLASS-*B* AMPLIFIERS.—Class-B amplifiers are biased so that the plate current is approximately zero when no excitation voltage is applied to the grid. Current in a given tube then flows for approximately one-half of each cycle of grid excitation. The operation of a class-B amplifier is illustrated by the characteristic I_p-E_g curve in figure 4–2. Plate current flows only during the positive half cycles of the alternating signal voltage applied to the grid. Hence, the plate-current

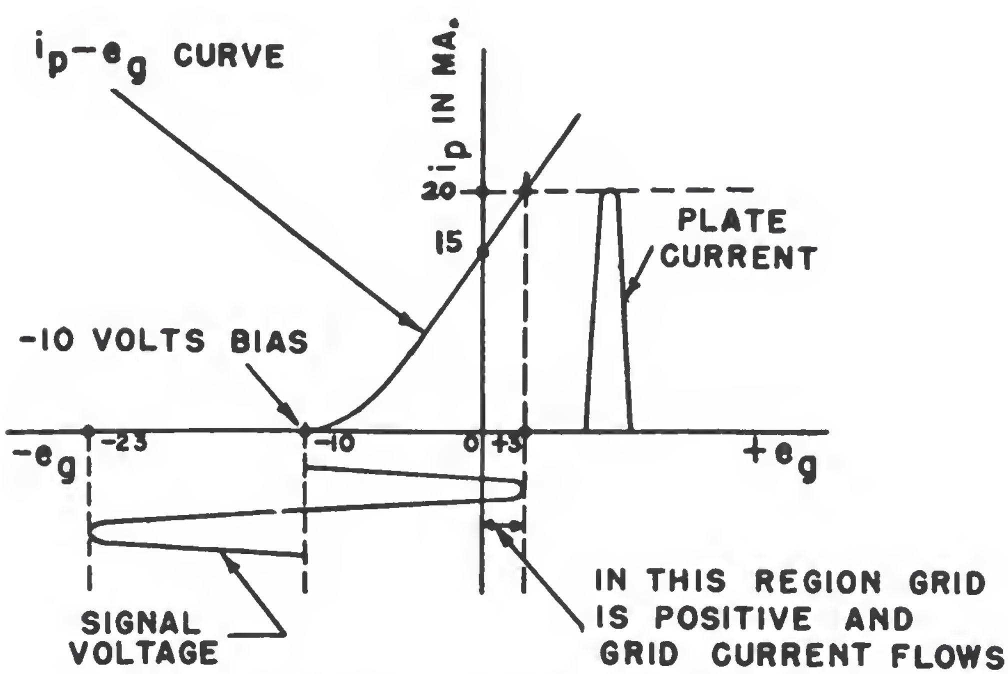


Figure 4–2.—Class-B operation.

waveform is only a partial reproduction of the signal-voltage waveform. The tube acts like a half-wave rectifier.

The signal voltage applied to the grid of a class-B amplifier usually has a much greater value than that applied to the grid of a class-A amplifier. The applied signal usually is so large that the grid is driven positive with respect to the cathode, and draws grid current.

The principal characteristics of class-B amplifiers are medium power output, medium plate efficiency (50–60 percent), and moderate power amplification. Because the alternating component of the plate current is proportional to the amplitude of the exciting grid voltage, the power output is proportional to the square of the exciting grid voltage.

Two class-B amplifiers can be used in push-pull output stages of a-f amplifiers for increased power output. In this circuit (fig. 4–3) each tube supplies that half of the wave-

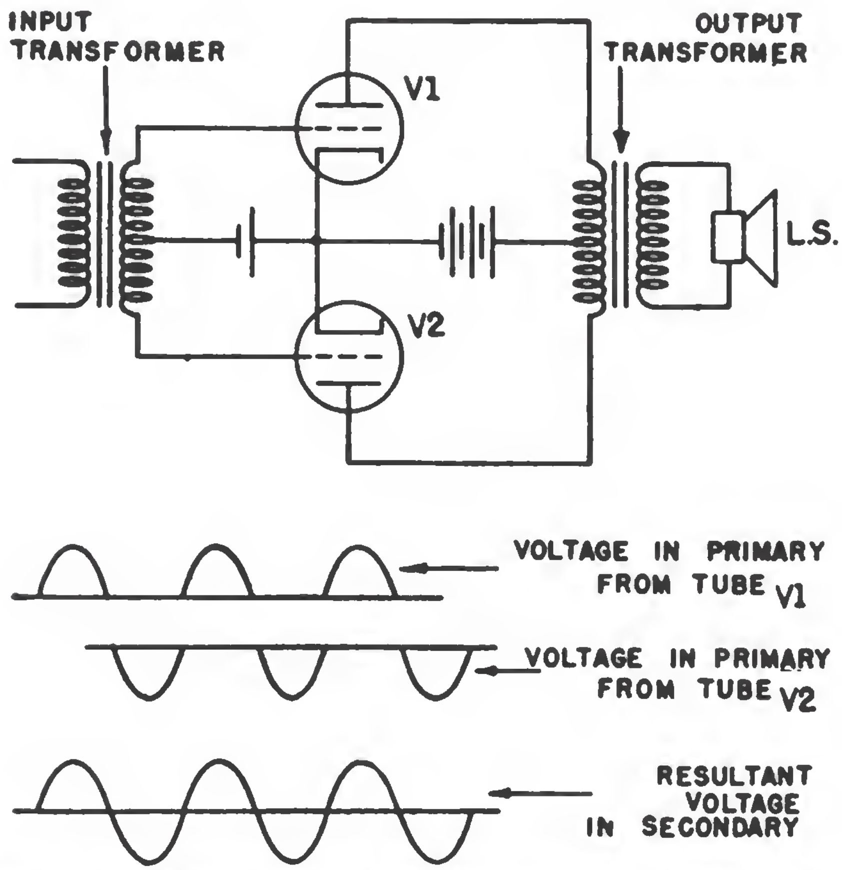


Figure 4–3.—Push-pull class-B amplifier circuit and output waveforms.

form not supplied by the other tube. The action of the class-B push-pull amplifier is similar to that of a full-wave rectifier. The plate-current waveform of the two tubes is combined in the load circuit through the mutual inductance of the output transformer and is nearly a true reproduction of the signal applied between the two grids. Push-pull class-B amplifiers, therefore, are widely used for audio power amplification. Because of their distorted outputs, single-ended class-B amplifiers are never used for this.

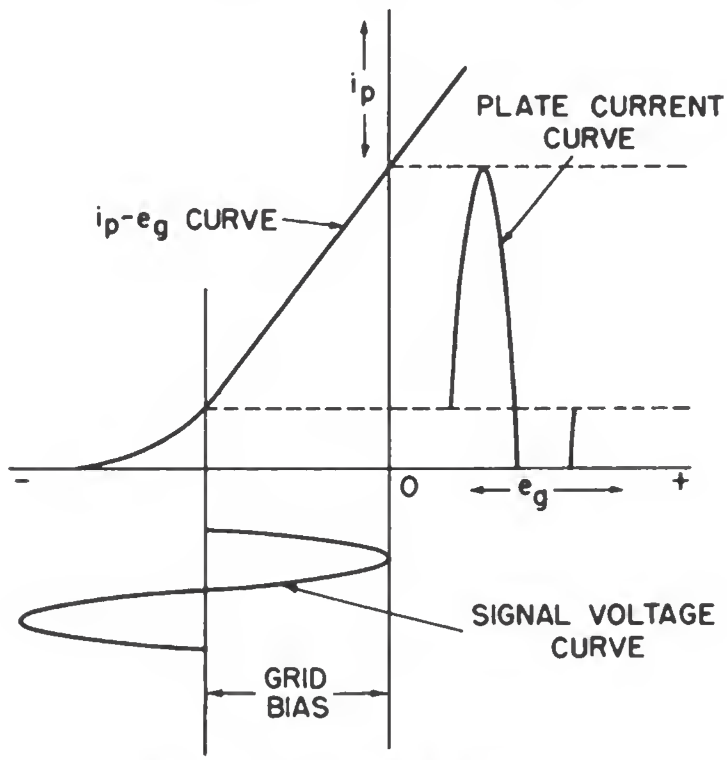


Figure 4-4.—Class-AB operation.

CLASS-AB AMPLIFIERS.—Class-AB amplifiers have grid biases and input signal voltages of such values that plate current in a single tube flows for appreciably more than half the input cycle but for less than the entire cycle. Class-AB operation is essentially a compromise between the low distortion of the class-A amplifier and the high efficiency of the class-B amplifier. The operation of a class-AB amplifier is illustrated by the characteristic I_p-E_g curve in figure 4-4. This amplifier operates slightly beyond the linear portion of its I_p-E_g curve, and there is some distortion in the output. For this reason push-pull amplifier circuits that cancel even-order harmonic distortion are generally used for class-AB audio amplifiers.

If the grid of a class-AB amplifier never becomes positive with respect to the cathode (that is, if no grid current flows), the amplifier is designated as class AB_1. If grid current flows during the positive peaks of the input cycle the amplifier is designated as class AB_2. Although a class-AB_2 amplifier delivers slightly more power to a load, the class-AB_1 amplifier does not require a driver that must deliver undistorted power to a load, the impedance of which drops to a low value during periodic intervals of grid current flow.

Class-C amplifiers.—Class-C amplifiers have biases that are appreciably greater than cutoff. Consequently, plate current in a single tube flows for appreciably less than half of each cycle of the applied grid signal voltage. The operation of a class-C amplifier is illustrated by the characteristic I_p-E_g curve in figure 4–5. The bias voltage is −20 volts, or

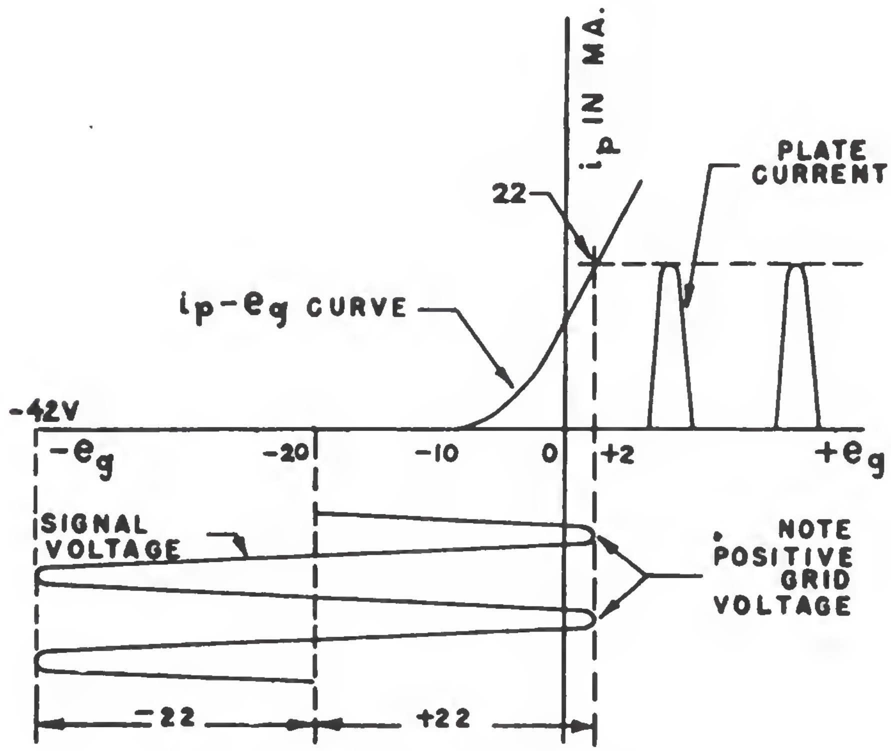


Figure 4–5.—Class-C operation.

twice the cutoff value. Plate current flows only during that portion of the positive half cycle of the applied alternating signal voltage in which the signal is greater than the cutoff bias of the tube. In other words, when an a-c signal is applied, plate current flows for appreciably less than one-half of each cycle. Note that the applied alternating signal voltage is large and exceeds the cutoff bias in order to swing the grid voltage sufficiently positive with respect to the cathode to ensure the correct value of plate current.

The principal characteristics of class-C amplifiers are high plate efficiency (70 to 75 percent), high power output, and low power-amplification ratio. Because the value of the alternating component of the plate current is directly proportional to the plate voltage, the output power is proportional to the square of the plate supply voltage.

Class-C amplifiers are not used as audio amplifiers, but they are used as r-f power amplifiers in transmitters. If power is delivered to a tuned load, the load will present a high impedance at the resonant frequency, but at other frequencies the load will have a much lower impedance. If the load is tuned to the same frequency as that applied to the grid, it will offer optimum loading at this frequency. Thus, low impedances will be offered to the harmonics of the frequency applied to the grid, and these undesirable frequency components can be effectively eliminated. Because audio amplifiers have high distortion in their outputs, they are NEVER operated class C.

Resonant Quality of Load

Amplifiers are also classified according to whether they are TUNED or UNTUNED—that is, according to whether they amplify a restricted or a wide range of frequencies respectively. Tuned amplifiers employ loads that consist of inductors and capacitors that have a maximum interchange of energy between them at the frequency to which they are tuned (resonant frequency). These inductor and capacitor networks are frequently called TANK CIRCUITS because they have a resonant interchange of energy and act as reservoirs in which energy is stored alternately in the inductor and in the capacitor.

TUNED AMPLIFIERS.—Tuned amplifiers are further subdivided into NARROW-BAND and WIDE-BAND amplifiers Whether a band of frequencies is considered narrow or wide depends on the ratio of the bandwidth to the center frequency. Thus, if the same bandwidth is considered in each case, the one covering the higher frequencies will be narrower than the one covering the lower frequencies. For example, narrow-band amplifiers are the i-f amplifiers in radio receivers; and wide-band amplifiers, which may have a range of several megacycles, are the r-f and i-f stages of television or radar receivers.

UNTUNED AMPLIFIERS.—Untuned amplifiers are not tuned to any specific band of frequencies. However, the circuit components can limit the range of frequencies that the circuit can handle. All audio amplifiers come under this classification.

DISTORTION IN AMPLIFIERS

The output of an ideal amplifier is identical with the input in all respects except for an increase in amplitude. This statement precludes the various wave-shaping and special-purpose amplifiers. However, a practical amplifier falls short of this ideal. Not all frequency components present in the input may be amplified equally; the relative phases of the various output frequencies may differ from those of the input; or the amplitude of the output voltage may not be proportional to the amplitude of the input voltage, and thus new frequencies will be introduced. These deviations from the ideal are known as FREQUENCY, PHASE (time-delay), and AMPLITUDE (nonlinear) DISTORTION respectively (fig. 4-6).

To obtain the special waveforms necessary in certain radar, television, or test circuits, distortion is deliberately introduced by the amplifier or an associated circuit. However, in certain other circuits less distortion of all three types is

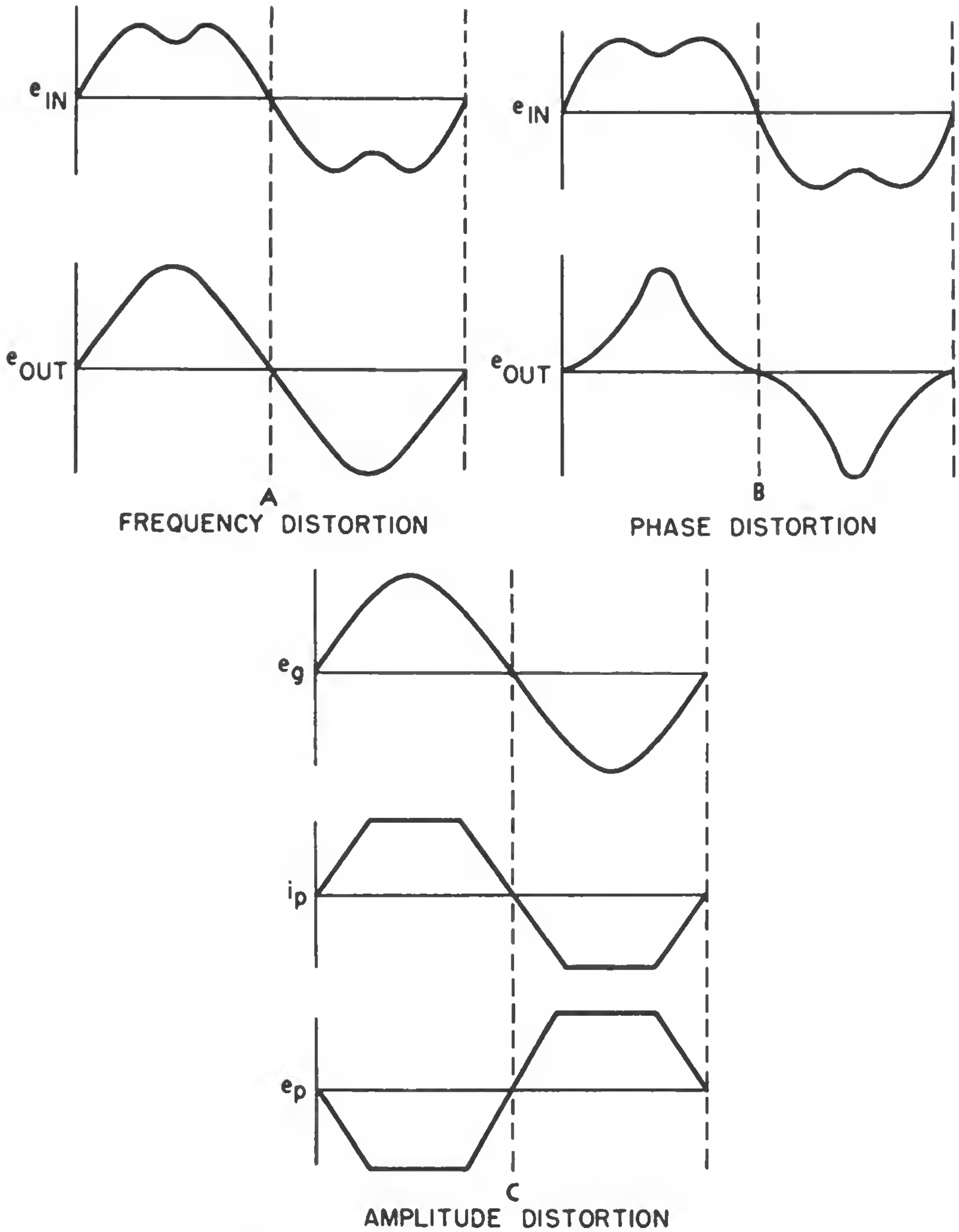


Figure 4—6.—Types of amplifier distortion.

permitted than would be tolerated in the case of radio amplifiers.

Frequency Distortion

When some frequency components of a signal are amplified more than others or when some frequencies are excluded, the result is FREQUENCY DISTORTION. Essentially, this type of distortion results from bandwidth restrictions imposed by the various amplifier circuit components. For example, if a coupling circuit does not pass the third or higher harmonics that are present in the input, the circuit introduces frequency distortion.

The input and output of a two-stage amplifier that has introduced frequency distortion is shown in figure 4–6, A. The input, e_{in}, contains the fundamental and the third harmonic. The output, e_{out}, contains only the fundamental because the amplifier was unable to pass the third harmonic. Frequency distortion can occur at low frequencies if the coupling capacitor between the stages is so small that it presents a high series impedance to the low-frequency components of a signal. Distortion can also occur at high frequencies because of the shunting effects of the distributed capacitances in the circuit.

Phase Distortion

Most coupling circuits shift the phase of a sine wave, but this shift has no effect on the shape of the output. However, when more complex waveforms are amplified, each component frequency that makes up the overall waveform may have its phase shifted by an amount that depends on its frequency. Thus, the output is not a true reproduction of the input waveform.

The input and output of a two-stage amplifier that has introduced phase distortion are shown in figure 4–6, B. The input signal, e_{in}, consists of a fundamental and a third harmonic. Although the amplitudes of both components have been increased by identical ratios, the output, e_{out}, is considerably different from the input because the phase of the third harmonic has been shifted with respect to the fundamental. Basically, phase distortion is present whenever the component frequencies in the input of an amplifier are not all passed through in the same amount of time.

Phase (time-delay) distortion is not important in the amplification or reproduction of sound because the ear is unable to detect relative phase shifts of the individual components. However, such distortion is important in radar, television, and measuring equipment where the waveform must be accurately maintained during amplification. Phase distortion can be reduced by varying the amount or type of coupling.

Amplitude Distortion

If a signal is amplified by a vacuum tube that is not operating on the linear portion of its characteristic curve, amplitude (nonlinear) distortion will occur. In the nonlinear region, a change in grid voltage does not result in a change in plate current that is directly proportional to the change in grid voltage. For example, if a tube is overdriven by applying a grid signal that drives the tube beyond the linear portion of the characteristic curve (nonlinear distortion) and

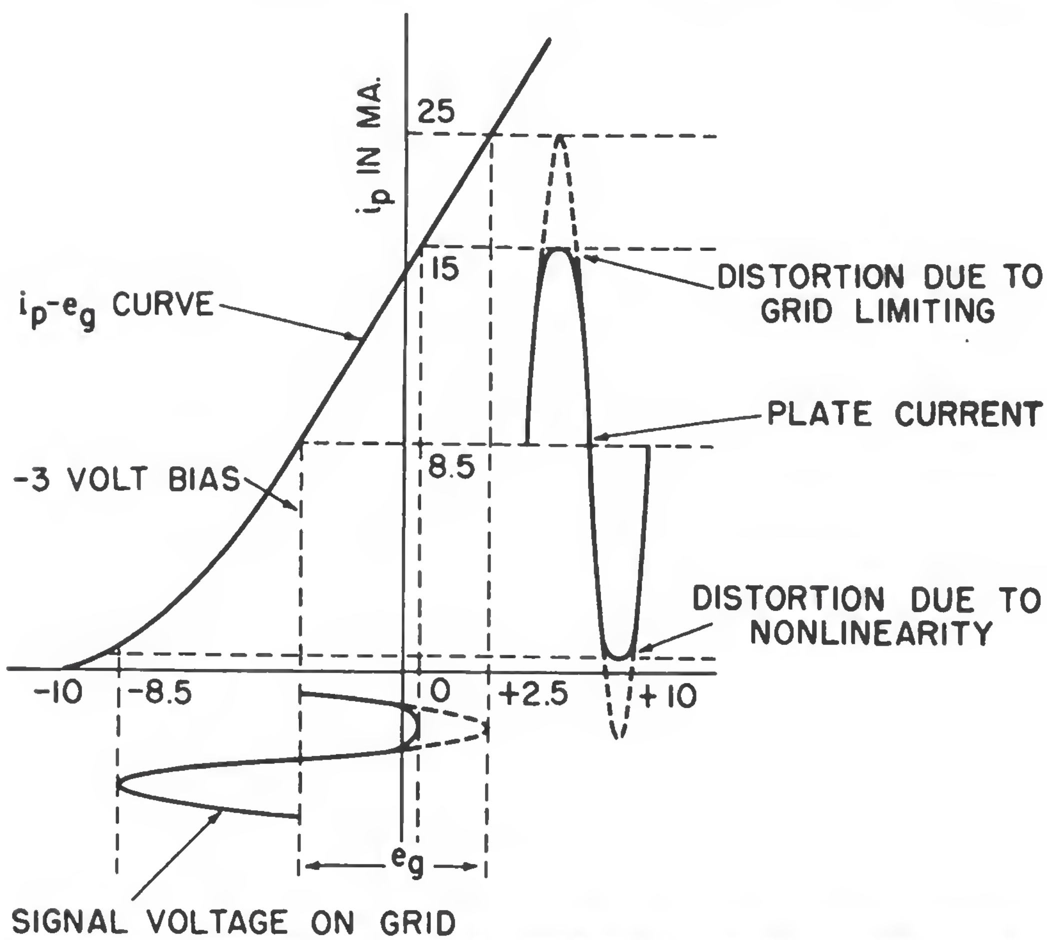


Figure 4–7.—Distortion in a class-A amplifier due to excessive signal voltage.

also to the point where the grid draws current (grid limiting distortion), the resultant signal is distorted in amplitude, as shown in figures 4–6, C, and 4–7. This type of distortion is to be expected because for a portion of the negative half of the grid swing, the tube operates on a nonlinear portion of the characteristic curve; and for a portion of the positive swing, the grid draws current.

Beyond the linear portion of the curve, a further increase in negative grid potential will not cause a proportionate reduction in plate current. Beyond the point where the grid draws current, the positive swing of grid voltage is limited by the loss in voltage within the source impedance and there can be no further increase in plate current. The result of this nonlinearity is the production of harmonics that were not present in the input of the amplifier. This concept is better understood if it is recalled that any complex periodic waveform can be considered as being composed of a number of sine waves of different frequencies and amplitudes. The sine wave that has the same frequency as the complex periodic wave is called the FUNDAMENTAL. Frequencies higher than the fundamental are called HARMONICS. Thus, from the complex waveform is obtained a number of harmonics plus the fundamental frequency.

At the higher frequencies, the harmonics can be reduced by the use of a parallel resonant circuit as a plate load, by link coupling, or by filtering. At the audio frequencies, however, there is an overlap of frequencies, and filtering is not practicable. The best solution is to operate the tube on the straight portion of the characteristic curve for class-A operation or to operate it in a push-pull arrangement for class-B operation.

Complex waveforms are necessary in certain television, radar, and test-equipment circuits. These waveforms include square waves, saw-tooth waves, and peaked waves. In each of these waveforms the distortions are deliberately introduced.

COUPLING METHODS

A single stage of voltage or power amplification normally is not sufficient for radio or audio applications. To obtain the necessary gain, it is often necessary to connect several stages together. The output of one stage becomes the input of the next stage throughout the series of stages. This arrangement is called a CASCADE AMPLIFIER.

A cascade amplifier is designated according to the method used to couple one amplifier stage to the next stage. There are a number of methods each having certain advantages and disadvantages. The choice for a particular application depends on the needs of the circuit. The basic methods are (1) resistance-capacitance (R-C) coupling, (2) impedance coupling, (3) transformer coupling, and (4) direct coupling. Before the details of each coupling method are considered it is desirable to establish the equivalent circuit of a vacuum-tube amplifier. The characteristics of an amplifier are determined more readily by replacing the tube with its equivalent circuit and analyzing this circuit.

Equivalent Circuit of a Vacuum-Tube Amplifier

Current variations in the load impedance of a vacuum tube result from the application of a single voltage to the grid of the tube. The same variations would be produced if the vacuum tube were replaced by a generator that develops a voltage of $-\mu e_s$ acting in the plate-cathode circuit of the tube and having an internal resistance equal to the plate resistance of the tube. The plate resistance and the load impedance would then be in series. Such an arrangement is called the CONSTANT-VOLTAGE GENERATOR FORM of an equivalent amplifier circuit and is more convenient when triodes are used. The equivalent amplifier circuit can also take the CONSTANT-CURRENT GENERATOR FORM, which is more convenient if multielement tubes are used in which the plate resistance is much higher than the load resistance. An actual amplifier circuit is shown in figure 4–8, A, and both

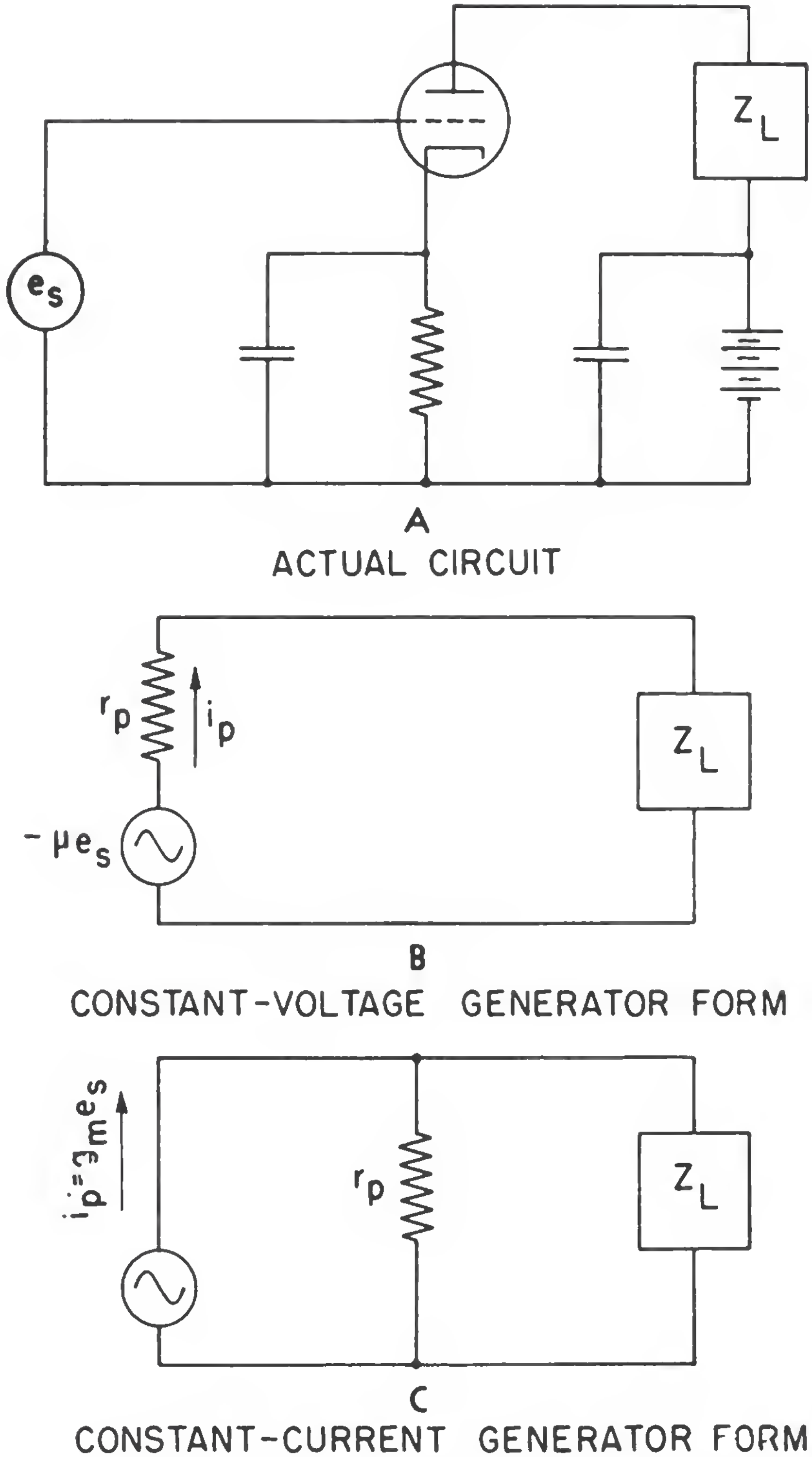


Figure 4–8.—Actual and equivalent amplifier circuits.

forms of equivalent amplifier circuits are shown in figures 4–8, B and C.

The minus sign used with the equivalent generator merely indicates that this signal is of opposite polarity to that of the grid signal. As previously explained, when the signal voltage applied to the control grid is at its maximum positive instantaneous value the plate current is also maximum. At this instant the voltage drop in the load impedance is maximum, and therefore, the voltage available at the plate is minimum. As a result there is a phase difference of 180° between the instantaneous grid and plate voltages.

The application of Ohm's law to the simple equivalent series circuit of figure 4–8, B, shows that the plate current flow is

$$i_p=\frac{-\mu e_s}{r_p+Z_L},$$

where i_p is the instantaneous plate current, μ the amplification factor, e_s the instantaneous grid voltage, r_p the plate resistance, and Z_L the load impedance. The current, i_p, must flow through the load impedance, Z_L, and therefore the output voltage is

$$i_p Z_L=\frac{-\mu e_s Z_L}{r_p+Z_L}.$$

It is apparent from this equation that the output voltage of an amplifier is not simply μ times the applied signal. Because any vacuum tube has internal resistance called PLATE RESISTANCE, part of the equivalent generator voltage appears across this resistance and is thus not available across the load. It is often convenient to consider the plate resistance and the load impedance as a voltage divider across which the voltage generated within the tube is applied.

The equivalent circuit of an amplifier considers only those components of current and voltage that are produced as the result of applying a signal voltage to the amplifier grid. The actual currents and voltages include the signal components acting in the equivalent circuit, together with the d-c components that exist in the actual circuits.

The steady values that are present when no signal is applied are of no particular interest as far as the performance of the amplifier is concerned. Therefore, it is unnecessary to superimpose the steady values on the results calculated on the basis of the equivalent circuit. Actually, when an a-c signal is applied to the grid, the equivalent circuit indicates the alternating signal voltage and the currents that are superimposed on the d-c quantities present when no signal is applied.

The equivalent circuit gives the performance of the amplifier only to the extent that r_p and μ (used in setting up the equivalent circuit) are constant over the range of variations produced in the control grid and the plate voltages by the signal voltage. Hence, when the signal voltage is small, the equivalent circuit is almost correct. However, as the signal voltage increases, the error involved in the equivalent circuit becomes proportionately larger. To determine the exact behavior of the amplifier, the equivalent circuit must be modified to account for the effects produced by variations in circuit components.

R-C Coupling

One of the most commonly used methods of connecting audio voltage amplifier stages is *R-C* coupling. Amplifiers coupled by this method are characterized by their relatively low cost, lack of heavy components, good fidelity over a comparatively wide frequency range, freedom from undesirable induced currents obtained from the a-c heater leads, and special suitability for use with pentodes and high-mu triodes.

An *R-C* coupled amplifier (usually called resistance-coupled amplifier) can be designed to have good response for almost any desired frequency range. For example, it can be designed to give fairly good amplification of all frequencies in the range from 100 to 20,000 cps. Slight modification of the circuits can extend the frequency range to cover the wide band required in video amplifiers. However, extension of the range can be obtained only at the cost of reduced amplification over the entire range. Thus, the *R-C* method of coupling amplifiers gives a good frequency response with minimum distortion, but it also gives low amplification.

Typical *R-C* coupled amplifiers are shown in figure 4–9. In figure 4–9, A, the d-c grid circuit includes *G*, *R*1, *R*2, and

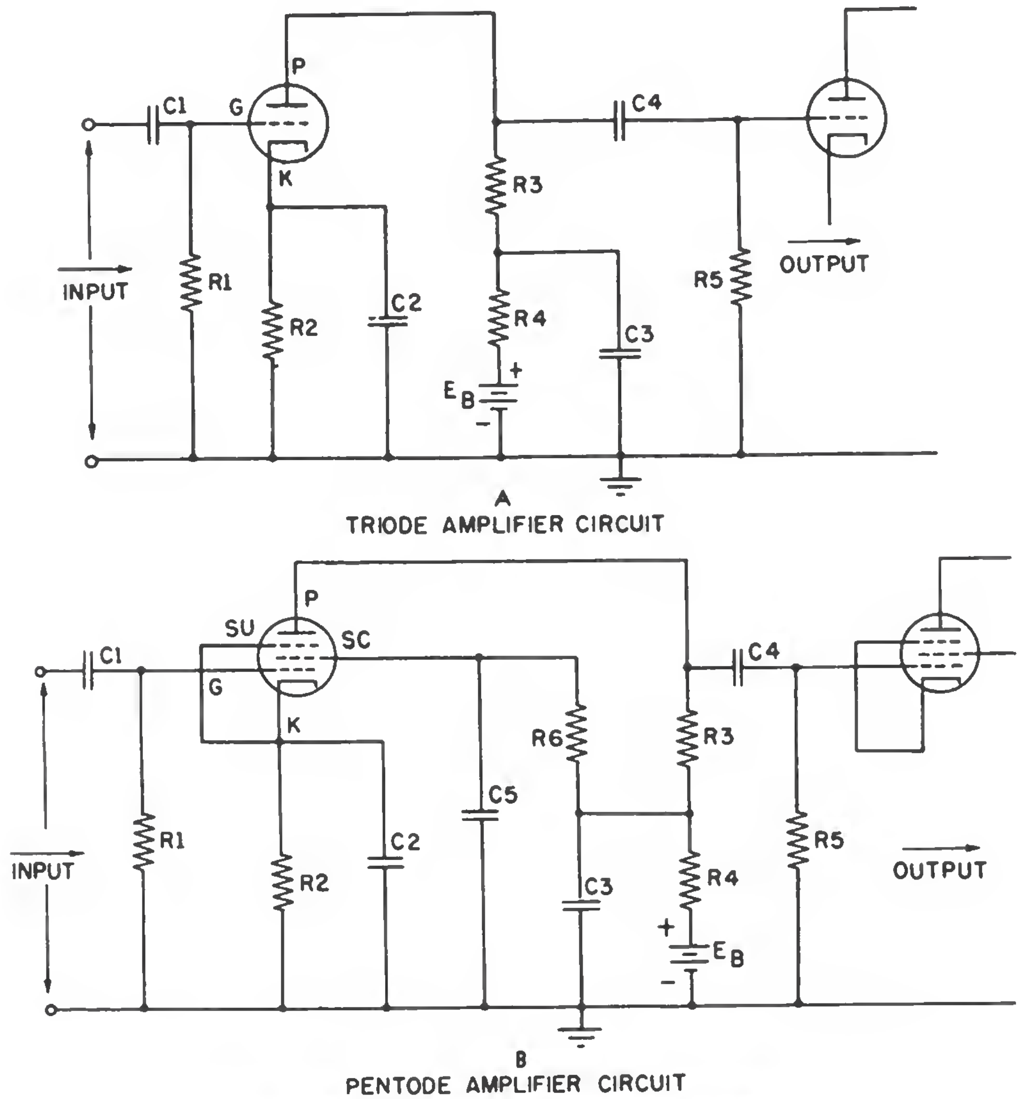


Figure 4–9.—Typical R-C coupled amplifiers.

K; and the a-c circuit includes *G*, *R*1, *C*2, and *K*. In figure 4–9, B, the d-c screen circuit includes *SC*, *R*6, *R*4, E_B, *R*2, and *K*; and the a-c circuit includes *SC*, *C*5, *C*2, and *K*. In each case, the d-c plate circuit includes *P*, *R*3, *R*4, E_B, *R*2, and *K*; and the a-c circuit includes *P*, *R*3, *C*3, *C*2, and *K*.

In order that the output voltage may be large, the load resistor should have as high a value as practicable. However, the higher this value becomes, the greater is the voltage drop across it and the lower is the voltage remaining between the plate and cathode of the tube. To obtain the required effective plate voltage, the voltage drop across the plate load must be subtracted from the plate supply voltage. Thus, there is a practical limit to the size of the plate load resistor if the plate is to be supplied with its rated voltage. If a larger plate resistor is necessary, the only alternative is to

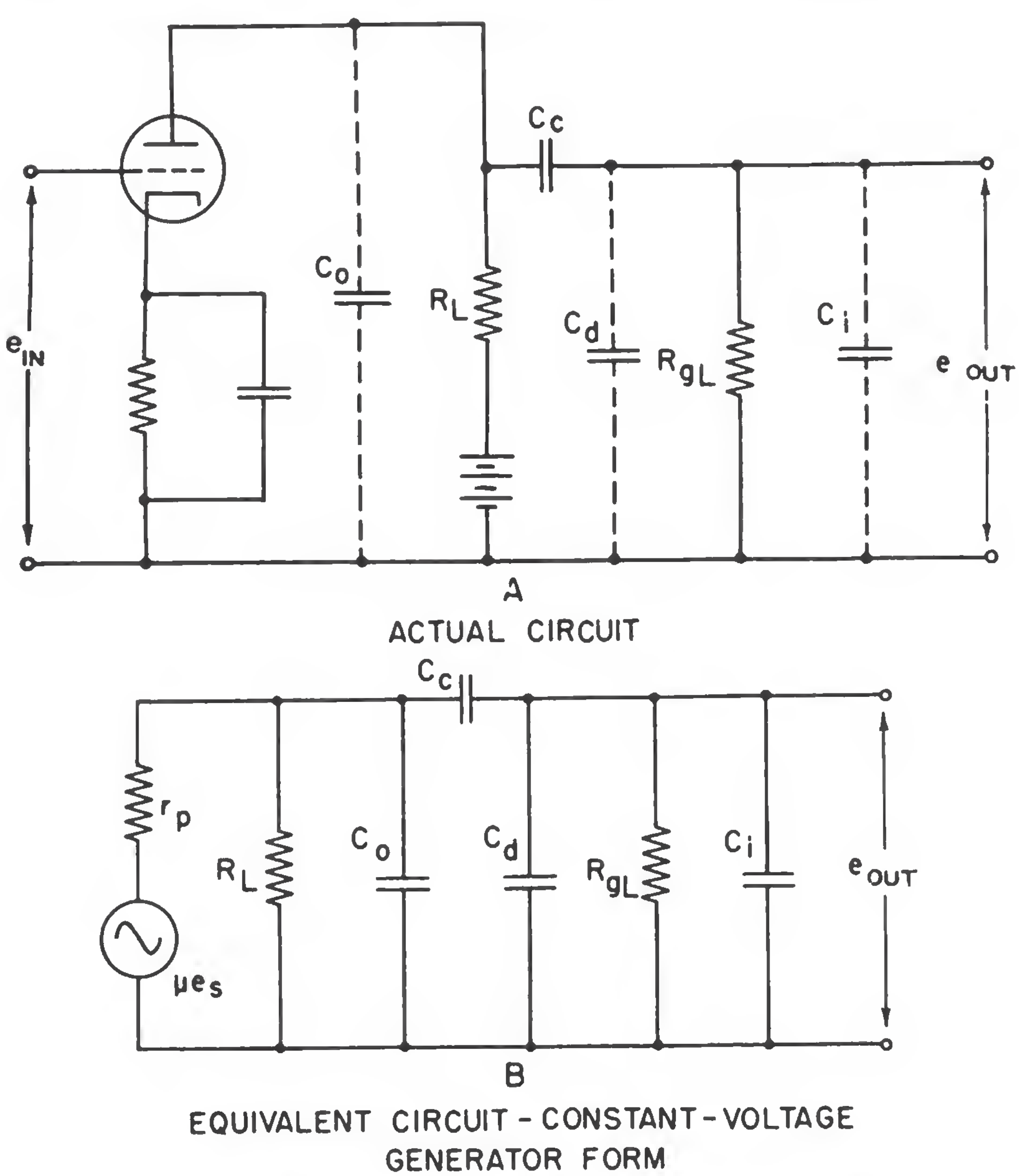


Figure 4–10.—Single-stage R-C coupled audio amplifier.

increase the plate supply voltage. There is a practical limit to the amount that the plate supply voltage can be increased.

The screen resistor (fig. 4–9, B) must have such a value that, when the *IR* voltage drop across it is subtracted from the supply voltage, the rated screen voltage will remain. The value of the cathode resistor is determined by the amount of bias needed on the control grid. The bypass capacitor, *C*2, must have a low reactance in comparison with the resistance of the cathode resistor, *R*2, for the range of frequencies to be amplified. The decoupling (or filter) circuit, *C*3*R*4, tends to prevent the a-c component of plate current from reaching the plate power supply because *R*4 offers a high series resistance and *C*3 offers a low shunt reactance to the a-c signal component.

A single-stage *R-C* coupled audio amplifier with its equivalent circuit is shown in figure 4–10. The typical frequency-response curves for this amplifier are shown in figure 4–11. The gain of the amplifier is poor for the higher and

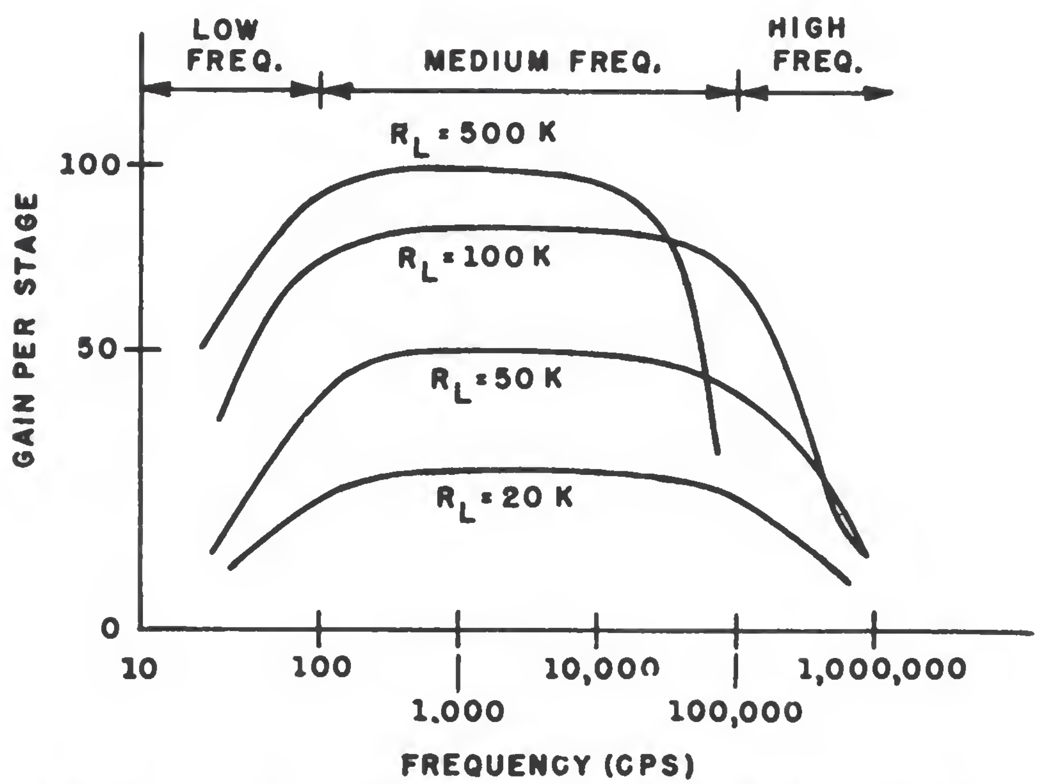
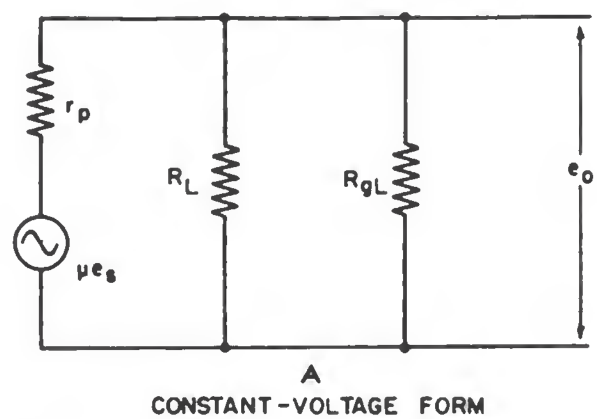


Figure 4–11.—Gain vs frequency of an *R-C* coupled amplifier for various plate loads.

lower frequencies (fig. 4–11). The reduction in gain at the higher frequencies is due to the fact that the load resistor R_L (fig. 4–10) is shunted by the output capacitance, C_o, of one stage, the input capacitance, C_i, of the next stage, and the distributed capacitance, C_d, of the coupling network. The reduction in gain at the lower frequencies is caused by the loss of signal voltage across the coupling capacitor, C_c, which has a high impedance at these frequencies. Other components indicated in these circuits (fig. 4–10) are plate resistance r_p and grid-leak resistance R_{gL}.

MIDDLE-FREQUENCY GAIN.—When an R-C coupled audio amplifier is used in the middle frequency (assumed to extend approximately from 100 to 10,000 cps), the equivalent circuit shown in figure 4–10 is modified to give the circuit shown in figure 4–12, A. Because the reactance of the coupling



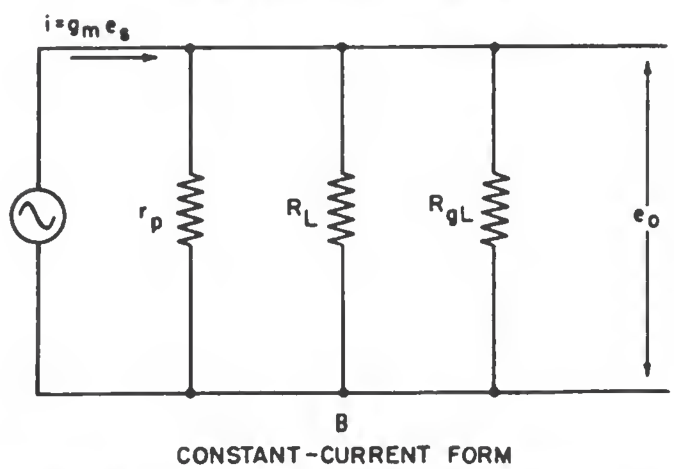


Figure 4–12.—Middle-frequency equivalent circuits.

capacitor, C_c, in the usual amplifier is very small at these frequencies it is considered as negligible in the equivalent circuit. Also, the reactance of the shunting capacitances, C_o, C_d, and C_i, is so high that they are considered the equivalent of an open circuit. Thus, the equivalent circuit is reduced to include only the generator, the series plate resistance, r_p, and the parallel resistors, R_L and R_{gL}. The amplification is practically independent of frequency and a flat response can be expected.

Voltage gain or voltage amplification is the ratio of the output signal voltage, e_o, to the input signal voltage, e_s. From figure 4–12, A, the voltage gain for the middle-frequency range is

$$\frac{e_o}{e_s}=\frac{i_pR_C}{e_s},$$

WHERE

$$i_p=\frac{\mu e_s}{r_p+R_C}$$

AND

$$R_C=\frac{R_L\times R_{gL}}{R_L+R_{gL}}.$$

R_C is the equivalent load resistance formed by the parallel combination of the plate load resistance, R_L, and the grid-leak resistance, R_{gL}. If the value of i_p is substituted in the voltage-gain equation,

$$\text{voltage gain}=\frac{\mu R_C}{r_p+R_C}.$$

From figure 4–12, B, the constant-current generator form of the equation can be established. The signal voltage, e_s, applied to the grid of the tube produces an output voltage, e_{out}, which is equal to the product of the equivalent signal current, g_me_s, and the combined resistance of r_p, R_L, and R_{gL} in parallel.

To set up an equation based on the preceding interpretation, divide both the numerator and denominator of the right-hand side of the equation for plate current by r_p—

$$i_p = \frac{\mu e_s}{r_p\left(1+\frac{R_C}{r_p}\right)}.$$

BECAUSE $g_m = \frac{\mu}{r_p}$,

$$i_p = g_m e_s \frac{r_p}{r_p + R_C},$$

AND

$$e_o = g_m e_s \frac{r_p R_C}{r_p + R_C}.$$

This form of the equation indicates that the application of a signal voltage, e_s, to the grid causes a current, $g_m e_s$, to flow through the parallel combination of r_p, R_L, and R_{gL}. This circuit is shown in figure 4–12, B. Note that R_C is the parallel combination of R_L and R_{gL}. The output voltage, e_o, is the product of this current and the parallel combination of resistances—that is, the equivalent resistance, R_{eq}.

The middle-frequency gain for the constant-current generator is thus established as

$$\text{middle-frequency gain} = \frac{e_o}{e_s} = \frac{(g_m e_s)\left(\frac{r_p R_C}{r_p + R_C}\right)}{e_s}$$

$$= g_m \frac{r_p R_C}{r_p + R_C} = g_m R_{eq}.$$

LOW-FREQUENCY LIMIT.—In the lower range of frequencies amplified by an *R-C* coupled amplifier, C_o, C_d, and C_i (fig. 4–10, B) are less important than they are in the middle-frequency range. Therefore, they can be neglected in the equivalent circuit. The reactance of the coupling capacitor, C_c, however, becomes increasingly significant at the low frequencies and cannot be neglected. The low-frequency equivalent circuit is shown in figure 4–13. The upper limit of the low-frequency band for which this circuit is applicable is the frequency at which the output voltage falls to 70 percent of its value at the middle frequencies.

The lower the frequency the higher becomes the reactance of the coupling capacitor because

$$X_C=\frac{1}{2\pi f C_c}.$$

Therefore at the lower frequencies more of the output voltage is dropped across the coupling capacitor and less is applied across the grid resistor, R_{gL}. The signal is thus re-

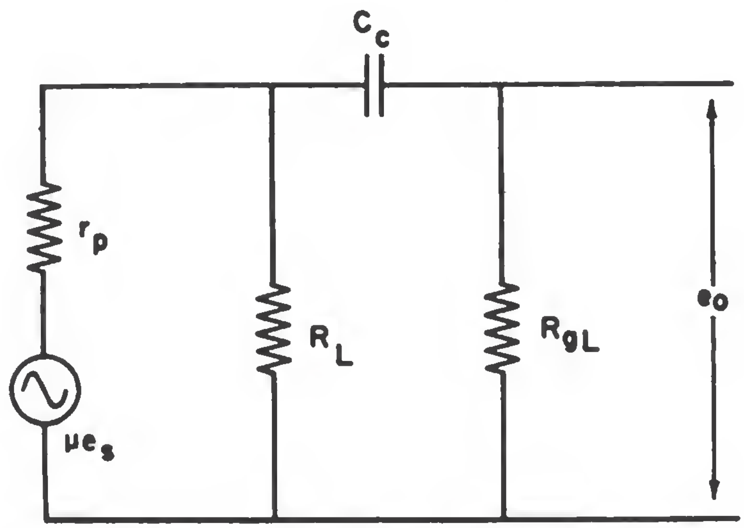


Figure 4—13.—Low-frequency equivalent circuit.

duced at the lower frequencies. It is essential then to choose a value for C_c that will offer negligible reactance at the lowest frequency to be amplified. There is a practical limit to the value of capacitance that can be used because too high a value may cause a type of regeneration called MOTORBOATING.

An expression for the gain at low frequencies, under the conditions established in figure 4–13, can be obtained from the equation

$$\text{low-frequency gain}=\frac{e_o}{e_s}=\frac{\mu R_L R_{gL}}{R_{gL}(r_p+R_L)+r_p R_L+X_C(r_p+R_L)},$$

where X_C is the inductive reactance of coupling capacitor C_c, and R_L is the resistance of the load.

HIGH-FREQUENCY LIMIT.—In the high-frequency range, C_o, C_d, and C_i of the general equivalent circuit (fig. 4–10, B) become significant. These capacitances are the limiting factors in *R-C* coupled amplifiers at high frequencies. These parallel capacitances have been combined and designated as C_s in figure 4–14. The lower limit of frequency for which

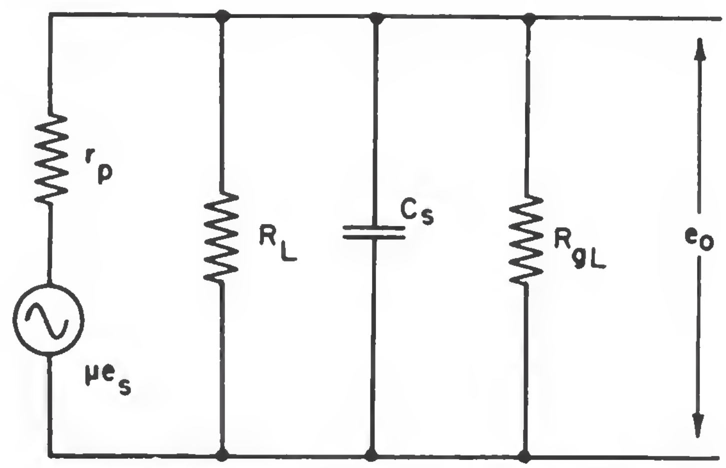


Figure 4–14.—High-frequency equivalent circuit.

this circuit is applicable is the frequency at which the output voltage falls to 70 percent of its value at the middle frequencies.

It is apparent that the reactance of C_s at the middle and low frequencies is high compared with R_L and can be neglected. As the frequencies increase, the reactance of C_s decreases and eventually reaches a value comparable to that of R_L. Because the resultant parallel impedance (composed of X_{Cs}, R_L, and R_{gL}) becomes progressively lower at higher frequencies, a lower voltage is developed across the load to be applied to the input of the next stage. Thus, the amplification is reduced.

When it is desired to extend the high-frequency range, tubes having low interelectrode capacitances, such as pentodes, are used to keep the shunt impedance high with respect to R_L. Also, the value of R_L is reduced so that its impedance at the highest frequency to be amplified remains appreciably less than the impedance of the shunting capacitance. The lowering of the load resistance reduces the over-all amplification of all frequencies passing through the amplifier, but such an adjustment is necessary in circuits where substantially uniform amplification of a wide frequency range is desired.

An expression for the gain in the high-frequency range, under the conditions established in figure 4–14, can be obtained from the equation

$$\text{high-frequency gain} = \frac{e_o}{e_s} = g_m R_{eq} \frac{1}{\sqrt{1+(R_{eq}/X_s)^2}}.$$

Impedance Coupling

Impedance or inductance-capacitance coupling is obtained by replacing the load resistor, R_L, of a normal R-C coupled amplifier with an inductor, L, as shown in figure 4–15. To

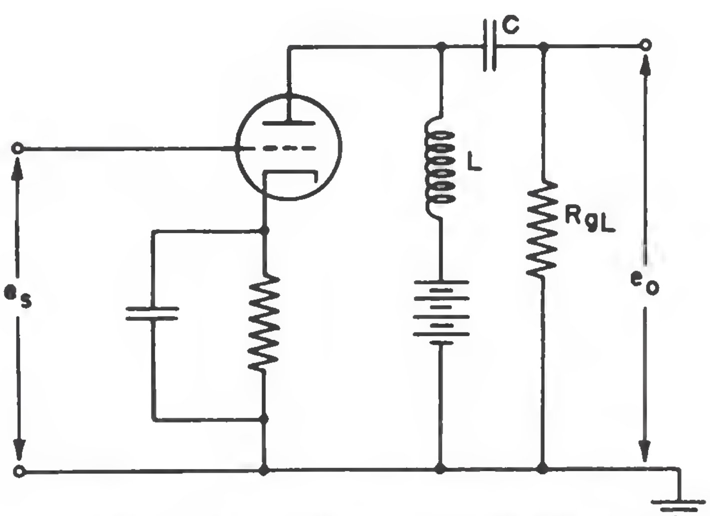


Figure 4–15.—Impedance-coupled amplifier.

obtain as much amplification as possible, particularly at the lower frequencies, the inductance is made as large as practicable. To avoid undesirable magnetic coupling, a closed-shell type of inductor is used. Because of the low d-c resistance of the inductor, the tube is able to operate at a higher plate voltage.

The degree of amplification for the various frequencies is not so uniform as it is with the R-C coupled amplifier. The reason for this lack of uniformity is that the low impedance, Z_L, varies with the frequency as

$$Z_L=\sqrt{R^2+X_L^2},$$

where X_L equals $2\pi fL$, and R is the effective resistance of the coil.

The d-c resistance of the coil is very low as compared with the load resistor in an R-C coupled circuit. The inductive reactance, X_L, varies directly with the frequency. Thus, Z_L increases with the frequency. The higher frequencies will be amplified more than the lower frequencies because for a given input signal the amplification of the stage depends upon the value of the signal voltage built up across the load impedance.

As in the case of R-C coupled amplifiers, the high-frequency gain is limited because the interelectrode and distributed capacitances tend to bypass these frequencies to ground. The distributed capacitance between the turns of the coil greatly increases the capacitance to ground and plays a major part in limiting the use of this coupling at the higher frequencies. The highest voltage gain occurs at the frequency at which the coil is in parallel resonance with its distributed capacitance.

Transformer Coupling

A typical transformer-coupled stage of amplification (fig. 4–16, A) has certain advantages over other types of coupling. The amplification per stage can be greater than the amplication of the tube because a step-up ratio can be used in the transformer. D-c isolation of the grid of the succeeding stage is also provided without the necessity for a blocking capacitor. Also the d-c drop across the coupling capacitor, which is necessary in R-C coupling, is avoided. This type of coupling is also used to couple a high-impedance source to a low-impedance load, or vice versa. It can be used as a simple means of providing phase inversion for a push-pull amplifier without the use of special phase-inverting circuits.

317993 O—55——9

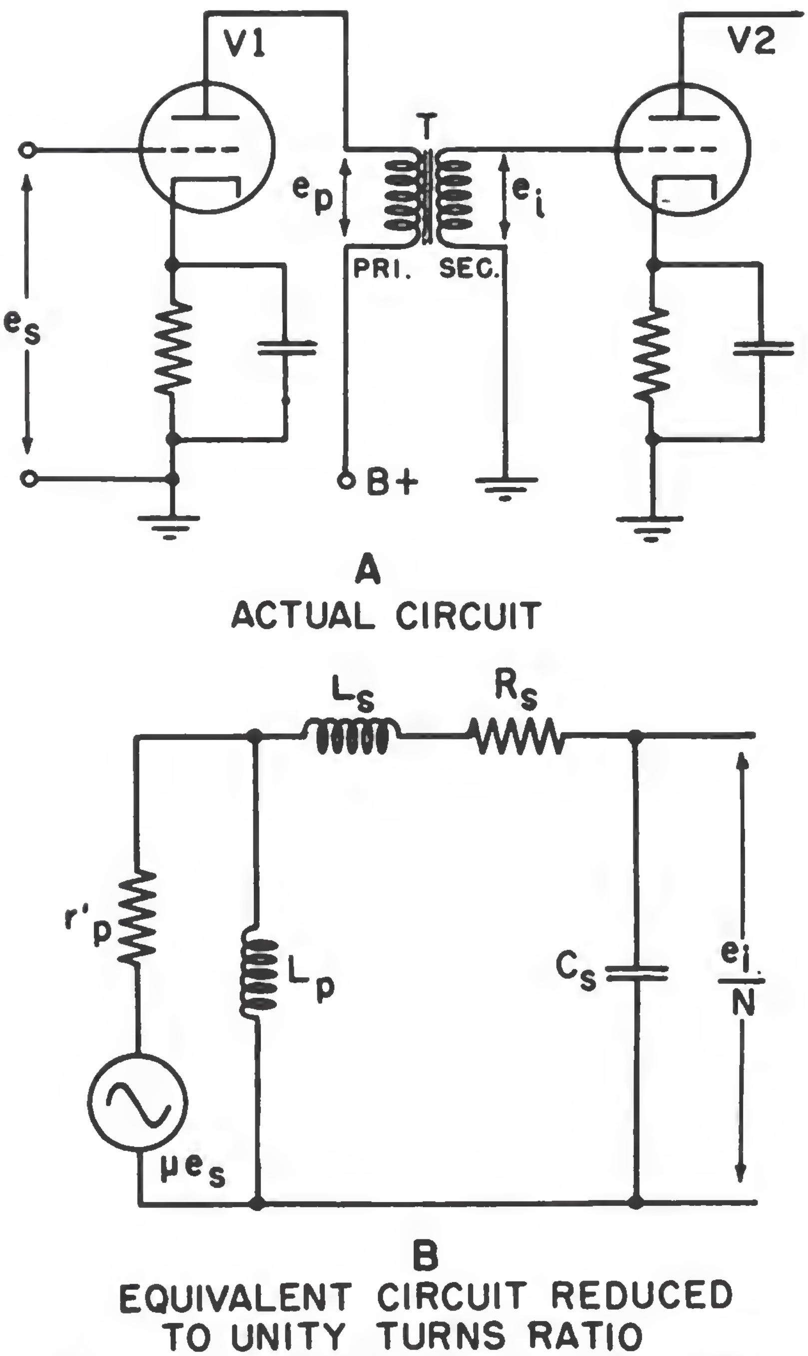


Figure 4–16.—Single-stage transformer-coupled amplifier.

Transformer coupling has the disadvantages of higher cost, more space requirement, the necessity for greater shielding, and the possibility of poorer frequency response at the higher and lower frequencies. The voltage gain as a function of frequency throughout the audio frequency range is shown in figure 4–17.

The primary of transformer T (fig. 4–16, A) is connected in the plate circuit of $V1$, and the secondary is connected between the grid and cathode of $V2$. An input signal, e_s, applied between the grid and cathode of $V1$, appears as an output voltage, e_p, across the primary of the transformer. If

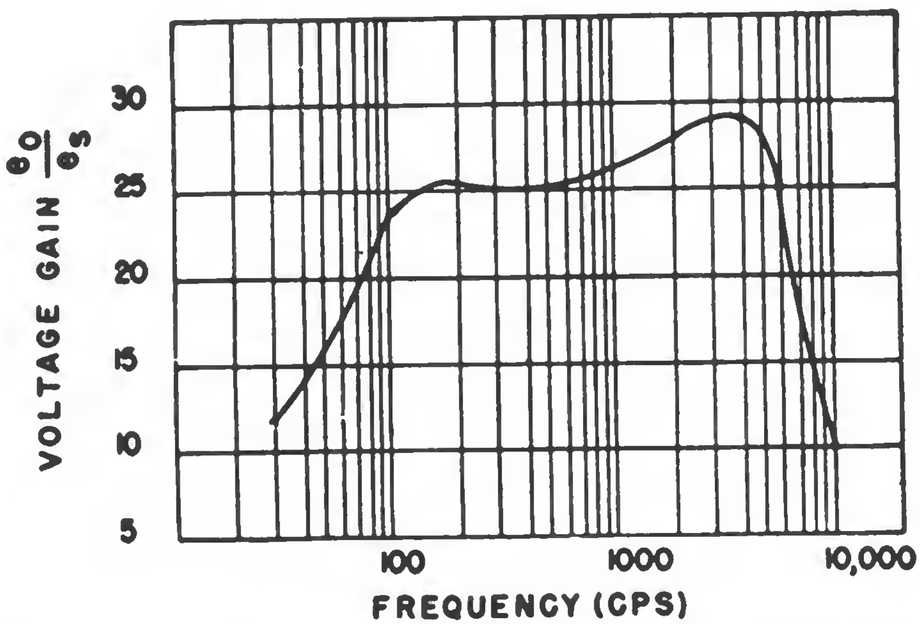


Figure 4–17.—Voltage gain vs frequency of a transformer-coupled amplifier.

it is assumed that the reactance of the primary (with the secondary open-circuited) is very large compared with the plate resistance of the tube, the signal e_p will be approximately μ times as great as the input signal, e_s. The output signal, e_i, applied to the input of $V2$, is approximately N times as great as e_p, where N is the secondary-to-primary turns ratio of the transformer. This approximation holds only for the middle range of a band of frequencies because the coupling between primary and secondary is not unity. The gain is lower for both the higher and lower frequencies because the effective load impedance is less at these ranges.

Like those of R-C coupled amplifiers, complete equivalent circuits of transformer-coupled amplifiers are complex networks. An anlysis of them can be considerably simplified by a separate consideration of their gains at the middle, low, and high frequencies.

MIDDLE-FREQUENCY GAIN.—In the middle range of audio frequencies the reactance of the primary inductance is sufficiently high to make it essentially an open circuit, and the small shunting capacitances of the secondary windings and the tube can be neglected. Therefore, the equivalent circuit (fig. 4–16, B) can be reduced to the form shown in figure 4–18. In this figure, r'_p is the sum of the plate resistance and

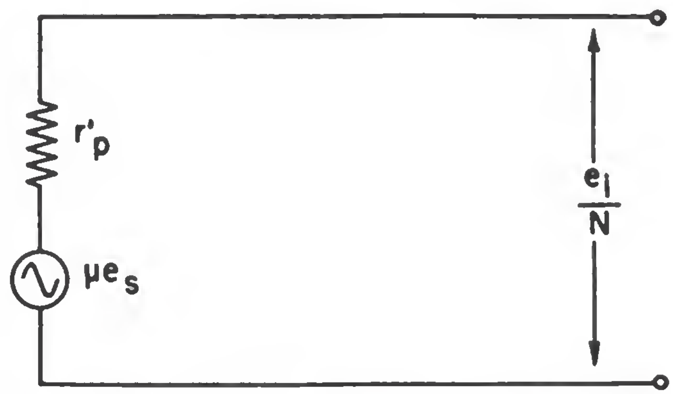


Figure 4–18.—Equivalent circuit of transformer-coupled amplifier for middle-frequency operation.

the resistance of the primary winding in series, and N is the secondary-to-primary turns ratio of the transformer. Because there is no drop through r'_p, the output voltage, $\frac{e_1}{N}$, is

$$\frac{e_1}{N}=\mu e_s.$$

The middle-frequency gain is the product of the amplification factor of the tube and the secondary-to-primary turns ratio of the transformer, or

$$\text{middle-frequency gain}=\frac{e_1}{e_s}=\mu N.$$

LOW-FREQUENCY LIMIT.—At the lower frequencies the shunting effect of the interelectrode and distributed capacitances is even less than it is at the middle frequencies.

The reactance of the transformer primary is

$$X_L=2\pi fL.$$

Because this reactance varies directly with the frequency, it must be considered at the lower frequencies. The equivalent circuit modified for low-frequency operation is shown in figure 4–19. To simplify the derivation of an expression for low-frequency gain, the resistance of the primary and the

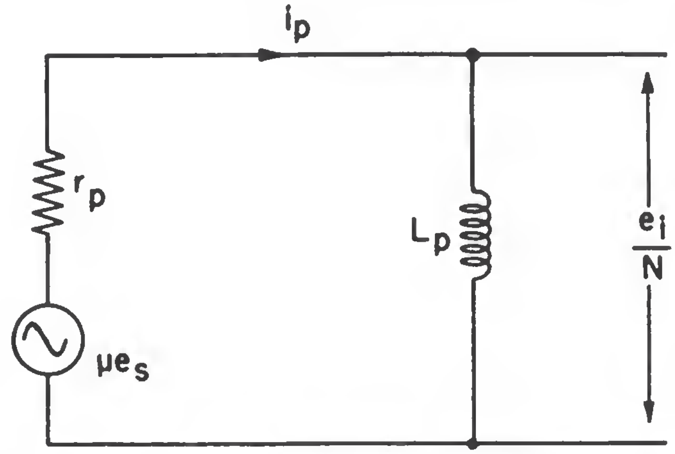


Figure 4–19.—Equivalent circuit of transformer-coupled amplifier for low-frequency operation.

secondary is neglected. The plate signal current, i_p, is readily established as

$$i_p=\frac{\mu e_s}{r_p+j\omega L_p},$$

where $j\omega L_p$ is the inductive reactance of the primary and L_p, the incremental inductance of the primary.

The voltage across the primary is

$$e_p=i_p j\omega L_p=\frac{\mu e_s}{r_p+j\omega L_p}\times j\omega L_p.$$

If each term in the numerator and denominator is divided by $j\omega L_p$ and the denominator, which contains j, is rationalized, the voltage across the primary is

$$e_p=\frac{\mu e_s}{1-j\left(\frac{r_p}{\omega L_p}\right)}.$$

The voltage across the secondary, e_i, is the turns ratio, N, times the voltage across the primary, e_p. Therefore, the gain can be expressed as

$$\text{gain}=\frac{e_i}{e_s}=\frac{N\mu}{1-j\left(\frac{r_p}{\omega L_p}\right)}.$$

It is evident that the decrease in the reactance of the transformer primary causes a gradual falling off in gain at the lower frequencies. This same effect also results from the use of high-gain tubes having inherently high plate resistance.

HIGH-FREQUENCY LIMIT.—At the higher frequencies the primary reactance is high and is neglected in the equivalent circuit. The effect of shunting capacitances, however, cannot be neglected and the effect of leakage inductance upon the current drawn by the shunting capacitances must be considered. These factors have been considered in the simplified equivalent circuit shown in figure 4–20. This circuit has the

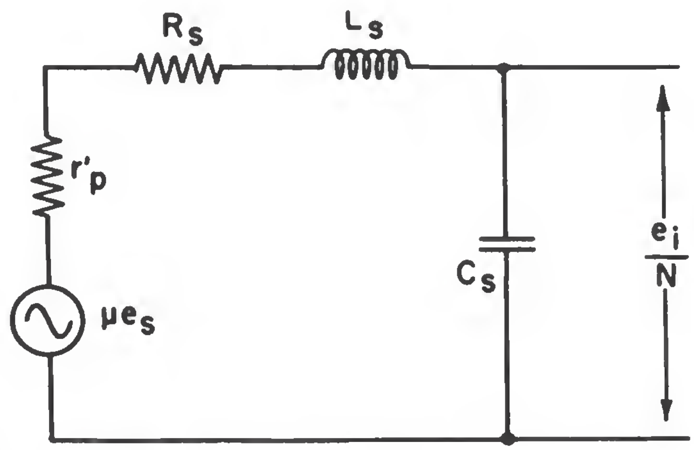


Figure 4–20.—Simplified equivalent circuit of a transformer-coupled amplifier for high-frequency operation.

same form as a series resonant circuit having relatively high resistance. In figure 4–20, r'_p is the combined plate and primary coil resistance, R_s the resistance of the secondary winding referred to the primary side, L_s the total leakage inductance referred to the primary side, and C_s the stray capacitance. This capacitance is made up of the secondary distributed capacitance and the input capacitance of the tube to which the output voltage is fed and is expressed in terms of the primary side.

To derive the expression for gain, the output voltage developed across C_s is given as $\frac{e_i}{N}$, where N is the secondary-to-primary turns ratio of the transformer. The output voltage,

e_t, is divided by N because the various impedances and resistances are referred back to the primary from the secondary circuit—

$$\frac{e_t}{N}=iX_C$$

AND

$$i=\frac{\mu e_s}{\sqrt{(r'_p+R_s)^2+\left(\omega L_1-\frac{1}{\omega C_s}\right)^2}}.$$

THEREFORE,

$$\frac{e_t}{N}=\frac{\mu e_s\frac{1}{\omega C_s}}{\sqrt{(r'_p+R_s)^2+\left(\omega L_1-\frac{1}{\omega C_s}\right)^2}},$$

OR

$$e_t=\frac{N\mu e_s\frac{1}{\omega C_s}}{\sqrt{(r'_p+R_s)^2+\left(\omega L_1-\frac{1}{\omega C_s}\right)^2}}.$$

THUS,

$$\text{gain}=\frac{e_t}{e_s}=\frac{N\mu\frac{1}{\omega C_s}}{\sqrt{(r'_p+R_s)^2+\left(\omega L_1-\frac{1}{\omega C_s}\right)^2}}.$$

Although the Q (ratio of X_L to R) of such a circuit is low and the response curve rather broad, the resonance effect is sufficiently pronounced to increase the gain at and near the resonant frequency. Proper circuit design ensures that the resonant frequency will occur above the audible limit. Above resonance the gain falls off rapidly.

Direct Coupling

In each of the coupling circuits that have been considered, the coupling device isolates the d-c voltage in the plate circuit from the d-c voltage in the next grid circuit. However, these devices are designed to transfer only the a-c component with minimum attenuation.

In a direct-coupled amplifier the plate of one tube is connected directly to the grid of the next tube without the use of a capacitor, a transformer, or any other coupling device. Because the plate of a tube must have a positive voltage with respect to its cathode and the grid of the next tube must have a negative voltage with respect to its cathode, proper circuit

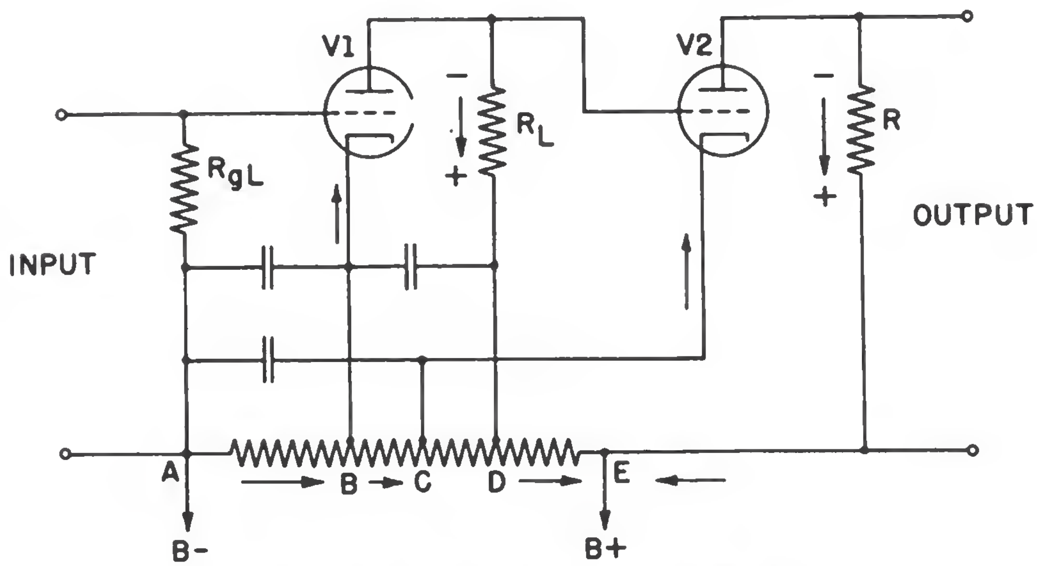


Figure 4–21.—Direct-coupled amplifier.

operation requires the use of a special voltage divider. A direct-coupled amplifier in which the plate of $V1$ is connected directly to the grid of $V2$ is shown in figure 4–21.

The voltage distribution is best understood by tracing it from the most negative end of the voltage divider. The grid of $V1$ is connected to point A through R_{gL}. The proper grid bias of $V1$ is obtained by connecting the cathode to the divider at point B so that the total current flow from A to B produces the required voltage drop. The plate of $V1$ is connected through R_L to point D. R_L also serves as the grid resistor for $V2$.

A certain amount of the supply voltage appears across R_L because the plate current from $V1$ flows through R_L. The amount of voltage drop here must be considered in choosing point D on the divider. Point D is so located that approximately half of the available voltage is applied to the plate of $V1$. The plate of $V2$ is connected through a suitable output load, R, to point E, the most positive point on the divider. The voltage drop across R_L alone would place too high a negative bias on the grid of $V2$. Therefore, it is necessary to connect the cathode of $V2$ at point C, which is negative with respect to D, in order to lower the bias on the grid of $V2$ since the voltages across R_L and CD are in opposition. Point C, along with resistor R, also determines the proper plate operating voltage for $V2$.

The entire circuit is a complex resistance network that must be adjusted carefully to obtain the proper plate and grid voltages for both tubes. Stable operation is difficult to achieve if more than two stages are used in this type of amplifier. Any small changes in the voltages of the first tube are amplified and thus make it difficult to maintain proper bias on the final tube connected into the circuit. Because of the instability, direct-coupled amplifiers are practically always limited to two stages. Furthermore, the power supply must be twice that required for one stage.

When the tube voltages are properly adjusted to give class-A operation, the circuit serves as a distortionless amplifier the response of which is uniform over a wide frequency range. This type of amplifier is especially effective at the lower frequencies because the impedance of the coupling elements does not vary with the frequency. Thus a direct-coupled amplifier can be used to amplify very low frequency variations in voltage. Also, because the response is practically instantaneous, this type of coupling is useful for amplifying pulse signals where all distortion caused by the coupling elements must be avoided.

FEEDBACK AMPLIFIERS

A FEEDBACK AMPLIFIER transfers a voltage from the output of the amplifier back to its input. If the signal fed back is in phase with the input signal it is called POSITIVE, DIRECT, or REGENERATIVE, FEEDBACK because it adds to the voltage of the input. If the signal fed back to the input is 180° out of phase with the applied signal it is called NEGATIVE, INVERSE, or DEGENERATIVE, FEEDBACK because it subtracts from the voltage of the input.

Principle of Feedback Amplifier

The principle of the feedback amplifier can be understood in part from a consideration of figure 4–22. A signal volt-

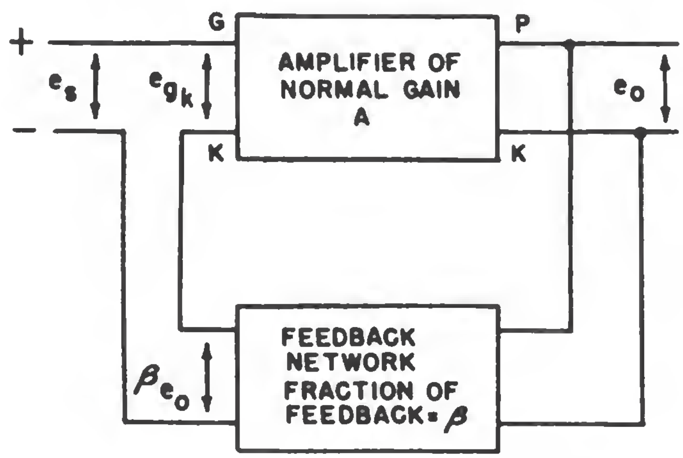


Figure 4–22.—Feedback employing series injection.

age, e_s, is applied to the input terminal. Let a portion, βe_o, of the resultant output voltage, e_o, be fed back in series with e_s in such a way that the signal, e_{gk}, appearing between the grid and the cathode is of the form

$$e_{gk}=e_s+\beta e_o. \qquad (4\text{–}1)$$

Because the normal gain, A, of the amplifier is defined as

$$A=\frac{e_o}{e_{gk}},$$

THEN

$$e_o=Ae_{gk}. \qquad (4\text{–}2)$$

If the value of e_{gk} given in equation (4–1) is substituted in equation (4–2),

$$e_o = Ae_s + \beta Be_o,$$

AND

$$e_o = \frac{Ae_s}{1-\beta A}.$$

The resultant gain, A_r (feedback considered), is

$$A_r = \frac{e_o}{e_s}.$$

THEREFORE,

$$A_r = \frac{A}{1-\beta A}.$$

The resultant gain of the amplifier is expressed in terms of the gain without feedback, A, and the fraction of the output, β, fed back to the input. A_r, A, and β may be complex quantities.

Positive Feedback

If the quantity of $1-\beta A$ is less than 1, the gain of the amplifier is increased over what it would be without feedback, and the amplifier is said to be positive or regenerative. Under these conditions the response curve is sharpened and the gain is increased, but the frequency range of uniform response is reduced. Thus, positive feedback permits both an increase in gain and an increase in selectivity.

The increase in gain, however, is accomplished by an exaggeration of any undesirable distortion or noise that was introduced within the amplifier itself. For this reason positive feedback is not used if a distortionless output is required. If the feedback factor βA is increased until it is equal to 1, the quantity $1-\beta A$ reduces to zero, and the resultant gain theoretically becomes infinite, or at least large enough to sustain oscillations. This action means that no input voltage would be required to obtain an output voltage. Under this condition the system ceases to be an amplifier and becomes an oscillator. A discussion of this aspect of feedback is considered in the chapter on oscillators.

If the quantity of $1-\beta A$ is greater than 1, the amplification is less than it would be without feedback, and the amplifier is said to be negative or degenerative. Generally, the feedback factor, βA, is made so much larger than 1 that the resultant amplification for all practical purposes can be expressed as

$$A_r = \frac{1}{\beta}. \tag{4-3}$$

ADVANTAGES.—Negative feedback can be used to reduce nonlinear distortion, or to make the output waveform more nearly similar to the input waveform by reducing nonlinearities that are introduced within the amplifier itself. This use can be understood from the following considerations.

The input signal applied to the grid of a vacuum-tube amplifier is amplified by an amount determined by the μ of the tube, but any nonlinearities introduced within the tube are not amplified. If a portion, βA, of the output is fed back 180° out of phase with the input, the distortion component of this 180° out-of-phase voltage is amplified along with the input signal. This distortion component tends to cancel the distortion component introduced within the tube. Thus, the output may be practically free of nonlinear distortion. However, the over-all gain of the desired signal is also reduced, but this reduction may be compensated for by increasing the number of stages. Distortions caused by the flow of grid current cannot be corrected by negative feedback because this distortion occurs at the source, and not within the amplifier tube.

Noise introduced within an amplifier can be reduced by negative feedback in the same manner that nonlinear distortion is reduced, and the same limitations apply. For feedback to be effective, the noise to be canceled out must be generated in the tube around which the feedback is applied. Thus, thermal agitation, induced hum, microphonics, and shot effects introduced in the early stages of a receiver cannot be reduced by negative feedback unless the feedback is applied at those stages.

Negative feedback in those stages is not practical because the amplification, particularly at the high frequencies encountered in most radar receivers, is low and negative feedback would reduce it even more. Additional stages, each with its own circuit noises, would have to be added to make up for the reduced gain. Negative feedback is very effective, however, in reducing noises introduced into the high-level stages of an amplifier.

If the feedback factor, βA, is much greater than 1, as was assumed in the case of the degenerative amplifier, the resultant gain is inversely proportional to β. Furthermore, if β (the portion of the output voltage fed back to the input) is obtained by means of a resistance network, the resultant amplification is essentially independent of frequency.

When it is desired to have the amplification vary in some specific manner with respect to frequency, the feedback network through which β is obtained can be designed to attenuate those frequencies that are desired in the output of the amplifier. Thus, if the high frequencies are to be amplified more than the low frequencies, the high frequencies will be attenuated in the feedback network more than the low frequencies. The low frequencies will be fed back to the grid in phase opposition to the input signal, and will therefore be reduced in the output.

The gain of a feedback amplifier can be made independent of the load impedance if the load impedance is not a part of the feedback network. This can be understood if it is assumed that, as the effective load resistance is reduced, the a-c component of plate potential is correspondingly reduced. Accordingly, the feedback is reduced and the gain is increased. Thus, the increased gain counteracts the tendency of the output to drop. On the other hand, if the effective load resistance is increased so that there is an increase in the a-c component of plate voltage, the feedback is increased and the gain is reduced in proportion. From these considerations it is apparent that the gain can be made substantially independent of the load resistance.

The gain is independent also of such factors as variations in supply voltage or aging of the tubes because the gain is proportional only to the feedback factor.

Feedback amplifiers in which the feedback factor, βA, is much larger than 1 (negative feedback) can be used to reduce nonlinear distortions and noise within the tube. Frequency distortion can also be reduced. In other words, amplitude and phase characteristics can be corrected by means of negative feedback. Likewise, the effects of variations in load and plate voltage supply as well as the effects of tube aging can be effectively counteracted. The sacrifice for these advantages is a reduction in gain.

METHODS OF OBTAINING NEGATIVE FEEDBACK.—In a practical amplifier, negative feedback can be obtained in a number of ways and it may involve one, two, or in rare instances more than two stages. Also, it may employ voltage, current, or compound feedback.

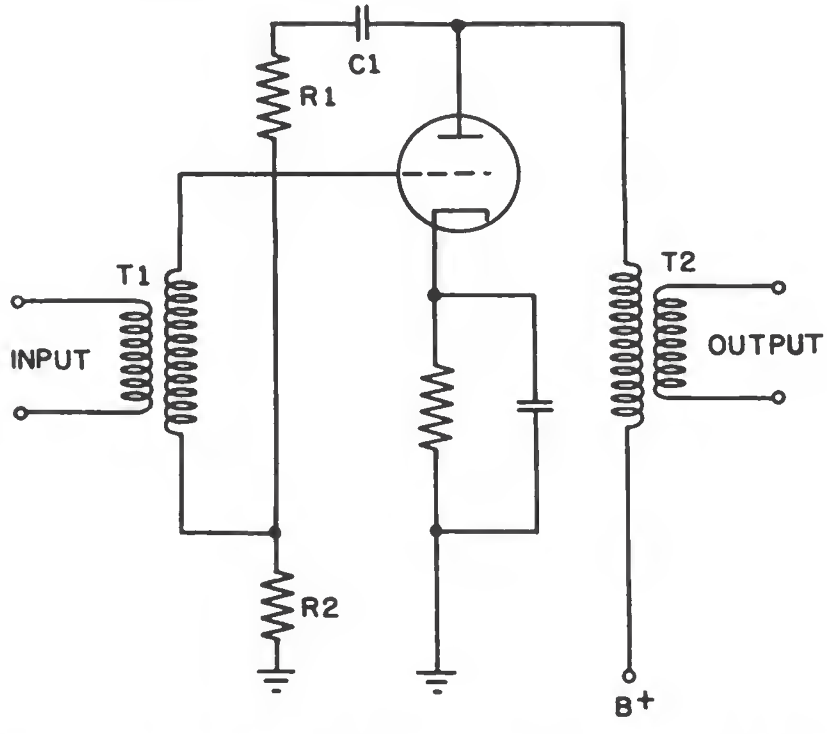


Figure 4–23.—Degenerative amplifier employing voltage feedback.

A common method of obtaining negative feedback employs a voltage divider circuit, as shown in figure 4–23. In this circuit a portion of the output voltage is fed to the input through the $R1C1$ network.

Assume that at a given instant the input is such that the grid is less negative. The plate current increases and the plate becomes less positive because of the increased voltage across the load. This reduction in plate potential is fed back through $C1$ and $R1$ to the top of $R2$. Because the electron flow is from top to ground through $R2$, a negative voltage is added to the positive-going signal through the secondary of transformer $T1$.

Another method of obtaining negative feedback employs current feedback, as shown in figure 4–24. In this circuit the cathode resistor has no bypass capacitor. If it is assumed

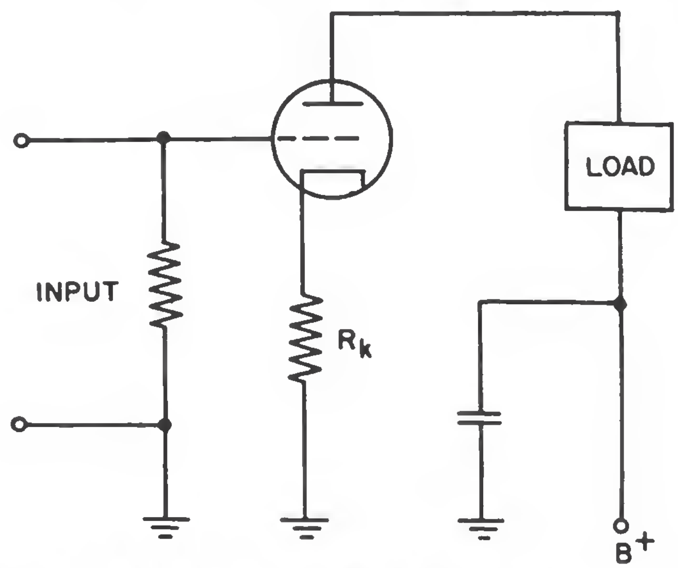


Figure 4–24.—Degenerative amplifier employing current feedback.

that at a given instant the grid is less negative, the plate current will then increase. Because R_k is not bypassed, signal currents in the plate circuit will flow through it from ground to cathode. The regular bias produced by the d-c component of the plate current will have added to it the bias produced by the signal component. This additional bias voltage is in phase opposition to the positive-going voltage on the grid, and degeneration occurs.

Similarly on the negative half cycle of the input signal when the grid is made more negative, the cathode resistor current and voltage drop decrease, thereby checking the negative swing of the grid voltage.

The principle that an output voltage can be developed across an unbypassed cathode resistor, is utilized in the design of cathode followers. Similarly, the principle that the output voltage across a cathode resistor is 180° out of phase with the output voltage between the plate and ground is utilized in the design of phase inverters. These circuits are considered later in this chapter.

If proper phase relations are established, negative feedback involving more than one stage can be employed. A two-stage negative-feedback amplifier employing voltage feedback is shown in figure 4–25. Special consideration must be given to the phase relations throughout the circuit.

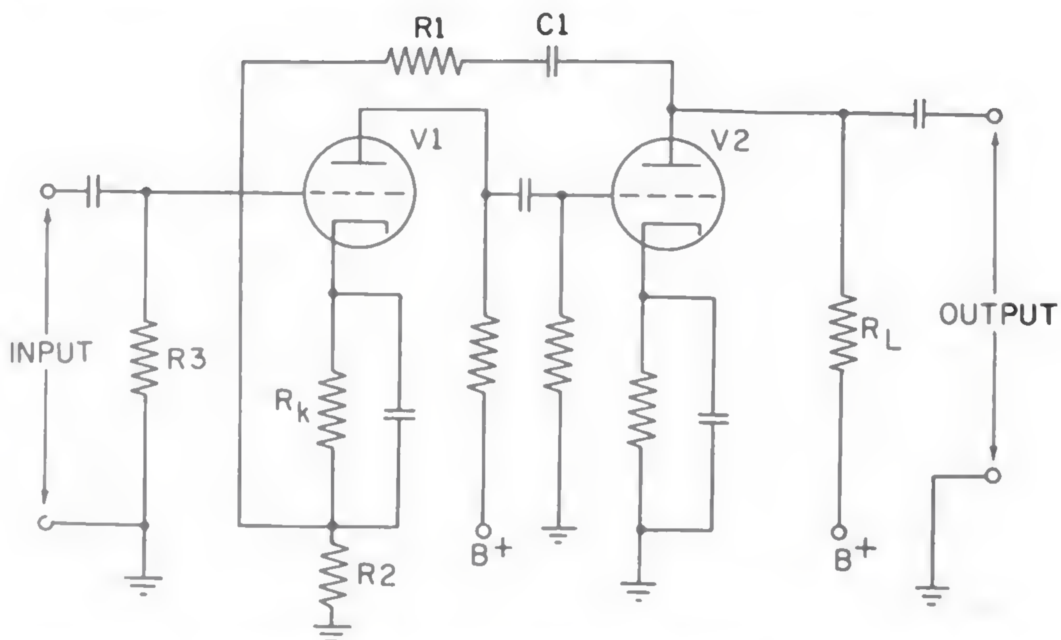


Figure 4–25.—Degenerative two-stage amplifier employing voltage feedback.

Assume that at a given instant the input voltage is such as to make the grid of *V*1 less negative. Plate current then increases in *V*1, and the plate voltage decreases, causing the grid of *V*2 to become more negative. At the same instant the plate of *V*2 becomes more positive because of the reduction in plate current. This increase in potential is fed back through $C1$ and $R1$ to the top of $R2$.

The flow of electrons from ground up through $R2$ and $R1$ to the left plate of $C1$ develops an additional series voltage which is added to the normal bias, thus increasing the positive cathode potential with respect to ground. The increase in cathode bias reduces the value of the positive-going signal impressed on the grid. In brief, the input signal is reduced by the amount of the feedback voltage.

Various combinations of voltage and current feedback circuits can be employed to satisfy specific requirements. Thus, a compound feedback employing both current and voltage feedback can be employed in a single stage, or current feedback can be employed in one stage of a two-stage amplifier section, and in addition voltage feedback can be employed between the stages.

CATHODE FOLLOWERS

To achieve uniform amplification over a wide frequency range an amplifier should have a low effective input capacitance and a low effective load impedance. The over-all response can also be improved by the use of degenerative feedback. The cathode follower possesses these qualities, and in addition it can be used to match the impedance of one circuit to that of another.

The cathode follower is a single-stage degenerative amplifier the output of which appears across the unbypassed cathode resistor. The high input impedance and the low output impedance make it particularly useful for matching a high-impedance source to a low-impedance load. Thus, the cathode follower might be used between a pulse-generating stage and a transmission line the effective shunt capacitance of which might be great enough to cause objectionable effects. However, more power can be delivered when the source is matched to the load. For example, a conventional amplifier having high output impedance would supply less power to a low-impedance coaxial line than would a cathode

317993 O—55——10

follower having an impedance that corresponds to the load impedance.

The advantages obtained by the use of a cathode follower can be obtained only at the sacrifice of a voltage gain that is less than unity. However, the circuit is capable of producing power gain.

As the name implies, the output voltage FOLLOWS the input voltage—that is, it has not only the same shape, but also the same instantaneous polarity (phase).

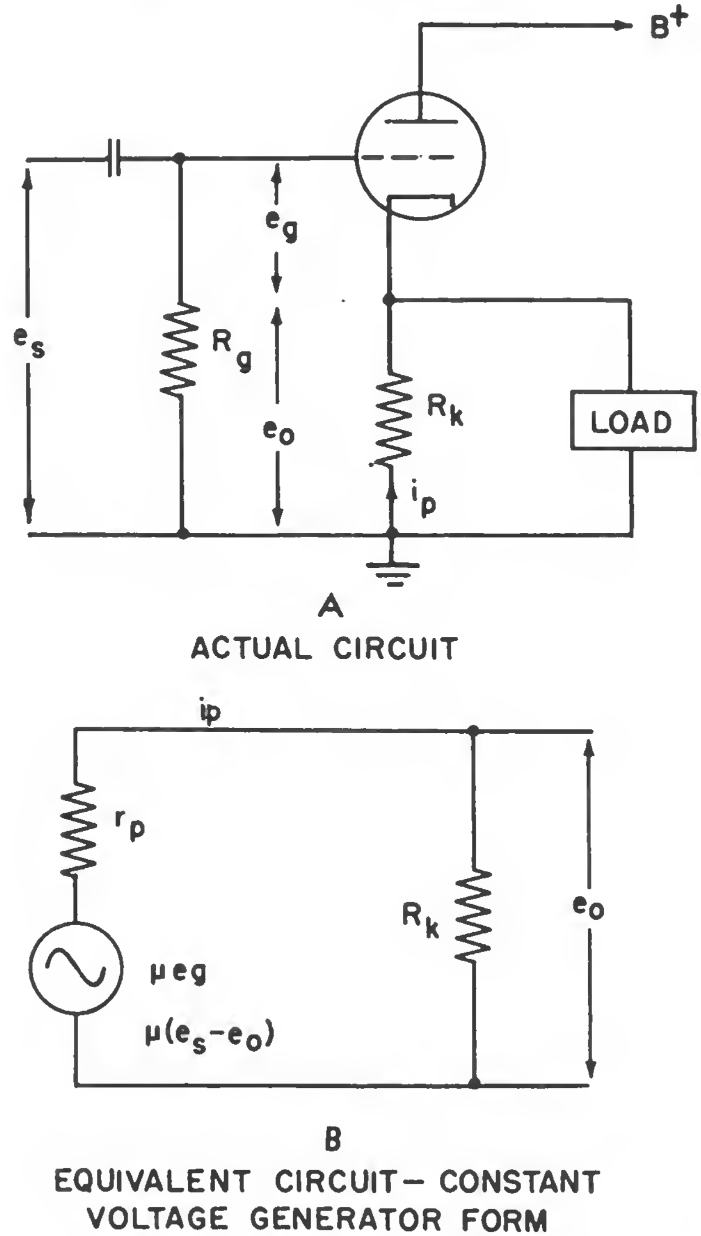


Figure 4–26.—Conventional cathode follower and equivalent circuit.

Circuit Operation

A conventional cathode follower is shown in figure 4–26. Under no-signal conditions a certain amount of plate current flows through R_k, and this flow establishes a normal bias. When a positive-going signal is applied to the grid, the plate current increases. This increase causes an increase in the voltage drop across R_k, making the cathode more positive with respect to ground than it was under the no-signal condition. When a negative-going signal is applied to the grid, the opposite effect occurs. Thus, the polarity of the output voltage follows the polarity of the voltage applied between grid and ground.

Since R_k is not bypassed, degeneration occurs because when a positive-going signal is impressed on the grid there is an increase in plate current through R_k and a proportional increase in the negative bias on the grid. The opposite effect occurs when a negative-going signal is impressed on the grid.

Voltage Gain

An expression for the voltage gain of a cathode follower is found by referring to the circuits shown in figure 4–26. The following equation can be established by inspection:

$$e_s = e_g + e_o,$$
$$e_o = e_s - e_g = i_p R_k,$$

AND

$$e_g = e_s - e_o = e_s - i_p R_k;$$

ALSO

$$i_p = \frac{\mu e_g}{r_p + R_k} = \frac{\mu (e_s - i_p R_k)}{r_p + R_k}.$$

It also follows that

$$\mu (e_s - i_p R_k) = i_p r_p + i_p R_k,$$

And i_p can be solved as

$$i_p = \frac{\mu e_s}{r_p + R_k(\mu + 1)} \qquad (4\text{–}4)$$

The output voltage, e_o, is the product of i_p and R_k, and

$$e_o = \frac{\mu e_s R_k}{r_p + R_k(\mu+1)}.$$

Thus, the voltage gain is

$$\text{V.G.} = \frac{e_o}{e_s} = \frac{\dfrac{\mu e_s R_k}{r_p + R_k(\mu+1)}}{e_s} = \frac{\mu R_k}{r_p + R_k(\mu+1)}. \tag{4–5}$$

When pentodes are used, the amplification factor is very large compared with unity. Thus, equation (4–5) can be reduced to

$$\text{V.G.} = \frac{R_k}{\dfrac{r_p}{\mu} + R_k} = \frac{R_k}{\dfrac{1}{g_m} + R_k}$$

Because

$$\frac{r_p}{\mu} = \frac{1}{g_m}.$$

It is apparent that the denominator is always greater than the numerator. Hence, the gain is always less than one.

Input Impedance

The input impedance of a cathode follower is high, and the effective input capacitance is low compared with that of a conventional amplifier. Both of these effects result from the degenerative action of the cathode resistance.

Under no-signal conditions the grid is negative with respect to the cathode. When a positive-going signal is applied to the grid the bias is increased, because of degenerative action, to such an extent that no grid current flows. The result is the same as if the input impedance had been increased. The same reasoning can be applied throughout the input cycle.

The reduced input capacitance results from the fact that degeneration reduces the effective input voltage, or in effect increases the input impedance, and thus causes less current to flow through the tube capacitances. The cathode follower has high input impedance and presents negligible loading to the circuit that drives it.

Output Impedance

An equation for the output impedance of a cathode follower is derived if the numerator and denominator of the right-hand side of equation (4–4) are first divided by $\mu+1$. THUS,

$$i_p = \frac{\left(\frac{\mu}{\mu+1}\right) e_s}{\frac{r_p}{\mu+1} + R_k}.$$

The tube now has an effective amplification factor of $\frac{\mu}{\mu+1}$ and an effective a-c plate resistance of $\frac{r_p}{\mu+1}$.

From the equivalent circuit of figure 4–26, B, the internal impedance, Z_o (with μe_g shorted), is the parallel combination of R_k and r_p. Therefore,

$$Z_o = \frac{\left(\frac{r_p}{\mu+1}\right) R_k}{R_k + \frac{r_p}{\mu+1}} = \frac{R_k r_p}{R_k(\mu+1)+r_p}.$$

The impedance is generally resistive, and if the amplification factor is large relative to unity, the term "$R_k(\mu+1)$" may be reduced to "$R_k\mu$." Hence, the resulting equation can be reduced further by dividing the numerator and denominator by r_p. Thus,

$$Z_o \doteq R_o = \frac{R_k}{\frac{R_k u}{r_p}+1} = \frac{R_k}{R_k g_m + 1}.$$

The output impedance is low, and accordingly there is a minimum of amplitude distortion of the output signal, although current is drawn from the output terminals.

Distortion Caused by Limiting

Under normal operating conditions, the output of a cathode-follower amplifier is practically free of amplitude distortion. However, if the input signal swings the grid voltage too far negative the output waveform will be limited, or distorted in amplitude, with respect to the input waveform. Beyond a certain negative value of grid voltage the plate current will be cut off, and any further increase in negative grid potential will cause no corresponding decrease in plate current.

If the signal swings the grid voltage in a positive direction far enough for the grid to draw current, the loss in voltage in the driving source limits the output signal and distortion again occurs.

The cathode-follower amplifier can be modified (fig. 4–27)

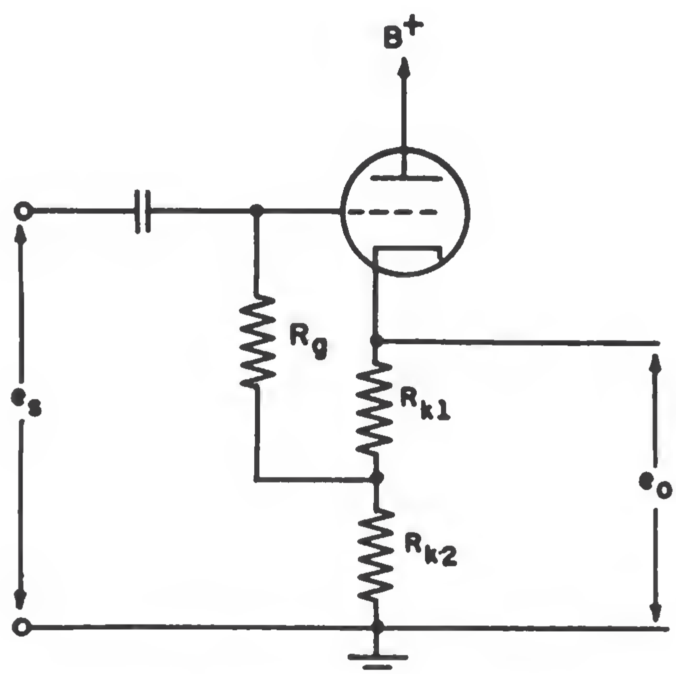


Figure 4–27.—Cathode follower modified to prevent limiting.

to adjust the grid bias to the correct value when the cathode resistance is greater than the value required to give the correct grid bias. In this modified circuit, the grid resistor, R_g, is connected to a point above ground on the cathode resistors, R_{k1} and R_{k2}. This point is determined by the input voltage level. Thus the grid bias is reduced by an amount equal to the drop across R_{k2}.

Advantages of Using a Cathode Follower

As previously stated, one of the principal advantages of a cathode follower is that it can be used to match a high-impedance source to a low-impedance load. Thus, it can take the voltage developed across a high-impedance source and supply a low-impedance load with only slightly less voltage but with a correspondingly large increase in current. One or more of the circuit elements of a cathode follower can be varied to obtain a more precise impedance match if the match is critical.

When tubes having a high mutual conductance are used, the low value of output impedance extends the operation into the upper range of frequences because the shunting effects of interelectrode and distributed capacitances are proportionately smaller. Because no blocking capacitor is used (fig. 4–26, A), the low-frequency response is also good.

The degenerative effect caused by the unbypassed cathode resistor increases the input impedance. Thus there is less shunting effect offered to the previous stage, and therefore this stage has a better frequency response.

As previously stated, the input and output voltages have the same instantaneous polarity. When pulses are used it may be necessary to feed a positive-going or a negative-going pulse to a load without polarity inversion. Thus the cathode follower can serve two purposes—to prevent polarity inversion and to afford an impedance match.

Circuit stability is also improved, as in regular amplifiers, by degenerative feedback. For example, amplitude distortion occurring within the tube, the effect of plate-supply voltage variations, aging of tubes, and the production of harmonics are counteracted by this type of circuit. However, these advantages are obtained at the expense of an over-all reduction in voltage gain. Normally the voltage gain is slightly less than unity, but the circuit is capable of producing a gain in power.

PHASE INVERTERS

Since phase is generally associated with time, it is somewhat of a misnomer to apply this term to a device that simply changes a positive-going signal to a negative-going signal or vice versa. However, in the case of a sine-wave signal, the effect is the same as if there had been a 180° phase shift.

Paraphase amplifiers (phase splitters) produce, from a single input waveform, two output waveforms that have opposite instantaneous polarities. If these two waveforms were produced as the result of a single sine-wave input they might be considered 180° out of phase, one waveform having been displaced 180° along the time axis.

One type of phase inverter is the transformer. The instantaneous polarity of the load can be reversed with respect to the source by reversing either the connections of the secondary leads of the transformer to the load or the primary leads of the transformer to the source. A conventional *R-C* coupled vacuum-tube amplifier also produces an output the polarity of which is opposite to that of the input. If no gain is desired, various methods can be employed to produce unity gain. Either single-tube or two-tube amplifiers can be used to convert one input waveform into two output waveforms of opposite polarity. Such amplifiers are called PHASE SPLITTERS or PARAPHASE AMPLIFIERS because they produce a pair of phases.

Transformer Phase Inverter

In operation, all transformers produce across the secondary an emf that is opposed to the change in flux producing it. The instantaneous polarity of the actual output voltage across a load depends on how the leads from the secondary are connected. A phase inversion of square waves and sine waves is indicated in figure 4–28. With square waves the polarity has simply been inverted. When this inversion applies to sine waves, it may be more conveniently referred to as a 180° phase shift. The effect is the same as if the waveform had been moved 180° along the time axis. If no increase in voltage is desired, a 1-to-1 turns ratio is employed.

A transformer with a center-tapped secondary, or one with

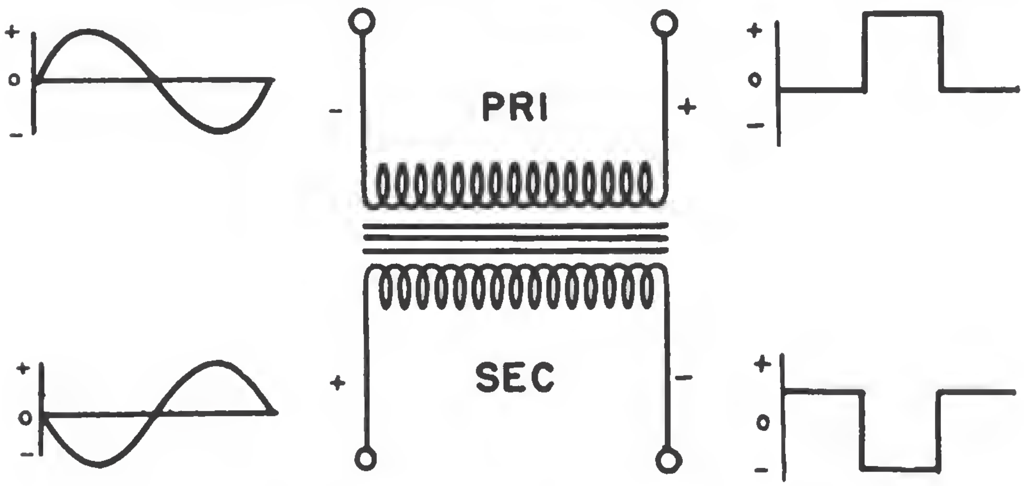


Figure 4–28.—Transformer phase inversion.

a center-tapped resistor shunting the secondary, is used in class-B push-pull input circuits to supply instantaneous voltages of opposite polarity to the grids of the tubes, as shown in figure 4–29.

If at a given instant the polarity of point *X* goes negative with respect to the grounded center tap, point *Y* will go positive with respect to the center tap. Thus, a negative potential will be applied between grid and ground of *V*2. At the same instant a positive potential will be applied be-

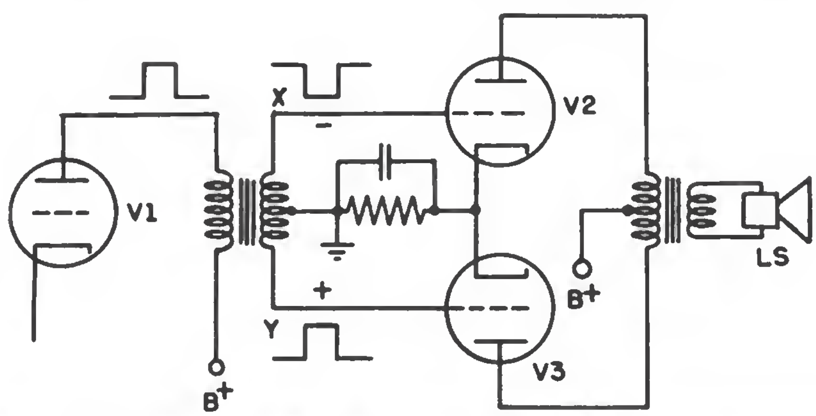


Figure 4–29.—Center-tapped transformer driving a push-pull amplifier.

tween grid and ground of $V3$. This condition is necessary for proper operation of a push-pull amplifier. The transformer must be tapped at the exact electrical center. Otherwise, the combined signal present in the output transformer will not be symmetrical with respect to the tap.

This type of transformer phase inverter has limited application because of distortions and losses inherent in transformers. For example, the loss in voltage through leakage reactance is greater for higher frequencies than for lower frequencies. The shunting capacitance losses also increase with frequency. Because in many circuits harmonics must be transmitted unattenuated and undistorted, the transformer phase inverter is generally replaced with a circuit that performs phase inversion without the use of transformers. The paraphrase amplifier is such a circuit.

Electron-Tube Phase Inverter

Every vacuum tube used as a conventional *R-C* coupled amplifier introduces polarity inversion—that is, a negative-going signal between grid and ground causes a positive-going signal to be produced across the load. If there is to be no gain in amplitude some method must be employed to reduce the normal gain to unity. One method of reducing the normal gain is through the use of degenerative feedback. Degenerative feedback is readily obtained by omitting the cathode bypass capacitor.

Another method of reducing the gain is to employ a voltage divider in the input circuit. For example, if the normal gain of the tube is 100, the grid would be tapped down on the divider so that one-hundredth of the available voltage would be applied between grid and ground. If harmonics are to be included, some method must be employed to reduce the input shunting effects of capacitance.

Single-Tube Paraphase Amplifier

One of the simplest forms of single-tube paraphase amplifiers is shown in figure 4–30. The values of resistors $R2$ and

$R3$ are the same. Therefore, their voltage drops are equal because they carry the same current. The instantaneous polarities of the a-c signal component, however, are opposite because at the instant a positive-going signal is applied to the grid, point X becomes less positive with respect to

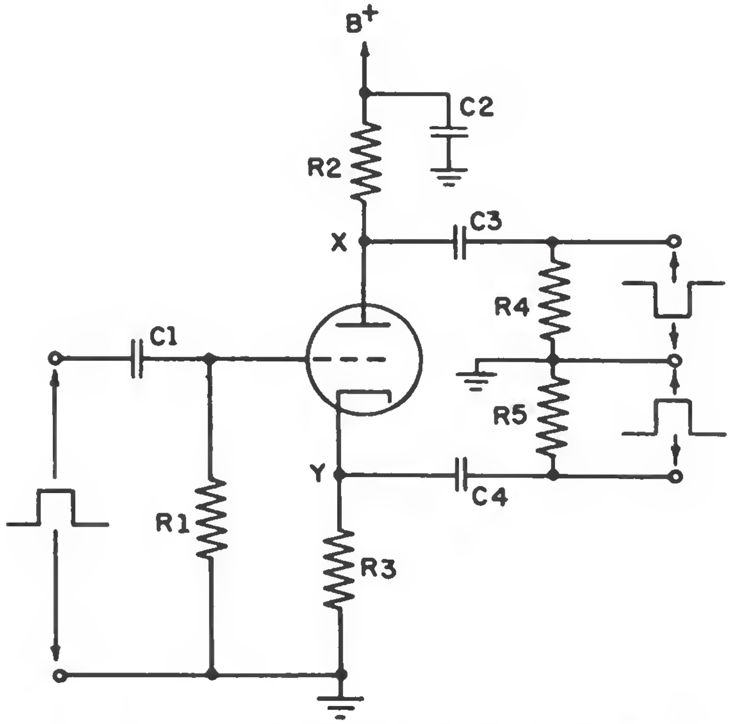


Figure 4–30.—Single-tube paraphase amplifier.

ground and point Y becomes more positive. These signals with the polarities indicated (fig. 4–30) are impressed across load resistors $R4$ and $R5$ through blocking capacitors $C3$ and $C4$. $C2$ is the plate supply bypass capacitor.

This basic type of single-tube paraphase amplifier can be modified to avoid some of the degenerative action caused by the unbypassed cathode resistor or it can be compensated to permit a better frequency response.

Two-Tube Paraphase Amplifier

A two-tube paraphase amplifier utilizes one tube as a regular amplifier and a second tube as a phase inverter. These functions can be performed by two sections of the same tube.

The combination is frequently referred to as a **PHASE INVERTER.**

One of the simpler forms of two-tube paraphase amplifiers is shown in figure 4–31. Tube *V*1 operates as a conventional amplifier having normal gain. Tube *V*2 operates as a phase inverter, the input of which is reduced to the same

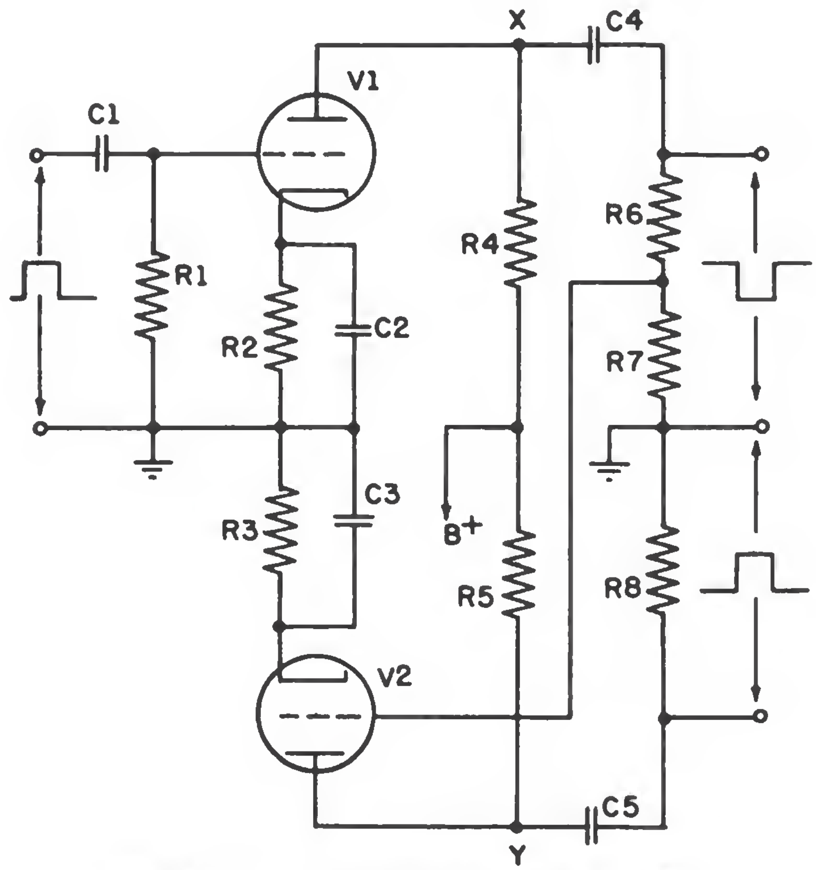


Figure 4–31.—Two-tube paraphase amplifier.

value as the input of *V*1. Thus *V*2 amplifies the signal as much as *V*1 and the output is essentially symmetrical about the zero-voltage reference line.

A positive-going signal on the grid of *V*1 causes an increase in plate current and a reduction in positive plate potential at point *X*. This reduction in positive potential is transmitted as a negative-going signal through coupling capacitor *C*4 to resistors *R*6 and *R*7. The grid input to *V*2 is tapped down on resistors *R*6 and *R*7 to feed the proper negative swing in potential to *V*2. If *V*1 has a gain of 50, the resistance of $R7$ should be one-fiftieth of the total value of $R6$ and $R7$. At the instant a positive-going signal is applied to the grid of $V1$ a negative-going signal is thus applied to the grid of $V2$. The positive potential at point Y is increased, and a positive-going signal is applied to resistor $R8$, through coupling capacitor $C5$. At the same time the negative-going signal appears across resistors $R6$ and $R7$.

If the operating conditions of the two tubes are carefully chosen and the circuits are properly adjusted, the two amplified output signals should be essentially undistorted and of opposite instantaneous polarity. In actual practice this method presents some difficulty because the adjustments are critical. However, it is widely used as a means of driving class-A push-pull audio power amplifiers.

QUIZ

1. How are electron-tube amplifiers classified?
2. What are the operating frequency ranges over which amplifiers operate when classified according to frequency?
3. Distinguish between voltage and power amplifiers.
4. Why must the value of load impedance be as large as practicable in a voltage amplifier?
5. How does the magnitude of the plate load impedance affect the power output of a power amplifier?
6. What are four classes of amplifier operation with respect to the type of bias?
7. What are the principal characteristics of class-A amplifiers?
8. What are the principal characteristics of class-B amplifiers?
9. Why are push-pull class-B amplifiers used widely for audio power amplification?
10. What is the principal characteristic of class-AB amplifiers?
11. What are the principal characteristics of class-C amplifiers?
12. What are two types of amplifiers classified according to resonant quality of load?
13. What are three types of distortion in amplifiers?
14. What are four basic methods of coupling amplifier stages?

15. How is amplifier tube behavior simplified for the purpose of circuit analysis?
16. What is a widely used method of coupling audio voltage amplifier stages?
17. Name three advantages of *R-C* coupled amplifiers.
18. What is an advantage of impedance-coupled amplifiers?
19. Name a disadvantage of impedance-coupled amplifiers.
20. Name four advantages of transformer-coupled amplifiers.
21. Name four disadvantages of transformer-coupled amplifiers.
22. Name an advantage of direct-coupled amplifiers.
23. Name a disadvantage of direct-coupled amplifiers.
24. What is the function of a positive feedback amplifier?
25. What is the function of a negative feedback amplifier?
26. Name three advantages of using negative feedback.
27. Name four methods of obtaining negative feedback.
28. What is a cathode follower?
29. What is the phase relation between the output and input voltages of a cathode follower?
30. How do the input impedance and the effective input capacitance of a cathode follower compare with those of a conventional amplifier?
31. What is the relative magnitude of the output impedance and the amplitude distortion of a cathode follower?
32. What is the effect on the output waveform with respect to the input waveform of a cathode follower if the input signal swings the grid voltage too far negative?
33. Name four advantages of using a cathode follower.
34. Name four types of phase inverters.
35. Name two disadvantages of a transformer phase inverter.
36. Omitting what circuit component will produce degenerative feedback in a vacuum-tube amplifier?
37. Name two methods of reducing the gain in an electron-tube amplifier.
38. For what purpose are two-tube paraphase amplifiers widely used?

CHAPTER 5

OSCILLATORS

INDUCTANCE-CAPACITANCE OSCILLATORS

An electronic oscillator is a device for converting direct current into alternating current at almost any desired frequency. Oscillators operating within a range of from about 20 to 20,000 cycles are known as a-f oscillators whereas oscillators operating at higher frequencies are known as r-f oscillators. A vacuum tube can function as an oscillator because of its ability to amplify. To cause an amplifier to produce sustained oscillations, the output circuit must be coupled to the input circuit so that a portion of the output voltage is fed back into the grid circuit in phase with the input signal. This signal is amplified and when it is increased beyond a certain critical point, sustained oscillations result.

In a vacuum tube there is a normal phase shift of 180° between the grid and plate signals. Hence, without an additional shift of 180° the output voltage of one stage returned to the grid of the same stage would oppose the grid signal and not have the correct polarity to sustain oscillations. Therefore, to provide a regenerative or positive feedback, it is necessary to shift the feedback voltage another 180° so that it is in phase with the initial grid voltage. In addition the feedback must have sufficient magnitude to supply the losses in the grid circuit.

The feedback can be accomplished by resistive, capacitive, or inductive coupling. The frequency of the oscillations produced in a circuit depends upon the values of inductance and capacitance in the circuit. Thus if the reactive components of the oscillator tank circuit are properly selected, the circuit can be tuned to oscillate at the desired frequency. These components may be in the grid circuit, the plate circuit, or both. The oscillations are generated in the tuned circuit and the vacuum tube functions as a switch that automatically controls the release of energy into this circuit to maintain the oscillations.

Principle of Oscillations

A-c oscillations can be produced in a tuned *L-C* circuit by periodically charging the capacitor from an external d-c source as shown in figure 5–1, A. The resonant tank determines the frequency of the output voltage developed across the unit. The reactance of the inductor increases and the reactance of the capacitor decreases as the frequency increases. If the capacitance and inductance are fixed there is one fundamental frequency at which a resonant interchange of energy occurs between the inductor and the capacitor. At this particular frequency the inductive reactance of the inductor is equal to the capacitive reactance of the capacitor. The circuit resonates at this frequency.

If switch *S* (fig. 5–1, A) is closed momentarily, capacitor *C* charges negative at plate *B* and positive at plate *A*, as shown at 0° in figure 5–1, B. This charge is represented by the capacitor voltage curve, e_c, which is positive maximum at this instant. When the switch is opened, the capacitor discharges through inductor *L* at a rate determined by the values of inductance and capacitance in the tank circuit. The discharge current, i, establishes a magnetic field around the inductor. The rate of change of current is maximum at 0° and thus the induced emf, e_L, in the coil is maximum. When the capacitor becomes fully discharged, as shown at 90° in figure 5–1, B, this magnetic field collapses as the current decreases, inducing in the inductor a voltage that maintains the current flow in the original direction. This action charges the capacitor in the opposite direction, as shown at 180°, so that plate *A* is negative with respect to plate *B*.

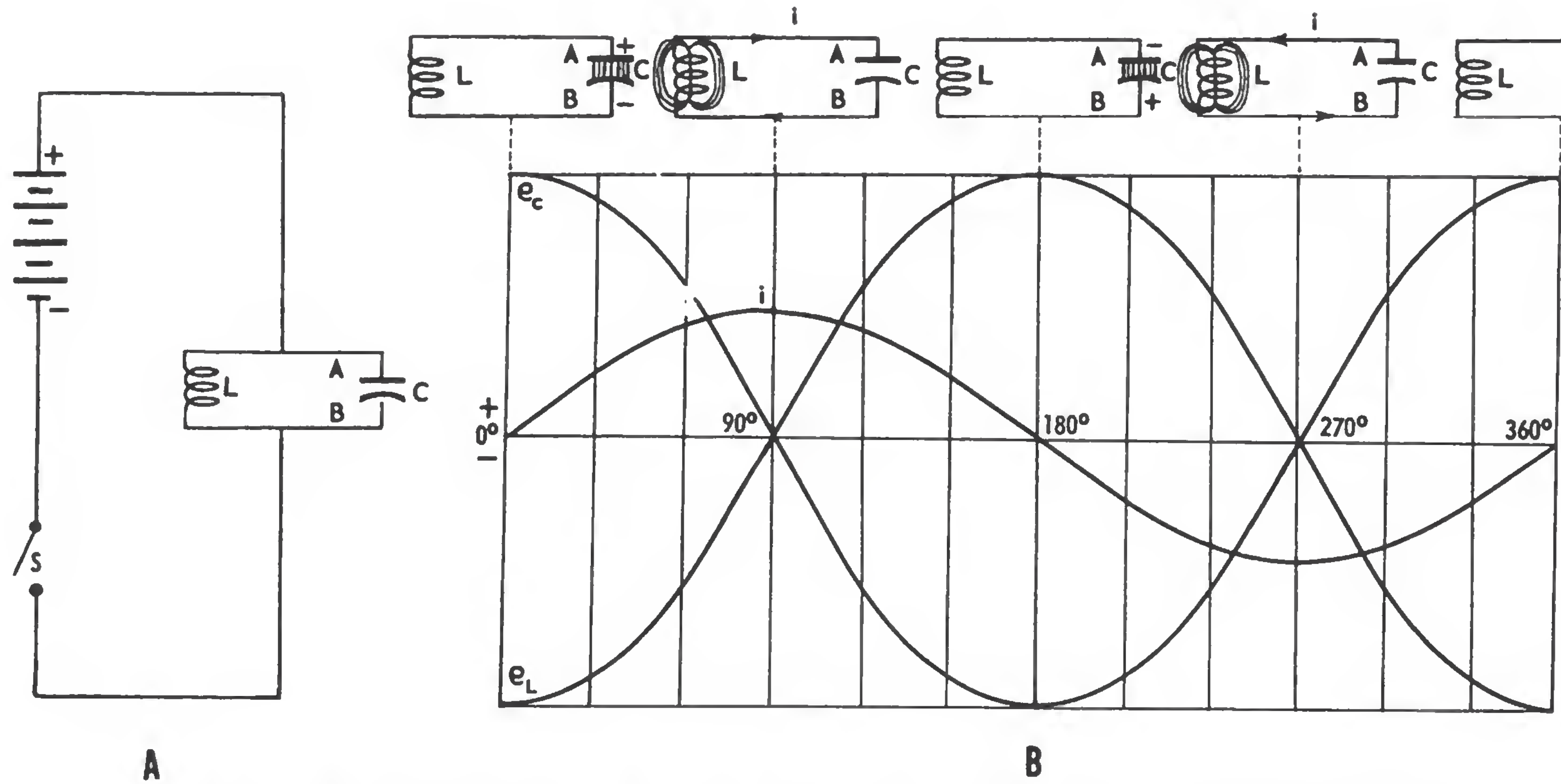


Figure 5–1.—Resonant oscillations. A, Circuit; B, sine curve voltage relation of reactive components.

When the field has collapsed, the capacitor discharges again through the inductor, this time in a direction opposite to the original direction of current flow. The capacitor voltage is zero when the current is maximum at 270°. This current establishes a magnetic field of opposite polarity around the inductor. Thus, a current oscillates back and forth, alternately charging the capacitor in one direction and then in the other. The alternating voltage developed across the tuned circuit is of sine waveform.

The alternating current has a certain frequency that is determined by the length of time required to charge and discharge the capacitor through the inductor. The larger the values of capacitance and inductance, the longer is the time required and, therefore, the lower the frequency.

If there were no losses in the resonant circuit, the oscillations would continue indefinitely at the same amplitude because there would be nothing to impede the flow of alternating current. However, all circuits and circuit elements have some effective resistance. A portion of the energy that is alternately stored in the capacitor and in the inductor is transformed into heat in this resistance and represents a loss of energy. Therefore, the amplitude of the alternating current decreases with each succeeding cycle, and eventually the current ceases to flow. The smaller the value of the effective resistance in series with the inductor and capacitor the greater is the number of consecutive cycles for a single impulse of energy introduced to the circuit. Conversely, if the circuit resistance is too great, oscillations cannot be sustained.

Oscillator Circuit

The energy necessary to sustain oscillations can be supplied to the tank circuit (fig. 5–1, A) more conveniently if the switch is replaced with a vacum tube, as shown in figure 5–2, A. The energy to supply the tank circuit losses comes from the battery periodically when the grid signal causes the vacuum tube to conduct. The frequency of this signal is the same as the resonant frequency of the oscillating tank circuit so that the tube permits the battery to furnish energy to the tank circuit at the correct time. This circuit (fig. 5–2, A) serves as an amplifier. A part of the amplified output voltage across the tank is fed back to the grid of the tube by coupling grid coil $L2$ to the tank coil $L1$ (fig. 5–2, B).

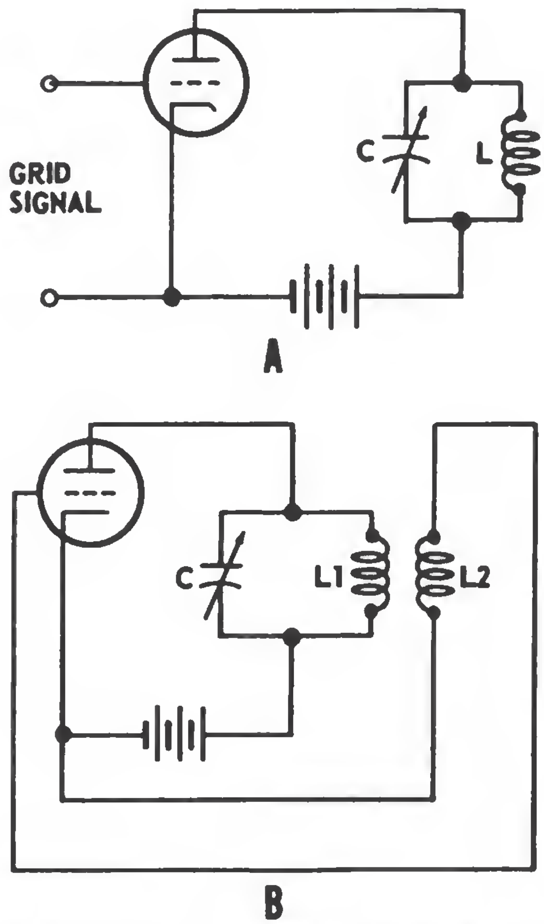


Figure 5–2.—Simple oscillator. A, Amplifier circuit; B, regenerative amplifier circuit.

Thus no external signal is necessary to sustain oscillations. The tube is grid-leak biased to limit plate current to the desired value and to make the oscillator self-starting.

If the polarity of the feedback is correct, the oscillator is self-excited and continues to oscillate as long as the d-c supply is connected. If the polarity of the feedback is incorrect the oscillations may be started by reversing the leads to $L2$. If the plate circuit is opened, oscillations cease. If the circuit is closed again, oscillations start because any random variations, no matter how small, are rapidly amplified to a greater degree at the start because of the correspondingly low grid-leak bias.

Methods of Biasing

As previously stated an oscillator is in reality an amplifier in which a portion of the amplified output is fed back from the plate circuit to the grid circuit (fig. 5–2, B). Vacuum-tube oscillator circuits usually operate with a high negative grid bias, which permits plate current to flow only during the small part of each cycle when the alternating grid voltage is near its positive peak. Also, the grid of the tube is allowed to draw current. The energy for the grid circuit must be supplied by the tank circuit. However, the disadvantage of supplying grid-circuit losses from the oscillating tank is more than balanced by the high values of tank current that result and the increased efficiency in the conversion of d-c energy into a-c energy.

Frequency of Oscillations

As mentioned previously, the frequency at which oscillations take place in a vacuum-tube oscillator is determined by the resonant frequency of the tuned circuit. The approximate frequency of oscillations is the frequency at which the inductive reactance equals the capacitive reactance. Thus,

$$X_L = X_C$$

$$2\pi f L = \frac{1}{2\pi f C}$$

$$f = \frac{1}{2\pi\sqrt{LC}}, \qquad (5\text{–}1)$$

where f is the approximate frequency of oscillation in cycles per second, L the inductance in henrys, and C the capacitance in farads. If the value of either L or C is decreased, the frequency of oscillations increases. Conversely, if the value of either L or C is increased, the frequency of oscillations decreases.

TYPES OF OSCILLATORS

Vacuum-tube oscillators are divided into two main classes—(1) SELF-CONTROLLED, or SELF-EXCITED, OSCILLATORS and (2) CRYSTAL-CONTROLLED OSCILLATORS. A further subdivision is the method of coupling the feedback, such as inductive coupling, external capacitive coupling, or interelectrode capacitive coupling. Most oscillators are named after the person who first demonstrated the practical use and operation of the oscillator.

Self-Controlled Oscillators

TICKLER-COIL OSCILLATOR.—The tickler-coil oscillator shown in figure 5–3 is the simplest type of self-excited oscillator. The tank circuit consists of *L*1 and *C* in the grid circuit. The feedback from plate to grid is accomplished

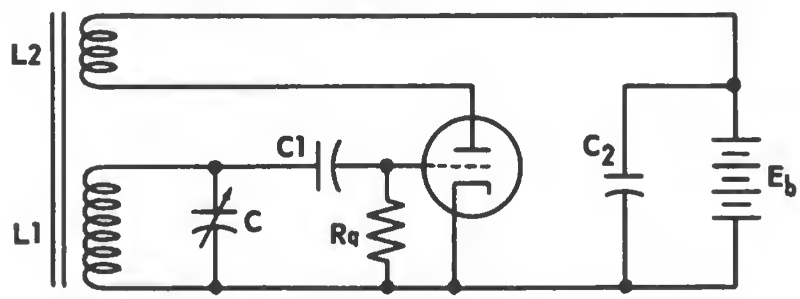


Figure 5–3.—Tickler-coil oscillator.

by means of transformer action (mutual inductive coupling) between the tickler coil, *L*2, and the grid coil, *L*1. As mentioned previously, because the tube normally introduces a phase shift of 180°, the feedback network must provide another phase shift of 180° so that the feedback voltage is in phase with the initial grid voltage. Grid-leak resistor R_g and capacitor *C*1 bias the tube for class-C operation. Capacitor *C*2 is an r-f bypass around the plate supply, E_B.

When the oscillator is placed in operation, the bias is slightly positive because of the position of the grid in the electric field existing between the cathode and the plate, and the amplification is at its maximum. The plate current rises very rapidly to a high value limited by the plate voltage. The rising plate current causes an expanding magnetic field that induces a voltage in $L1$. If the coils are connected so that the polarity of this voltage drives the grid positive, the increase of plate current is made larger. During this brief interval, C is charging due to the voltage induced in $L1$, and $C1$ is charging due to the flow of grid current while the grid is positive.

As a result of the reduction in plate voltage previously described, the plate current is limited to a maximum finite value. As the current nears this limiting value it increases less rapidly and the voltage induced in $L1$ is reduced. C begins to discharge through $L1$ and the voltage across the tank begins to decrease. Therefore, the grid starts to go negative and thus reduces the plate current. This action causes the magnetic field of $L2$ to start collapsing and consequently induces a voltage of reversed polarity in $L1$. This voltage accelerates the change in voltage across the tank; the plate current falls to zero; and the collapsing magnetic field causes C to charge in the opposite direction. When the magnetic field has collapsed completely, C again discharges but the direction of current flow is reversed, and the grid is driven in a positive direction so that the plate current again flows and the cycle repeats.

$C1$ charges when the grid is positive and discharges through R_g when the grid is negative. If R_g and $C1$ are selected so that the R-C time constant is relatively long with respect to the time for one cycle, a steady voltage is established on $C1$. This steady value is the bias voltage that determines the operating point of the tube.

The amplitude of oscillation becomes stable when the energy fed back from the plate circuit to the grid circuit is sufficient to supply the circuit losses. Plate current flows for only a small part of the cycle but the flywheel action of the tank maintains the cycle of oscillation.

When an oscillator circuit is operating, grid current flows during a part of each cycle. Thus, a test for the proper operation of an oscillator is to measure the grid current or the grid-bias voltage across R_g.

HARTLEY OSCILLATOR.—The Hartley oscillator circuit shown in figure 5-4, A, is very similar to the tickler-coil circuit previously described. In the Hartley oscillator circuit a single coil is used instead of the transformer coupling be-

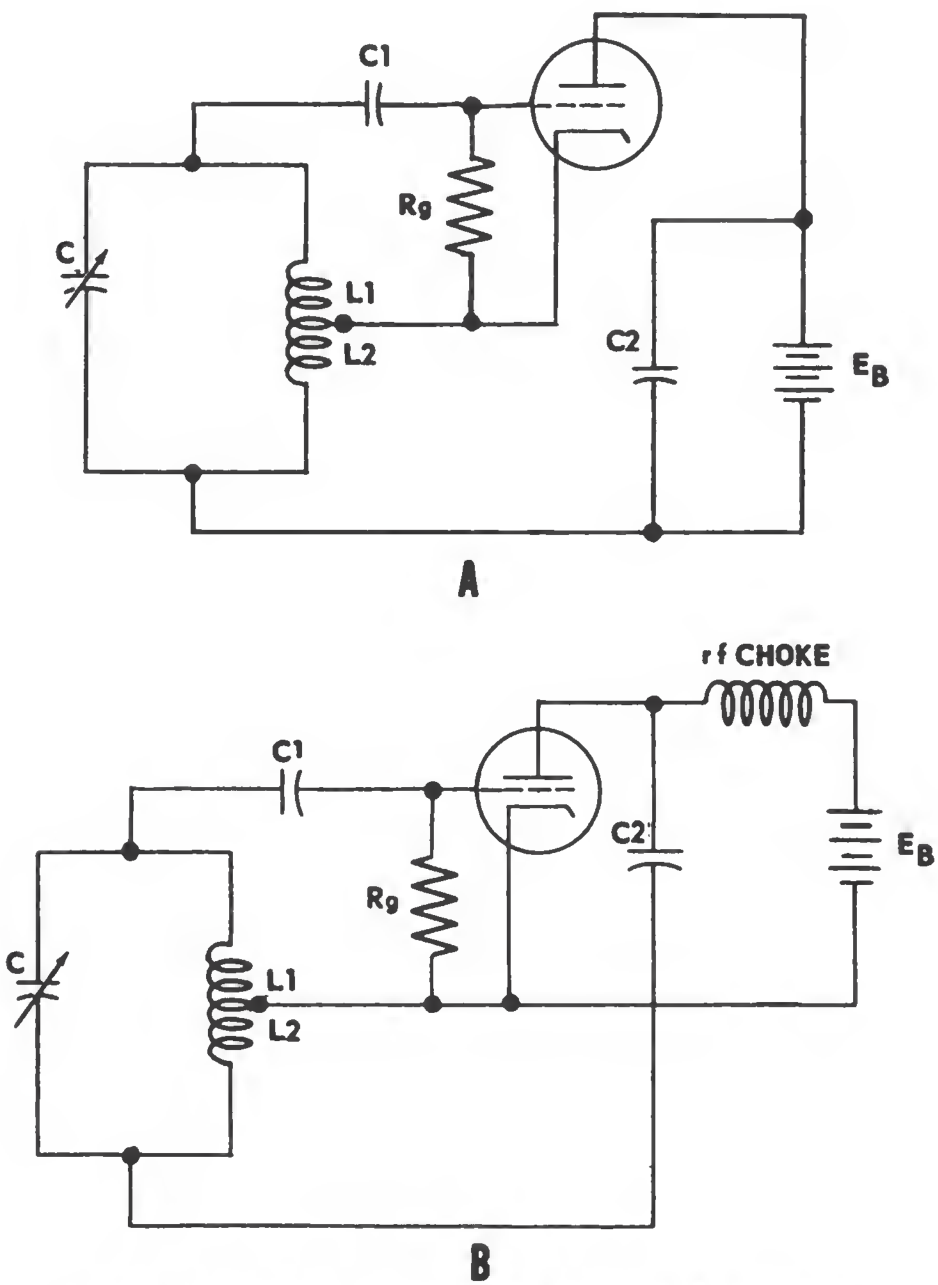


Figure 5-4.—Hartley oscillator. A, Series-fed; B, shunt-fed.

tween the plate and grid circuits. This circuit is called a SERIES-FED HARTLEY OSCILLATOR because the plate voltage is in series with the plate and with the part of the coil that is in the plate circuit. The single-tapped coil, which is part of a resonant circuit, forms a voltage divider with one section in the grid circuit and the other in the plate circuit. The ratio of a-c plate voltage to a-c grid voltage is equal to the voltage gain of the amplifier. Capacitor *C* is connected across the entire coil. Magnetic coupling thus exists between the two sections of the coil. The resonant frequency is determined by the values of *C*, *L*1 and *L*2. The voltage induced in the grid section by the plate section is the feedback voltage and is applied to the grid of the tube to maintain oscillations. The amount of feedback can be varied by changing the position of the tap on the coil. Bias is developed by the same method as that used in the circuit shown in figure 5–3.

If the circuit is connected as shown in figure 5–4, B, the oscillator is called a SHUNT-FED HARTLEY OSCILLATOR. Capacitor *C*2 couples the variations in plate voltage to *L*2 of the tuned circuit but blocks the direct current from the tank. The r-f choke provides a low resistance path for the direct current and a high impedance to r-f current.

COLPITTS OSCILLATOR.—The Colpitts oscillator shown in figure 5–5 is essentially the same as the Hartley oscillator except that the tank circuit employs a voltage divider consisting of two series-capacitors, one in the grid and the other

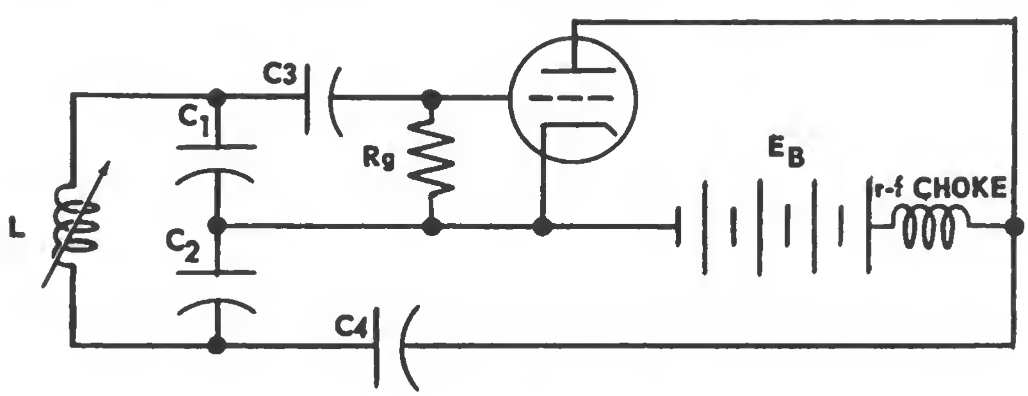


Figure 5–5.—Colpitts oscillator.

in the plate. The feedback is called CAPACITIVE FEEDBACK because it is obtained from the voltage drop across the tank capacitor in the grid circuit. Tuning usually is accomplished by varying the inductance L. Shunt feed must be used because the cathode is connected between the two tank capacitors and there is no d-c path from this point in the tank circuit. Therefore, grid-bias resistor R_g must be connected directly between the grid and cathode to provide a d-c path for grid current and the plate supply is returned directly to the cathode. The a-c component of plate voltage is coupled to the tank by capacitor $C4$.

The a-c component of output voltage appearing between plate and cathode is coupled through plate blocking capacitor $C4$ in the form of an electron movement. This electron movement in turn produces a movement in the plate excitation capacitor $C2$. Because of inductance L, this action also causes a current to flow in capacitor $C1$. This current results in a potential difference across $C2$ and $C1$. The potential difference across $C1$ excites the grid with the correct phase and oscillations are sustained.

TUNED-PLATE TUNED-GRID OSCILLATOR.—The tuned-plate tuned-grid oscillator has a tuned tank circuit in both the grid and plate circuits, as shown in figure 5–6. This oscillator is often referred to by the initials "TPTG." Because of their locations, there is no inductive coupling between the plate and grid coils. The feedback energy from the plate to the

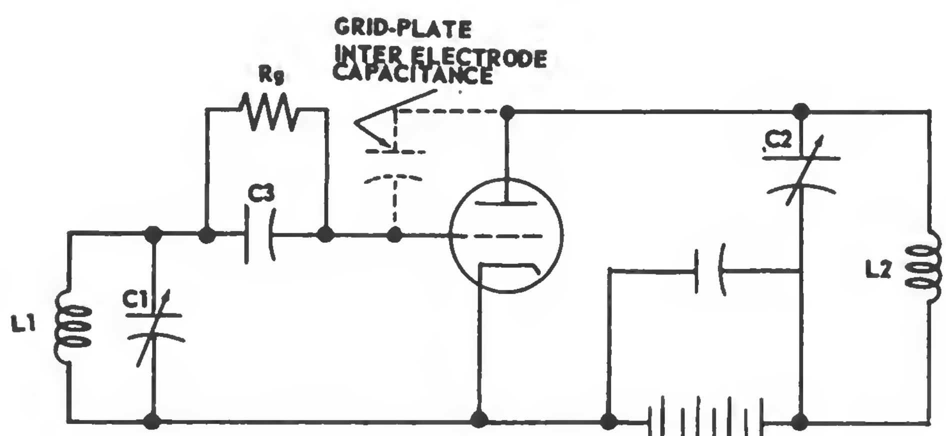


Figure 5–6.—Tuned-plate tuned-grid oscillator.

grid, necessary to sustain oscillations, is fed from the plate to the grid through the interelectrode capacitance of the tube. In order to have the feedback voltage of the correct phase, the plate tank circuit is tuned to a frequency slightly higher than the grid tank circuit. The tank circuit having the highest Q determines the frequency of oscillation. This is usually the grid tank circuit. Varying the tuning of either tank circuit varies the amount of feedbank. The correct phase shift of feedback voltage is accomplished by causing the plate tank to present inductive reactance to the circuit made up of the grid-plate-tube capacitance and the tuned grid circuit in series.

ELECTRON-COUPLED OSCILLATOR.—The load in any of the oscillators previously described is either in the form of an amplifier input circuit or of an antenna coupling device. Any variation in these external circuits changes the operating conditions in the plate circuit of the oscillator, and consequently changes the frequency of oscillations.

An electron-coupled oscillator circuit having a relatively high frequency stability is shown in figure 5–7. The cathode,

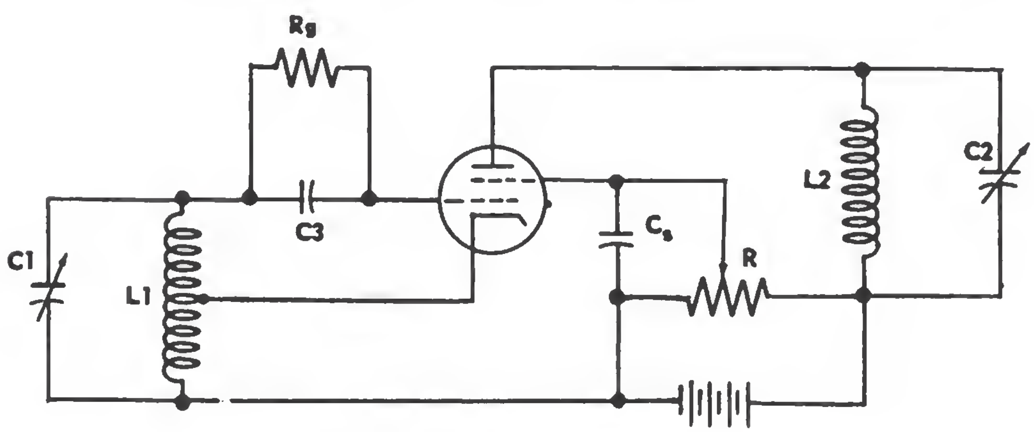


Figure 5–7.—Electron-coupled oscillator.

control grid, and screen grid form a series-fed Hartley oscillator with inductive coupling to supply the feedback energy. The screen of the tube acts as the plate of the oscillator circuit. The oscillator portion of the circuit is connected to the plate circuit, without external coupling devices, by means of the electron stream which flows through these elements from cathode to plate. The electron stream actually couples the energy from the oscillator to the plate. The control grid determines the amount of current that flows from the cathode to the plate and the voltage developed across the parallel resonant plate tank circuit is an amplified voltage.

Both amplification and oscillation take place in the same tube. Because of the isolation of the oscillator section from any load variations, the frequency stability of the electron-coupled oscillator is superior to that of other types of oscillator circuits previously discussed. An increase in screen voltage decreases the frequency of the oscillations, while an increase in plate voltage increases the frequency. Therefore, if the screen grid is properly tapped down on resistor R, the effect of voltage variations in the B-supply will be counteracted and the oscillator frequency will be unaffected. Frequency stability is best when the ratio of the plate-to-screen voltage is about 3 to 1.

Crystal-Controlled Oscillators

The crystal in a crystal-controlled oscillator is used to hold the frequency of an oscillator to an exact value. This type of oscillator depends for its action upon a crystal, usually quartz. Certain crystalline substances (such as quartz, Rochelle salt, and tourmaline) exhibit an interesting property. If a mechanical force is applied to one of these substances, a voltage is developed. Conversely, if a source of alternating voltage is applied to such a substance, a change in the physical shape of the substance results, accompanied by mechanical vibrations. This relation between mechanical and electrical effects is known as the PIEZOELECTRIC effect, previously explained. Although many substances exhibit piezoelectric properties, quartz is the most suitable for crystal oscillators.

Quartz crystals are usually cut into plates from the original crystal. Electrical contact with the crystal plate is obtained by mounting the crystal between two metal plate holders. A slight mechanical pressure is exerted on the metal plates by a spring device.

When a crystal starts vibrating at its resonant frequency, only a small force of the same frequency is necessary to obtain vibrations of a large amplitude. The mechanical resonant frequency of a crystal depends chiefly upon its thickness. When an alternating voltage is applied to a crystal that has the same mechanical frequency as the applied voltage, it vibrates. Only a small voltage is necessary to keep it vibrating and the crystal generates an appreciable voltage at its resonant frequency.

If a crystal is placed between the grid and cathode of a vacuum tube and a small amount of energy from the plate circuit is fed back to it, the circuit acts as an oscillator. The natural resonant frequency of the crystal is critical. At a slightly higher or lower frequency, the amplitude of the crystal vibrations is almost zero, and when the crystal stops vibrating it produces no voltage. Thus, the frequency of a crystal-controlled oscillator must be the same as that of the crystal.

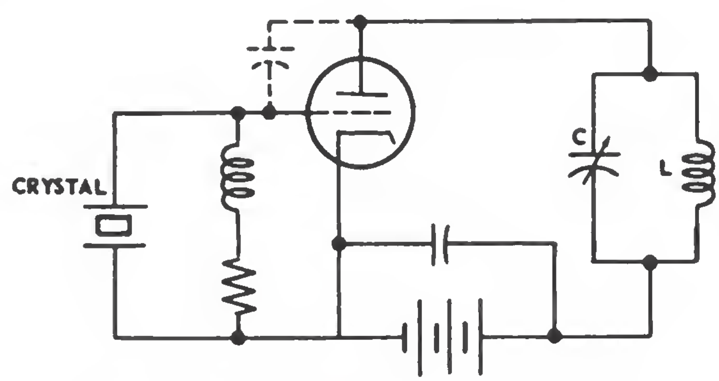


Figure 5–8.—Crystal-controlled oscillator.

A crystal-controlled oscillator is shown in figure 5–8. This circuit is the same as the TPTG oscillator circuit (fig. 5–6) except that in the crystal-controlled oscillator the crystal replaces the tuned-grid circuit. Thus, a crystal is similar to a high-Q resonant tank circuit. The feedback takes place through the interelectrode capacitance within the tube from plate to grid.

Oscillations occur at the resonant frequency of the crystal, and the plate circuit is tuned APPROXIMATELY to this frequency. Erratic and unstable operation results if the plate circuit is tuned exactly to the crystal frequency. During oscillation, the crystal vibrates at its resonant frequency. The strength of these vibrations depends upon the feedback voltage. If the feedback is too great, the vibrations may become strong enough to crack or break the crystal. The use of a tetrode or a pentode overcomes this difficulty because the interelectrode capacitance is reduced by the screen grid, thereby reducing the magnitude of the feedback voltage. Oscillations are still generated because tetrodes and pentodes are more sensitive than triodes and require less grid voltage for satisfactory operation.

If a d-c milliammeter is placed in the battery lead to the plate-tank circuit (fig. 5–8), and the tuning capacitor now changed from a low value to a high value (from above to below resonance), the plate current is seen to decrease slowly to a minimum and then suddenly jump to a maximum. At this point oscillations cease. This action is illustrated by the plate-current tuning curve in figure 5–9.

There is a pronounced rise in plate current at point *A* when the crystal oscillator goes out of oscillation—that is, going

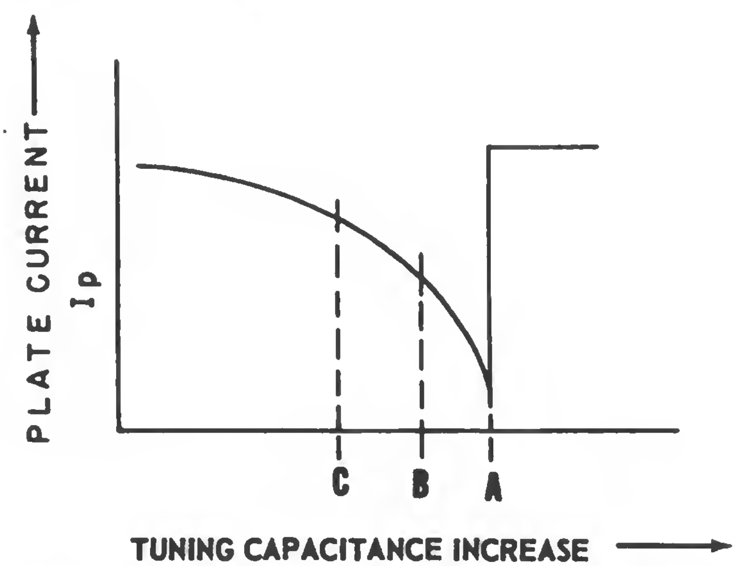


Figure 5–9.—Crystal oscillator plate-current tuning curve.

from minimum to maximum capacitance the plate circuit is tuned slightly above the resonant frequency of the crystal, and the output of the plate tank circuit becomes maximum as plate current dips to the minimum at point *A*. Although maximum output occurs at this point, a crystal oscillator should be operated between points *B* and *C* on the tuning curve because the point of maximum output, *A*, on the curve produces unstable operation.

The crystal frequency is slightly below the natural resonant frequency of the plate tank. Therefore, the tank looks like an inductor. The feedback circuit is a series connection of the plate tank, grid crystal, and plate-to-grid capacitance of the tube. As long as the feedback is positive, the oscillator operates at the crystal frequency. As the capacitance is increased beyond *A*, the tank suddenly looks like a capacitor instead of an inductor and the feedback becomes negative instead of positive. Therefore, oscillations cease and plate current rises rapidly.

Thus if the plate tank circuit is operated at point A the oscillator becomes very erratic—it may operate intermittently or stop after a brief oscillation. Also, when cathode bias is used the plate current under load may rise during tuning and exceed the nonoscillating value of current. Under this condition, the oscillator should be operated between the equivalent points *B* and *C* on the corresponding rising plate-current curve (not shown in the figure).

As mentioned previously, the crystal frequency is slightly below the natural resonant frequency of the plate tank. Thus, the tank resembles an inductance. The feedback circuit is a series connection of the plate tank, the grid crystal, and the grid-plate interelectrode capacitance of the tube. The feedback is positive and the oscillator operates at the crystal frequency when the plate tank is inductive. The sudden increase in plate current at point *A* (fig. 5–9) occurs because the natural resonant frequency of the plate tank swings from above to below the crystal frequency at this point. Thus, the tank resembles a capacitance instead of an inductance and the feedback is negative instead of positive and therefore oscillations cease.

PIERCE CRYSTAL OSCILLATOR.—The Pierce crystal oscillator is a special type of crystal-controlled oscillator that requires no tuning control. The circuit for a Pierce crystal oscillator is shown in figure 5–10. The crystal is connected effectively

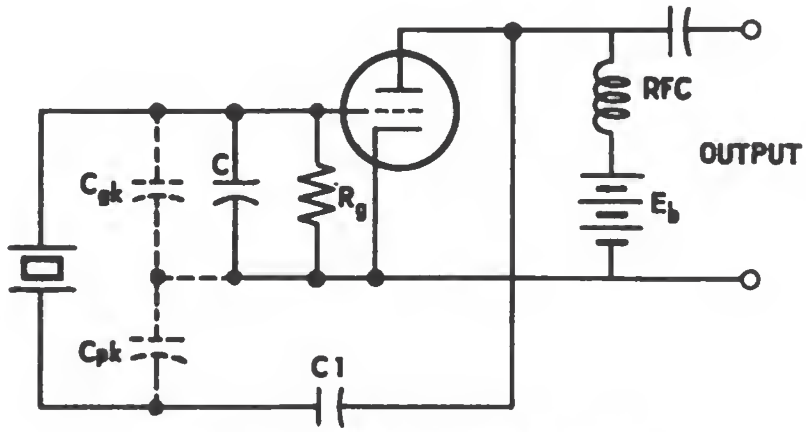


Figure 5–10.—Pierce crystal oscillator.

from plate to grid. The circuit can be considered the equivalent of a Colpitts oscillator with the tuned circuit replaced by the crystal and the voltage division accomplished through the plate-to-cathode and grid-to-cathode capacitance of the tube. This capacitance is represented in the figure by the broken lines.

The amount of feedback depends upon the grid-to-cathode capacitance. A fixed capacitor, C, is sometimes required between the grid and cathode to provide the proper amount of excitation for the tube because excitation is not otherwise capable of adjustment except by a change in plate voltage. This capacitance is not critical and ordinarily it is not necessary to change the capacitor when the bands are changed. Capacitor $C1$ keeps the direct voltage off the crystal and provides an r-f path between the crystal and plate. Resistor R_g is the grid-leak resistor which, together with capacitor C, supplies the grid bias. The chief disadvantage of this type of oscillator is low output.

RESISTANCE-CAPACITANCE OSCILLATORS

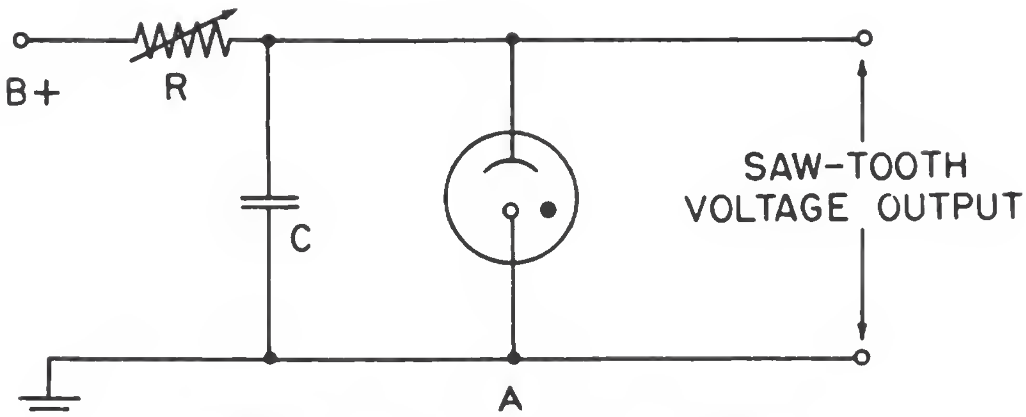
Many oscillators use resistance-capacitance networks to provide regenerative coupling between the output and input circuits and to determine the oscillation frequency. Such oscillators are called RESISTANCE-CAPACITANCE (*R-C*) oscillators. Examples of *R-C* oscillators are the SAW-TOOTH GENERATOR, PHASE SHIFT OSCILLATOR, WIEN-BRIDGE OSCILLATOR, and free-running MULTIVIBRATOR.

Saw-Tooth Generator

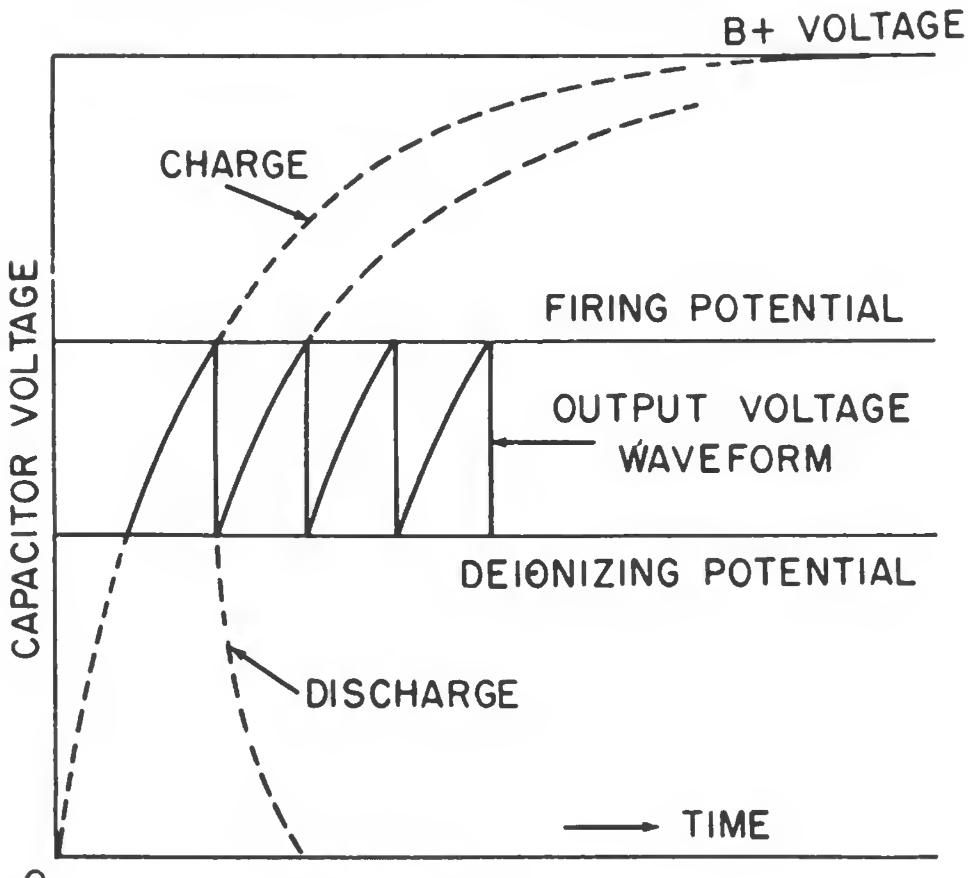
Voltages having saw-tooth waveforms are widely used in television, radar, and test equipment. One of the simplest devices for developing this type of waveform is the gas-tube relaxation oscillator, shown in figure 5–11, A. Capacitor *C* is charged through resistor *R* until the potential across *C* reaches a value high enough to ionize the gas in the tube. Until this time the tube had a high impendance, but now its impendance drops to a low value and *C* discharges rapidly through it. When the voltage across *C* falls below the ionizing potential, the initial high impendance across the tube is reestablished and the capactor stops discharging. Since the voltage across *C* is less than the value required to ionize the tube, the capacitor again charges up.

The frequency of the saw-tooth voltage depends upon the *R-C* time constant and is varied by adjusting *R*.

A consideration of figure 5–11, B, indicates that the output voltage (solid curves) varies between the deionizing potential and the firing potentiol of the gas tube. The full B-supply voltage is not applied across *C* (broken curves) because the firing potential is a much lower value. Likewise *C* does not completely discharge because when the deionizing potential is reached, *C* stops discharging. The voltage built up across the ouput follows a normal *R-C* charging curve. The discharge follows a similar curve except that the discharge time is only a small fraction of the charge time, be-



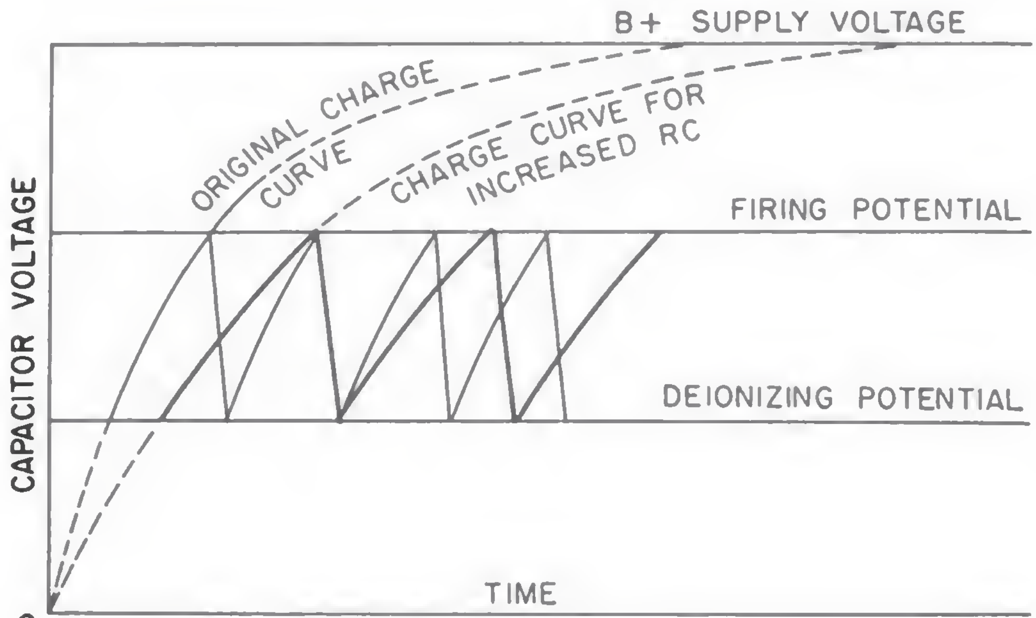
A
NEON SAW-TOOTH GENERATOR



B
WAVEFORMS

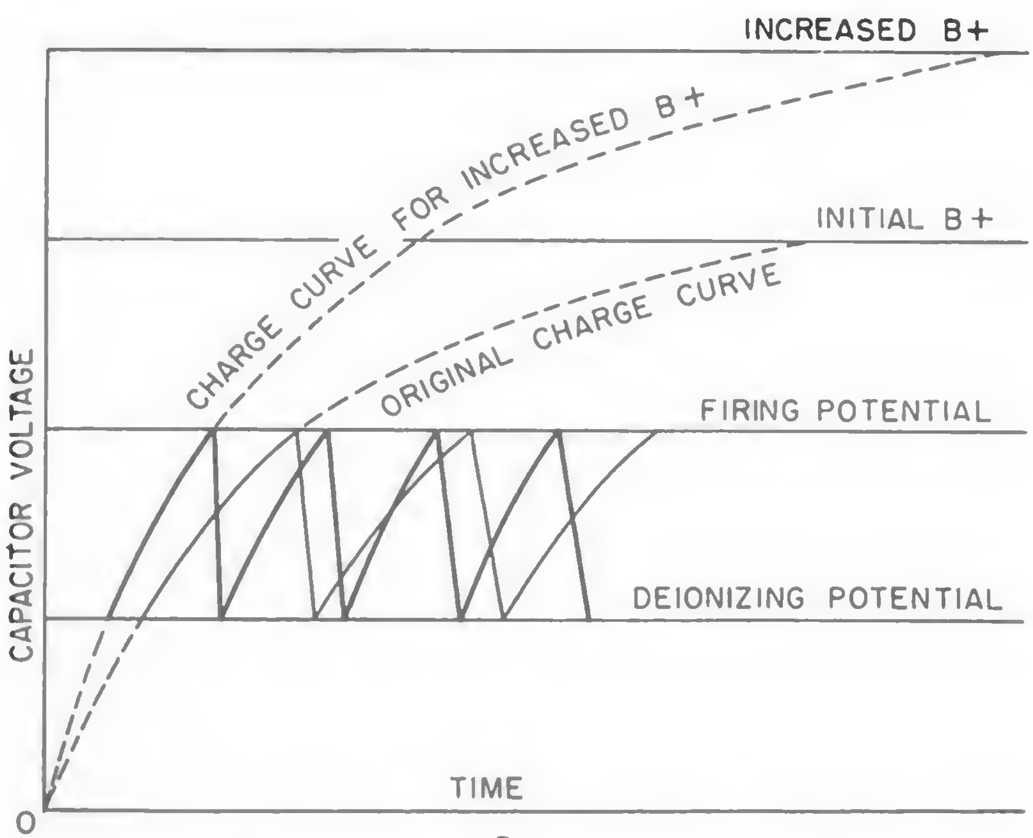
cause the resistance of the discharge path is only a small fraction of the resistance of the charging path.

The output voltage curves for increased *R-C* time constant and for increased B-supply potential are shown in figure 5–12. For example, in figure 5–12, A, increasing the resist-



A

R-C TIME CONSTANT INCREASED—FREQUENCY REDUCED



B

SUPPLY VOLTAGE INCREASED—FREQUENCY INCREASED

Figure 5–12.—Curves resulting from a variation in circuit constants.

ance, R, increases the time necessary for C to charge to the ionizing potential, and the frequency is correspondingly decreased. Increasing the supply voltage (fig. 5–12, B) decreases the time necessary to charge C to the firing potential, and thus the frequency is increased.

The thyratron, or gas-filled triode, is generally used to produce saw-tooth waveforms and has certain advantages over the simple neon-tube saw-tooth generator. It is more stable; changes in the applied voltage or frequency do not alter its characteristics so readily; also the deionizing time is reduced. The thyratron operates much the same as the neon tube except that the ionizing potential is controlled by the grid. The deionizing potential is affected very little by the grid bias. The more negative the grid with respect to the cathode the higher is the ionizing potential and the lower the frequency. A simple thyratron saw-tooth generator circuit and the output waveforms with high and low values of grid potential are shown in figure 5–13. The approximate frequency of the saw-tooth voltage is given by the following equation:

$$f=\frac{1}{2.302RC\log_{10}\dfrac{E_b-E_2}{E_b-E_1}}.$$

where f is the frequency in cycles per second, R the total charging resistance in megohms, C the total capacitance in microfarads, E_b the plate supply E_2 the deionization potential, and E_1 the ionization potential in volts.

In this circuit the B-supply voltage of course must be larger than the ionizing potential of the tube. If a low potential is used the output will have greater nonlinearity; in other words, a longer time will be required for the capacitor, C, to become charged, and therefore the full charge curve is used. On the other hand, if a high voltage is used, only the lower more linear portion of the curve is utilized before the ionization potential is reached.

A gas-tube relaxation oscillator does not produce oscillations that are stable in frequency. It can be synchronized

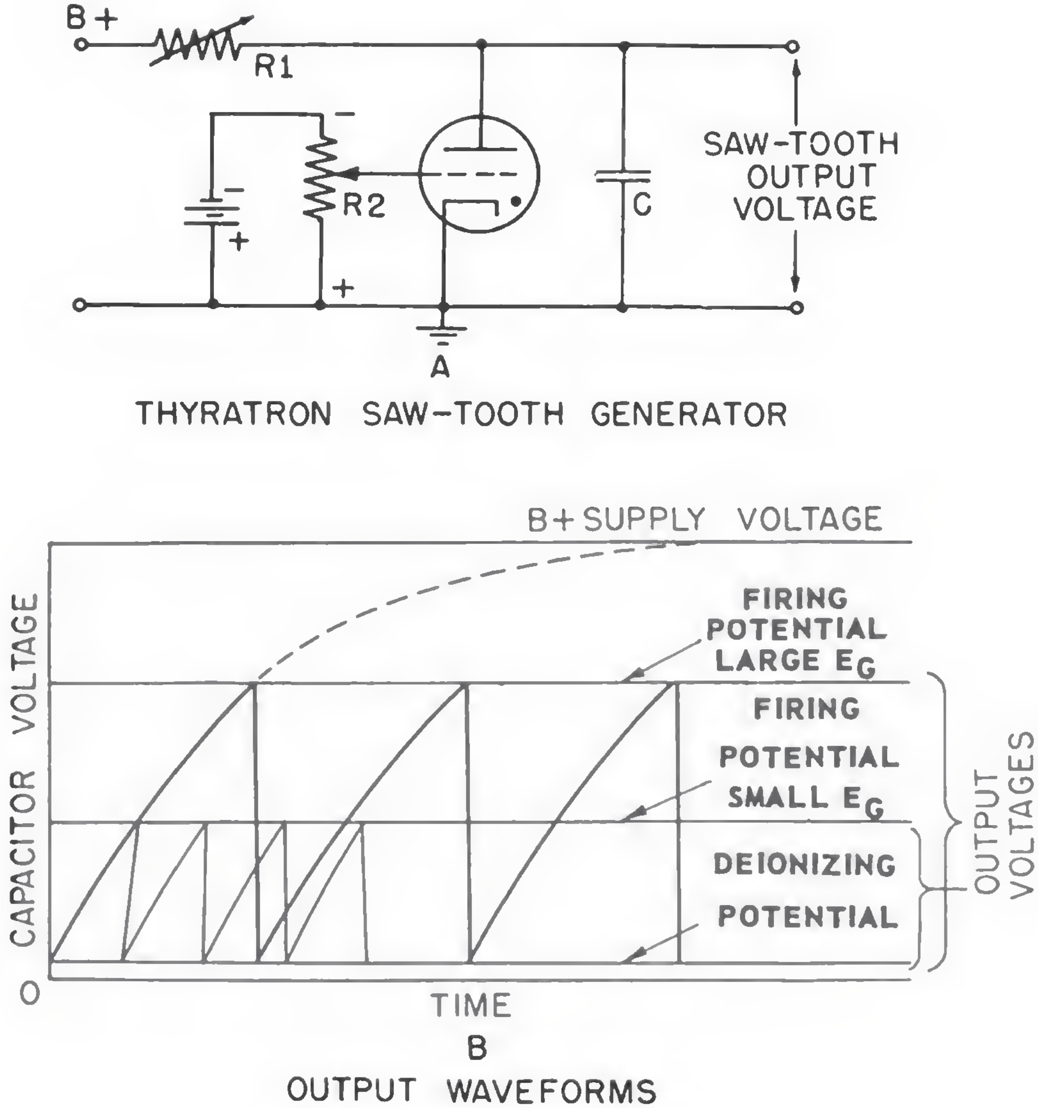


Figure 5–13.—Thyratron saw-tooth generator.

with a constant frequency, however, by injecting a small voltage of the desired frequency on the grid. A saw-tooth oscillator stabilized in this manner is shown in figure 5–14, A.

The oscillator is adjusted until its natural frequency is somewhat lower than that of the synchronizing signal, as indicated by the broken saw-tooth curve (without sync signal) in figure 5–14, B. Without the sync signal the tube fires at points *A*, *C*, and so forth. With the sync signal the firing potential varies according to the instantaneous value of the grid potential. In other words, when the positive half of the sync signal is applied to the grid, the firing potential is reduced and the tube fires at points B, D, and so forth. When the negative half of the sync signal is applied, the firing potential is increased. By applying the synchronizing voltage the time for each oscillation is reduced from AC to BD, and the oscillator is locked to the frequency of the sync voltage. The oscillator may also be locked to a multiple or submultiple of the sync voltage.

The vertical and horizontal sweep oscillators in television

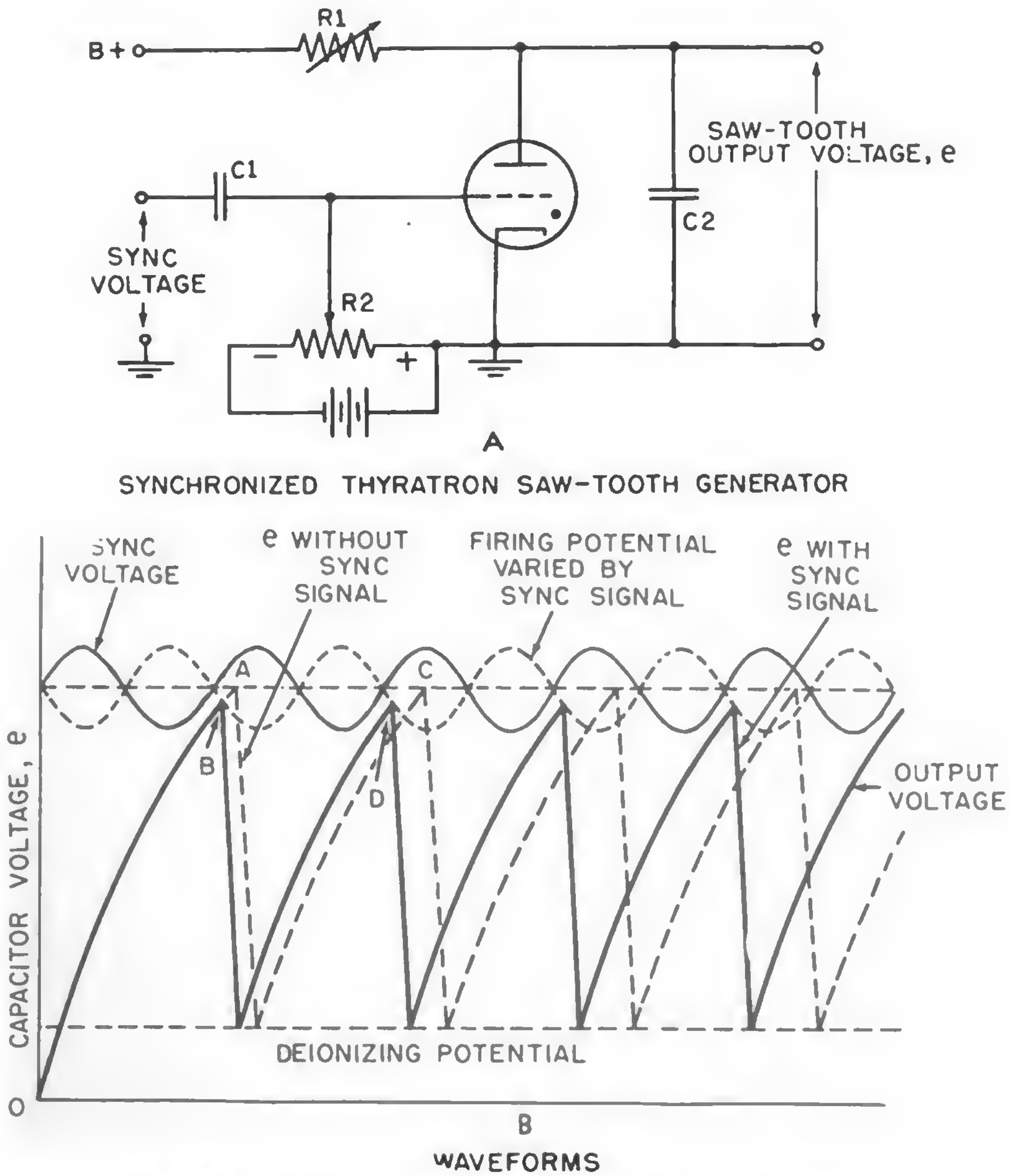


Figure 5–14.—Synchronized thyratron saw-tooth generator.

receivers are typical circuits controlled by sync pulses sent out by the transmitter.

Phase-Shift Oscillator

The phase-shift oscillator circuit consists of a single amplifier tube and a phase-shifting feedback circuit. As previously explained, the conventional feedback oscillator requires that the signal fed back from the plate to the grid be shifted 180° in order to sustain oscillations. In phase-shift oscillators this function is accomplished by three resistance-capacitance networks, as shown in figure 5–15, A. The oscillations are started by any slight circuit changes, such as variations in the plate supply, or random tube noises.

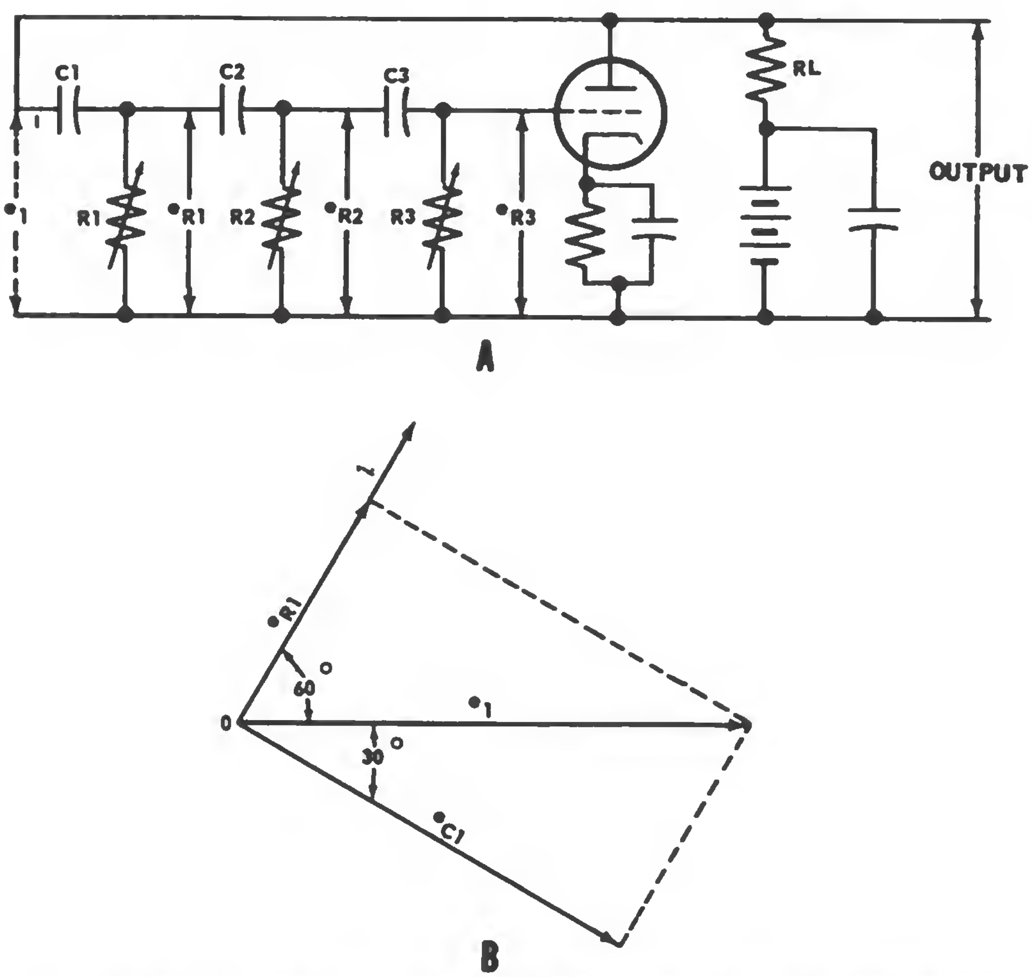


Figure 5–15.—Phase-shift oscillator. A, Circuit; B, vector diagram.

When such disturbances occur, the slight change is amplified, inverted 180° at the plate, and inverted another 180° by the *R-C* network from which it is returned in phase with the original grid excitation voltage of the tube for reamplification.

When an alternating voltage is applied to the first *R-C* network consisting of capacitor *C*1 and resistor *R*1, a current flows in this circuit. The magnitude of this current is determined by the total impedance. In this example the impedance is capacitive, and *C*1 is chosen so that the current, i, leads the impressed voltage, e_1, by 60° as shown by the vector diagram in figure 5–15, B. The voltage drop, e_{r_1} which occurs across *R*1, is in phase with the current that flows through it. Therefore, the voltage, e_{r_1} also leads the impressed voltage by 60°.

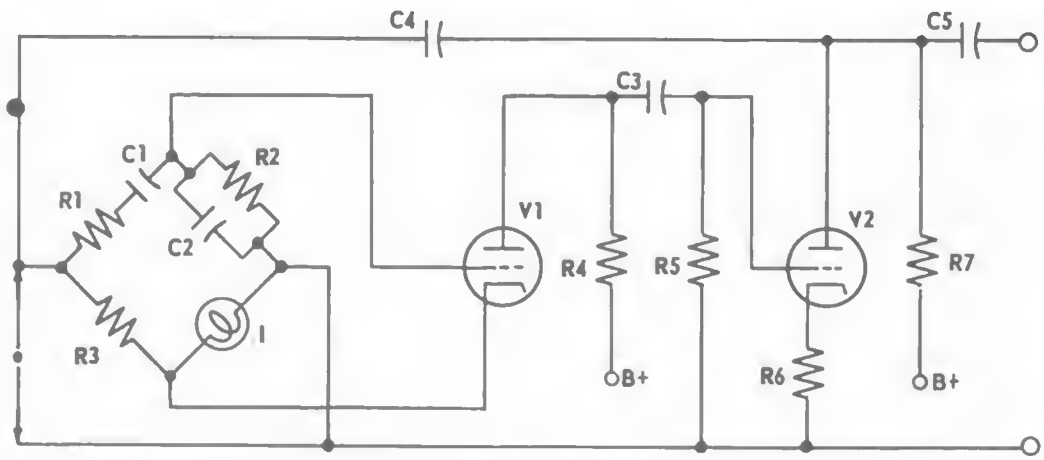
When the output of this *R-C* network is applied to the second and similar *R-C* network, another shift of 60° of the output voltage occurs, making the output voltage of the second *R-C* network 120° ahead of the voltage applied to the first *R-C* network.

When the output of the second *R-C* network is applied to the third and similar *R-C* network, another shift of 60° occurs, making the voltage applied to the grid 180° ahead of the voltage at the input to the first *R-C* network. Thus, the voltage at the grid is in the correct phase to sustain oscillations.

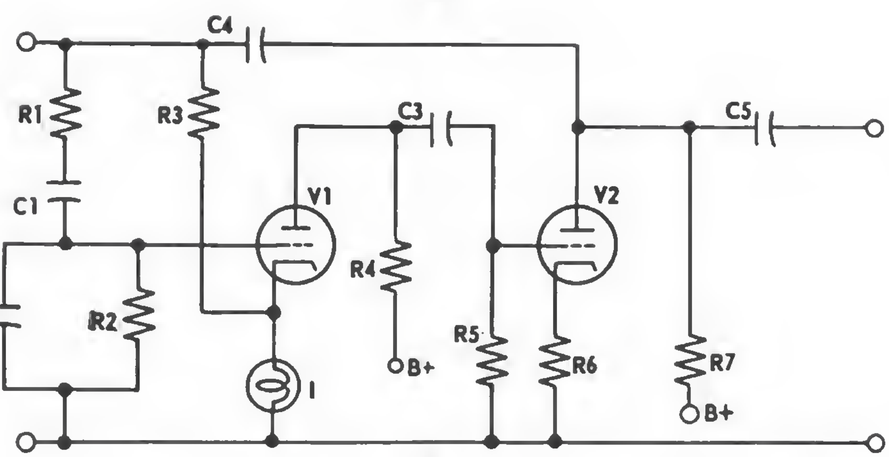
The phase-shift oscillator is used principally when a fixed frequency is desired because the three resistors *R*1, *R*2, and *R*3 must be set to obtain the final phase shift of 180°. To increase the oscillation frequency it is necessary to decrease either the resistance or capacitance. To decrease the oscillation frequency, it is necessary to increase the resistance or capacitance. If the bias on the tube is adjusted to a value that barely allows sustained oscillations, the output waveform of the phase-shift oscillator is almost sinusoidal and the frequency stability of the circuit with respect to voltage changes is very good.

Wien-Bridge Oscillator

The Wien-bridge oscillator (fig. 5–16) employs a frequency-selective Wien-bridge circuit as the resistance-capacitance feedback network. The feedback circuit shows that the phase-shifting element of the circuit is a frequency-selective bridge. Tube *V*1 serves as an oscillator and amplifier, and tube *V*2 serves as an inverter. This circuit would oscillate without the *R-C* bridge because of the 180° phase shift produced by tubes *V*1 and *V*2. The voltage fed back to the grid of *V*1 then must reinforce the initial signal that causes oscillations to be set up and maintained. However, this system would oscillate over a very wide range of frequency. Voltages of any frequency or any combination of frequencies can



A



B

Figure 5–16.—Wien-bridge oscillator. A, Actual circuit; B, simplified circuit.

cause oscillation. The bridge circuit, therefore, is used to eliminate feedback voltages of all frequencies except that frequency desired in the output, and thus provides a stable output frequency.

A simplified circuit of the Wien-bridge oscillator is shown in figure 5–16, B. For discussion, this circuit shows the feedback paths more clearly than figure 5–16, A. The bridge allows a voltage of only one frequency to be effective in the circuit because of the degeneration and phase shift provided by this circuit. Oscillation can take place only at the frequency, f_o, that permits the voltage across $R2$ (the input signal to $V1$) to be in phase with the output voltage of $V2$, and for which the positive feedback voltage exceeds the negative feedback voltage. Voltages of any other frequency cause a phase shift between the output of $V2$ and the input of $V1$ and are attenuated by the high degeneration of the circuit so that the feedback voltage is not adequate to maintain oscillation at any frequency other than f_o.

The degenerative feedback voltage is provided by the voltage divider which consists of resistor $R3$ and lamp I. The function of I is to compensate automatically for changes in the circuit so that sufficient feedback is always applied to $V2$. When the current in the circuit increases, the resistance of the lamp filament increases. A greater negative feedback voltage is developed across the increased resistance. Thus, more degeneration is provided which reduces the gain of $V1$ and thereby holds the output voltage at a nearly constant amplitude. Because there is no phase shift across this voltage divider, and because the resistances are practically independent of frequency, the amplitude of the negative feedback voltage is constant for all the frequencies that may be present in the output of $V2$.

The regenerative feedback voltage is provided by the voltage divider, which consists of $R1$, $C1$, $R2$, and $C2$. If the frequency is very high, the reactance of the capacitors is almost zero. Conversely, if the frequency is reduced toward zero, the current that can flow through either $C2$ or $R2$ is reduced to almost zero by the very high reactance of $C1$. Therefore, the voltage between the grid of $V1$ and ground falls almost to zero. At some intermediate frequency the positive feedback voltage is a maximum but the phase shift that occurs in the positive feedback circuit permits only a single frequency to be generated.

The resistance of $R1$ is equal to $R2$. When $R1C1$ equals $R2C2$, the voltage across $R2$ is in phase with the output voltage of $V2$. If the frequency of the output of $V2$ increases, the voltage across $R2$ tends to lag the voltage at the plate of $V2$. If the frequency decreases, the voltage across $R2$ leads the output voltage of $V2$.

The frequency at which the circuit oscillates is

$$f_o = \frac{1}{2\pi\sqrt{(R_1C_1)^2}} = \frac{1}{2\pi R_1 C_1}. \tag{5–2}$$

At this frequency the regenerative feedback voltage on the grid of $V1$ just equals or barely exceeds the degenerative feedback voltage on the cathode, and the regenerative feedback voltage is of the proper phase to sustain oscillation. At any other frequency, the degenerative feedback voltage is larger than the regenerative feedback voltage so that resultant degeneration of the amplifier suppresses these frequencies.

The Wien-bridge oscillator has many advantages over other types of audio oscillators. It can be made to produce a wide range of frequencies; the waveform is very nearly a true sine wave; the frequency stability is excellent; and the output-voltage amplitude is nearly constant over a very wide frequency range.

Multivibrator Oscillator

The free-running multivibrator is a two-stage resistance-coupled amplifier with feedback. The plate of the second stage is coupled to the grid of the first and the plate of the first to the grid of the second, as shown in figure 5–17.

If plate current rises more rapidly and to a higher value in $V1$ than in $V2$, E_{p1} falls and $C2$ discharges, making the grid of $V2$ negative, and blocking $V2$ so that I_{p2} is zero. E_{p2} now equals E_B, charges $C1$ to E_B and biases $V1$ slightly positive. When $C2$ stops discharging, the grid bias on $V2$ approaches zero and the plate current of $V2$ rises. The plate voltage of $V2$ falls and $C1$ discharges making the grid of $V1$ negative. Thus the plate current of $V1$ is cut off.

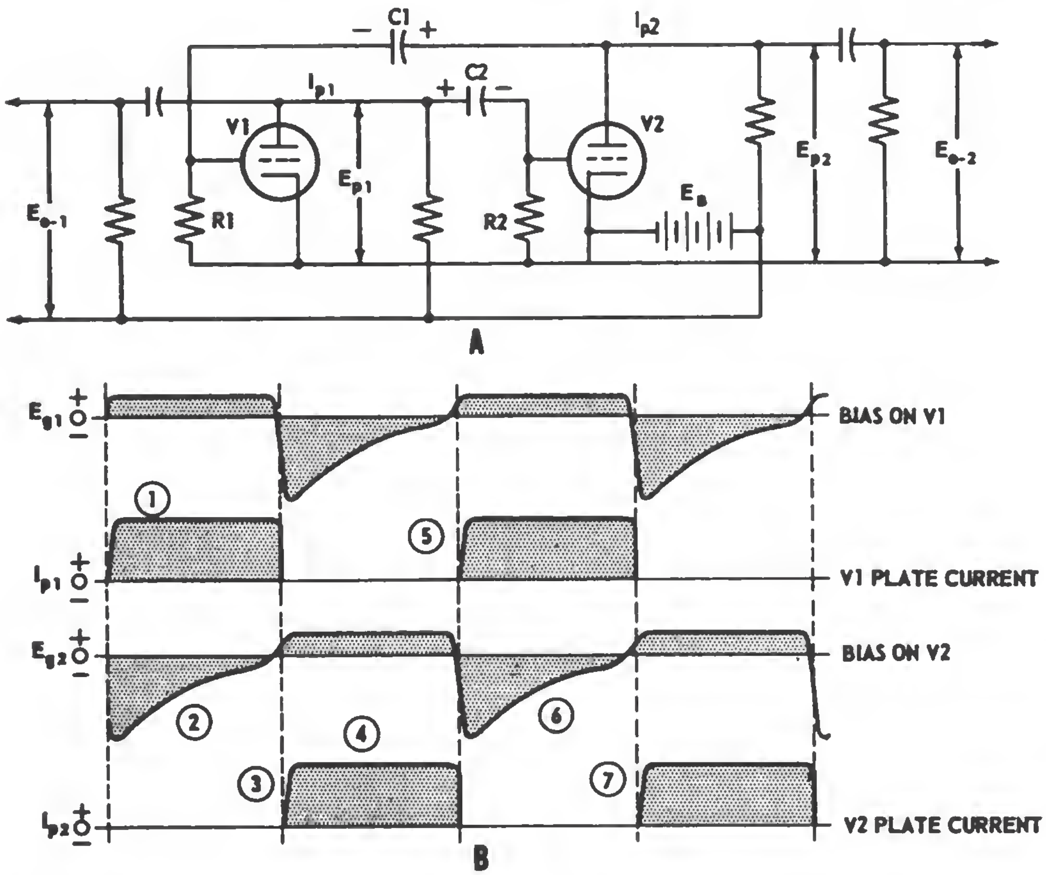


Figure 5–17.—Multivibrator oscillator. A, Circuit; B, voltage and current relations.

The plate voltage of $V1$ rises, charges $C2$, and makes the grid of $V2$ slightly positive. Hence the plate current of $V2$ goes to saturation. When $C1$ stops discharging, the bias on $V1$ approaches zero and the plate current of $V1$ rises. The plate voltage of $V1$ falls, and $C2$ again discharges making the grid of $V2$ negative. The plate current of $V2$ falls to zero and the plate voltage of $V2$ rises to E_B. $C1$ charges to E_B and biases $V1$ positive so that the plate current of $V1$ again goes to saturation. When $C2$ stops discharging the cycle continues to repeat.

The frequency, f, of the multivibrator oscillation is determined principally by the grid-leak resistances $R1$ and $R2$ and coupling capacitances $C1$ and $C2$. Thus,

$$f = \frac{1}{R_1C_1 + R_2C_2} \tag{5-3}$$

The frequency is also influenced to some extent by the remaining circuit constants, tube characteristics, and electrode voltages. The three main advantages of the multivibrator oscillator are: (1) The multivibrator oscillator can be adjusted to generate frequencies that range from about 1 cycle per minute to 100,000 cycles per second; (2) the multivibrator is useful because it generates a wave that is very rich in harmonics; and (3) because its frequency of oscillation is readily controlled.

QUIZ

1. How are oscillations sustained in a vacuum-tube oscillator?
2. What determines the frequency of the output voltage of an oscillator?
3. Name two main classes of oscillators.
4. How is the feedback from plate to grid accomplished in a tickler-coil oscillator?
5. For what class of operation is the tickler-coil oscillator biased?
6. Under what condition does the amplitude of oscillations become stable in an oscillator?
7. What are two types of plate-voltage feed for Hartley oscillators?
8. How is the feedback voltage in a Hartley oscillator obtained?
9. Why is the feedback in a Colpitts oscillator called capacitive feedback?
10. How is the feedback energy fed from the plate to the grid in a TPTG oscillator?
11. Which tank circuit in a TPTG oscillator usually has the highest Q and determines the frequency of oscillation?
12. How is the correct phase of the feedback voltage obtained in a TPTG oscillator?

13. How is the oscillator portion of the circuit in an electron-coupled oscillator connected to the plate circuit?

14. How is the frequency of the electron-coupled oscillator made independent of small variations in the supply voltage?

15. For what purpose are crystals used in oscillators?

16. In which circuit of a crystal oscillator is the crystal included?

17. How is feedback accomplished in the crystal oscillator?

18. What advantage is obtained by the use of a tetrode or pentode in place of a triode in a crystal oscillator when the feedback voltage becomes excessive?

19. Explain why unstable operation results in a crystal oscillator when it is operated at the point of maximum output on a plate-current-frequency curve.

20. What condition must exist between plate and grid to provide positive feedback for a crystal oscillator to operate at the crystal frequency?

21. How is the feedback voltage division accomplished in a Pierce crystal oscillator?

22. What type of networks are used in audio oscillators to eliminate *L-C* tank circuits and to provide regenerative coupling?

23. Name four examples of *R-C* oscillators.

24. How is the frequency adjusted in a saw-tooth generator?

25. How is the output voltage of a saw-tooth generator made linear?

26. How is the sync voltage applied to a saw-tooth generator?

27. How is the output voltage of a saw-tooth generator increased?

28. How are oscillations started in a phase-shift oscillator?

29. How is feedback accomplished in phase-shift oscillators?

30. Is the output frequency of a phase-shift oscillator normally fixed or variable?

31. What is the purpose of the Wien bridge in the Wien-bridge oscillator?

32. Name the four main advantages of the Wien-bridge oscillator.

33. Name the three main advantages of the multivibrator type of oscillator.

CHAPTER 6

ELECTRONIC TEST EQUIPMENT

Electronic test equipment is designed to measure the values of many unknown quantities in electric and electronic circuits. These measurements are used to determine the operating conditions of electric and electronic equipment. The accuracy with which they are made depends upon the type of instrument—that is, the sensitivity, rated accuracy, and useful range. The test equipments most commonly used by I. C. Electricians are the multimeter, tube tester, audio oscillator, and cathode-ray oscillograph.

ME–25A/U MULTIMETER

The ME–25A/U multimeter, also known as an electronic volt-ohm-milliammeter, is a combination electronic d-c and a-c voltmeter, ohmmeter, and milliammeter. It is capable of measuring direct voltages up to 5,000 volts, alternating voltages up to 1,000 volts, resistances up to 1,000 megohms, and direct currents up to 1,000 milliamperes.

The multimeter (fig. 6–1) is contained in a portable metal case provided with a removable hinged cover. The meter, switches, connectors, and jacks are mounted on the panel. The panel is colored gray and the controls are clearly marked with green and white designations for identification.

Operation

The ME–25A/U multimeter consists of the following circuits: (1) basic meter, (2) d-c voltmeter, (3) a-c

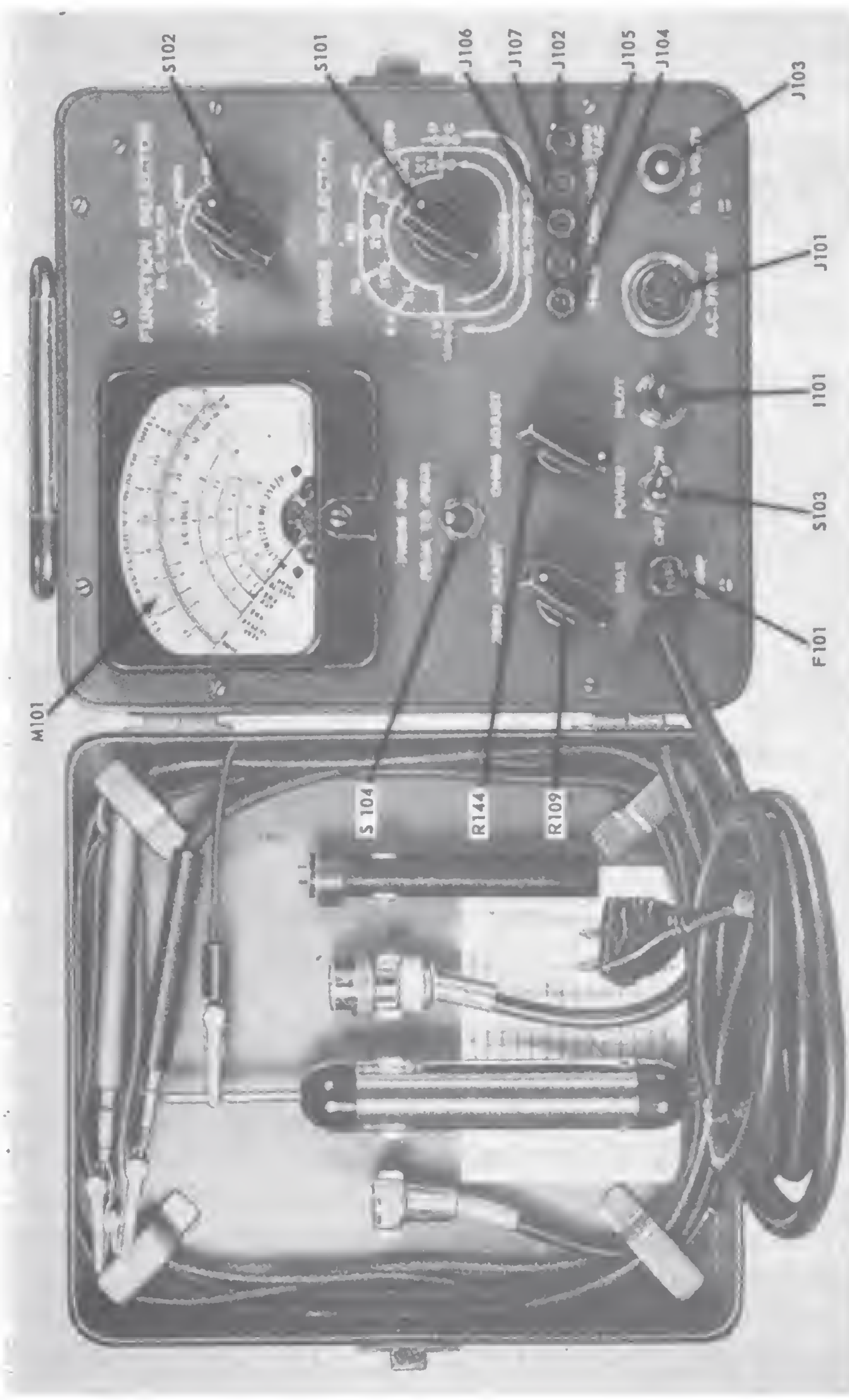


Figure 6–1.—ME–25A/U multimeter.

voltmeter, (4) ohmmeter, (5) milliammeter, and (6) power supply.

Basic meter circuit.—The basic meter circuit (fig. 6–2) is an electronic bridge. The meter is connected across one

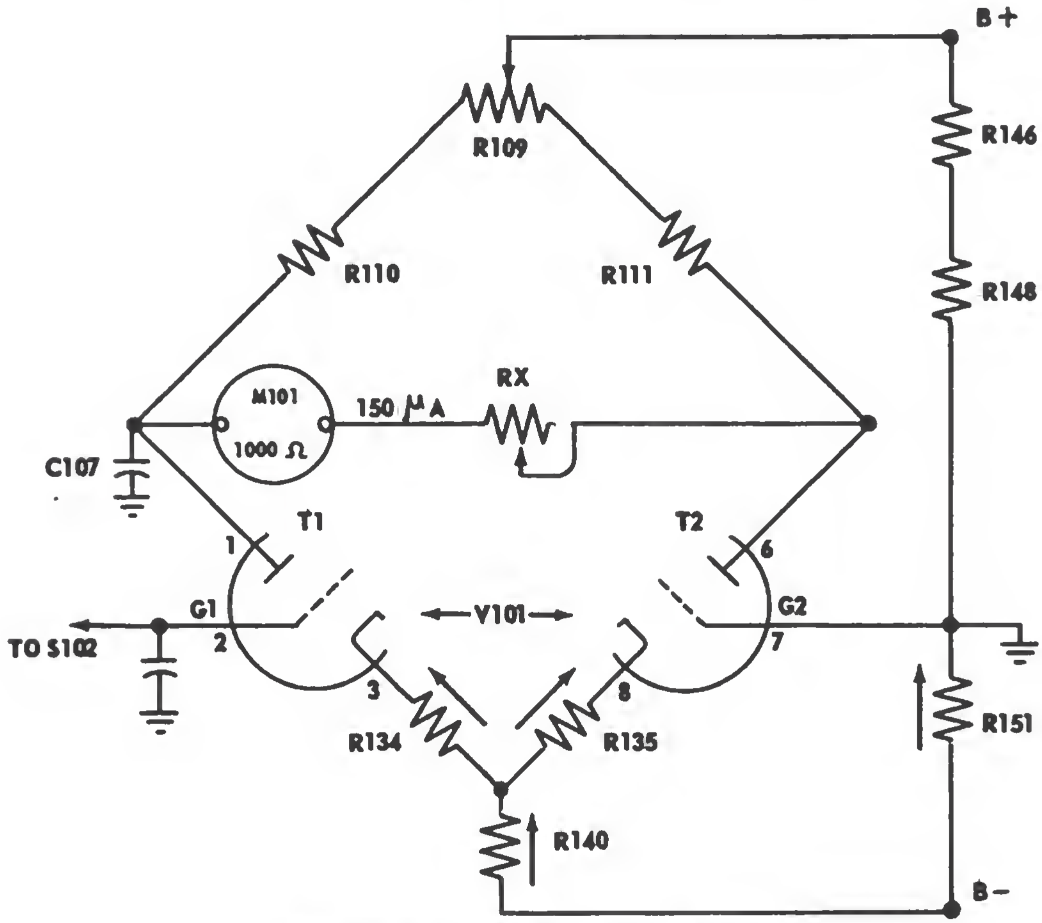


Figure 6–2.—Basic meter circuit.

pair of diagonally opposite corners and the d-c supply voltage is connected across the other pair. These connections are similar to those of a Wheatstone bridge. The two lower arms contain the triode elements of twin triode V101. The resistance of these arms is essentially the effective resistance of the triodes. Grid bias determines the effective resistance of the twin triode.

The two upper arms of the bridge contain resistors that terminate in potentiometer R109. This potentiometer is used to adjust the meter deflection to zero with no input. Under a condition of balance, the voltage drops across the two lower arms are equal and there is no difference in potential across the meter circuit.

When the multimeter is being used as a d-c voltmeter, a portion of the voltage being measured is applied to one of the grids, thus changing the effective resistance of that arm and unbalancing the bridge. The difference in potential developed across the meter circuit causes the meter to deflect in proportion to the magnitude of the voltage being measured.

In operation, one of the grids is always grounded and a voltage is applied to the opposite grid.

If grid *G*2 is grounded and negative voltage is applied to grid *G*1, a decrease in plate current through triode *T*1 results. This decrease in current causes the plate voltage of *T*1 to increase with respect to ground. At the same time, the voltage across common cathode resistor *R*140 decreases. When the voltage across *R*140 decreases it also effectively decreases the grid bias on triode *T*2, causing triode *T*2 to draw more current. When triode *T*2 draws more current its plate voltage decreases with respect to ground. The increase in plate voltage of *T*1 and the decrease in plate voltage of *T*2 are additive and the current flow through the meter deflects the needle up scale.

On the other hand, if the grid of *G*1 is grounded and a positive voltage is applied to the grid of *G*2, the same action occurs in *T*1 and *T*2 and the current through the meter increases in the same direction as before and the needle deflects up scale. However, if a positive voltage is applied to grid *G*1 with *G*2 grounded, or a negative voltage is applied to grid *G*2 with *G*1 grounded, the current through the meter reverses and the deflection is in the opposite direction.

Resistor *RX* is an adjustable calibrating resistor. A separate potentiometer is used in place of resistor *RX* for calibrating rms and peak-to-peak alternating voltages, direct voltages, and resistances.

D-c VOLTMETER CIRCUIT.—The d-c voltmeter circuit is shown in figure 6–3. Voltages up to 1,000 volts are applied directly through the d-c probe containing isolating resistor *R*112. This isolating resistor in the probe tip inserts 3.3 megohms and prevents capacity loading of the circuits under test.

For 5,000-volt d-c measurements a high-voltage extension adapter is screwed onto the end of the regular d-c probe.

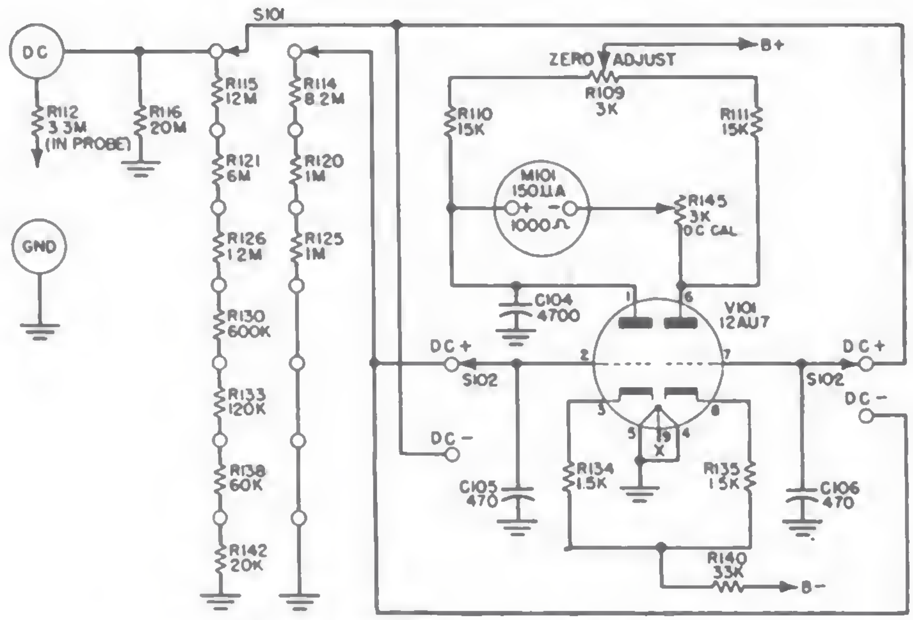


Figure 6–3.—D-c voltmeter circuit.

This high-voltage adapter contains an isolating and voltage-dropping resistor of 53.2 megohms. Voltages to be measured are applied from the adapter to the high end of the voltage-dividing network on range selector switch *S*101. Voltages from this network are fed to grid pin 7 of *V*101 for measurements of d-c voltages that are positive with respect to ground, and to grid pin 2 of *V*101 for measurements of voltages that are negative with respect to ground.

The voltage-dividing network of *S*101 is shunted to ground by a 20-megohm resistor, *R*116, in order to effect proper calibrations of the measuring networks. An additional section is used on selector switch *S*101 and comprises resistors *R*114, *R*120, and *R*125. These resistors are used respectively on the 1-, 2.5-, and 10-volt ranges. The purposes of these resistors is to permit a small amount of contact potential to

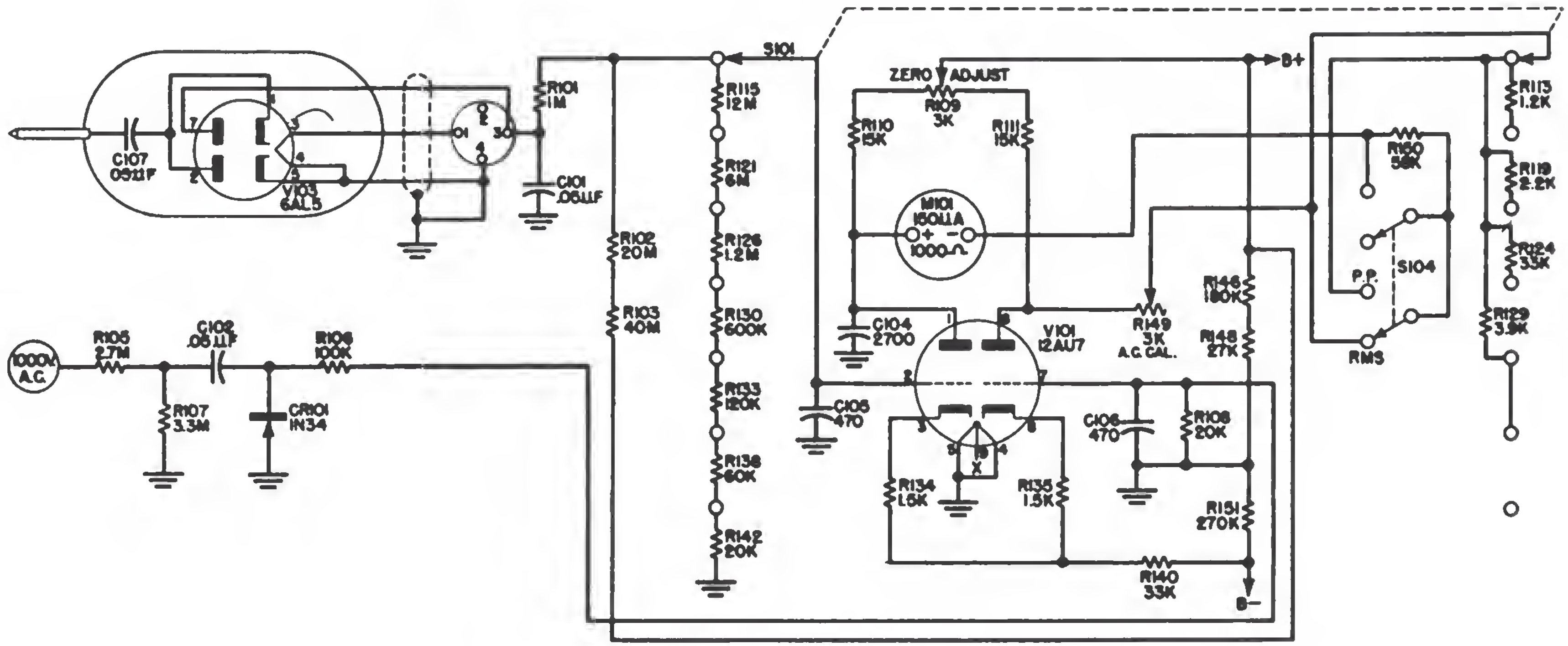


Figure 6–4.—A-c voltmeter circuit.

be developed on the grid that is not being used in connection with the main voltage-dividing network section of *S*101. The inactive grid is connected to the slider arm on this section of the switch. Both grids (pins 2 and 7) are bypassed to ground respectively by capacitors *C*105 and *C*106. These capacitors effectively ground the grids to any stray a-c voltages that might be picked up in the input circuits and thus affect the calibration of the equipment.

The nominal input impedance for d-c measurements up to 1,000 volts is about 13 megohms. If the voltage being measured is large enough to be read on the 5,000-volt range, high-voltage adapter *E*114 can be used to provide for an input impedance of about 66.5 megohms.

A-C VOLTMETER CIRCUIT.—The a-c voltmeter circuit is shown in figure 6–4. Two inputs are provided for a-c voltage measurements. One input for measurements up to 250 volts is through the voltage-doubling probe circuit using twin diode *V*103 and has a frequency range from about 20 cps to more than 100 megacycles. The other input for measurements up to 1,000 volts has a frequency range from 50 cps to about 3,000 cps. At 12,000 cps the error is 5 percent.

When peak-to-peak voltage switch *S*104 is pressed, the meter indicates peak-to-peak a-c volts. When *S*104 is released the meter calibration is in rms volts. Peak-to-peak voltage measurements are taken with the same a-c probe as for rms values, except for the 1,000-volt range.

Simplified circuits for the voltage doubler used with the 250-volt a-c probe are shown in figure 6–5. In this example the voltage being measured has an rms value of 10 volts and a peak value of 10 × 1.4, or 14 volts. During one alternation (fig. 6–5, A) the probe is positive with respect to ground. Tube *V*103*A* conducts momentarily and charges *C*107 to 14 volts peak. On the next alternation (fig. 6–5, B) it is assumed that *C*107 holds its charge. The probe is now negative with respect to ground. Tube *V*103*B* conducts and *C*101 charges up to 28 volts, which is the sum of the peak source voltage and the voltage across *C*107 in series.

The voltage across *C*101 in figure 6-4 is applied through decoupling resistor *R*101 across the voltage-divider network associated with range selector switch *S*101. Unless compensated for, the contact potential developed on the plate (pin 7) of *V*103 will alter the zero position of the meter when *S*101 is changed. *R*103 is adjusted so that the voltage from

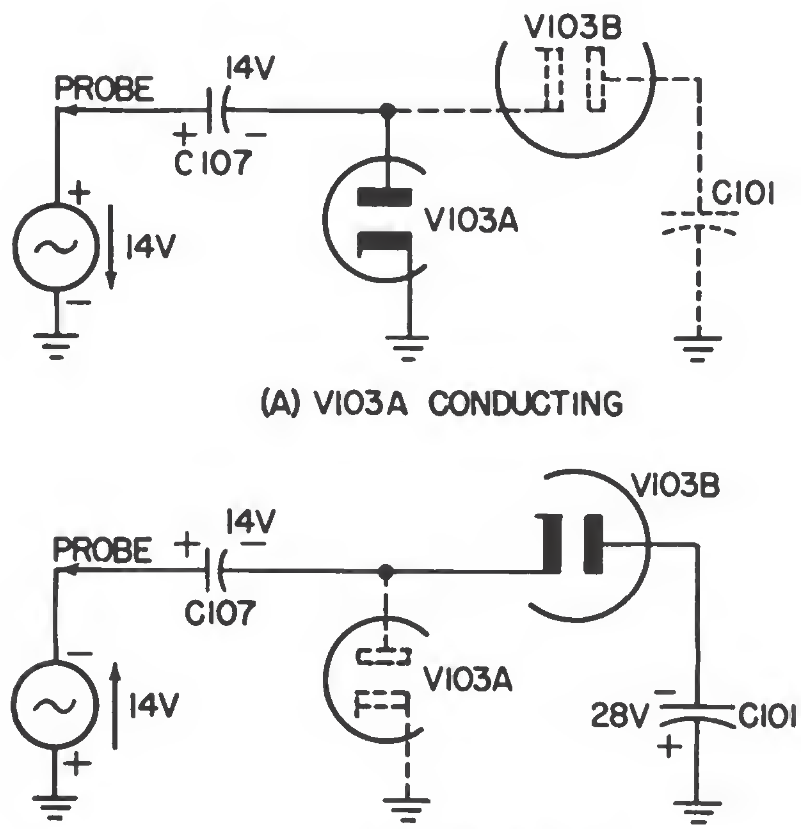


Figure 6-5.—Voltage doubler analysis.

the B+ supply cancels this contact potential. Thus, it is usually not necessary to move ZERO ADJUST control *R*109 when ranges are changed.

Because a-c voltages are measured between the probe and ground, rectified voltages from *V*103 are tapped from the voltage-divider network by range switch *S*101. This voltage is applied between the grid (pin 2) and ground of *V*101. The grid bias is thus altered and the bridge is unbalanced. Meter *M*101 deflects as a result of the unbalance and the a-c voltage at the probe is indicated on the meter scale.

As mentioned previously, when switch *S*104 is operated to the PEAK-TO-PEAK position, the meter is calibrated in terms of the peak-to-peak value of the applied voltage. This value is twice the peak value and 1.4×2, or 2.8, times the rms value. In the PEAK-TO-PEAK position of *S*104 the negative side of the meter is connected through range switch *S*101 to one of the range calibration resistors (*R*113, *R*119, *R*124, or *R*129) in series with calibration rheostat *R*149. When switch *S*104 is in the RMS position, resistor *R*150 is connected in series between the negative terminal of the meter and *R*149. The range calibration resistors are not in the meter circuit.

When using the 1,000-volt probe, the meter deflection is proportional to the average value of the applied alternating voltage, but is calibrated in terms of its rms value. This voltage is applied through a dividing network consisting of resistors *R*105 and *R*107 (fig. 6–4) and through blocking capacitor *C*102 to crystal rectifier *CR*101. The rectified voltage from the anode of *CR*101 is fed through decoupling resistor *R*106 between grid pin 7 and ground of tube *V*101. This grid is returned to ground by resistor *R*108.

Two charts showing the relation between decibels and voltages are provided with the meter (fig. 6–6). One chart is based on the relation that 0 decibel equals 0.001 watt at 600 ohms and the other chart is based on the relation that 0 decibel equals 0.006 watt at 600 ohms. A voltage reading on the meter can be converted to its relative decibel value by means of the appropriate chart.

For example, to convert a meter reading of 40 volts (rms) to its relative decibel value based on the 0.001-watt level: (1) Locate the 40-volt value on the abscissa; (2) read vertically upward to the intersection of the 600-ohm diagonal line; and (3) read horizontally across to the ordinate, which has a value of +35 decibels.

Similarly, the relative decibel value of this 40-volt meter reading, based on the 0.006-watt level, is +27 decibels.

OHMMETER CIRCUIT.—The ohmmeter circuit is shown in figure 6–7. Two pin jacks on the meter panel are used for

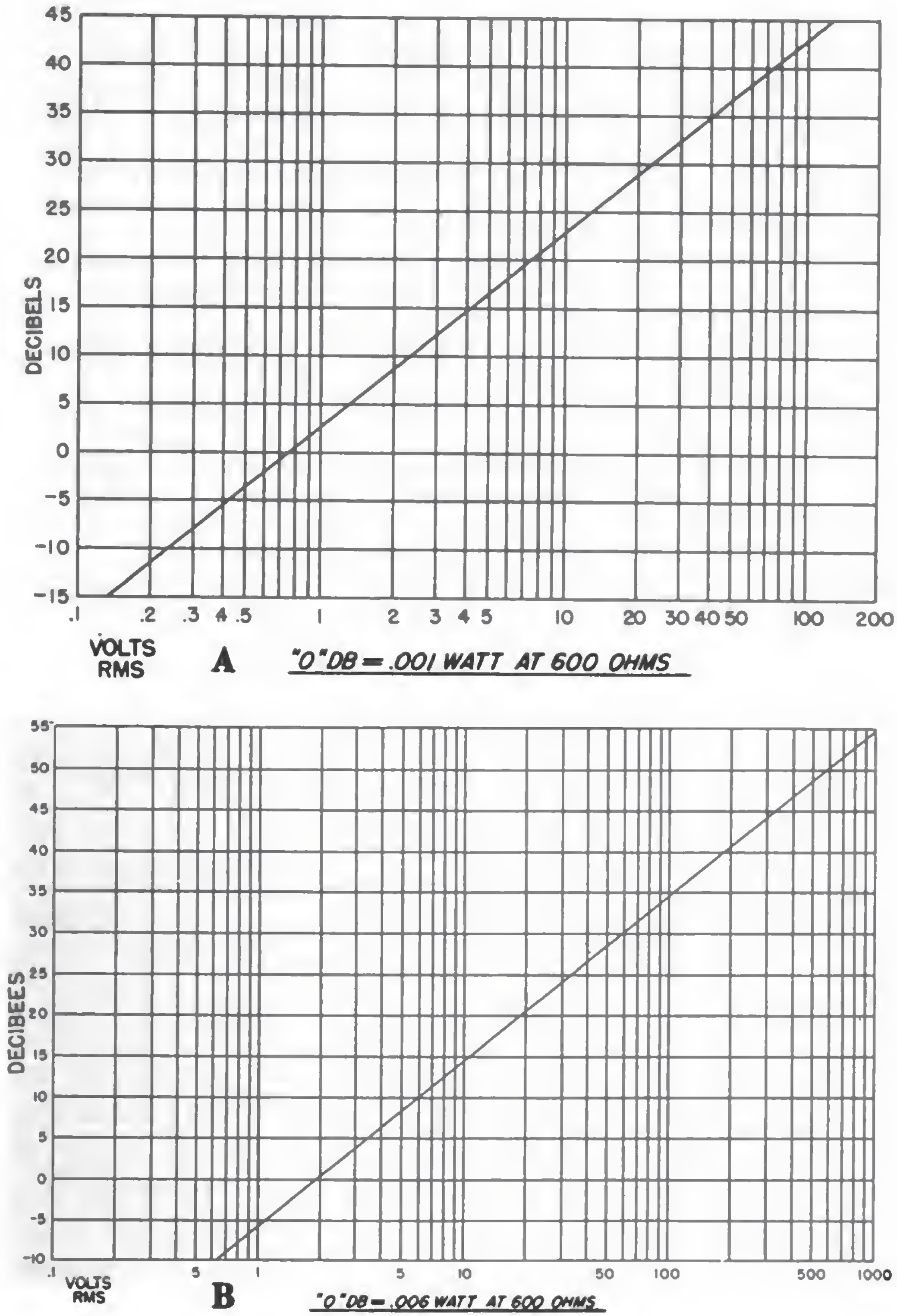


Figure 6–6.—Decibel charts.

connecting external resistances to the resistance-measurement circuit of the ohmmeter section. Pin 7 of tube *V*101 is operated at ground potential and grid pin 2 is fed from the 1.5-volt battery, *BT*101, through a series of calibration resistors on the OHMS section of the RANGE SELECTOR. With no external resistance connected, grid pin 2 is operated at a negative

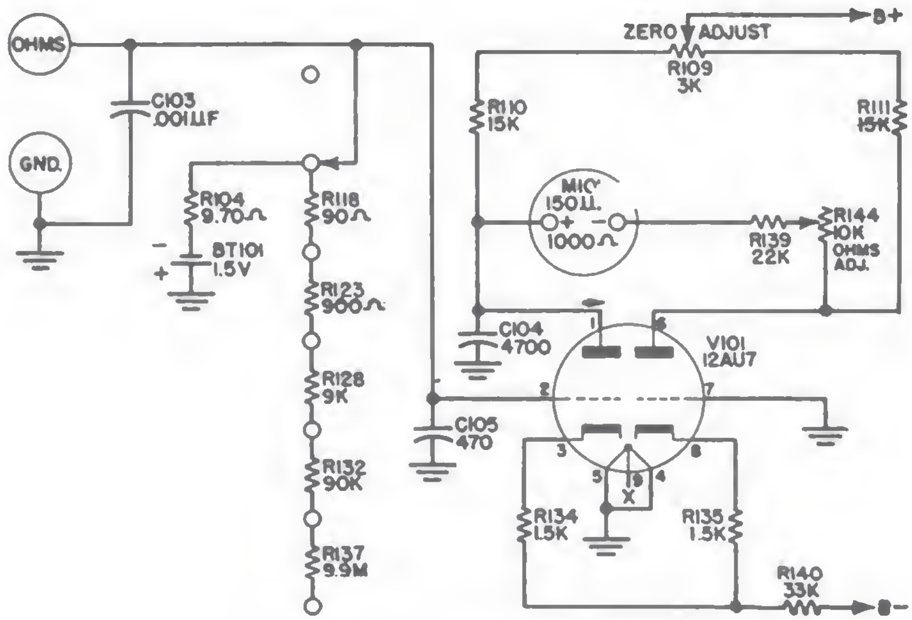


Figure 6–7.—Ohmmeter circuit.

potential of 1.5 volts with respect to ground irrespective of the range being used. The OHMS ADJUST, *R*144, is adjusted so that the meter reads full scale, or infinity ohms. With the ohms input circuit short-circuited, the ZERO ADJUST is adjusted so that the meter reads at the extreme left, or zero ohms. With an unknown resistor connected across the input terminals marked OHMS and GND and with the RANGE SELECTOR operated to the proper range, the voltage is altered between grid pin 2 of tube *V*101 and ground. Meter *M*101 is calibrated in terms of the unknown resistance because the voltage appearing between the grid and ground is proportional to this external resistance.

MILLIAMMETER CIRCUIT.—The milliammeter circuit shown in figure 6–8 is a conventional type and measures direct cur-

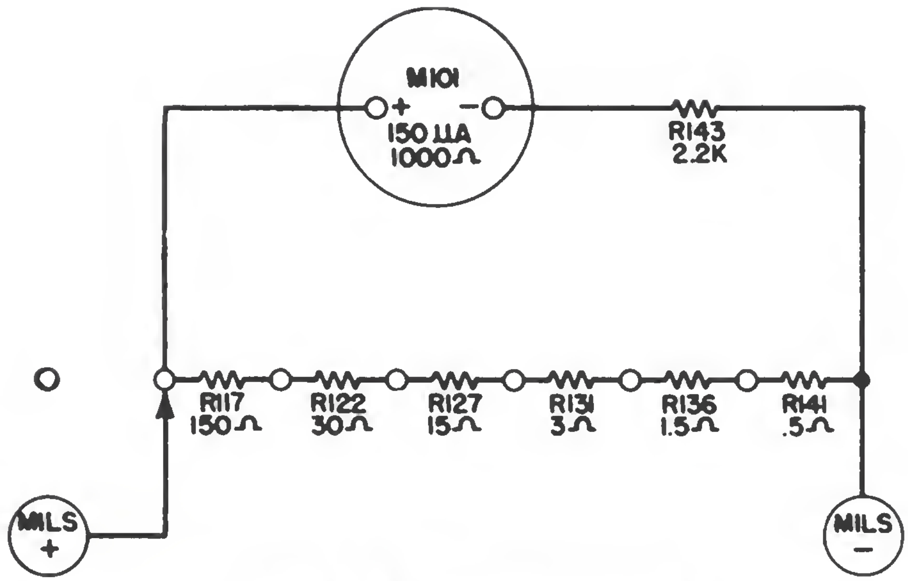


Figure 6–8.—Milliammeter circuit.

rents up to 1,000 milliamperes. The shunt resistance varies inversely with the range. Always start with the highest range to avoid possible damage to the meter.

POWER SUPPLY CIRCUIT.—The power supply circuit is shown in figure 6–9. Except for the 1.5-volt battery, *BT*101 (fig. 6–7), all voltages for the operation of the multimeter are obtained from the power supply. Tube *V*102 is connected as a full-wave rectifier to power supply transformer *T*101. The primary of this transformer is connected to the power supply line cord through fuse *F*101 and power on-off switch *S*103, both of which are located on the meter panel.

The transformer has a 350-volt and a 6.3-volt secondary

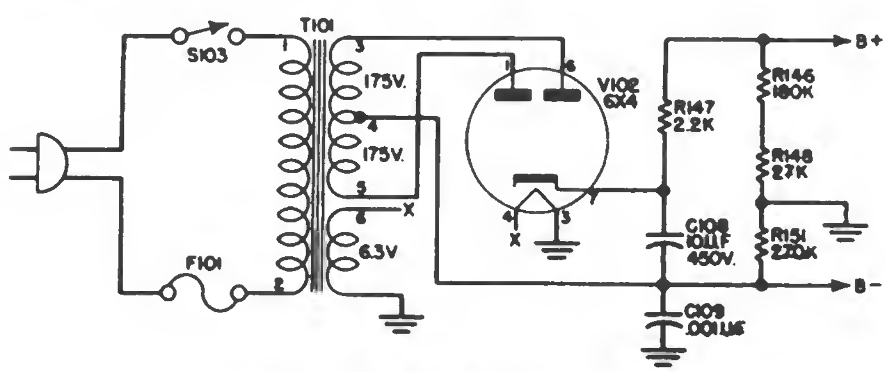


Figure 6–9.—Power supply circuit.

winding. The 350-volt winding is center-tapped and is returned to ground through resistor *R*151. Capacitor *C*109 acts as a filter across *R*151. Capacitor *C*108 and *R*147 filter the rectified output of *V*102. The d-c output is applied to the network consisting of resistors *R*146 and *R*148 in series between B+ and ground, and resistor *R*151 from B− to ground. The voltage developed across this network is approximately 150 volts. The 6.3-volt winding is provided for the operation of all heaters of the tubes.

Controls

Refer to the schematic diagram of the ME–25A/U multimeter, figure 6–10, and the photograph in figure 6–1 to identify the controls.

SWITCHES AND SELECTORS.—Power switch *S*103 energizes the internal circuits of the equipment. The power-line cord is connected to a single-phase, 125-volt, 60-cycle power supply.

The FUNCTION SELECTOR, *S*102, connects the internal circuits to permit measuring (1) alternating voltages, either through the a-c probe or from the 1,000–VAC jack; (2) direct voltages, either positive or negative with respect to ground; (3) resistances in ohms; or (4) direct currents in milliamperes.

The RANGE SELECTOR, *S*101, selects the various measurement ranges as determined by the FUNCTION SELECTOR.

The PRESS FOR PEAK-TO-PEAK switch, *S*104, is a spring-loaded switch that provides for measuring peak-to-peak alternating voltages. When this switch is in the NORMAL position the voltage measured is in terms of the rms value.

The ZERO ADJUST, *R*109, permits the adjustment of the meter pointer to zero for measuring alternating voltages, direct voltages, and resistances.

The OHMS ADJUST, *R*144, provides adjustment of the meter to full scale, or infinity, with the test leads open-circuited.

CONNECTORS AND JACKS.—Connector *J*101, marked A-C

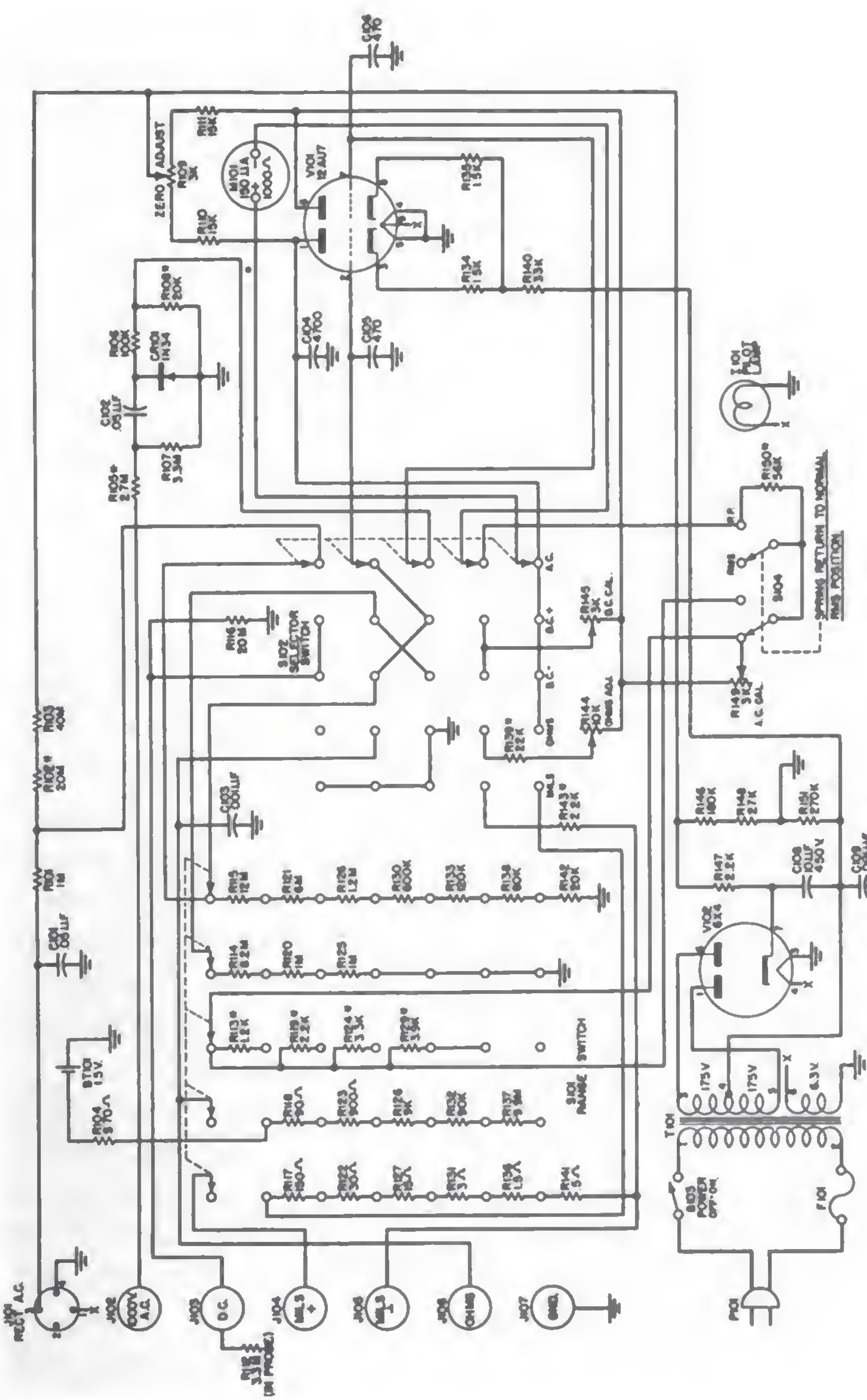


Figure 6—10.—ME–25A/U multimeter schematic diagram.

PROBE, is the input connector for alternating-voltage measurements when the a-c probe is used.

Connector $J103$, marked D-C VOLTS, is the input connector for direct-voltage measurements when the d-c probe is used.

Jack $J104$, marked +MILS, and jack $J105$, marked −MILS, are the input jacks for use with two unshielded leads when direct currents are measured.

Jack $J106$, marked OHMS, is the ouput jack for the red unshielded lead when resistances are measured.

Jack $J107$, marked GND, is the common ground connection input jack when alternating voltages, direct voltages, and resistances are measured.

Jack $J102$, marked 1,000 VAC, is the input jack for use when alternating voltages are measured with the 1,000-volt range.

TV–3/U TUBE TESTER

Electron tubes do not last indefinitely. The end of the useful life of a tube is usually preceded by a reduction in electron emission—that is, the cathode no longer supplies the number of electrons necessary for proper operation of the tube. However, a tube may show normal emission and still not operate properly because the tube efficiency depends on the ability of the grid voltage to control the plate current. The dynamic mutual conductance test is the most accurate method for testing electron tubes because it measures the grid-plate transconductance and indicates the actual operation of the tube and not merely the condition of the emitting surface.

The terms "mutual conductance" and "transconductance" are used interchangeably. When the prefix "dynamic" accompanies these terms as in "dynamic mutual conductance" or "dynamic transconductance," the meaning includes the effect of load impedance in the plate circuit of the tube being tested. The dynamic characteristic is not the same as the static characteristic because, when a load impedance is present, the voltage at the plate of the tube differs from plate supply voltage by the drop in the load impedance.

The static characteristic of a tube involves a change in two of three quantities, the third being held constant. Thus, the transconductance of a triode is the change in plate current divided by a given change in grid voltage while the plate voltage is held constant. On the other hand, the dynamic transconductance is the change in plate current divided by a given change in grid voltage, when a plate load impedance exists in the plate circuit, and the plate voltage is allowed to swing.

Very often the prefix "dynamic" is omitted for the sake of brevity. If "dynamic" is omitted, the meaning can be identified by looking for the plate-load impedance in the plate circuit of the tube being tested. If the plate-load impedance is included, the characteristic obtained is dynamic.

The TV–3/U tube tester (fig. 6–11) is contained in a portable aluminum case with a built-in compartment for accessories and is provided with a removable hinged cover. The

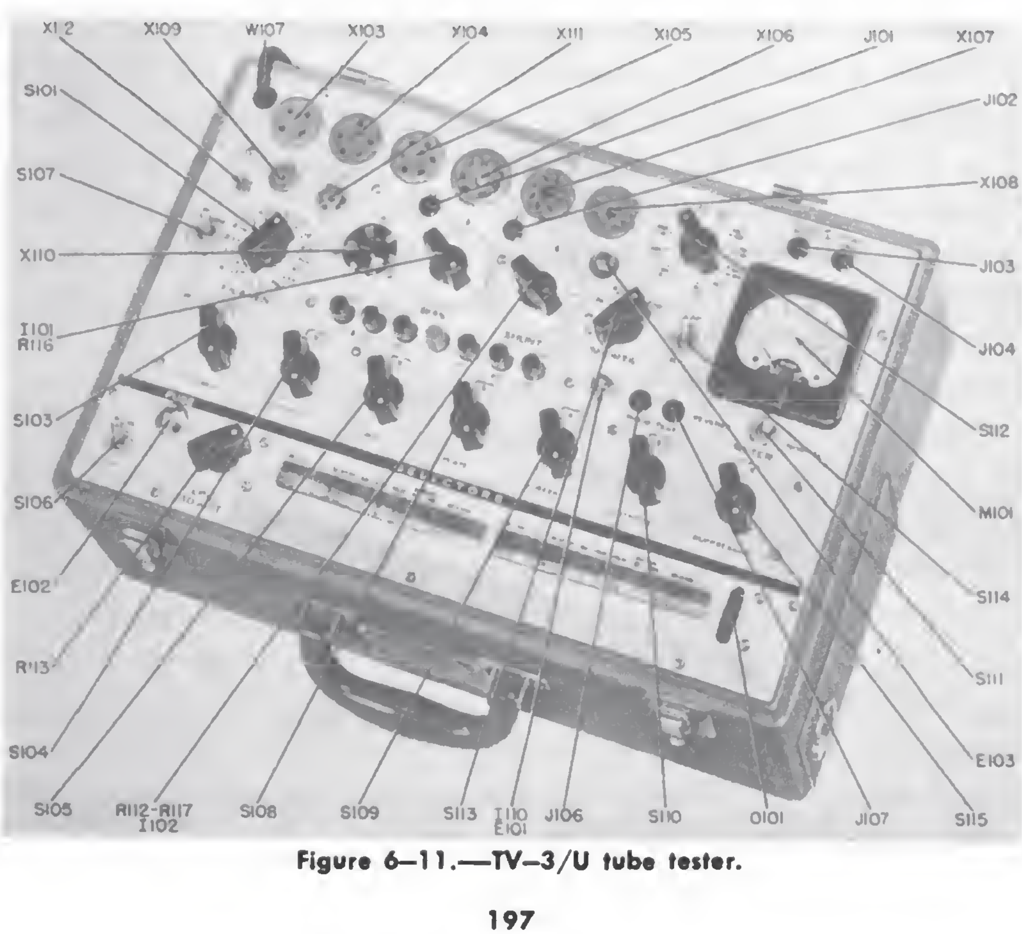


Figure 6–11.—TV–3/U tube tester.

meter, switches, connectors, and controls are mounted on the meter panel and are clearly marked for identification.

The tube tester is of the dynamic transconductance type. It is designed to test and measure the values of transconductance of receiving tubes and many small transmitting tubes. In addition to the tube tester section, this equipment includes a multimeter section using the same indicating meter. The tube tester is capable of measuring transconductances up to 15,000 micromhos, direct and alternating voltages up to 1,000 volts, resistances up to 100 megohms, capacitances up to 50 microfarads, and direct currents up to 200 milliamperes.

Tube Tester Section Operation

The TV–3/U tube tester consists of the following circuits: (1) power supply, (2) line-voltage test, (3) short-circuit test, (4) rectifier test, (5) transconductance test, (6) gas test, (7) noise test, (8) voltmeter, (9) ohmmeter, (10) capacity test, and (11) milliammeter.

POWER SUPPLY CIRCUIT.—The power supply circuit is shown in figure 6–12. All voltages for the operation of the tube tester are obtained from the power supply transformer, *T*101. The primary of this transformer is connected to a single-phase, 105- to 125-volt, 50- to 1,600-cycle source through power switch *S*106, LINE ADJUST control *R*113, and fuse lamp *E*102. When the line adjust control is operated in conjunction with the line test circuit, it standardizes the voltage at 93 volts across the primary of transformer *T*101.

Secondary winding 1 of power transformer *T*101 consists of a multitapped winding designed to supply the various filament voltages for the tubes being tested, and also for rectifier emission tests. The voltages indicated in figure 6–12 are for the condition of rated load. The no-load voltages are somewhat higher. For example, the no-load voltage measured from point *H* to point *I* is approximately 124 volts with 93 volts on the primary.

Secondary windings 2 and 3 supply approximately 170 volts to the plates of tube *V*101, which supplies plate voltage to the tube being tested. Secondary winding 2 is also tapped to the tube being tested. Secondary winding 2 is also tapped at 20 volts to supply voltage for diode emission tests.

Secondary winding 4 is a center-tapped 5-volt winding, which supplies filament voltage for rectifier tube *V*101.

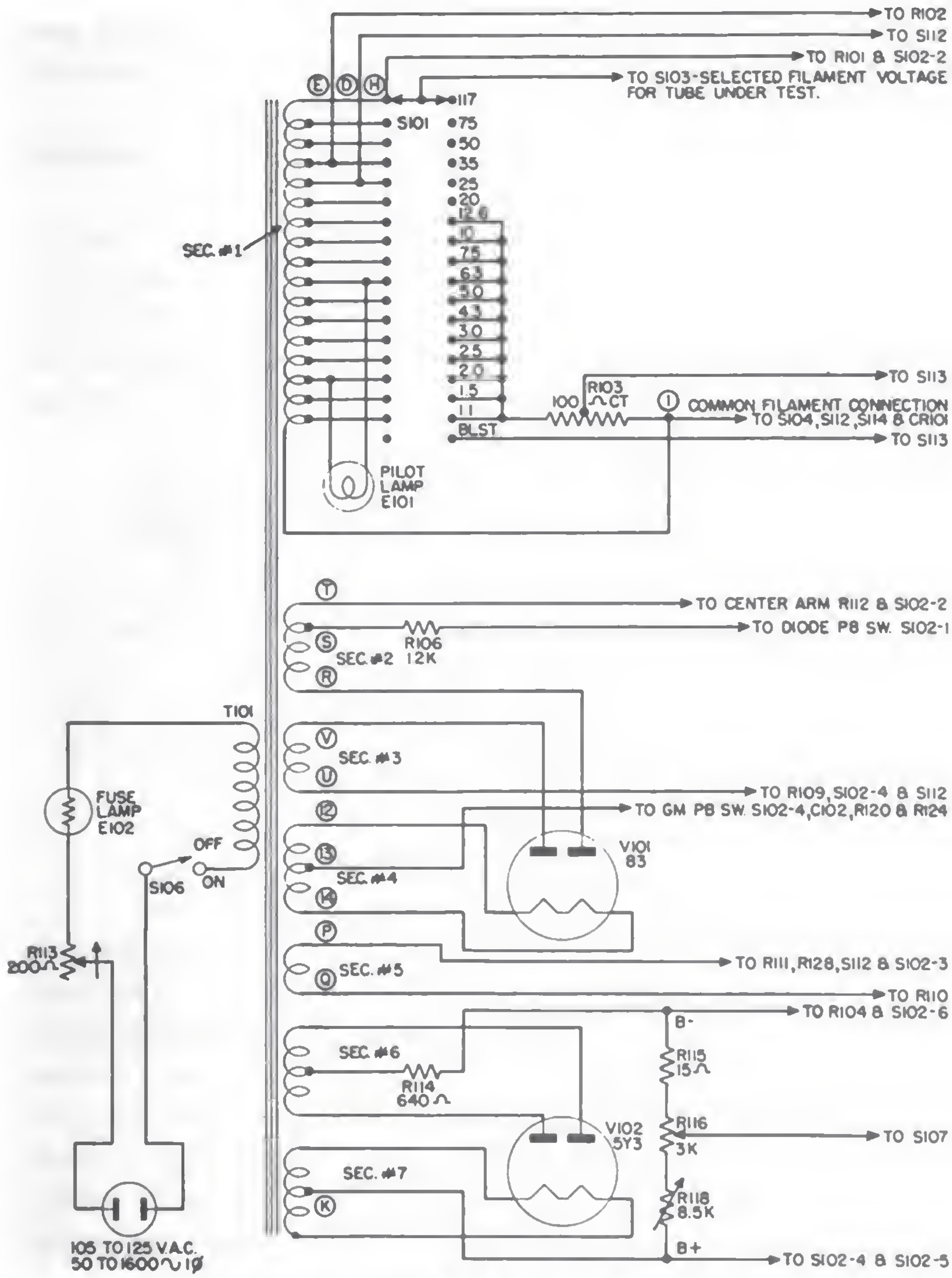


Figure 6–12.—Power supply circuit.

Secondary winding 5 supplies an a-c signal of 5 volts for transconductance tests.

Secondary winding 6 is a center-tapped 320-volt winding which supplies the plates of screen voltage rectifier *V*102. Tube *V*102 supplies a rectified voltage for the screen of the tube under test. This voltage is applied across a voltage divider which consists of resistors *R*114, *R*115, *R*116, and *R*118. Bias control resistor *R*116 and adjustable resistor *R*118 provide the bias for transconductance tests.

Secondary winding 7 is a center-tapped 5-volt winding which supplies the filament of tube *V*102.

LINE-VOLTAGE TEST.—Pressing the LINE ADJ push switch *P*7 (fig. 6–11) connects meter *M*101 through resistor *R*101 and copper oxide rectifier *CR*101 to points *H* and *I* of the power supply (fig. 6–12). A simplified schematic of the line-voltage test circuit is shown in figure 6–13. Resistor

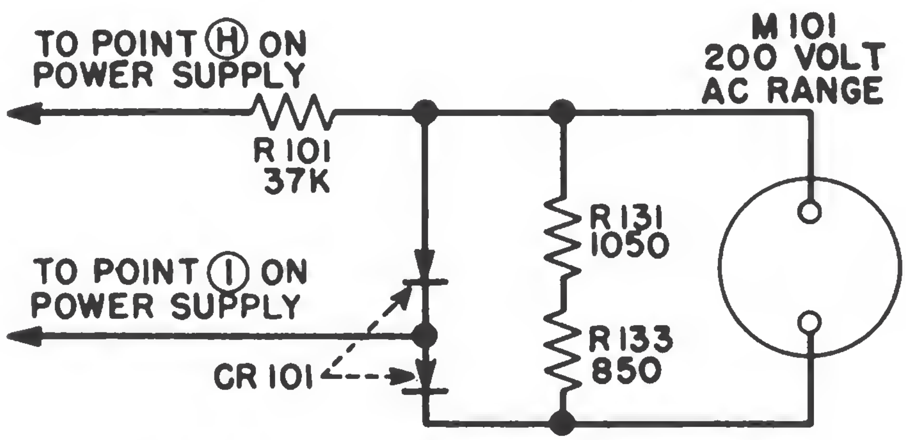


Figure 6–13.—Simplified line-voltage test circuit.

*R*101 is in series with the meter and its rectifier. Resistors *R*131 and *R*133 are in series across the meter. The calibration is such that when the secondary voltage across points *H* and *I* of winding 1 is 124 volts (rms) the meter indication is 100 volts or LINE TEST. With 93 volts across the primary of *T*101, the secondary voltage across winding 2 (points *H* and *I*) is 124 volts. Therefore, if LINE ADJ push switch *P*7 is held down, and LINE ADJUST control *R*113 is turned until the pointer of meter *M*101 is over the LINE TEST mark, a standard voltage of 93 volts (rms) is applied across the primary of *T*101.

SHORT-CIRCUIT TEST.—An alternating voltage of 93 volts is applied from the primary of transformer *T*101 to the circuit for testing shorts in tube elements. The circuit (fig. 6–14) includes capacitor *C*105, the various elements of the

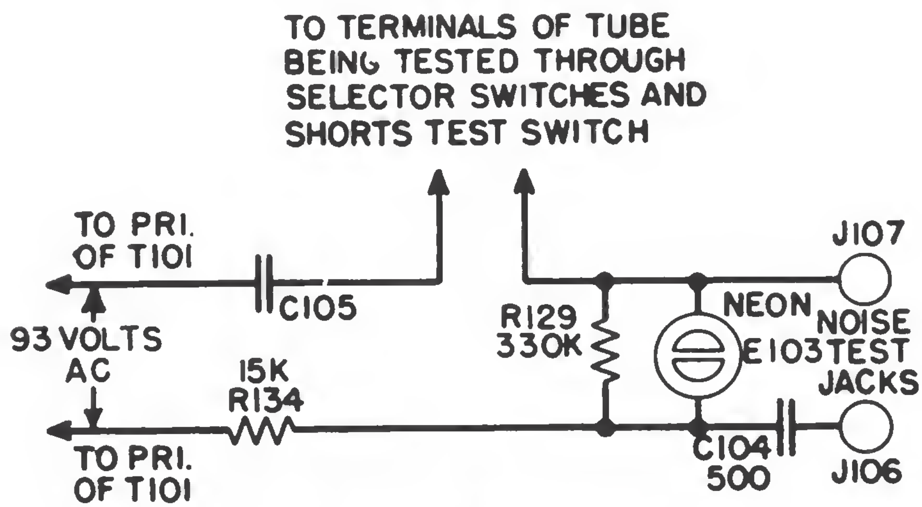


Figure 6–14.—Short-circuit test.

tube under test, a neon lamp, and SHORTS test switch S113. The SELECTORS must be set correctly for the tube being tested. Any shorts that develop between the tube elements will complete the circuit from capacitor *C*105 to the neon lamp and cause the lamp to glow.

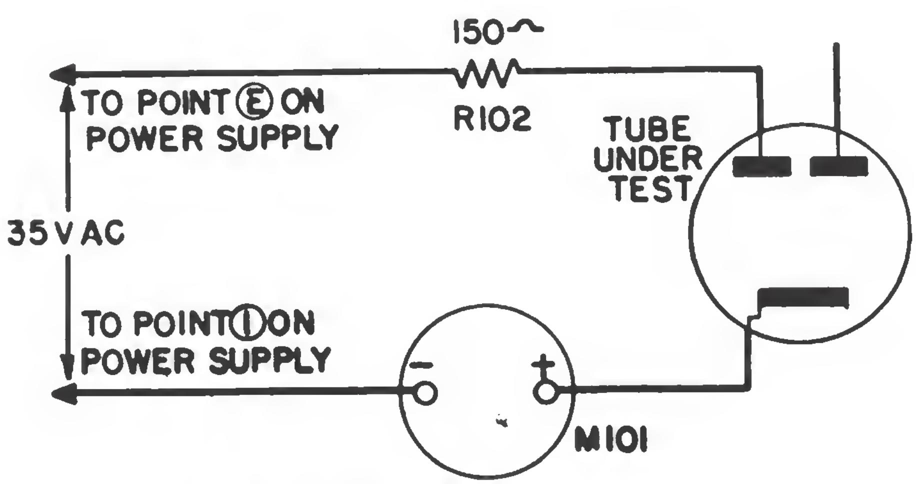


Figure 6–15.—Rectifier test circuit.

RECTIFIER TEST.—The rectifier test circuit (fig. 6–15) is used for making emission tests only, of diode tubes and diode sections of multipurpose tubes because these tubes have no transconductance characteristics.

Push switch *P*3 (fig. 6–11) is used for testing regular power rectifier tubes such as the type-5Y3. Pressing this push switch applies an a-c potential of 35 volts between the cathode and plate of the tube being tested and through resistor *R*102 and meter *M*101 in series, causing the tube to rectify. The rectifying action of the tube being tested causes a direct current to flow through the meter. The current indicated by the meter is proportional to the electron emission of the tube. Good tubes cause the meter pointer to indicate above the point in the center of the scale marked RECTIFIER OK. Tubes reading below this line should be rejected.

Push switch *P*2 (fig. 6–11) is used for checking cold-cathode rectifiers such as the type OZ4. Pressing this switch establishes a circuit similar to that shown in figure 6–15 but applies an a-c potential of 287 volts between the cathode and plate of the tube under test. This voltage is sufficiently high to ionize the tube and start conduction. Good tubes cause the pointer to indicate above the point in the center of the scale marked RECTIFIER OK.

Push switch *P*1 (fig. 6–11) is used for testing detector diodes. Pressing this switch establishes a circuit similar to that shown in figure 6–15 but applies an a-c potential of 20 volts to protect the delicate cathodes of these tubes. Good tubes cause the pointer to indicate above the point marked RECTIFIER OK.

TRANSCONDUCTANCE TEST.—The transconductance test circuit (fig. 6–16) is used to measure directly the mutual conductance of amplifier-type vacuum tubes because the emission test is not sufficient. The value of transconductance, g_m, is expressed in micromhos and is a performance indication of the tube because it shows how effectively a tube is converting a small change in grid voltage to a large change in plate current. The proper d-c grid bias for the tube being tested is supplied by rectifier tube *V*102. Setting BIAS control potentiometer *R*116 at the value indicated on the test-data chart adjusts this negative bias voltage to the correct value for the particular tube being tested.

An alternating potential of 5 volts rms from secondary winding 5 of power transformer *T*101 is applied in series with the grid bias. This voltage alternately swings the grid

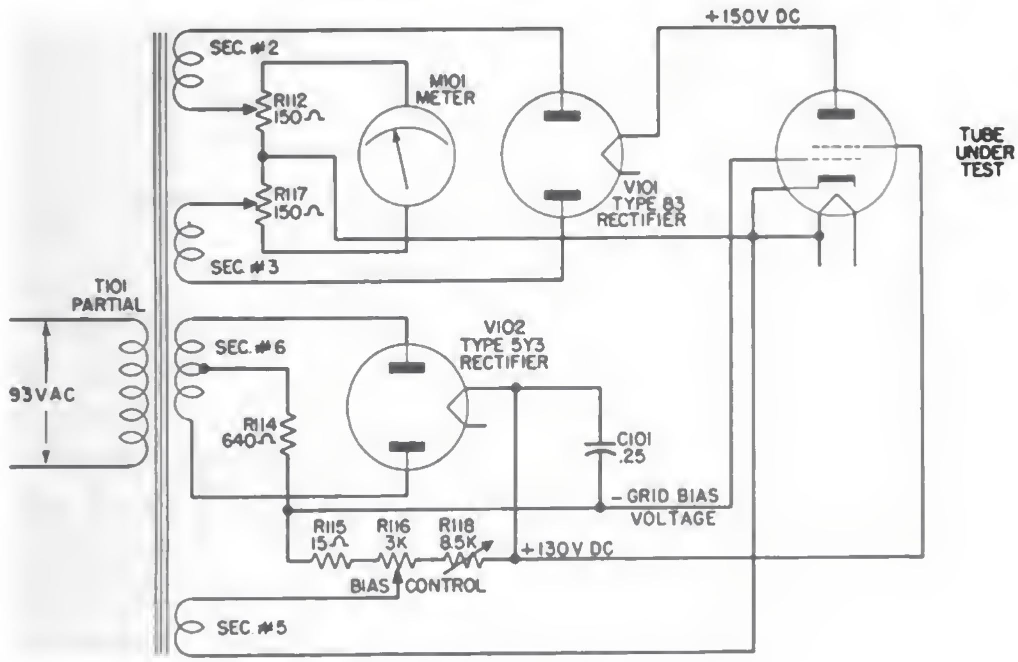


Figure 6–16.—Transconductance test circuit.

in positive and negative directions from the d-c bias, thereby producing the grid-voltage change ($\Delta\ e_g$), required for a dynamic transconductance test.

The plate voltage for the tube being tested is supplied by another full-wave rectifier tube, *V*101. The meter that measures the plate-current change ($\Delta\ i_p$), is in the return circuit of the rectifier supply. The meter circuit consists essentially of a dual potentiometer formed by resistors *R*112 and *R*117 shunted across the meter. Setting dial *I*102 (fig. 6–11) on certain points adjust the dual potentiometer for the three ranges of micromhos (3,000; 6,000; and 15,000) for the NORMAL HIGH SIGNAL of 5 volts; and for the two ranges of micromhos (6,000 and 15,000) for the LOW SIGNAL of 1 volt.

GAS TEST.—Pressing GAS 1 push switch *P*5 (fig. 6–11) applies definite values of plate voltage and grid-bias voltage to the tube under test, causing a definite value of plate current to flow. The plate current is indicated on meter *M*101 as shown in the simplified circuit for the gas test (fig. 6–17).

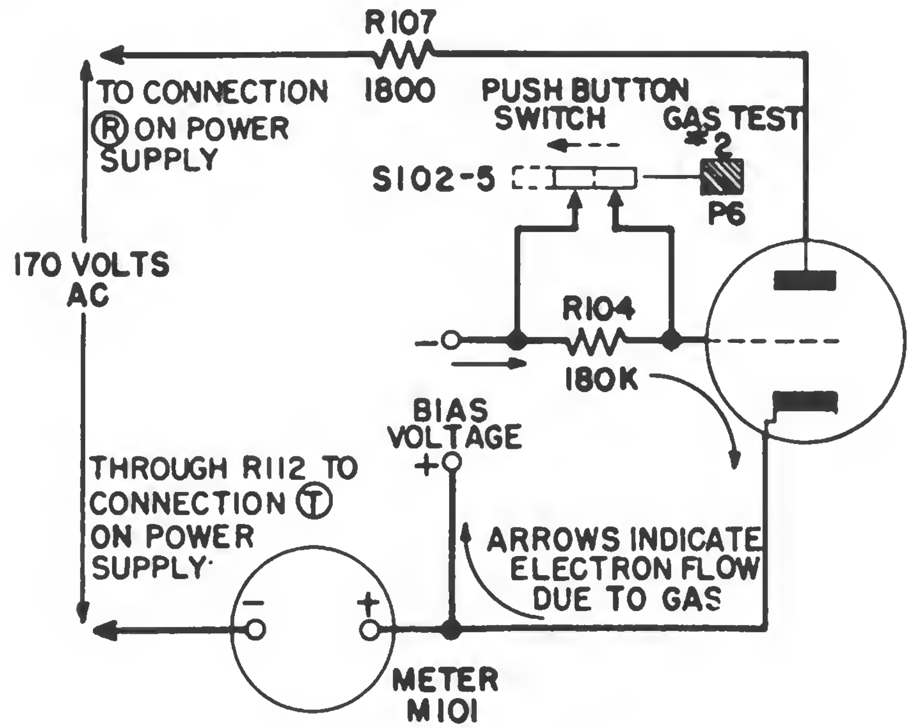


Figure 6–17.—Gas test circuit.

Pressing GAS 2 push switch *P*6 inserts a 180,000-ohm resistor, *R*104, in the grid circuit. If reverse grid current flows from the bias source through the grid circuit to the cathode because of gas in the tube, this current develops a voltage drop across resistor *R*104. This voltage drop reduces the negative bias on the grid, causing a corresponding increase in the plate current being measured by meter *M*101. If the tube contains gas, the pointer of the meter will move up scale. This increase in meter reading should not exceed 1 scale division.

NOISE TEST.—The short-circuit test (fig. 6–14) is also used for making noise tests of electron tubes. NOISE TEST jacks *J*106 and *J*107 are connected to the antenna and ground posts of any radio receiver thus shunting the neon lamp across the receiver input. SHORTS test switch *S*113 is then turned through positions 1, 2, 3, 4, and 5, while the tube being tested is lightly tapped. An intermittent short between tube electrodes applies alternating voltage from the power transformer to the neon lamp. The intermittent oscillations that occur in the neon lamp when the circuit is completed by the short are reproduced by the loudspeaker or headphones as an audible signal similar to static.

Multimeter Section Operation

The TV-3/U tube tester includes a multimeter section which may be used to measure direct or alternating volts, ohms, d-c milliamperes, or microfarads. When the multimeter section is used, the 11-position master switch, *S*112 (fig. 6–11), is the range selector switch which connects the indicating meter in the appropriate circuit, depending on the type of measurement and magnitude of the quantity involved.

VOLTMETER CIRCUIT.—The d-c and a-c voltmeter circuit (fig. 6–18) consists of meter *M*101 shunted by resistor *R*131 in series with *R*133. A series of resistors (*R*132, *R*137, *R*138 and *R*139) is tapped to provide range selection. One end of the series is connected to the common connection between

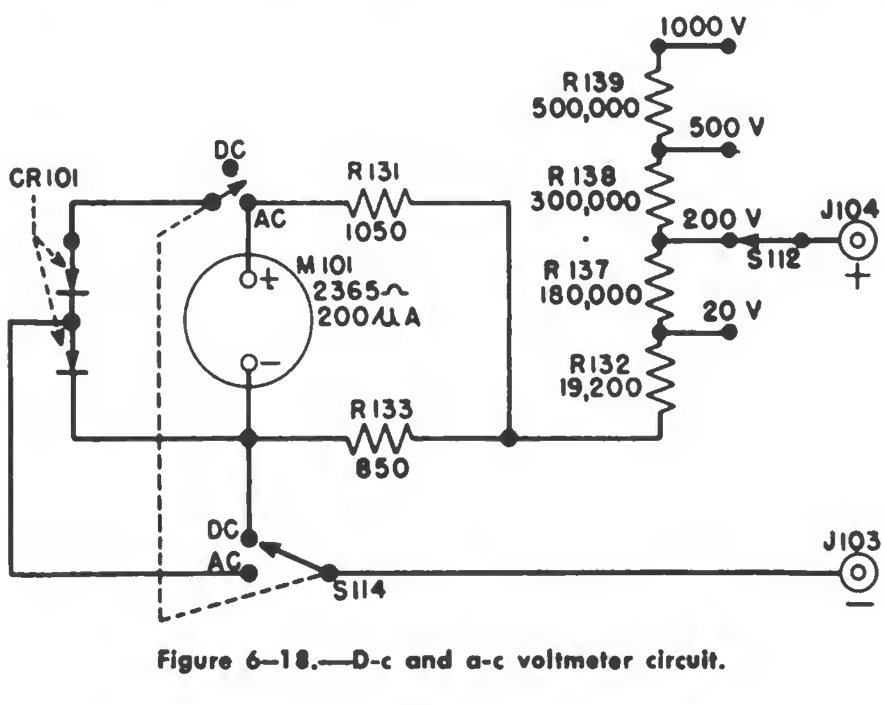
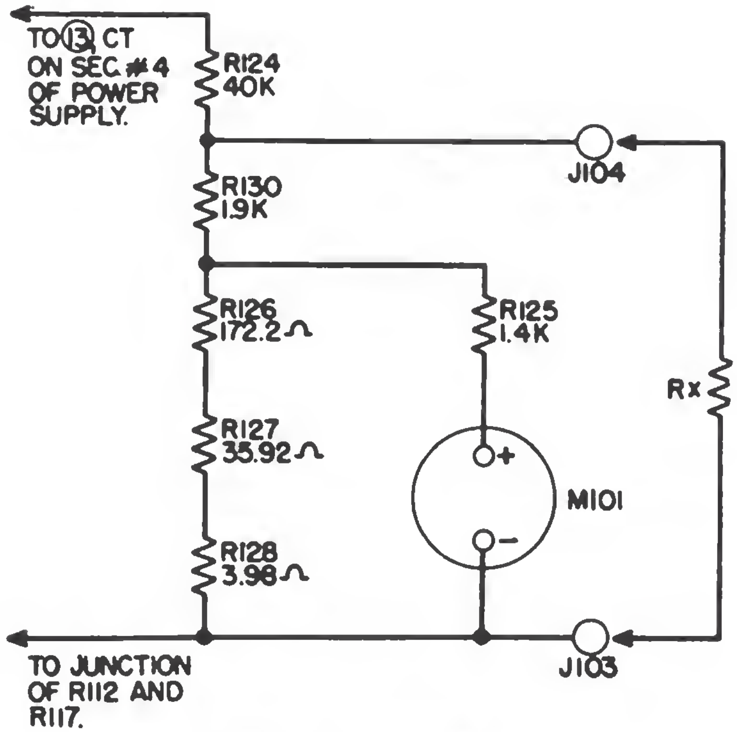
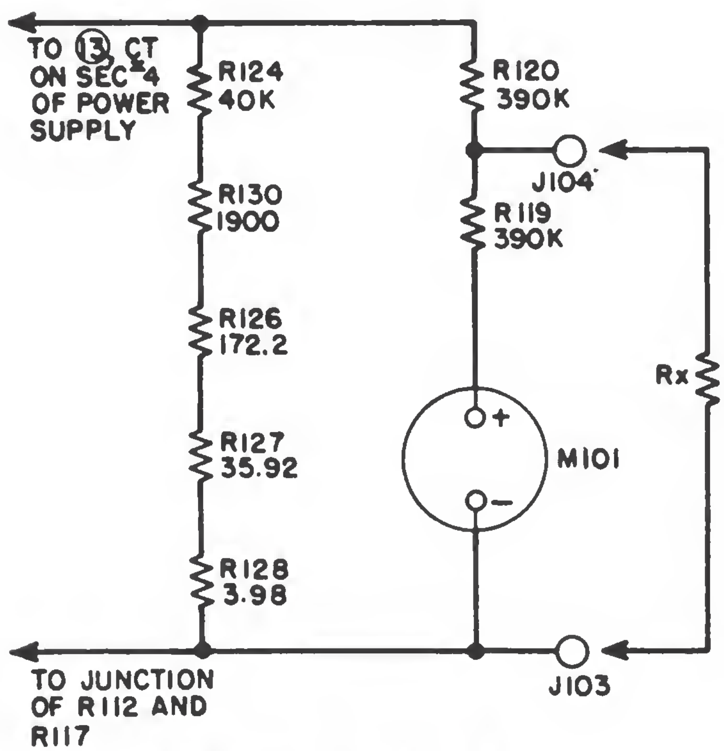


Figure 6–18.—D-c and a-c voltmeter circuit.



A Ohms – X1 RANGE



B Ohms – X100 RANGE

Figure 6–19.—Ohmmeter circuit.

*R*133 and *R*131. Master switch *S*112 connects jack *J*104 to the proper tap of the series resistors for the selected voltmeter range.

When direct voltages are measured, copper oxide rectifier *CR*101 is disconnected by switch *S*114. When alternating voltages are measured, copper oxide rectifier *CR*101 acts as a full-wave rectifier conducting current through the meter in the same direction on both alternations of the input voltage. The meter sensitivity for both direct- and alternating-voltage measurements is 1,000 ohms per volt. The ranges for both direct and alternating voltages are 0-20, 0-200,0-500, and 0-1,000 volts.

OHMMETER CIRCUIT.—The ohmmeter circuit (fig. 6–19) consists of the ohms-*X*1 range and the ohms-*X*100 range, shown respectively in figure 6–19, A and B. Each range has a voltage-divider network that is selected by master switch *S*112 (fig. 6–11), which also connects meter *M*101 across part of the voltage divider. No batteries are used in this circuit. The power to operate the meter is obtained from the built-in power supply. Therefore, when resistances are measured, power switch *S*106 (fig. 6–11) must be turned on. The unknown resistance is shunted across a portion of the voltage-divider network including the meter, so that the deflection varies with the unknown resistance.

When master switch *S*112 is set on the OHMS-*X*1 range, the ohms scale reads directly. The center of the scale is 2,000 ohms and can be read from 10 ohms to 1 megohm.

When master switch *S*112 is set on the OHMS-*X*100 range, the scale is multiplied by 100. The center of the scale is 200,000 ohms and can be read from 1,000 ohms to 100 megohms.

CAPACITY TEST CIRCUIT.—The capacity test circuit is shown in figure 6–20. A standard a-c potential is applied across the capacitor which is connected to jacks *J*103 and *J*104 in series with either resistor *R*135 or *R*136, depending upon the range selected by master switch *S*112. The current through the resistors varies with the unknown capacity.

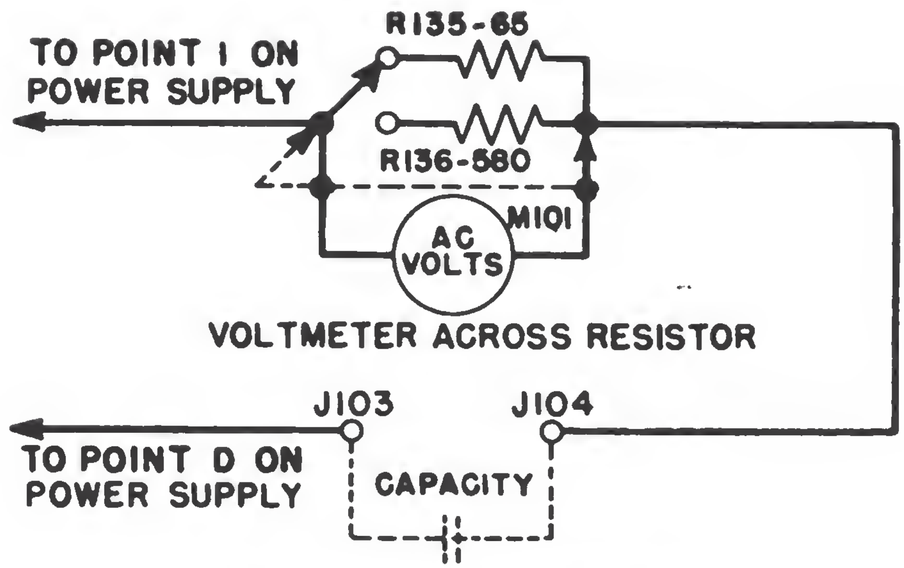


Figure 6–20.—Capacity test circuit.

The voltage drop across either series resistor *R*135 or *R*136 is measured by meter *M*101 which is calibrated directly in microfarads. Capacity is measured in two ranges, 0-5 and 0-50 microfarads.

MILLIAMMETER CIRCUIT.—The milliammeter circuit (fig. 6–21) is of the conventional type for measuring d-c milliamperes. This circuit consists of a 0-20 and a 0-200 milli-

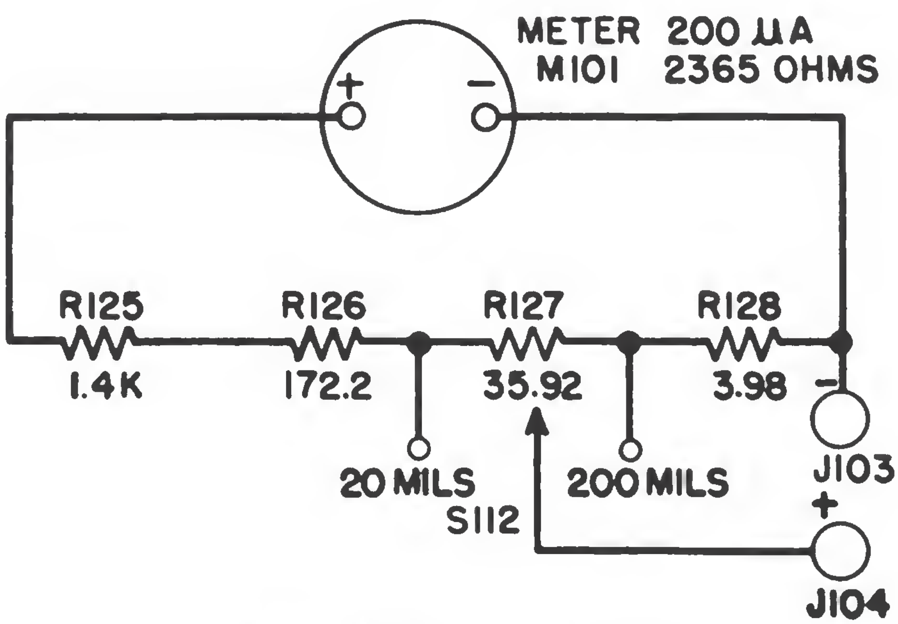


Figure 6–21.—Milliammeter circuit.

ampere range. When taking readings always use the highest range first to avoid possible damage to the meter. Range switch *S*112 changes the range from 200 mils to 20 mils without removing the shunt from the meter movement during the transition.

Controls

All controls for the TV–3/U tube tester are shown on the control panel (fig. 6–11).

TOGGLE SWITCHES.—Power input to the equipment is controlled by ON-OFF switch *S*106.

Toggle switch *S*107, marked NORMAL-LOW SIGNAL, provides for the selection of either 5 alternating volts or 1 alternating volt for exciting the grid of the tube under test.

Toggle switch *S*111, marked METER-REVERSE-NORMAL, reverses the polarity of voltage applied to meter *M*101 when certain types of tubes are tested.

Toggle switch *S*114, marked CAP A-C and D-C, connects copper oxide rectifier *CR*101 in the analyzer circuit for measuring alternating voltage and capacity only.

SELECTOR SWITCHES.—Master switch *S*112 sets up the proper internal circuit connections either for the tube tester section or for the multimeter section.

Selector switch *S*101, marked FILAMENT VOLTAGE, provides for the selection of filament voltages from 1.1 through 117 alternating volts in 17 steps. The position marked BLST provides for testing ballast tubes.

Selector switches *S*103 and *S*104, both marked FILAMENT; *S*105 marked GRID; *S*108 marked PLATE; *S*109 marked SCREEN; *S*110 marked CATHODE; and *S*115 marked SUPPRESSOR provide proper switching of the internal circuits to apply correct test voltages to the various pins of the tube under test.

Selector switch *S*113, marked SHORTS, has five test positions which connect the various elements of the tube under test to the short test circuit containing neon indicator lamp *E*103. A sixth position, marked TUBE TEST, connects the tube to the test circuits after the short test is completed.

LINE ADJUST $R113$ controls the input voltage to (1) power transformer $T101$ for proper standardization of the tube tester section, and (2) the ohms and capacity circuits.

BIAS control $R116$ is used to adjust to the proper value the bias voltage applied to the tube under test.

The SHUNT control is a dual potentiometer consisting of resistors $R112$ and $R117$, and controls the sensitivity of the meter circuit to the proper level for the tube under test.

PUSH SWITCHES.—Push switches actuate the final circuit selector switches for the type of test to be made.

Push switch $P1$, marked DIODE, is used for low-power diodes such as type-6H6 tubes.

Push switch $P2$, marked 0Z4, is used for cold-cathode rectifiers such as type-0Z4 tubes.

Push switch $P3$, marked RECT, is used for rectifiers such as types 5Y3, 6X4, and 83.

Push switch $P4$ (red), marked G_m, is used for testing the transconductance of amplifier tubes only.

Push switch $P5$, marked GAS 1; and push switch $P6$, marked GAS 2, are used for testing the gas content of tubes.

Push switch $P7$, marked LINE ADJ, is used for adjusting the line.

For more detailed instructions refer to the appropriate manufacturer's instruction book furnished with the equipment in use aboard your ship.

LAJ–2 AUDIO OSCILLATOR

The LAJ–2 audio oscillator is a resistance-capacitance type of equipment that generates audio frequencies. It is used to check the performance of audio amplifiers.

The audio oscillator (fig. 6–22) is contained in a portable metal case provided with a removable cover. The controls are mounted on the front panel and are clearly marked for identification. The equipment is designed to deliver a maximum of 250 milliwatts (12.2 volts) into a 600-ohm load with the attenuator control set to full gain. Higher im-

Figure 6–22.—LAJ–2 audio oscillator.

pedances increase the maximum available output voltage without appreciably altering the output waveform. Lower impedances lower the maximum available output voltage and cause a distortion of the output waveform.

Operation

A schematic diagram of the LAJ–2 audio oscillator is shown in figure 6–23. This equipment consists of (1) two-stage resistance-capacitance oscillator, (2) two-stage amplifier, (3) attenuator, and (4) power supply.

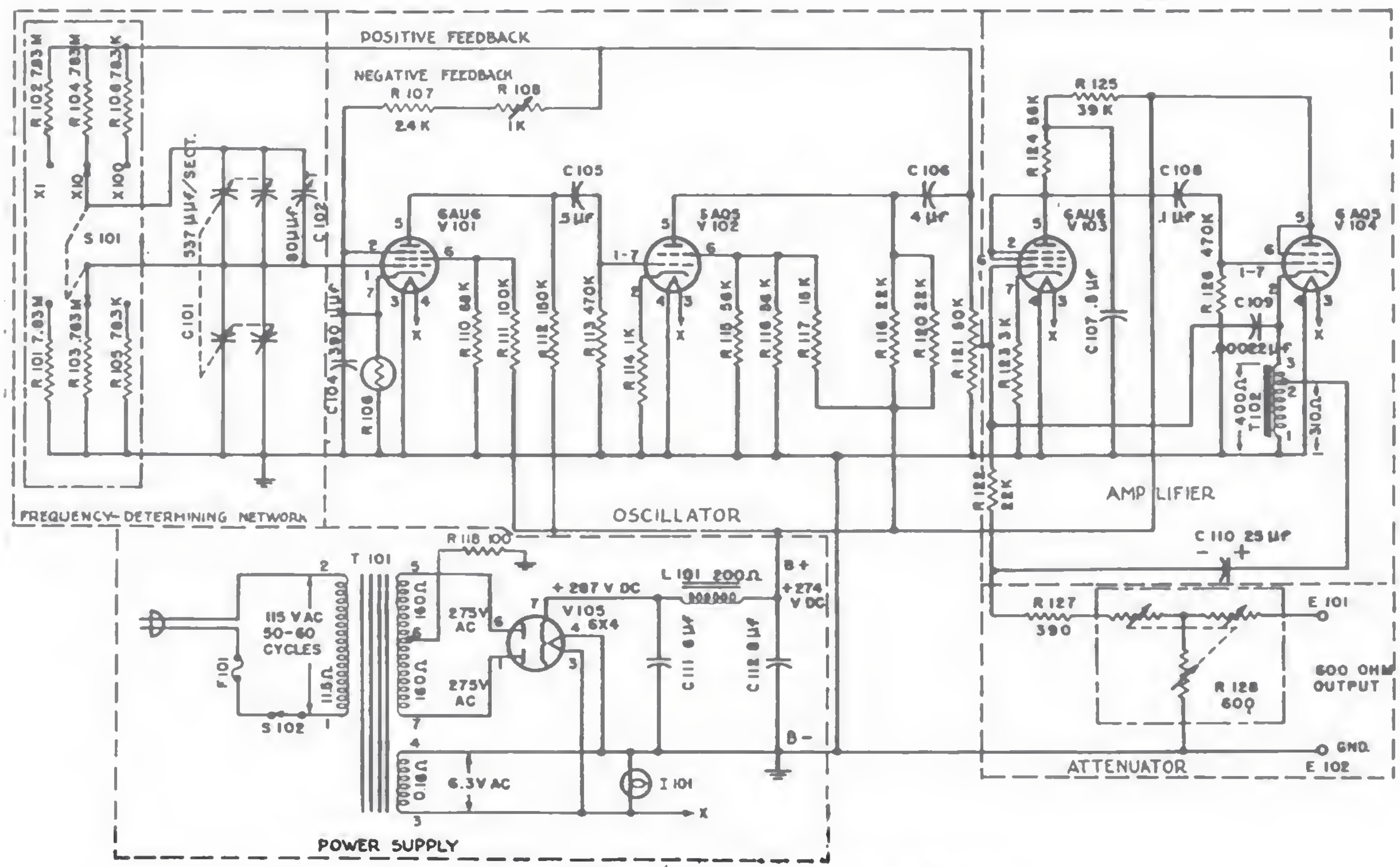


Figure 6–23.—Audio oscillator circuit diagram.

Oscillator circuit.—The oscillator circuit (fig. 6–23) is basically a two-stage amplifier coupled to a Wien bridge. The Wien bridge oscillator is discussed in chapter 5. A portion of the output of tube *V*102 is fed back to the grid of tube *V*101 as positive feedback. In addition, negative feedback is employed in the proper phase relation to stabilize the operation of the oscillator and keep the output constant over a wide range of frequencies.

The frequency-determining network (fig. 6–23) consists of two banks of variable capacitors and two groups of resistors wired to range switch *S*101. The resistor group consisting of resistors *R*102, *R*104, and *R*106 is in series with the associated variable capacitor bank, *C*102. The resistor group consisting of resistors *R*101, *R*103, and *R*105 is in parallel with the associated variable capacitor bank, *C*101. The values of the series group of resistors and the parallel group of resistors are fixed for each range.

The system is designed so that the voltage applied to the control grid of oscillator tube *V*101 is in phase with the voltage applied to the entire frequency-determining network. Also, the grid voltage is always one-third of the voltage applied to the entire network.

The resonant frequency of the network is inversely proportional to the product of the resistance and capacitance. Large changes in resonant frequency are possible for a given set of components by adjustment of capacitors *C*101 and *C*102 (fig. 6–23). A frequency change of more than 10 to 1 is accomplished with each set of resistors and the audio frequency range is covered by using three separate sets of resistance values.

The frequency of the oscillator is determined by the equation

$$f=\frac{1}{2\pi\sqrt{R_sR_pC_sC_p}}. \qquad (6\text{–}1)$$

Resistors *R*101, *R*104, and *R*106 are designated as R_s when used in the circuit one at a time. Resistors *R*101, *R*103, and

$R105$ are designated as R_p when used in the circuit one at a time. Resistor R_s is in series with variable capacitor $C102$ for a given range. Resistor R_p is in parallel with variable capacitor $C101$ for the same range. The capacitance of $C102$ is designated as C_s and the capacitance of $C101$ as C_p. Tuning capacitors $C101$ and $C102$ are ganged together so that C_p is equal to C_s. The values of R_s and R_p are equal for a given range.

The frequency of the oscillator is determined by the simplified equation

$$f=\frac{1}{2\pi R_s C_s}, \qquad (6\text{–}2)$$

where f is in cycles per second, R_s in ohms, and C_s in farads.

The NEGATIVE FEEDBACK voltage in the oscillator is obtained from the output oscillator tube $V102$ and is fed back to the cathode of oscillator tube $V101$. The magnitude of the negative feedback is determined by the resistor network consisting of variable resistor $R108$, resistor $R107$, capacitor $C104$, and incandescent lamp $R109$. The lamp has a positive temperature coefficient but has sufficient thermal inertia so that its temperature is substantially constant at all audio frequencies. Because of its positive temperature coefficient, the oscillations cannot build up to a value in excess of the power rating of tube $V101$. The resistance of the lamp increases with increased current. Degeneration in the cathode circuit of tube $V101$ increases, causing less amplification in the oscillator with increased plate current. Hence, the lamp serves as an automatic amplitude limiter.

AMPLIFIER CIRCUIT.—The amplifier circuit (fig. 6–23) is a two-stage, negative-feedback power amplifier using output tube $V104$ as a cathode follower. The output is taken from autotransformer $T102$ in the cathode circuit of tube $V104$. Capacitor $C110$ couples the autotransformer to the output circuit, from which negative feedback is coupled through resistor $R122$ to the grid of tube $V103$. The negative feedback in this circuit provides a minimum distortion and maintains the gain of the amplifier substantially constant over a wide range of frequencies.

ATTENUATOR CIRCUIT.—The output of the amplifier is fed into a 600-ohm constant-impedance attenuator circuit (fig. 6-23). The range of the attenuator is continuously variable from less than 1 decibel to almost complete attenuation. The attenuator maintains the load on the amplifier and oscillator constant. Therefore, the oscillator frequency does not change with different settings of the amplifier control.

POWER SUPPLY CIRCUIT.—All voltages for this equipment are obtained from the power supply circuit (fig. 6-23), which utilizes transformer *T*101. The primary of this transformer is connected to the power-line cord through fuse *F*101 and on-off switch *S*102.

The transformer has a 550-volt and a 6.3-volt secondary winding. The 550-volt winding is center-tapped and is fed to rectifier tube *V*105, which is connected for full-wave rectification. The output of this tube, which is 287 volts, is filtered by the pi filter consisting of capacitor *C*111, inductor *L*101, and capacitor *C*112 and then is fed to the plates of the tubes. The rated voltage across output capacitor *C*112 is 274 volts.

The 6.3-volt winding is provided for the operation of all a-c heaters of the tubes.

Controls

FREQUENCY CONTROL DIAL.—The frequency control dial has (1) basic frequency scale and (2) linear scale. The basic frequency (*X*1) scale is calibrated from 20 to 200 cycles per second. The linear scale, located beneath the frequency scale, is calibrated from 0 to 100. This scale is for the convenience of the operator for reference purposes. The frequency control knob, *C*101, provides a means of selecting the frequency indicated on the frequency control dial.

RANGE SWITCH.—The range switch, *S*101, consists of (1) range *X*1 calibrated from 20 to 200 cycles per second; (2) range *X*10 calibrated from 200 to 2,000 cycles per second;

and (3) range $X100$ calibrated from 2,000 to 20,000 cycles per second.

ATTENUATOR CONTROL KNOB.—The attenuator control knob, $R128$, varies the power output of the equipment. Rotating the control knob clockwise increases the power output to its maximum value.

TERMINALS.—The output voltage is obtained from the two terminal posts, one marked OUTPUT and the other marked GND. The terminal post marked GND is grounded to the chassis but it is not connected to the incoming power source.

The LAJ–2 equipment is often used to trace a signal through an audio amplifier in order to locate the defective section or stage. The oscillator supplies the audio signal, which can be detected at various test points by means of a sound-powered telephone, cathode-ray oscilloscope, or high-impedance voltmeter. A vacuum-tube voltmeter can be used for this purpose but it will not indicate any distortion that may be present.

The audio oscillator and the sound-powered telephone require the insertion of an isolating capacitor in series with the test probes to protect them from d-c voltages present in the amplifier. A suitable rating for such a capacitor is $0.01\mu f$ at 600 volts for most amplifier circuits.

No attempt should be made to trace signals on high-power output stages having direct voltages in excess of 500 volts.

The audio oscillator may be used in connection with tracing a signal through a resistance-coupled audio amplifier, as shown in figure 6–24. The audio oscillator is connected between grid and ground of $V1$ through an isolating capacitor. One side of the sound-powered telephone being used to pick up the audio signal is grounded and the other is connected through a capacitor to the numbered test points. The oscillator is turned on and allowed to warm up. Then the output frequency is adjusted to about 1,000 cycles per second. The signal should be heard when the ungrounded earphone test probe is touched to test point 1. If it is not heard, the circuit may be open at the input jack or the grid of $V1$ may be grounded.

When the earphone test probe is touched to point 3 the signal should increase in amplitude compared to test point 1.

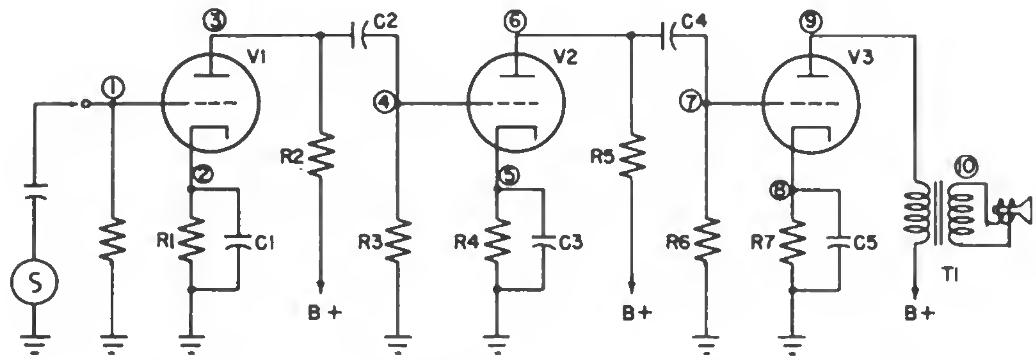


Figure 6–24.—Tracing a signal through an audio amplifier.

If the signal is weak, $C1$ may be open or shorted, or $V1$ may be defective.

If the signal is heard at point 2, $C1$ may be open.

If the signal is normal at point 3 and is not heard at point 4, $C2$ may be open or the grid of $V2$ grounded.

If the signal is weak or distorted at point 4, $C2$ may be shorted or leaky. Coupling capacitors should have an insulation resistance of at least 50 megohms.

If $C2$ develops a leak, part of the B-supply voltage is applied to the grid of $V2$ and the bias is reduced thus causing distortion and possible overloading of $V2$.

If the signal is normal at test point 7 and below normal at 9, the trouble is probably in $V3$, $R7$, or $C5$.

If the signal is normal at 9 and no sound emanates from the loudspeaker, the voice coil is probably open.

If there is no signal at 10, the secondary of output transformer $T1$ is probably open or grounded.

The LAJ–2 equipment is used advantageously for comparing waveforms, checking values of inductance and capacitance, comparing and calibrating frequencies, and many other applications.

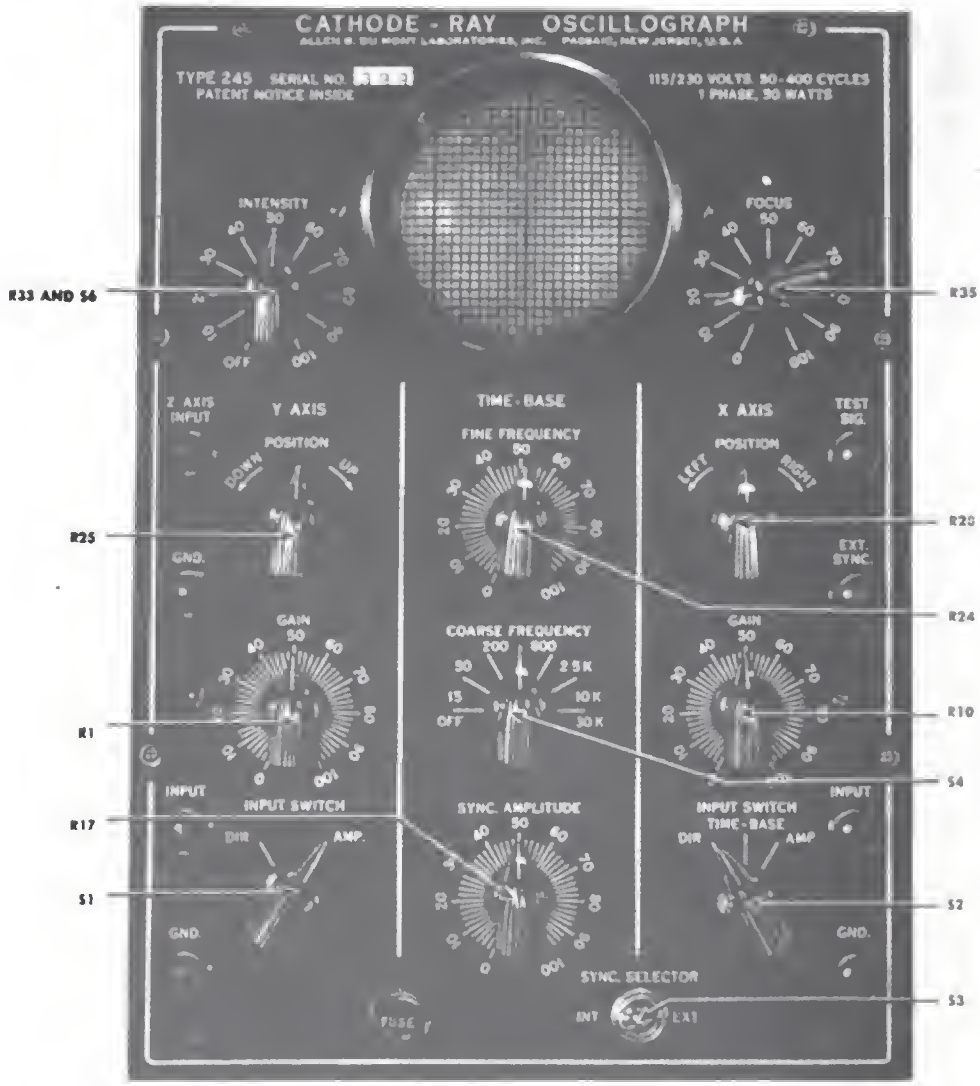


Figure 6–25.—OBL–1 cathode-ray oscillograph.

OBL–1 CATHODE-RAY OSCILLOGRAPH

The OBL–1 cathode-ray oscillograph (fig. 6–25) is a special type of circuit using a cathode-ray tube in which a fast-moving stream of electrons is formed into a narrow beam and allowed to strike a fluorescent screen. When the electrons strike the screen they cause it to fluoresce, or glow, and thus to produce an instantaneous visual trace. Because the indicating element is an electron beam, it has practically no inertia and therefore responds to rapidly changing electrical values that cannot be detected by a mechanical indicating system.

This equipment is used principally to measure direct voltages, alternating voltages, phase relations, frequencies, and the amplitudes and durations of waveforms.

The cathode-ray oscillograph is a self-contained portable unit housed in a metal cabinet provided with a carrying handle. The controls necessary for the operation of this equipment are mounted on the front panel and are clearly marked for identification. A 115/230-volt power selector switch, *S*5, is located at the rear of the chassis.

Operation

The OBL–1 cathode-ray oscillograph is essentially an indicating device designed to show the relation between an unknown quantity plotted along the *Y*-axis and a known quantity plotted along the *X*-axis. This equipment consists of (1) cathode-ray tube, (2) time-base (sweep-frequency) generator, (3) *Y*-axis amplifier, (4) *X*-axis amplifier, and (5) power supply. The time-base, or SWEEP circuit, generates a saw-tooth voltage waveform which is applied to the *X*-axis so that the unknown quantity can be plotted as a linear function of time.

CATHODE-RAY TUBE.—The cathode-ray tube (fig. 6–26) consists of a cathode, grid, two anodes, and two sets of de-

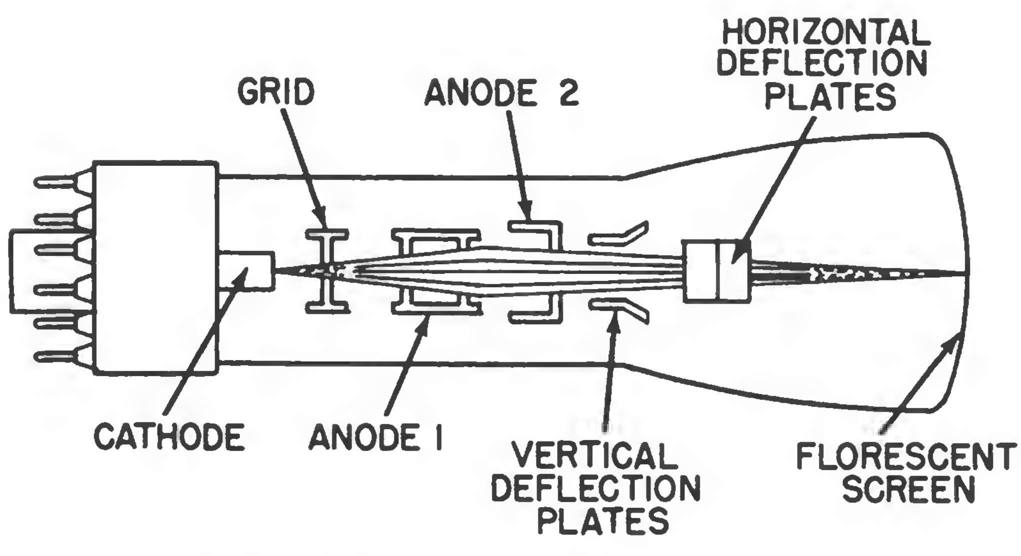


Figure 6–26.—Electrostatic deflection cathode-ray tube.

flection plates enclosed within an evacuated glass tube. These elements permit the electron beam to be changed in intensity, focused, and deflected either horizontally or vertically.

The electron gun (fig. 6–27), which shoots a stream of electrons toward the screen, consists of the cathode, control grid, and two anodes.

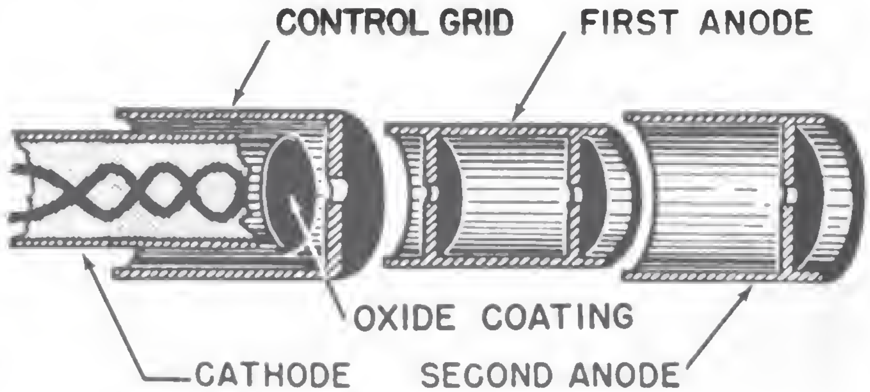


Figure 6–27.—Cutaway view of an electron gun.

The cathode is of the indirectly heated type. It is a small nickel sleeve having an oxide coating on the end adjacent to the anodes, and a filament enclosed within the sleeve. When the cathode is heated, a space charge forms within the tube. Practically all the emission is limited to the end of the cathode having the oxide coating.

The grid is a cylindrical shield that covers the cathode. The flat end of the grid adjacent to the anodes has a small hole through its center. The grid effectively controls the emission from the cathode and at the same time concentrates the electrons into a narow beam as they pass through the hole in the grid.

Anode 1 is operated at a positive potential with respect to the grid and anode 2 is operated at a still higher positive potential with respect to the grid. Thus, the electrons emitted from the cathode are directed and accelerated toward the anodes. When the electrons leave the grid they pass through anode 1 which trims the edges of the beam and then through anode 2 which increases the speed of the beam.

The difference in potential between the two anodes sets up an electric field between them. The action of this field bends the electron beam, thus producing a converging, or focusing, action on the beam. The beam continues on between the vertical and horizontal deflection plates and strikes the screen which fluoresces at the point of impact.

With no potential applied to the deflecting plates, the electron beam appears as a bright spot on the center of the screen.

In order to produce a pattern on the screen, the electron beam is deflected by two forces that act at right angles to each other. If a positive charge is applied to the right horizontal deflection plate, the spot will move to the right in proportion to the applied voltage because the stream of electrons is electrostatically attracted to the plate having an opposite charge. Likewise, if a negative charge is applied to the same plate, the spot will move to the left in proportion to the applied voltage because the stream of electrons is electrostatically repelled from the plate having a like charge. Hence, an alternating voltage applied to the horizontal deflection plates cause the spot to move to one side from the center (along the X-axis), to return to center, then to move to the other side and return. This motion is continuously repeated until the voltage is removed from the deflection plates.

Except at very low frequencies, the persistence of vision and the persistence of the fluorescent screen cause the pattern on the screen to have the appearance of a straight line. Deflections representing time are usually produced by applying a saw-tooth voltage to the horizontal deflection plates. Horizontal circuit connections are designated as X-axis terminals.

Likewise, an alternating voltage applied to the vertical deflection plates causes the spot to move up from the center (along the Y-axis), return to center, then move down and return. Deflections representing amplitude are usually produced by applying voltage to the vertical deflection plates.

Vertical circuit connections are designated as Y-axis terminals.

The amount of deflection depends principally upon (1) the amplitude of the voltages applied to the deflection plates and (2) the speed of the electrons in the beam. The deflection depends to some extent on the distance of the deflection plates from the screen. If the plates are moved farther from the screen the deflection is greater for a given voltage. Because the spacing of the deflection plates in a given tube is fixed and the speed of the electrons as they leave the electron gun is fixed for a given accelerating potential, the movement of the spot on the screen depends only on the voltage applied to the deflection plates.

The amount that the electron beam is moved by a change of 1 volt across the deflection plates is called the DEFLECTION SENSITIVITY of the tube. For increased sensitivity the deflection plates are made longer so that the electrons remain in the electric field for a longer time. When the plates are lengthened, they are usually bent out toward the glass envelope. This bending of the plates is necessary to prevent the electron beam from striking the deflection plates at the condition of maximum deflection.

The intensity, or brightness, of the spot is controlled by varying the bias on the grid. Therefore, when a negative charge is placed on the grid, a relatively small number of electrons can reach the screen, thus resulting in a spot of low intensity. Conversely, as the negative charge is reduced, the number of electrons permitted to pass the grid is increased, thus resulting in a spot of high intensity.

The intensity modulation of the spot or trace is controlled by applying a signal voltage of known frequency to the grid. The variations of this signal voltage modulate the emitted beam causing the spot or trace to become brighter or dimmer. This principle is used to provide reference points on the trace or pattern. The terminals connected to this circuit are designated as the Z-axis terminals.

A schematic diagram of the cathode-ray tube circuit is shown in figure 6–28. The necessary voltages for operating this tube are obtained from the power supply through the voltage-divider network consisting of resistors *R*33 through *R*38. The intensity of the beam is adjusted by moving the potentiometer arm on *R*33. This action changes the grid bias. Focusing to the desired sharpness is obtained by moving the potentiometer arm on *R*35 to provide the correct potential for anode 1. Anode 2 is grounded and is thus at a high positive potential with respect to the cathode.

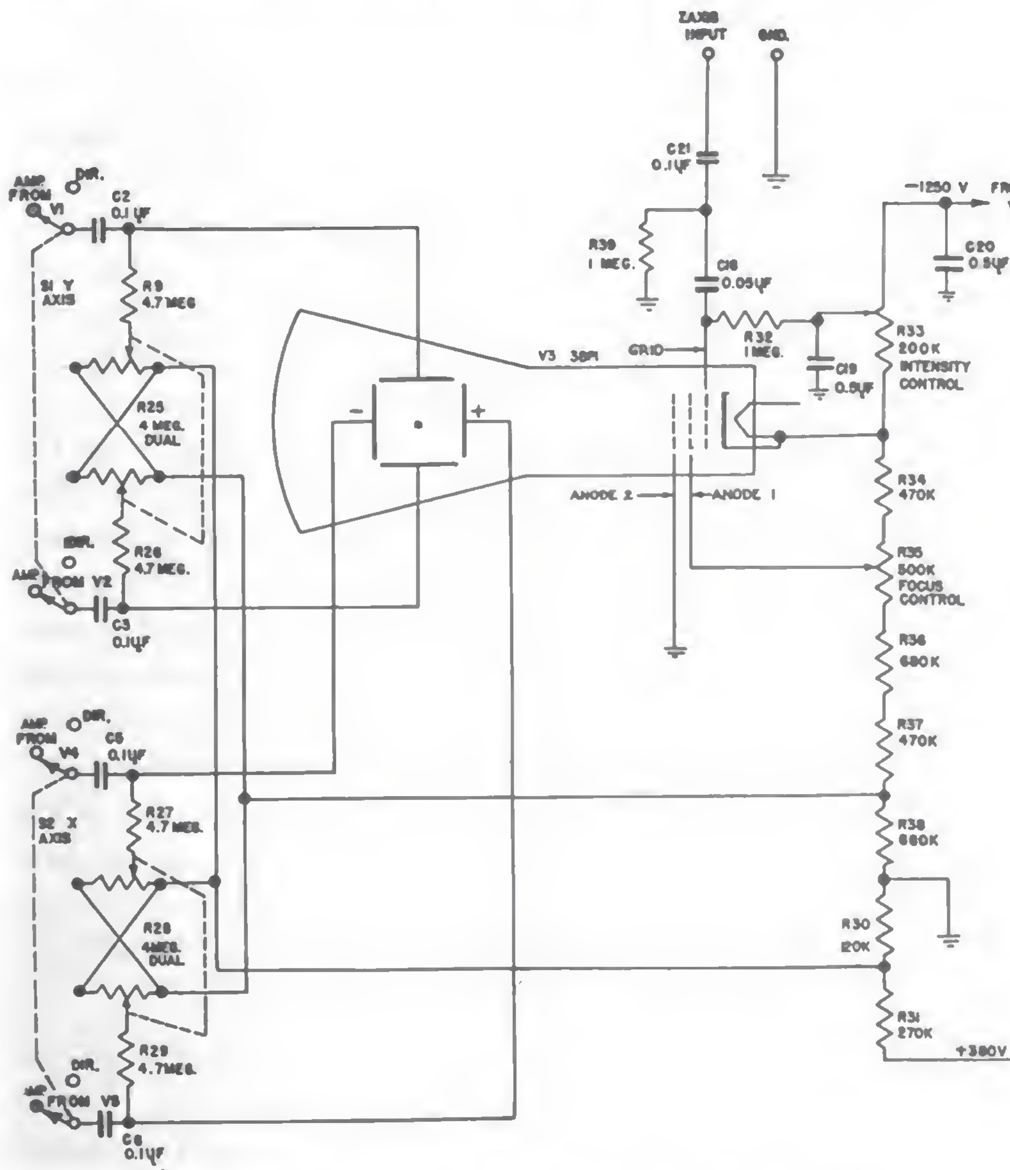


Figure 6–28.—Circuit diagram of the cathode-ray tube.

A voltage-divider network is provided for positioning the spot on the screen. Dual potentiometer *R*25 controls the vertical position and *R*28 controls the horizontal position. When the arms of both *R*25 and *R*28 are in their midpositions, the d-c voltages across both sets of plates are zero and the spot is centered on the screen.

When the arms of *R*28 are set to give zero voltage on the horizontal deflecting plates, the spot appears somewhere along the *Y*-axis, depending on the position of the arms of *R*25. Moving the arms of *R*25 from the extreme left position to the extreme right position moves the spot along the vertical axis from the lower to the upper edge of the screen.

Conversely, when the arms of *R*25 are set to give zero voltage on the vertical deflecting plates, the spot appears along the *X*-axis, depending on the position of the arms of *R*28. Moving the arms of *R*28 from the extreme left position to the extreme right position moves the spot along the horizontal axis from the right to the left edge of the screen.

The vertical and horizontal positioning controls apply d-c voltages across corresponding pairs of deflection plates. These voltages establish the static position of the spot on the screen. At the same time the circuits permit the application of a-c signal voltages across the plates with the formation of various screen patterns. Adjusting the positioning control then changes the position of the pattern on the screen.

TIME-BASE GENERATOR.—When the cathode-ray tube is used to investigate voltage waveforms the test signal is applied to one pair of deflecting plates at the same time a voltage that varies linearly with respect to time is applied to the other pair of plates. The screen pattern then shows the instantaneous values of a-c voltage occurring over a period of time. The time-base voltage is produced by an *R-C* oscillator having a saw-tooth output voltage waveform (fig. 6–29).

The oscillator is of the relaxation type employing a thyratron discharge tube across capacitor bank *C*10 to *C*15. Varying the capacitance from 0.2 μf to 100 $\mu\mu f$ varies the output frequency from a low to a high value. With one capacitor selected, the voltage across it rises exponentially with respect to time. Thyratron $V6$ receives this rising voltage on its plate. When the voltage increases to the ionization value the tube conducts and the capacitor discharges rapidly through the tube from cathode to plate. Thus the output

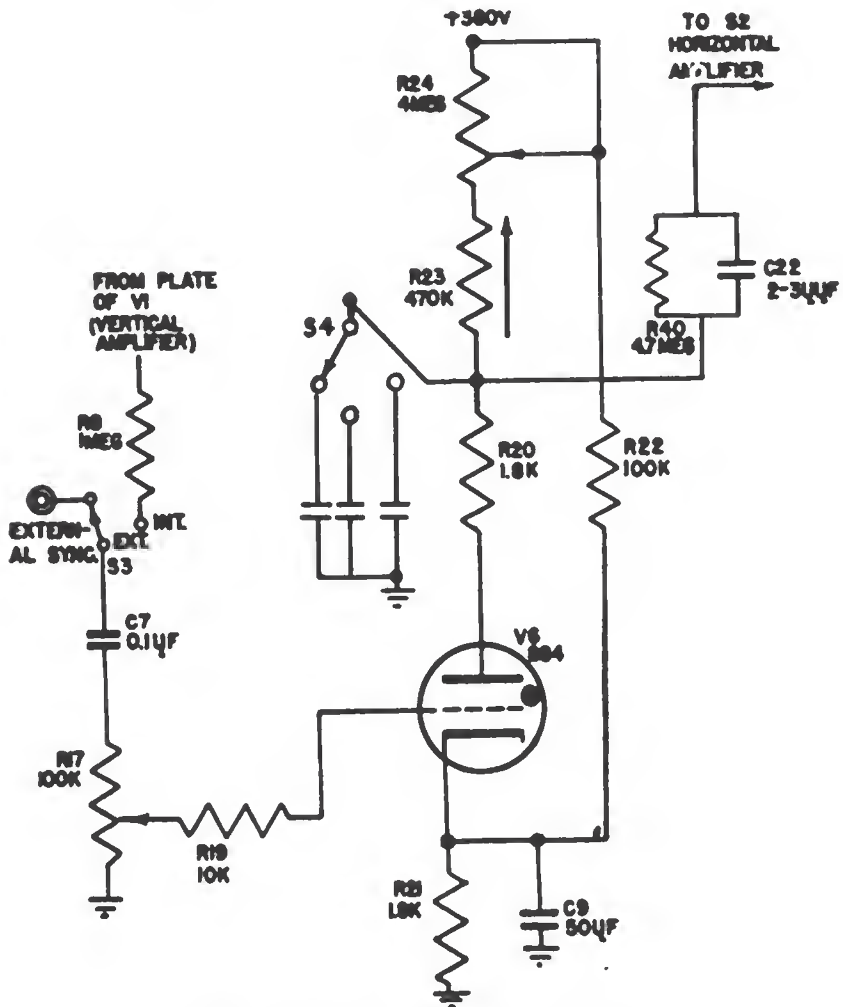


Figure 6–29.—Time-base generator.

voltage consists of a gradually rising voltage over a period of time, at the end of which the voltage drops quickly to a low value. Thus the output waveform resembles a saw tooth. The ionization potential of $V6$ depends on the grid bias developed across $R21$. The output frequency depends on the time required to charge the capacitor shunted by $V6$.

Capacitors $C10$ through $C15$ are selectively connected in

Elect
values o
circuits.
operati
The acc
type of
and use
by I. C.
oscillat

The
volt-oh
a-c vol
of mea
voltag
and di
The
case p
switch
The p
marke

The
circui

makes the period of the signal and the period of the sweep equal. Thus the signal pattern appears stationary on the screen. This condition is called SYNCHRONIZATION.

In operation, the linear saw-tooth output voltage is applied to the horizontal plates of the cathode-ray tube. This voltage is used to deflect the spot or trace along the X-axis of the screen from left to right at a constant velocity, then to

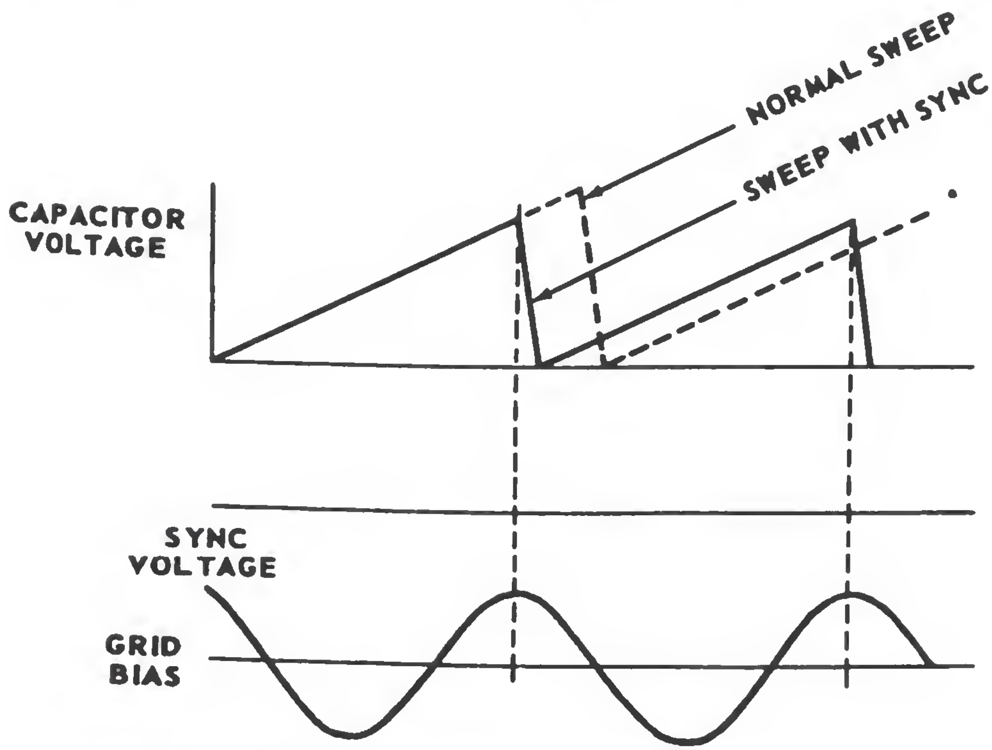


Figure 6–30.—Synchronization of a sweep voltage.

return the spot almost instantly to its original starting position from which the cycle is repeated continuously. This action is called the SWEEP VOLTAGE, or SWEEP SIGNAL, and the rate at which the cycles are repeated is called the SWEEP FREQUENCY. That portion of the wave during which the spot is carried along the horizontal axis is located between points A and B (fig. 6–30) thus representing the sweep time. That portion of the wave between points B and C represents the return time, or flyback time—that is, the period during which the voltage decreases from maximum to minimum and during which the spot is returned to its original starting position.

parallel with tube *V*6, through switch *S*4, so that individual selections can be obtained for coarse adjustment of the sweep frequency. Resistor *R*20 limits the peak current drawn by tube *V*6 when the capacitor discharges through it. The plate voltage is obtained through resistors *R*23 and *R*24.

Potentiometer *R*24 is used to select the correct value of resistance in the plate circuit and thus allows for fine adjustment of the sweep frequency. As selected by COARSE FREQUENCY switch *S*4, the capacitor (*C*10 to *C*15) is allowed to charge to a relatively low potential determined by the ionization potential of tube *V*6. This voltage is set by a fixed negative bias obtained from the bleeder consisting of resistors *R*21 and *R*22 on the low-voltage power supply.

Capacitor *C*7 blocks any external direct voltage from the grid of tube *V*6 when an external synchronizing signal is used.

If the frequency of the sweep generator is slightly different from that of the signal, the pattern will drift slowly one way or the other across the screen. To stabilize the pattern, the frequency of the sweep generator is made equal to, or a multiple of, the signal frequency. The sweep frequency is then controlled automatically by applying a portion of the signal voltage to the grid of tube *V*6 so that the tube fires at a particular voltage. The synchronization relies on the influence that the grid exerts on the ionization of the tube. The frequency of the sweep generator varies with the ionization potential of the tube. The higher the ionization potential, the lower is the frequency, if the *R-C* time constant is unchanged.

The relation between the sweep generator voltage and a signal voltage of sine waveform, shown in figure 6–30, represents a condition in which the two frequencies are not quite the same. The sync signal lowers the grid bias of tube *V*6 an ionizes the tube. The sweep frequency is made equal to the signal frequency by injecting a portion of the signal frequency as a sync signal in series with the grid-bias supply. When the signal voltage has a positive peak, the sync voltage also has a positive peak and the tube ionizes. This action makes the period of the signal and the period of the sweep equal. Thus the signal pattern appears stationary on the screen. This condition is called SYNCHRONIZATION.

In operation, the linear saw-tooth output voltage is applied to the horizontal plates of the cathode-ray tube. This voltage is used to deflect the spot or trace along the X-axis of the screen from left to right at a constant velocity, then to

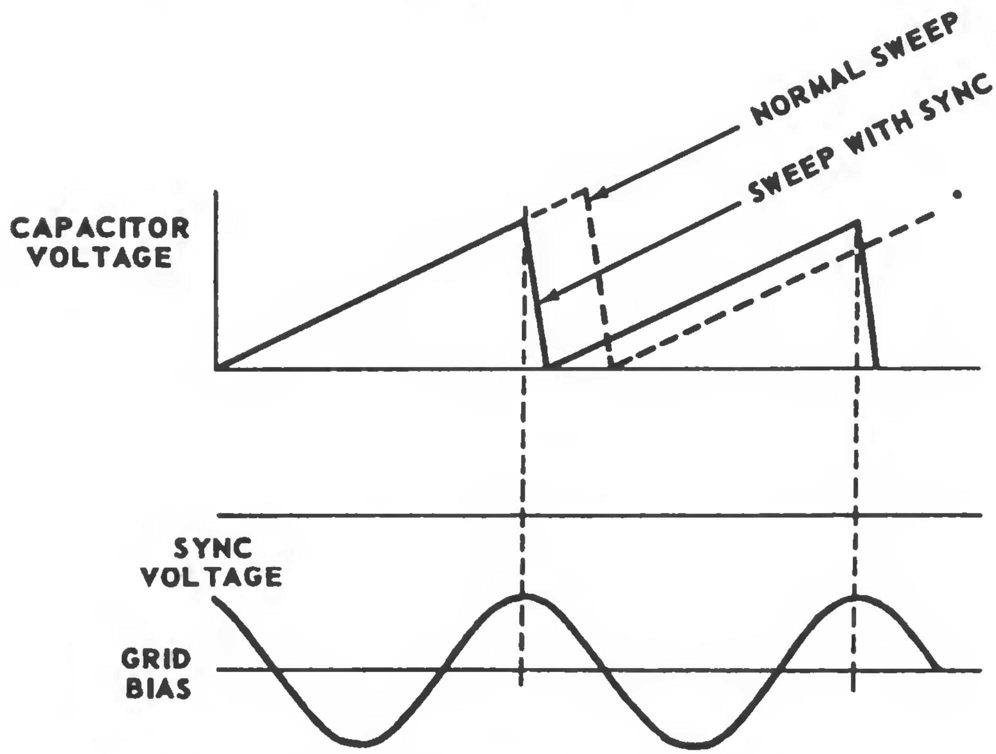


Figure 6–30.—Synchronization of a sweep voltage.

return the spot almost instantly to its original starting position from which the cycle is repeated continuously. This action is called the SWEEP VOLTAGE, or SWEEP SIGNAL, and the rate at which the cycles are repeated is called the SWEEP FREQUENCY. That portion of the wave during which the spot is carried along the horizontal axis is located between points A and B (fig. 6–30) thus representing the sweep time. That portion of the wave between points B and C represents the return time, or flyback time—that is, the period during which the voltage decreases from maximum to minimum and during which the spot is returned to its original starting position.

Y-AXIS AMPLIFIER.—The *Y*-axis amplifier (fig. 6–31) increases the amplitude of the test signal from the external circuit before it is applied to the vertical deflection plates. It is a video amplifier with good frequency response ranging from a few cycles to more than 2 megacycles.

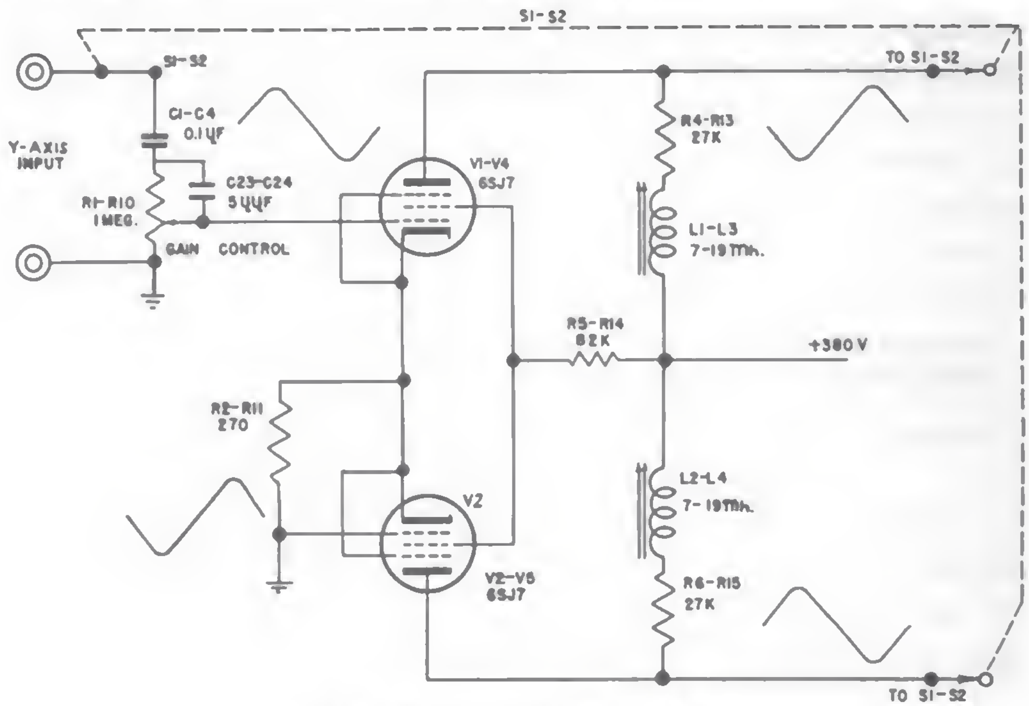


Figure 6–31.—Y-axis amplifier.

The incoming signal that is to be examined is applied to the *Y*-axis terminals marked INPUT and GND. These terminals are connected through capacitor *C*1 so that only the a-c component of the signal appears across GAIN control potentiometer *R*1. Capacitor *C*23 compensates for high-frequency phase shift when the contact arm of *R*1 is at a position near the grounded end of the resistor. This compensation improves the frequency response of GAIN control *R*1 so that the signal applied to the grid of *V*1 has the same waveform as that applied to the input terminals.

The signal variations appearing on the grid of tube *V*1 cause variations in the plate-current flow. The signal-voltage variations appear in opposite phase and are greatly amplified across the plate load of tube *V*1, consisting of resistor *R*4 and inductor *L*1 in series. Inductor *L*1 improves the frequency response of the circuit. The value of this inductance is such that its reactance at higher frequencies causes an effective increase in the plate load. This increase compensates for the shunt loading effect of normal circuit capacities that would otherwise cause a loss of gain at the higher frequencies.

Tube *V*2 acts as a phase inverter, making it possible to apply the output signals to the vertical deflecting plates so that their effect on the electron beam is additive.

A signal applied to the grid of *V*1 also appears across cathode resistor *R*2 because of the variations in plate current through *V*1. When the grid voltage of *V*1 swings in a positive direction, the voltage applied to the grid of *V*2 swings in a negative direction because the two grids are connected in opposite phase with respect to the applied signal. The signal on the grid of *V*1 undergoes a 180° phase inversion when it appears at the plate of *V*1. Likewise, the signal applied to the grid of *V*2 undergoes a 180° phase inversion when it appears at the plate of *V*2. Because the two inputs are 180° out of phase, the two outputs are also 180° out of phase. The plate of *V*1 is coupled to one of the vertical deflecting plates and the plate of *V*2 to the other. Thus as the signal swings the plate voltage of *V*1 positive, the plate voltage of *V*2 swings negative and the electron beam is attracted by one deflecting plate at the same time it is repelled by the other. This action is known as PUSH-PULL DEFLECTION. The amplifier is called a CATHODE-COUPLED PARAPHASE AMPLIFIER.

X-AXIS AMPLIFIER.—The *X*-axis amplifier increases the amplitude of the signal applied to the horizontal deflection plates. The horizontal amplifier must handle a wide range of frequencies to keep the sweep linear.

The *X*-amplifier circuit and the *Y*-amplifier circuit previously described are identical. A switch in the input circuit makes provision for input from the *X*-axis terminal or for connection to the output of the sweep generator.

Power supply circuit.—The power supply circuit (fig. 6–32) consists of a low-voltage section and a high-voltage section. Power transformer *T*1 is provided with a double primary winding that can be connected either as a series or as a parallel winding by means of selector switch *S*5 so that the equipment can be operated either from a 115-volt or a

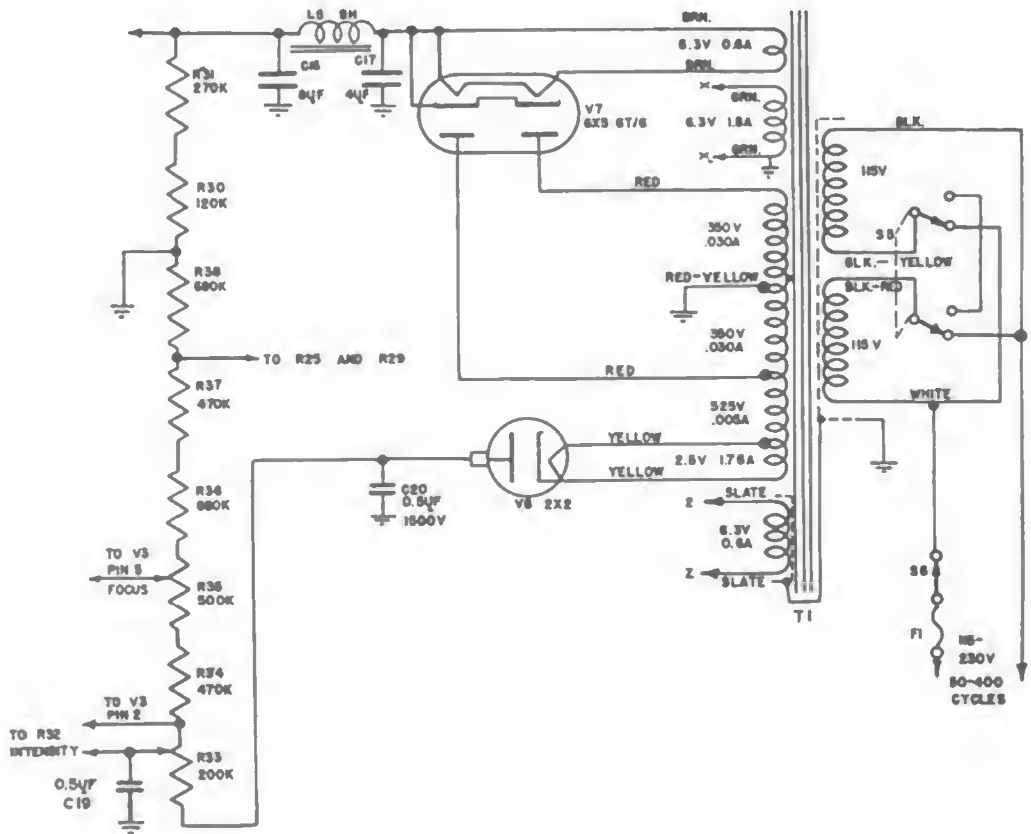


Figure 6–32.—Power supply circuit.

230-volt single-phase power supply. In addition to the filament secondaries for the rectifier tubes, two filament secondaries marked *X*-*X*′ and *Z*-*Z* are provided.

The *X*-*X*′ connection supplies the heaters of the amplifier and sweep generator tubes. One side of this winding is grounded. A lead connecting the other side of this winding through a limiting resistor to a TEST SIG jack on the front panel provides a convenient connection to a source of power-line frequency.

The *Z*-*Z* winding is connected to the heater of cathode-ray tube *V*3. Power to transformer *T*1 is controlled by power switch *S*6 through fuse *F*1.

The low-voltage section provides the power for operating the amplifiers and the sweep generator. Tube *V*7 is a full-wave rectifier the output of which is filtered by the capacitor-input network consisting of capacitor *C*17, inductor *L*5, and capacitor *C*16.

The high-voltage section provides the voltages necessary for operating the cathode-ray tube. The high-voltage supply is negative with respect to ground because it facilitates the application of voltages to the deflection plates, which are nearly at ground potential. Tube *V*8 is a half-wave high-voltage rectifier, the output of which is filtered by capacitor *C*20, resistor *R*33, and capacitor *C*19. This output is then fed to the cathode-ray bleeder network from which the various potentials are obtained for cathode-ray tube *V*3.

Controls

The efficient operation of the OBL–1 oscillograph depends upon the correct selection of input terminals and switch positions, and the proper adjustment of the various controls (fig. 6–25).

BEAM CONTROLS.—POWER SWITCH *S*6, which energizes the oscillograph, is operated by the INTENSITY control knob. The power is OFF when this knob is in the extreme counterclockwise position.

The INTENSITY control, *R*33, adjusts the intensity, or brilliance, of the pattern on the screen of the cathode-ray tube. When the equipment is energized, this control is set at the midposition until the trace appears, and then is adjusted until the trace has the desired intensity.

The FOCUS control, *R*35, adjusts the clarity and sharpness of the pattern appearing on the screen. Because the FOCUS and INTENSITY controls are independent of each other, there is an optimum setting of the FOCUS control for each position of the INTENSITY control.

The Y-AXIS position, $R25$, adjusts the spot or trace along the Y-axis of the cathode-ray tube screen. When the control knob is turned clockwise, the spot is moved upward and when the control knob is turned counterclockwise, the spot is moved downward.

The X-AXIS position, $R28$, adjusts the spot or trace along the X-AXIS of the cathode-ray tube screen. When the control knob is turned clockwise, the spot is moved to the right and when this knob is turned counterlclockwise, the spot is moved to the left.

TIME-BASE CONTROLS.—The COARSE FREQUENCY rotary selector switch, $S4$, provides a means of selecting the approximate frequency range for the time-base generator. This switch has seven contact positions marked on the front panel. The sweep circuit is inoperative when this switch is in the extreme counterclockwise position marked OFF. When the control pointer is turned to any of the other six positions, the time-base output is applied to the horizontal amplifier when the X-axis INPUT SWITCH knob points to TIME-BASE. The sweep-frequency range is determined by the pointer position of the COARSE FREQUENCY switch.

The FINE FREQUENCY control, $R24$, provides a means of adjusting precisely the frequency after the range has been selected by the COARSE FREQUENCY switch. As the control knob is turned clockwise, the frequency becomes higher.

The SYNC SELECTOR, $S3$, is a single-pole, double-throw toggle switch which selects the source of the synchronizing signal applied to the time-base generator. When this switch is in the EXT position, the synchronizing signal is applied to the EXT SYNC terminal. When this switch is in the INT position, a portion of the signal from the plate circuit of the vertical amplifier is used to synchronize the time-base generator.

The SYNC AMPLITUDE, $R17$, adjusts the value of the synchronizing signal applied to the time-base generator. As the control knob is turned clockwise, the signal amplitude is increased. This increase in signal amplitude increases the synchronizing voltage, resulting in a proportional increase in the degree of control over the time-base generator. When in the position marked "0," the time-base generator is in a free-running condition.

AMPLIFIER GAIN CONTROLS.—The *Y*-axis GAIN control, *R*1, provides a means of adjusting the proportion of input signal that is applied to the grid of the vertical amplifier tube. Turning the gain clockwise applies greater signal amplitude, thereby increasing the amplifier output, and resulting in a greater vertical beam deflection.

The *X*-axis GAIN control, *R*10, provides a means of adjusting the proportion of input signal that is applied to the grid of the horizontal amplifier tube. Turning the gain clockwise applies greater signal amplitude, thereby increasing the amplifier output, and resulting in a greater horizontal beam deflection. This gain control is also used to regulate the time-base signal amplitude when the time-base circuit is in operation.

INPUT SWITCHES.—The *Y*-axis INPUT SWITCH selects the type of input (direct or amplified) to be applied to the vertical deflection plates of the cathode-ray tube. When the switch is in the position marked DIR, the vertical amplifier is disconnected from the circuit and the *Y*-axis input signal is fed directly to the vertical deflection plates. When the switch is in the position marked AMP, the *Y*-axis input signal is fed to the grid of the vertical amplifier and the output of the amplifier is then fed to the vertical deflection plates.

The *X*-axis INPUT SWITCH selects the type of input (direct or amplified) to be applied to the horizontal deflection plates of the cathode-ray tube. When the switch is in the position marked DIR, the horizontal amplifier is disconnected from the circuit and the *X*-axis input signal is fed directly to the horizontal deflection plates. When the switch is in the position marked AMP, the *X*-axis input signal is fed to the grid of the horizontal amplifier and the output of the amplifier is fed to the horizontal deflection plates. This switch has an additional position marked TIME-BASE which is used when it is desired to connect the time-base generator output to the X-axis amplifier.

INPUT TERMINALS.—The Y-axis INPUT terminal provides a means of connecting an external signal to the Y-axis INPUT SWITCH from which the signal is applied either directly or through the vertical amplifier to the vertical deflection plates.

The X-axis INPUT terminal provides a means of connecting an external signal to the X-axis INPUT SWITCH from which the signal is applied either directly or through the horizontal amplifier to the horizontal deflection plates.

The TEST SIG terminal provides a means of connecting a sinusoidal test signal of power-line frequency (from transformer secondary winding marked X-X') and applying it along either the Y-axis or the X-axis.

The EXT SYNC terminal provides a means of connecting an external synchronizing signal to the SYNC SELECTOR switch from which this external signal can be applied to the time-base generator.

The Z-axis INPUT terminal provides a means of connecting a modulating signal to the control grid of the cathode-ray tube. The modulating voltage varies the intensity of the beam.

The GND terminals provide convenient grounding points for establishing common grounds between the oscillograph and the equipment that is being tested.

Detailed instructions concerning the installation, operation, and maintenance of the oscillograph are contained in manufacturers' instruction books. Before operating this equipment, refer to the appropriate manufacturer's instruction book furnished with the equipment in use aboard your ship.

QUIZ

1. What electrical measurements can be made with the multimeter, or volt-ohm-milliammeter, when testing electronic circuits and components?
2. What six basic parts comprise the multimeter?
3. What is the basic meter circuit?
4. How is the basic meter circuit connected?
5. When taking direct voltage measurements, how are voltages up to 1,000 volts applied to the multimeter?
6. When taking direct voltage measurements, how are voltages above 1,000 volts applied to the multimeter?
7. When taking alternating voltage measurements, how are voltages up to 250 volts applied to the multimeter?
8. When taking alternating voltage measurements, how are voltages above 250 volts applied to the multimeter?
9. Define the prefix "dynamic" as used in the expression "dynamic mutual conductance," or "dynamic transconductance."
10. Why is the dynamic mutual conductance test preferred to an emission test?
11. What eleven electrical circuits comprise the tube tester?
12. What is the purpose of the line-voltage test?
13. What test is used to indicate the condition of a diode?
14. What is the purpose of the transconductance test?
15. What is the principle of operation of the tube gas test?
16. What indication is reproduced by the loudspeaker or headphones when conducting a noise test on a tube?
17. Name three ways of using an audio oscillator in electronic testing.
18. Name four measurements that may be made with a cathode-ray oscillograph.
19. Name five principal parts of a cathode-ray oscillograph.
20. What elements comprise the electron gun of the cathode-ray tube?
21. What are the polarities of anodes 1 and 2 of the electron gun with respect to the control grid?
22. What are the functions of anodes 1 and 2 of the electron gun?

23. What is the appearance of the electron beam on the screen of a cathode-ray tube if no deflection potentials are applied?

24. What is the appearance of the electron beam (spot) on the screen of a cathode-ray tube when an alternating voltage is applied only to the horizontal deflecting plates?

25. What is the appearance of the electron beam (spot) on the screen of a cathode-ray tube when an alternating voltage is applied only to the vertical deflecting plates?

26. Name two factors that affect the magnitude of the beam deflection.

27. How is the intensity (brightness) of the spot on the screen of a cathode-ray tube controlled?

28. What is the function of the time-base generator of an oscillograph?

29. What is the purpose of the Y-axis amplifier?

30. What is the purpose of the X-axis amplifier?

CHAPTER 7

ALARM AND WARNING SYSTEMS

Alarm and warning systems are provided in naval vessels to indicate abnormal or dangerous conditions in time to prevent casualties to machinery and personnel. The lubricating-oil low-pressure alarm system, for example, must provide an audible signal to indicate improper operation of the lube-oil system for a particular engine before dangerous conditions occur.

The principal components of shipboard alarm and warning systems are: (1) switches, (2) relays, (3) push switches, (4) thermostats, (5) audible signals, and (6) visual signals or indicators.

SWITCHES

The various alarm and warning systems used aboard ship are usually the simplest type of I. C. circuit. The majority of these systems consist of one or more switches that complete an electric circuit to various types of audible and visible alarm equipment. There are many kinds of switches in use and the type depends upon the circuit in which it is installed.

Manual Switch

The most commonly used type of manually operated switch is an enclosed, watertight, base-mounted, lever-operated switch (fig. 7–1). The interior is usually a JR-type switch that is operated by a lever. Two interiors, each containing three 2JR sections, are available. The JRM–300 interior has a spring return mechanism and the JR–304 interior has a positive detent mechanism. Five types of switches can be obtained by using slightly different arrangements of pins,

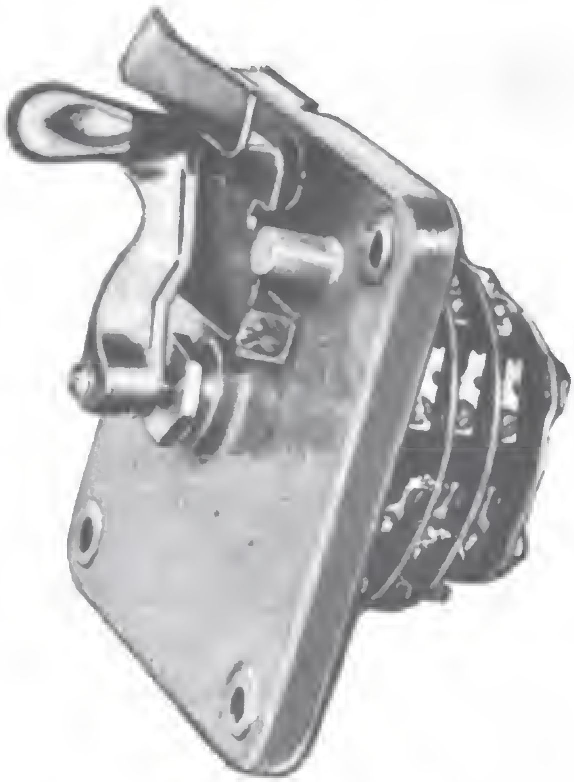


Figure 7–1.—Manual switch.

lever, and locking plate. Three of these types have two positions as follows:

1. M–21S—momentary action, spring return to left position.
2. M–22S—same as M–21S except furnished with a locking plate to lock the lever in either position.
3. M–23S—positive action in both positions, no spring return.

Two of these types have three positions as follows:

1. M–24S—single section, momentary action, spring return to center position.
2. M–25S—three sections, positive action in all positions, no spring return.

Each section of these switches is provided with eight uniformly spaced stationary contacts and two diametrically opposite movable contacts. The movable contacts close the circuit between two adjacent stationary contacts in each position of the rotor. The stationary contacts are silver-plated brass and the movable contacts are silver-plated copper.

Manually operated switches are used as the actuating devices for:

1. Boiler-feed signal system.
2. Diving alarm systems.
3. Elevator-warning and control-signal systems.
4. Fireroom-emergency signal system.
5. Flight-crash signal system.
6. Flight-deck landing observer's signal system.
7. Flight-deck warning signal system.
8. General and chemical-attack alarm system.
9. Sonar alarm system.
10. Collision-alarm signal system.
11. Rocket-warning signal system.
12. Steering emergency signal system.
13. Tank-stowage alarm system.
14. Barrier ready-light systems.
15. Traffic-control ready-light system.
16. Turret emergency alarm system.
17. Whistle-operating system.
18. Life-buoy-release system.

Pressure Switch

Pressure-operated switches are normally single-pole, single-throw, quick-acting switches. These switches contain either a bellows or a diaphragm that works against an adjustable spring (fig. 7–2). The spring causes the contacts to close automatically when the operating pressure falls below a specified value. The pressure at which the switches operate is adjustable within the ranges of 0-15, 15-25, 25-50, and

50-180 pounds per square inch. These switches can be used also to indicate an increase in pressure above a predetermined point.

Pressure-operated switches are used with the lubricating-oil low-pressure alarm system, air-pressure alarm system, and booster-feed pressure alarm system.

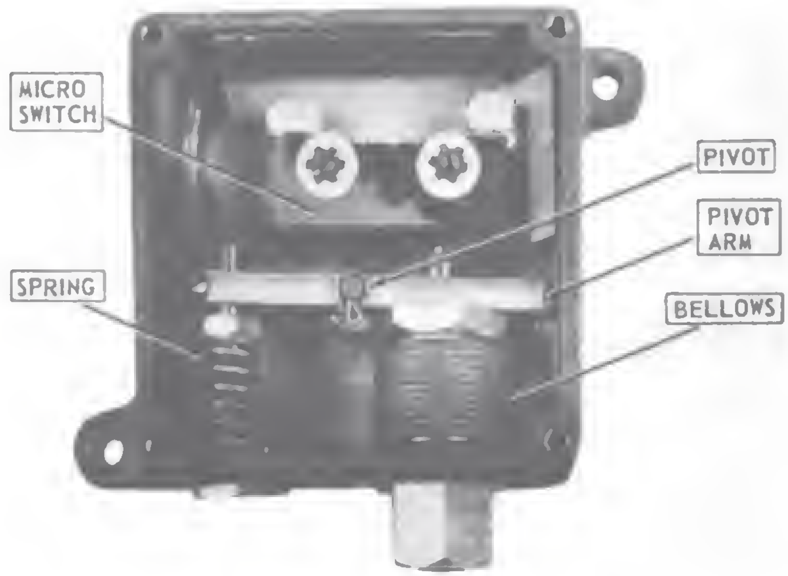


Figure 7–2.—Pressure switch.

Thermostatic Switch

Thermostatic, or temperature-operated, switches are usually single-pole, single-throw, quick-acting, normally open switches. These switches contain a bellows that works against an adjustable spring (fig. 7–3). The spring causes the contacts to close automatically when the operating temperature exceeds a specified value. The bellows motion is produced by a sealed-in liquid that expands with rising temperature. The sensitive element containing this liquid may be built into the switch or located in a remote space and connected to the switch by means of a capillary tube. The temperature range at which the switches operate is adjustable between 100° F. and 225° F.

Temperature-operated switches are used with the circulating-water high-temperature alarm system, cruising-turbine exhaust alarm system, and generator-air high-temperature alarm system.

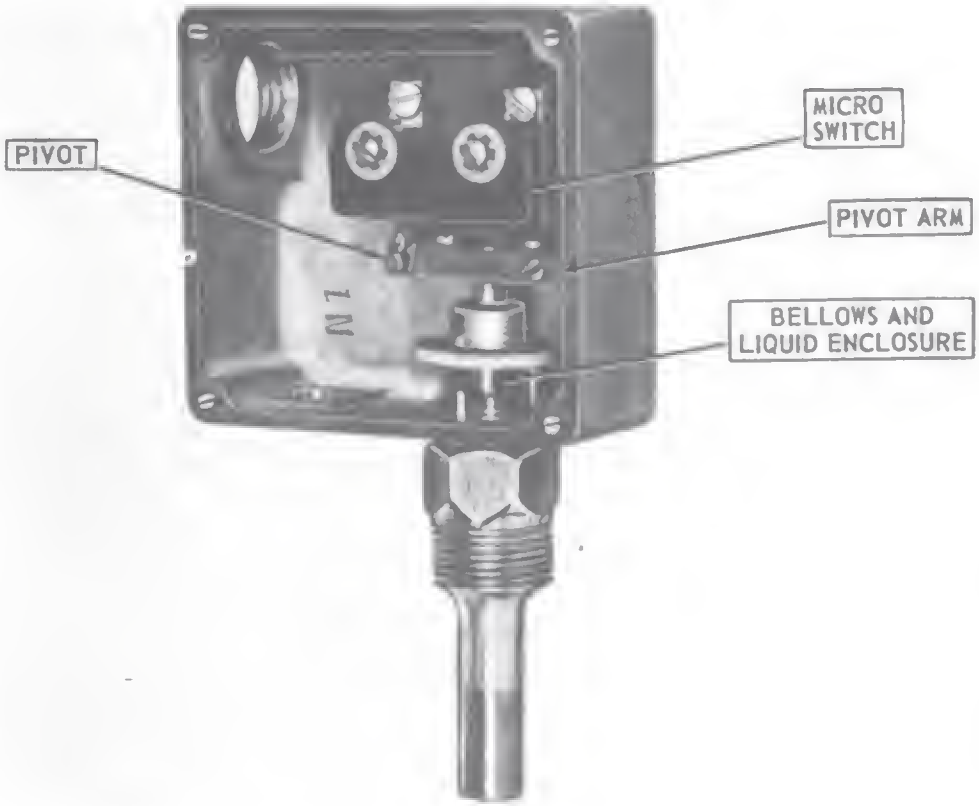


Figure 7–3.—Thermostatic switch.

Mechanical Switch

Mechanically operated switches are of the push-action type (type A–S) and the cam-action type (types P and P1). The push-operated switch is provided for bulkhead mounting. It is a single-throw or multiple-throw, momentary-action, normally open push switch. The push-action mechanism utilizes a straight-line movement of the shaft to operate the electrical contacts.

The cam-action switch consists of two single-pole, double-throw, micro switches operated by means of two adjustable cams mounted on the rotor shaft (fig. 7–4). The cam-action mechanism utilizes a rotary motion of the shaft to move cams, which in turn operate sensitive switches. The points of operation of the sensitive switches are varied by adjusting the angular positions of the cams with respect to the shaft on which they are mounted.

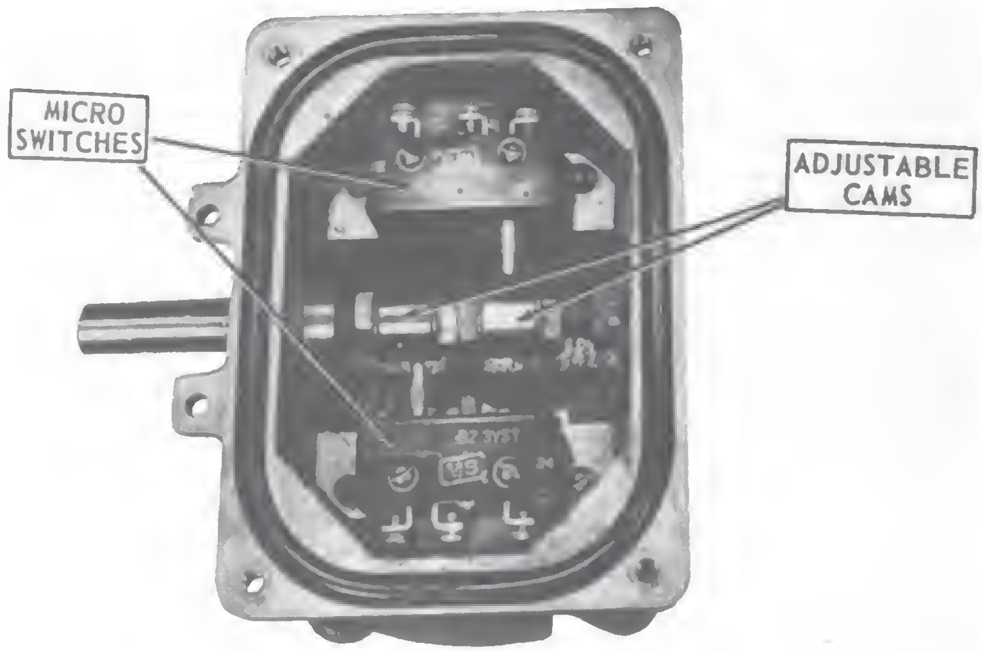


Figure 7—4.—Mechanical switch.

Mechanical switches are used with the:

1. Air-lock indicator system.
2. Carbon-dioxide release alarm system.
3. Clutch wrong-position indicator system.
4. Shaft-position alarm system.
5. Submersible-steering-gear alarm system.
6. Wrong-direction alarm system.
7. Barrier-up indicator system.
8. Clutch-and-brake indicator system, hull-opening indicator system, and valve-position indicator system.

Conductivity Switch

Conductivity switches consist of a pair of platinum-sheathed electrodes molded into an insulating base and protected against mechanical damage by a perforated nickel-copper shield. A 5 k-ohm resistor is in parallel with the electrodes to provide supervisory current. The conductivity switch is mounted so as to extend into pipe lines of the magazine flooding system. When water flows through the pipe, a circuit is completed by the water between the two electrodes and sounds an alarm.

Conductivity switches are used principally on the magazine-flooding alarm system.

RELAYS

A relay is an electromechanical device by means of which a current change in one circuit causes contacts to produce a change in the electrical conditions in its own or other circuits.

The most common type of relay consists of a coil wound on a soft-iron core, an armature, L-shaped heelpiece, and contact assembly. A washer of insulating material is fastened near each end of the iron core to hold the turns of wire on the core. The heelpiece is secured to one end of the core and extends along the side of the coil to the armature pivot assembly.

When current flows through the coil a magnetic field is set up around the coil. The magnetic circuit consists of the core, the heelpiece, and the armature. The magnetic field attracts the armature toward the core against the spring pressure of the contact assembly. The contact assembly may consist of an armature lever that operates contact springs, a lever arm that operates a sensitive switch, or other similar mechanical arrangement. For all practical purposes, the relay is a magnetic switch designed to operate when the current through the coil, or when the voltage across the coil, increases or decreases to a specified value.

Relays are used in alarm and warning systems to open and close circuits that may operate indicating lights, annunciator drops, or audible signals.

Motor Relay

Motor-operated relays consist of a motor, cams, contacts, and a relay mounted on a panel and enclosed in a splash-proof case (fig. 7–5).

When a manually operated general alarm switch at a remote station is closed for a period of 2 seconds, the motor-operated relay is energized and closes and opens the contacts

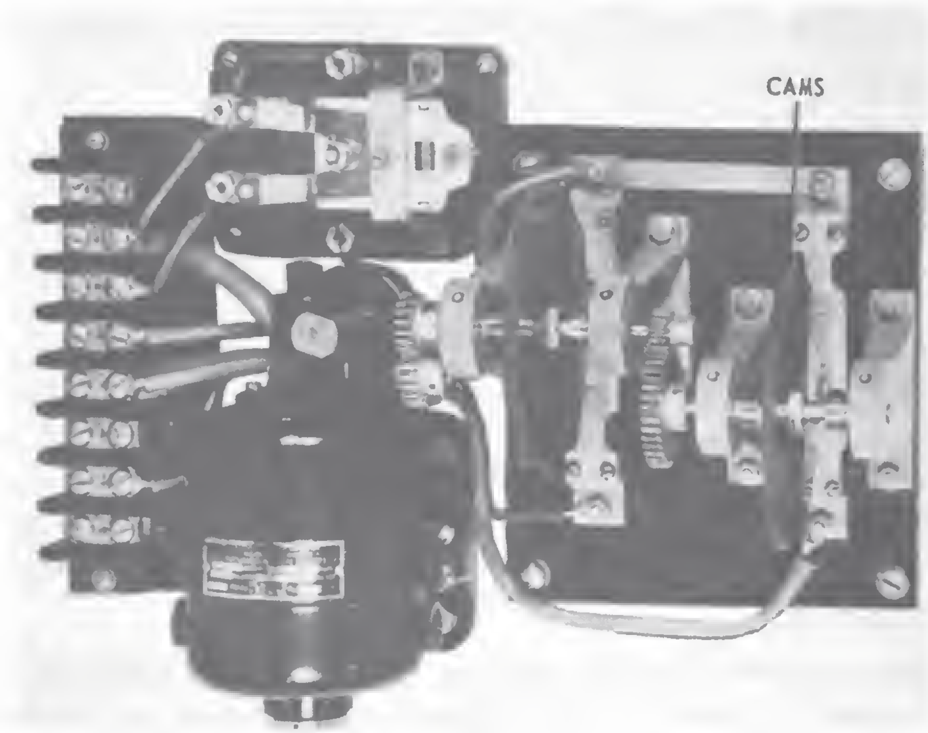


Figure 7–5.—Motor relay.

of a primary circuit at a prearranged rate. This prearranged rate of closing and opening the contacts is 90 times per minute (one-third second closed and one-third second opened) for a period of 15 seconds.

When a manually operated chemical-attack alarm switch at a remote station is closed, the motor-operated relay holds the contacts of the primary circuit closed until the manually operated switch is released.

Motor-operated relays are used in the general and chemical-attack alarm systems where these systems are not incorporated as a part of the battle-announcing system.

PUSH SWITCHES

Push switches are of the nonwatertight, watertight, and pressure-proof types.

The nonwatertight type is a single-pole, single-throw, momentary-action, normally open push switch. It is supported in a molded phenolic enclosure provided for surface mounting.

The watertight type is a single-pole, single-throw, momentary-action, normally open push switch. It is provided with a single switch or in two, three, four, or five groups. This push switch is housed in a sheet-steel enclosure provided for surface mounting.

The pressure-proof type of push switch is installed on the bridge of submarines. It is a single-pole, single-throw, momentary-action, normally open push switch. It has a metal diaphragm on which is mounted a device that actuates a sensitive switch. It is necessary to distort the diaphragm to operate the sensitive switch. Steady pressure against the diaphragm up to rated pressure of 550 pounds per square inch causes a uniform inward motion of the diaphragm without distortion and the switch does not operate. Pressing the button distorts the diaphragm slightly, and operates the sensitive switch. The push switch is housed in a bronze enclosure provided for surface mounting.

Push switches are used in the (1) officer's call-bell system, (2) voice-tube and sound-powered telephone call-bell system, and (3) train-warning signal system.

THERMOSTATS

The mercurial thermostat is the principal type of thermostat used aboard naval vessels. The thermostat element is a glass mercurial thermometer (fig. 7–6). The mercury expands through a capillary tube as the temperature increases. Connections are brought into the mercury column at three points that correspond to a low value of −16° F

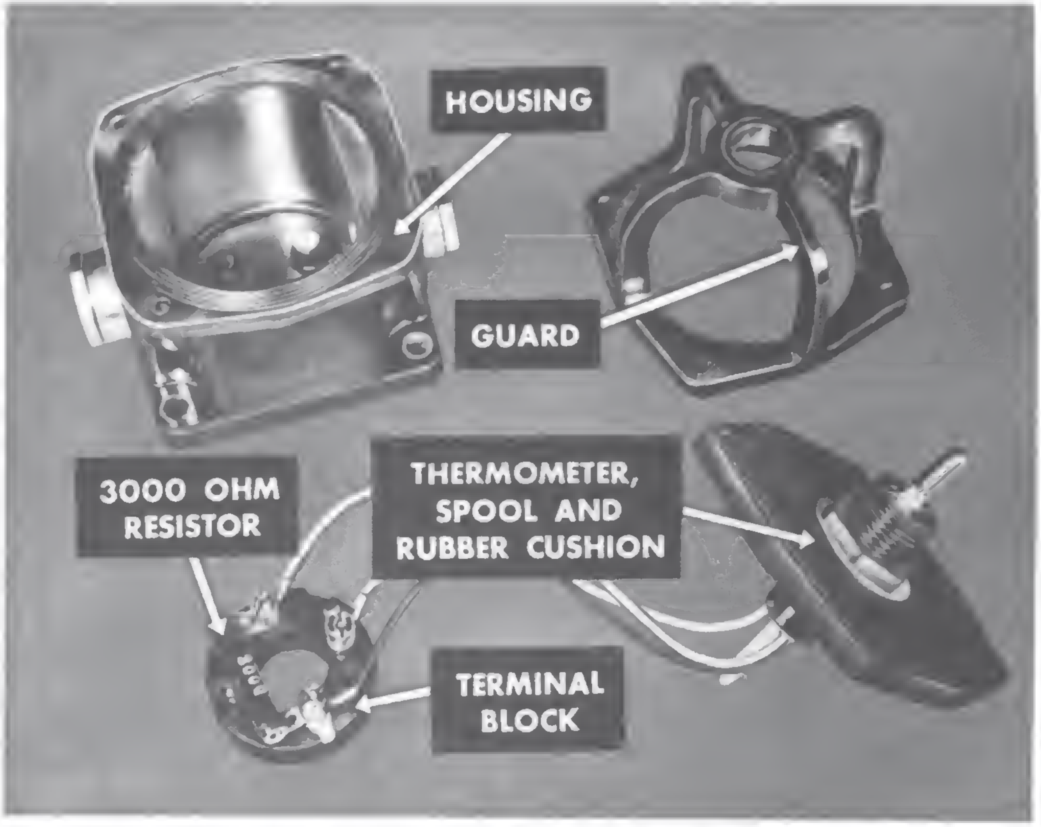


Figure 7–6.—Mercurial thermostat.

(lower contact); an intermediate value of 32° F (intermediate contact); and a high value of 105° F, 125° F, or 150° F (upper contact). The supervisory resistor is connected across the upper and intermediate contacts. The value of the intermediate contact is 20° F in the latest design of thermostats. The mercurial thermostat is housed in a molded phenolic enclosure provided for bulkhead mounting. The thermostat element contains hydrogen gas at a pressure of at least 5 atmospheres to minimize separation of the mercury column under shock. The element is attached to its case with special shock-proof and vibration-proof mountings.

Mercurial thermostats are installed in the high-temperature alarm system aboard ship.

AUDIBLE SIGNALS

There are many types of audible signals in use aboard modern naval vessels. The type of signal used depends upon the noise level of the location and the kind of sound desired. Most audible signals are such that a loud and penetrating noise is necessary, but in some cases softer, less strident signals are acceptable.

The principal types of audible signals are (1) bells, (2) buzzers, (3) horns, and (4) sirens.

Bells

Bells of the vibrating clapper type (fig. 7–7) have three different types of gongs—2½-inch diameter (types B1 and B2), 8-inch diameter (types B3 and B4), and cow-bell tone

Figure 7–7.—Type-B3 bell.

(types B5 and B6). Single-stroke bar-chime bells (types B7 and B8) are actuated by a solenoid and contain a resonated bar and an air chamber.

Buzzers

Buzzers are all of the low-intensity type (fig. 7–8) and are used only in quiet spaces. Type-Z1 buggers for operation on direct current are provided with make-and-break contacts whereas type-Z2 buzzers for operation on alternating current do not have contacts.

Horns

Nonresonated horns (types H1 and H2) utilize diaphragms actuated by vibrating armatures to produce sound of the required intensity.

Figure 7–8.—Type-Z1 buzzer.

Figure 7–9.—Type-H8 horn.

Resonated horns (types H3, H3H, H3I, H4, H4H, H4I, H24H, and H24I) also use diaphragms to produce the sound and in addition have resonating transducers to give the sound a distinctive frequency characteristic. The resonated horn is designed in a variety of types, differing chiefly as to intensity, frequency characteristics, or power supply.

Motor-operated horns as shown in figure 7–9 (types H8, H9, and H24), utilize electric motors to actuate the sound-producing diaphragms.

Sirens

Sirens (types S1, S2, S3, and S4) are used in very noisy spaces or to sound very urgent alarms (fig. 7–10). The sound is produced by an electric motor driving a multiblade rotor past a series of ports, or holes, in the housing. The air being forced by the rotor through these ports gives a siren sound, the frequency of which depends upon the number of ports, the number of rotor blades, and the motor speed.

Figure 7–10.—Type-S4 siren.

VISUAL SIGNALS

Visual signals are used in a great many alarm and warning systems to provide an additional means of identifying the alarm being sounded. Audible and visual signals are often used together. In noisy spaces audible signals are supplemented by visual signals and in dark spaces visual signals are supplemented by audible signals. In many instruments the same audible device is used in combination with several visual indicators. The principal types of visual signals are lamp-type indicators and annunciators.

Lamp-Type Indicators

Standard watertight lamp-type indicators are designed as single-dial, 2-dial, 3-dial, 4-dial, and 6-dial units (fig. 7–11).

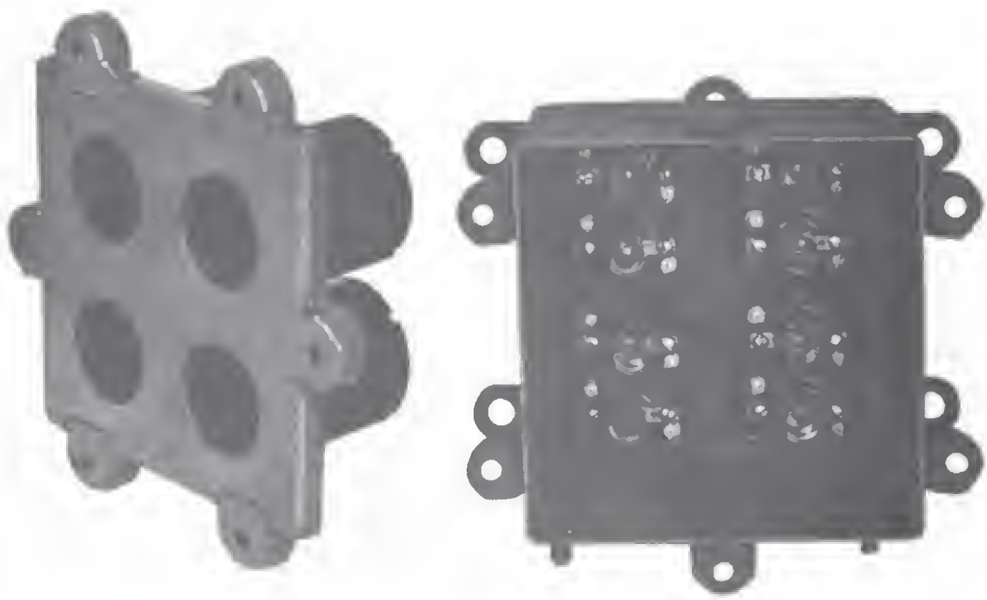


Figure 7–11.—Lamp-type indicator.

The indicator contains two 115-volt lamps connected in parallel and mounted behind each dial. The use of two lamps in parallel provides protection against the loss of illumination in case one lamp burns out. A colored-glass disk and sheet-brass target engraved with the alarm identification are illuminated from the rear by the two lamps. Glass disks are furnished in eight standard colors depending upon the application.

The 115-volt lamps are in parallel with the audible signal.

When the audible signal sounds, the lamps illuminate the colored glass and brass target of the indicator and identify the alarm being sounded.

This indicator is used in:

1. Lubricating-oil low-pressure alarm system (single engine installation).
2. Circulating-water high-temperature alarm system (single engine installation).
3. Fireroom-emergency signal system.
4. Boiler-feed signal system.
5. Hull-opening indicator system.
6. Main-ballast-tank indicator system.
7. Boiler-temperature alarm system.
8. Flight-deck landing observer's signal system.
9. Engine-control indicator system.
10. Airlock indicator system.
11. Traffic-control ready-light system.
12. Gasoline-compartment-exhaust-blower indicator system.
13. Catapult-control signal system.
14. Barrier ready-light system.
15. Barrier-up indicator system.
16. Air-pressure alarm system.
17. Booster-feed pressure alarm system.
18. Carbon-dioxide-release alarm system.
19. Cruising-turbine-exhaust alarm system.
20. Generator-air high-temperature alarm system.
21. Wrong-direction indicator system.
22. Battery-position order system.
23. Clutch-and-brake indicator system.
24. Valve-position indicator system.
25. Water-level indicator system.
26. Auxiliary low-diving plane tilt angle indicator system.
27. Auxiliary stern-diving plane-angle indicator system.
28. Auxiliary rudder-angle indicator system.

Standard watertight lamp-type indicators are designed also as 2-dial variable-brilliancy, 2-dial fixed-brilliancy, and

4-dial variable-brilliancy units. The indicator contains two 6-volt lamps in parallel mounted behind each dial. A colored-jewel disk and sheet-brass target are illuminated from the rear by the two lamps.

The 2-dial and 4-dial variable-brilliancy indicators are installed in the barrier-up indicator system. The 2-dial fixed-brilliancy indicator is used with the valve-position indicating system.

Special lamp-type indicator panels are designed to give good visibility at all viewing angles. These panels contain rows of prism-shaped red and green jewels. Each indicator has two 6-volt lamps in parallel. This type of indicator is used in the main-ballast-tank and hull-opening indicator system.

Another special lamp-type indicator consists of two indicator (red and green) lights. Six 115-volt lamps in parallel are provided for each indication. This indicator is used in the traffic-control ready-light system.

Annunciator-Type Indicators

Annunciators are of the drop type and the drum type. DROP-TYPE annunciators range in size from 4-drop to 100-drop. This type of annunciator is used with the officers' call-bell system and the voice-tube and sound-powered telephone call-bell system as described in the training course, *I. C. Electrician 3*, NavPers 10555.

The DRUM-TYPE annunciator consists of an electromagnet that operates a red drum target (fig. 7–12). A drum target, actuated by an electromagnet, is provided for each device being protected. The red drum target is held mechanically in a nonindicating position. When energized by the signal circuit, the electromagnet causes the drum to turn to the indicating position.

Each electromagnet actuates contacts for energizing the common audible signal alarm. When the eletromagnet is deenergized, it restores and removes the signal indications. A nameplate is provided on the panel to identify the alarm

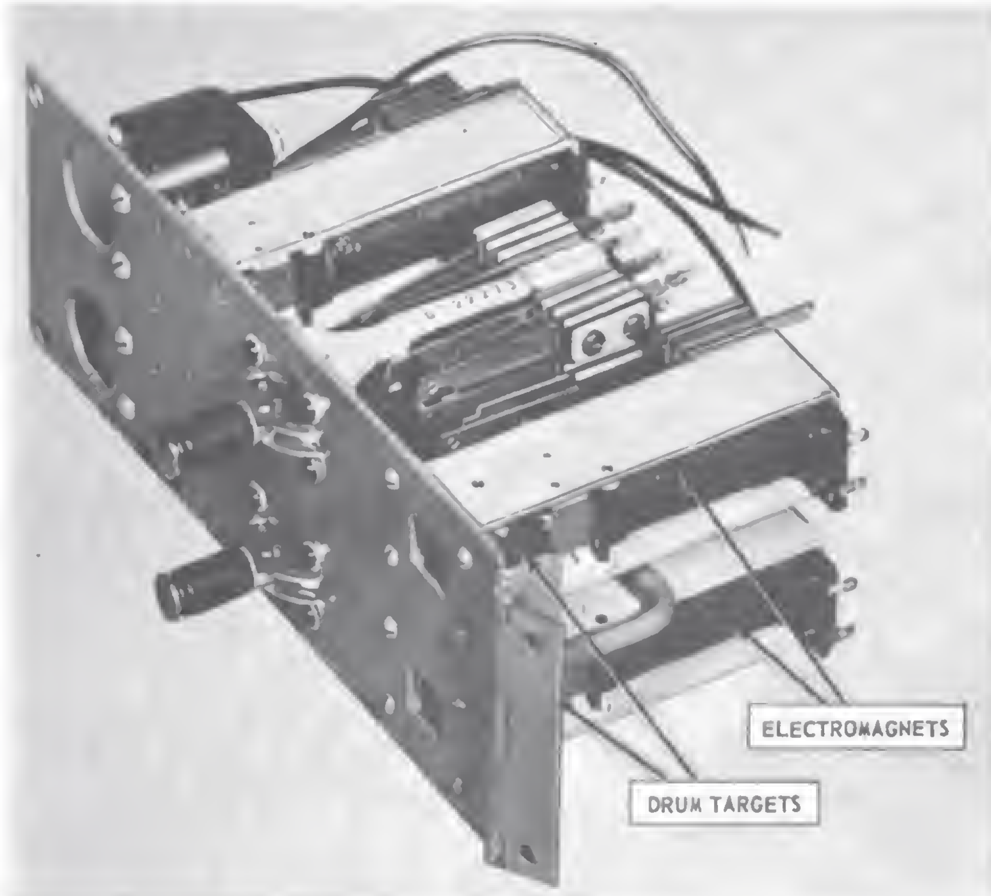


Figure 7–12.—Drum-type annunciator.

being sounded. A key-switch is provided to test the circuit and to cut off the alarm.

Drum-type annunciators are installed in the high-temperature and magazine sprinking alarm systems, and in the circulating-water high-temperature alarm and lubricating-oil low-pressure alarm systems.

HIGH-TEMPERATURE ALARM SYSTEM

The high-temperature alarm system, circuit F, is one of the alarm and warning systems you will be required to service. It is an electrical system installed aboard ship to detect and warn of fires or overheated conditions in important compartments and spaces.

All alarm systems used in naval vessels are of the closed-circuit supervisory type. Each circuit of the system consists

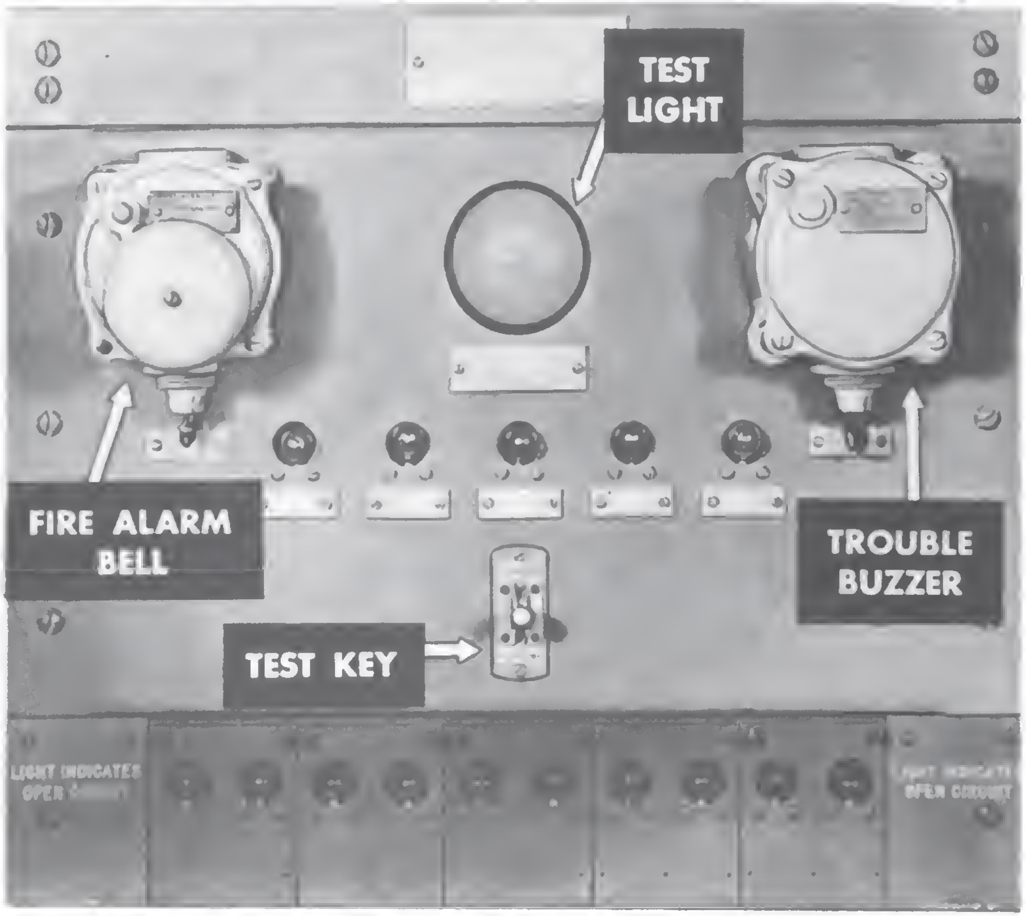


Figure 7–13.—Alarm panel of an alarm switchboard.

primarily of one trouble-alarm relay, one cutout key, one alarm signal, and one thermostat or group of thermostats.

Alarm Switchboard

The alarm switchboard is installed in a station which is continuously manned while both underway and in port. The alarm switchboard operates on 120-volt d-c service supplied from the main I. C. switchboard. The alarm switchboard consists of an upper section and a lower section.

The UPPER section comprises the alarm panel as shown in figure 7–13. This panel contains an alarm bell, a test light, a trouble buzzer, two ground-detector lamps, a pilot lamp, a trouble test lamp, a fire test lamp, and a test key. An alarm-bell relay, capable of operating up to four exten-

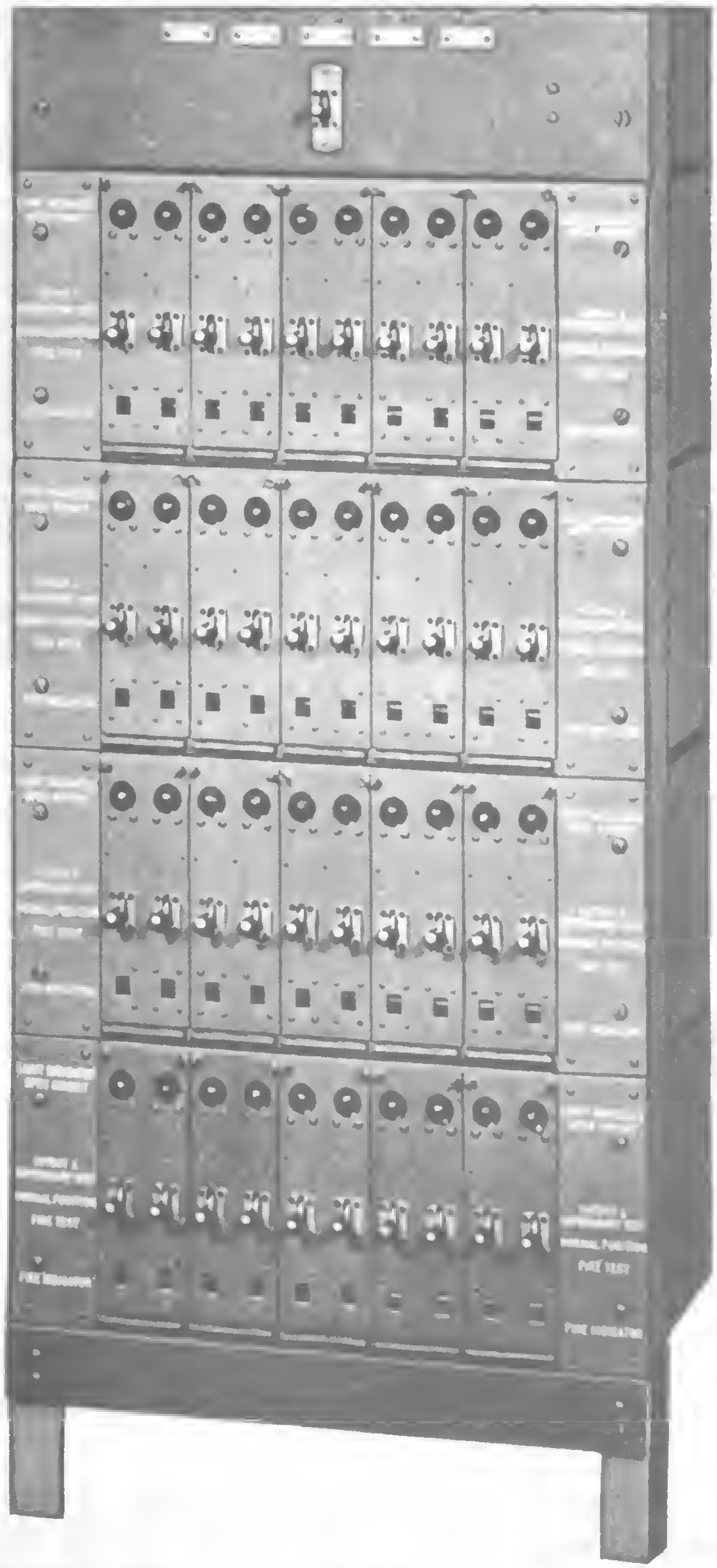


Figure 7–14.—Four 10-line panels of an alarm switchboard.

sion fire bells located in other parts of the ship, is mounted at the rear of the alarm panel. As long as the power supply to the switchboard is maintained, the pilot light at the center of the panel glows.

The LOWER section consists of as many 10-line or 20-line panels as are necessary to care for the total number of thermostatic high-temperature detector stations aboard the ship. Four 10-line panels capable of taking care of 40 lines are shown in figure 7–14. The switchboard apparatus for each two lines is mounted together on a hinged plate called an ALARM UNIT. Five or ten of these 2-line units are arranged to make up a 10-line or a 20-line panel. Each line individually supervises one thermostat or one group of thermostats. Each line is provided with a separate test key with a trouble light above, and a drum fire-indicator target below. A nameplate located above the test key identifies the compartment or the spaces served by that line.

Thermostats

As previously mentioned, the detection of fires or overheated conditions is accomplished by means of mercurial thermostats. These thermostats are installed at selected locations throughout the ship. Thermostats are installed on the overhead and require a free circulation of air for efficient operation. Barriers that would obstruct the free circulation of air should never be placed around thermostats in any compartment. On the other hand, thermostats should not be installed in the path of supply ventilation.

The thermostats are designed to close their contacts at temperatures of 105° F, 125° F, and 150° F. These types are similar except for their respective temperature ratings. When a thermostat is defective, care must be exercised to replace the thermostat with one having the same temperature rating.

The 125° F and 150° F thermostats are normally installed in storerooms, paint lockers, and similar spaces used to house combustible stores. The mercury thermostat shown in figure 7–15 is designed to operate at 150° F. The supervisory current path extends from the alarm switchboard to contact *C*, through the column of mercury to contact *B*, through the supervisory resistor to contact *A*, and back to the alarm switchboard. The resistor provides the necessary supervisory current for the trouble indicator. When the temperature of the air surrounding the mercury bulb reaches

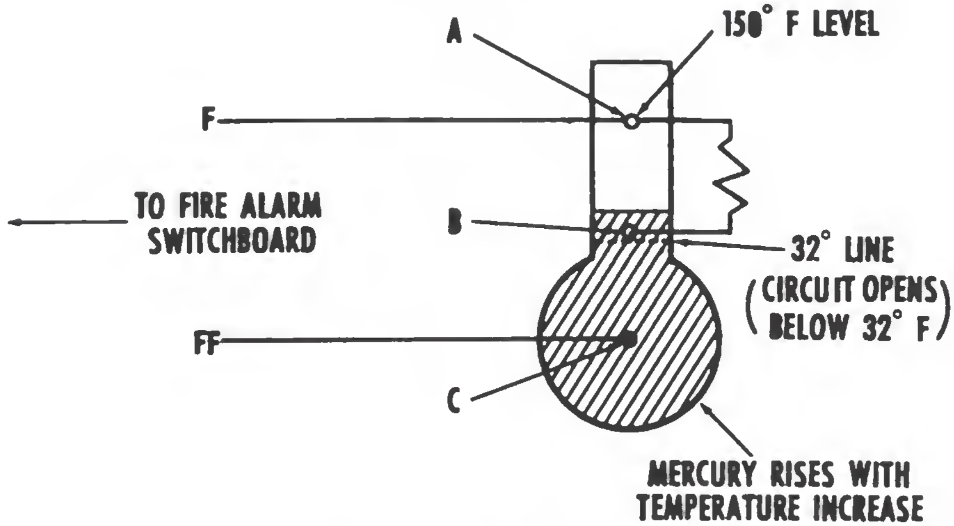


Figure 7–15.—Mercury thermostat.

150° F, the mercury is driven up to contact *A* and the resistor is shorted out. This action allows full current to operate the alarm.

The 105° F thermostat is normally installed in magazines. Because its function is to detect rises in temperature above the limits that are safe for magazine spaces, the upper contact is located so that the resistor is shorted out when the temperature reaches 105° F.

The 105° F, 125° F, and 150° F thermostats also indicate a freezing condition. Whenever the temperature of the air surrounding the thermostat drops below 32° F, the mercury falls below contact *B* (fig. 7–15) and opens the supervisory circuit. This action sounds the trouble alarm on the switchboard.

As many thermostats as are needed for the prompt detection of a fire can be connected to any one line. If more than one thermostat is used in a compartment, only one supervisory resistor is required, as shown in figure 7–16, A and B.

With such a connection, when any one of the thermostats in the group is overheated, the alarm operates. These thermostats or groups of thermostats are connected to the alarm switchboard by means of multiconductor cable. Each circuit on the alarm switchboard is marked to designate one

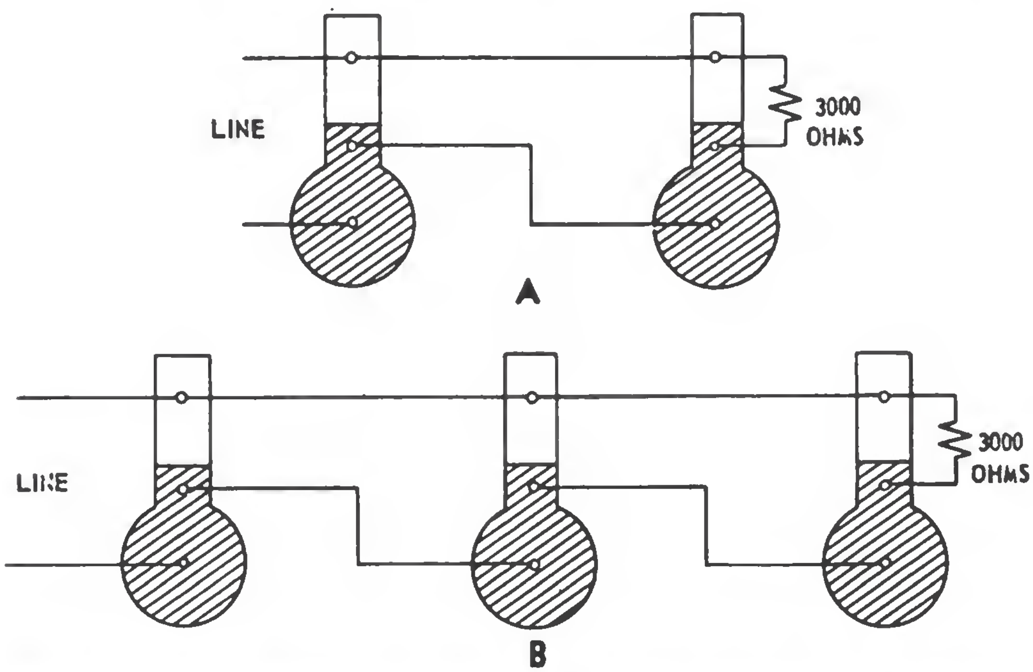
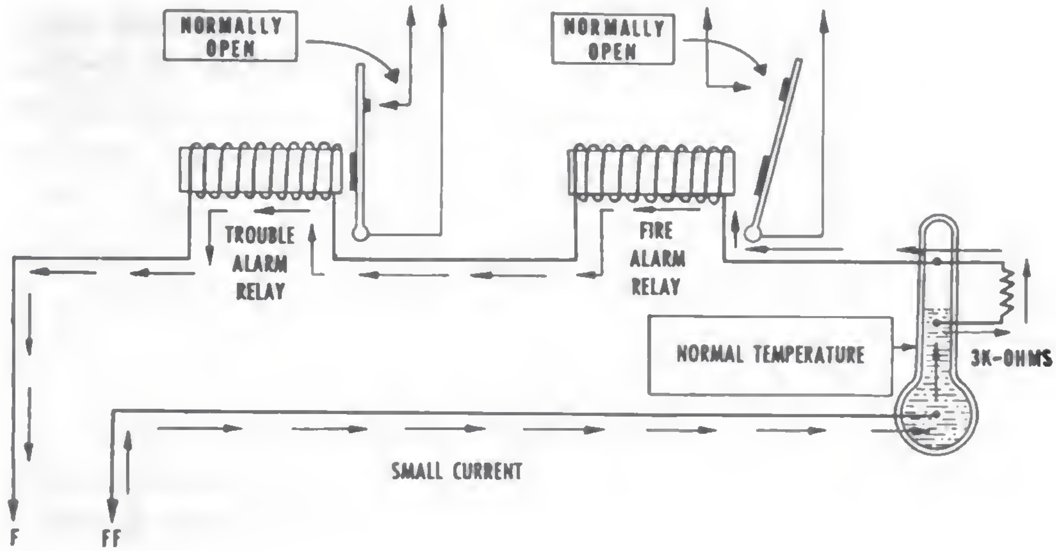


Figure 7–16.—Thermostat connections. A, Two thermostats per line; B, three or more thermostats per line.

compartment, and the thermostat, or group of thermostats, installed in each compartment is connected to the circuit marked for that compartment.

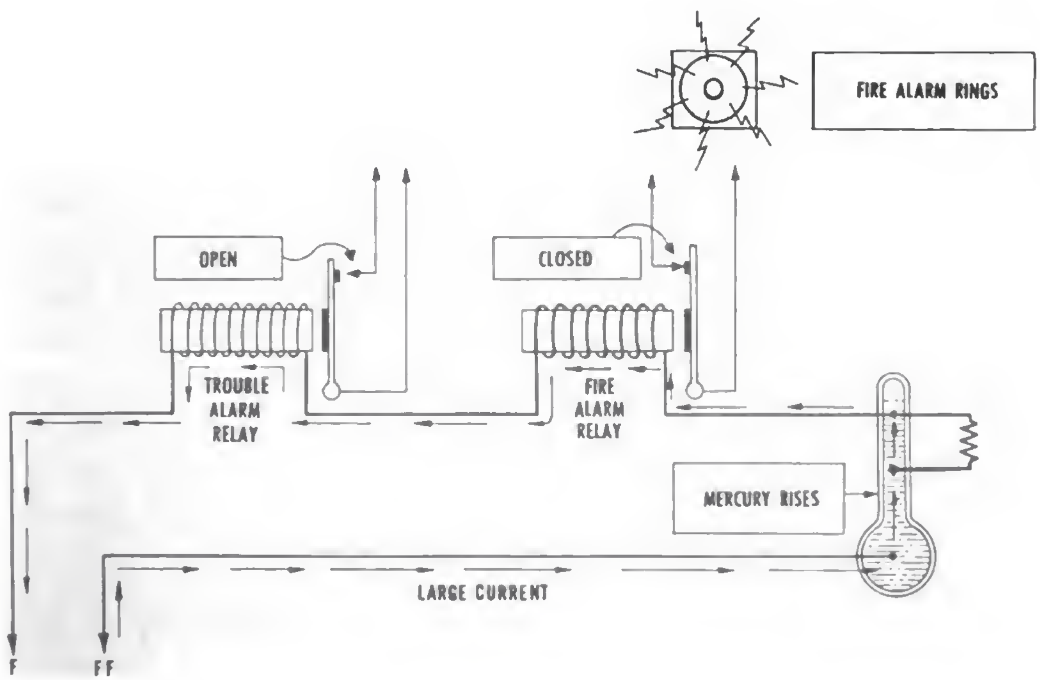
Operation

When conditions are normal, direct current at 120 volts flows from the negative power source, *FF* (fig. 7–17), to the lower contact of the thermostat, through the mercury column to the intermediate contact, through the 3 k-ohm resistor, the alarm relay, the trouble-alarm relay, and back to the positive source, *F*. The current is limited by the 3 k-ohm resistor to a value below that required to operate the alarm relay, but of sufficient magnitude to hold the armature of the trouble-alarm relay away from its back contacts.



120 V. D.C

Figure 7–17.—Operation of a high-temperature alarm—normal condition.



120 V. D.C

Figure 7–18.—Operation of a high-temperature alarm—high-temperature condition.

In case of a fire or other high-temperature condition (fig. 7–18), the mercury expands in the thermostat bulb and rises in the tube. When the mercury reaches the upper contact of the thermostat, the supervisory resistor is shorted out, and the current rises to a maximum value in the circuit. The increase in current energizes the alarm relay and closes its contacts. This completes the circuit to the alarm bell and causes a red fire-indicator target to appear on the alarm unit which serves that line.

When an open-circuit occurs, such as a break in the line or a broken thermostat bulb, or when the temperature of the air surrounding the thermostat drops below 32° F (fig. 7–19), the supervisory current no longer flows in the circuit and the trouble-alarm relay deenergizes. This action closes its back contacts and completes the circuit to the trouble buzzer and the trouble light on the alarm unit serving that line.

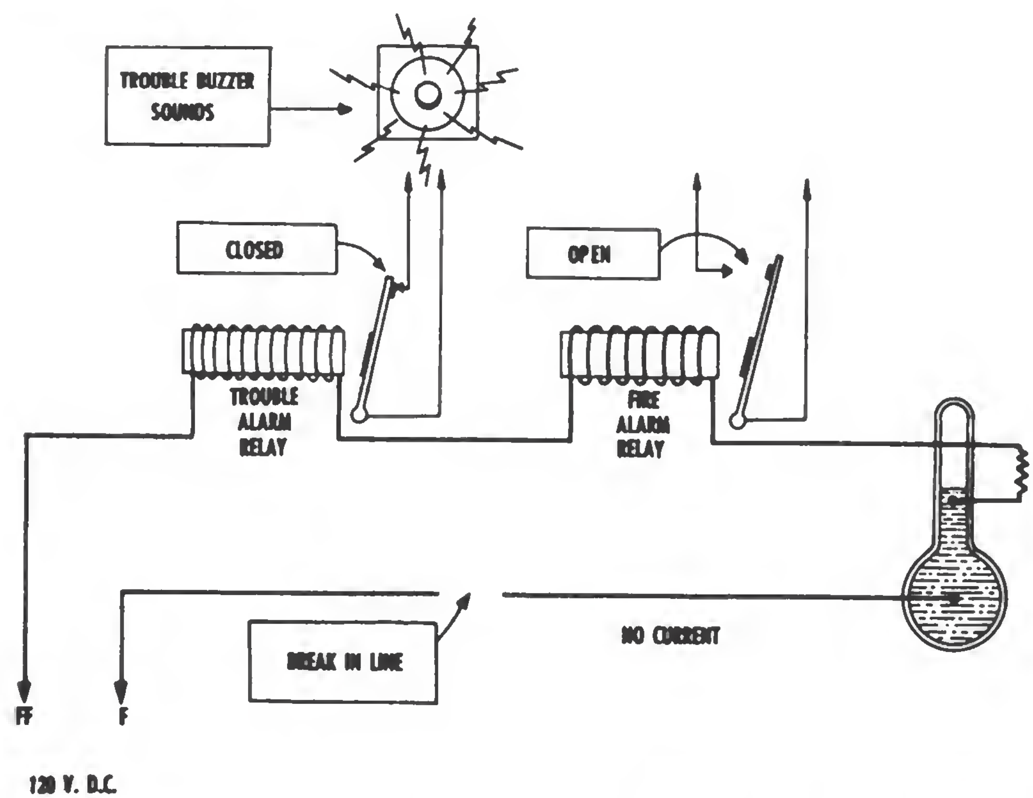


Figure 7–19.—Operation of a high-temperature alarm—open-circuit condition.

A switch is provided in each circuit for use in testing the circuit and for silencing either the fire bells or trouble buzzer when they sound an alarm. Complete tests and operating instructions are included in the manufacturer's instruction book that is provided for the alarm equipment installed in your ship. The instruction book should be studied carefully and its procedures followed closely at all times when servicing this equipment.

Sprinkling Alarm System

The sprinkling alarm system, circuit FH, is basically the same as the high-temperature alarm system except that conductivity-type switches are used instead of mercury thermostats.

LUBRICATING-OIL LOW-PRESSURE ALARM SYSTEM

The purpose of the lubricating-oil low-pressure alarm system, circuits 1EC and 2EC, is to sound an alarm whenever the pressure in the lubricating-oil supply line to the main engine and reduction gear, or to the turbine-driven or diesel-driven generators, and other auxiliary machinery falls below a predetermined minimum limit. Where the system is used for the main engines the circuit is designated "1EC" and when used for either turbine-driven or diesel-driven generators and other auxiliaries the circuit is designated "2EC." Both circuits are energized from individual switches on the I. C. switchboard.

An EC circuit includes one or more pressure-type switches installed in the lubricating-oil lines of the associated equipment. A dial-light indicator, drum-type annunciator, and siren are energized when the switch is closed because of a decrease in oil pressure. The control panel of the lubricating-oil low-pressure alarm is located near the operating control board of the machinery on which the switch is installed.

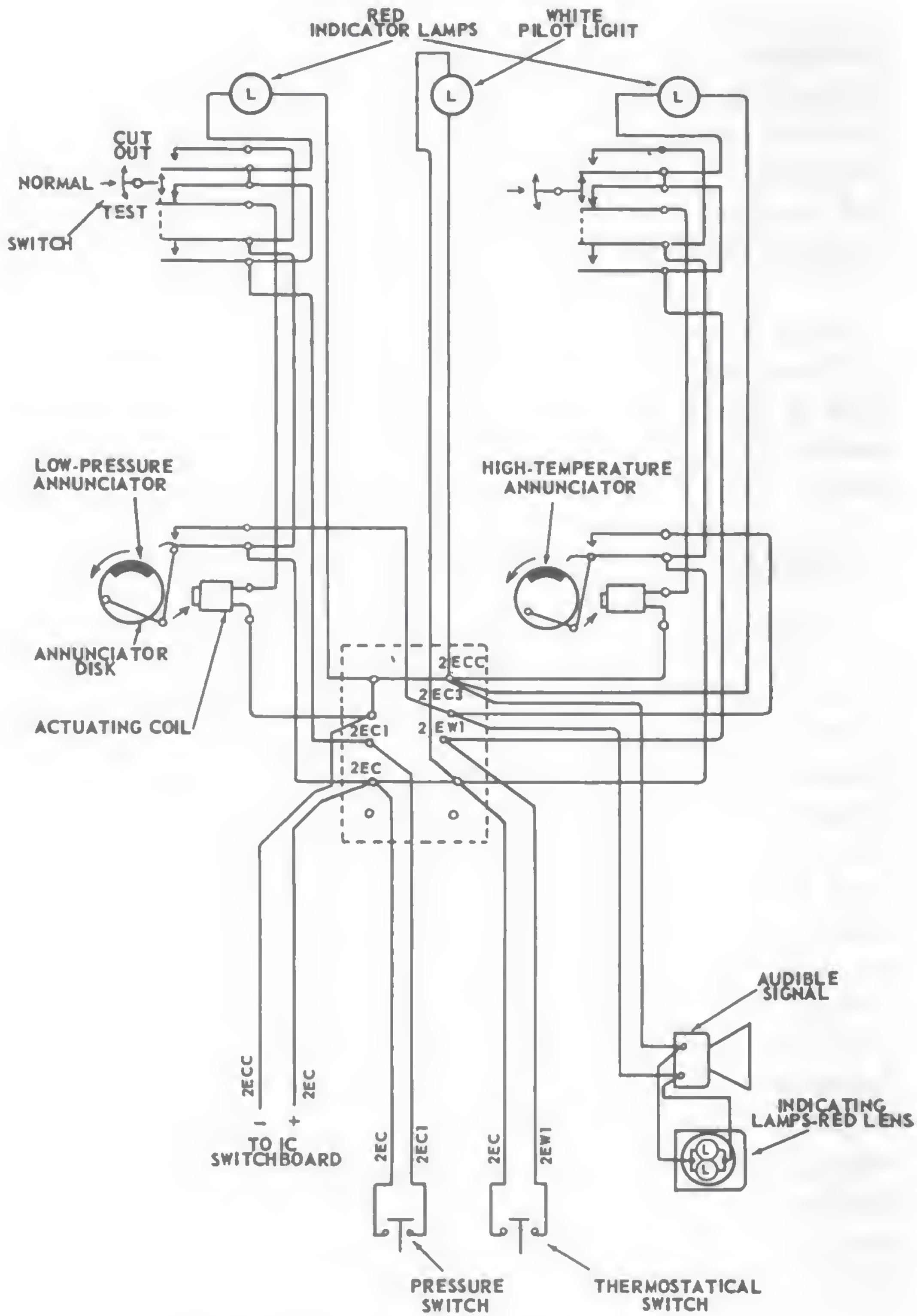


Figure 7-20.—Schematic of 2EC and 2EW circuits.

Circulating-Water High-Temperature Alarm System

The circulating-water high-temperature alarm system, circuits 1EW and 2EW, provides a means of automatically indicating when the circulating-water temperature of the main propulsion diesel engines or the large auxiliary diesel engines rises above a predetermined maximum limit. When the system is used for the main engines the circuit is designated "1EW" and when used for auxiliary engines the circuit is designated "2EW." The circulating-water high-temperature alarm system is usually combined with the lubricating-oil low-pressure alarm system (fig. 7–20), and consists of temperature-operated switches located in the circulating water lines of the engines. The thermostatical switch closes when a rise in temperature above a predetermined point is reached and energizes a lamp-type indicator, drum-type annunciator, and siren to sound the alarm.

QUIZ

1. What is the purpose of alarm and warning systems provided aboard ship?
2. Name the five types of switches used in alarm and warning systems.
3. What switch usually comprises the interior of a manually operated switch?
4. Describe the construction and operation of a pressure switch.
5. Describe the construction and operation of a thermostatic switch.
6. Name two types of mechanical switches.
7. What mechanism comprises a conductivity switch?
8. Define a relay.
9. For what purposes are relays used in alarm and warning systems?
10. Name the three principal types of push switches.
11. What is the principal type of thermostat used aboard ship?
12. Which of the connections brought into the mercury column connect to the 3 k-ohm resistor?

13. What is the purpose of the hydrogen gas contained in a thermostatic element?

14. What two factors determine the type of audible signal to be used aboard ship?

15. Name the four principal types of audible signals.

16. Name the two principal types of visual signals.

17. Why are two lamps in parallel provided with each indicator in a lamp-type indicator?

18. Why are the two lamps in parallel with the audible signal?

19. Name two types of annunciator indicators.

20. Explain the operation of a drum-type annunciator.

21. Explain the action of a mercury thermostat alarm circuit at 150° F.

22. Explain the action of a mercury thermostat alarm circuit at 32° F.

CHAPTER 8

SOUND AND SOUND EQUIPMENT

SOUND

Sound is a vibrating disturbance in an elastic medium that produces an auditory sensation capable of perception by the ear. The basic sources of sound are bodies in a state of vibration. The media that transmit sound are elastic materials which may be in the form of gases, liquids, or solids. Sound cannot travel through a vacuum.

Nature of Sound

Sound traveling through a medium must be a wave motion because the sources of sound are vibrating bodies. Most waves can be classified as either TRANSVERSE OF LONGITUDINAL. A transverse wave is one in which the particles of the medium vibrate at right angles to the direction of propagation. A longitudinal wave is one in which the particles of the medium move forward and backward in the direction of propagation.

Gases and liquids offer no sustained resistance to shears or to changes of shape and thus cannot transmit transverse elastic waves. On the other hand, gases and liquids offer elastic resistance to compression and thus can transmit only longitudinal waves. Therefore, sound discussed in this training course is considered as a longitudinal wave traveling progressively from particle to particle through air.

The vibration of a loudspeaker diaphragm causes the immediately adjacent air particles to execute similar motions.

Each forward motion of the diaphragm (fig. 8–1) compresses the air in front of it so that the momentary pressure of the air is raised above that at other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction from the diaphragm in the form of a compression wave.

Each backward movement of the diaphragm expands the

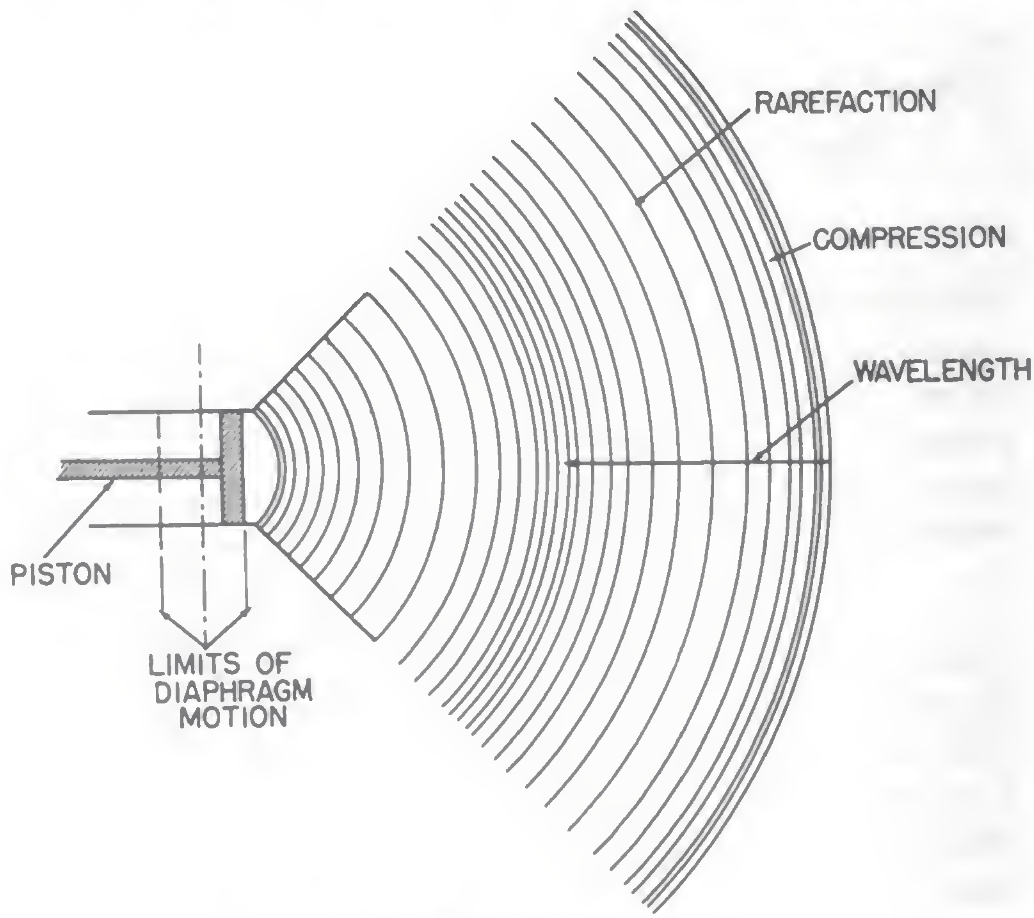


Figure 8–1.—Propagation of sound waves.

air so that the momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is similarly propagated in the form of an expansion or rarefaction wave and follows the compression through the medium. Hence, these conditions are transmitted outward from the loudspeaker as a wave disturbance consisting of alternate compressions and rarefactions in the medium.

The progress of any wave involves two distinct motions.

The wave itself moves forward with constant speed—that is, the configuration, or pattern, advances equal amounts in equal periods of time. The particles of the medium that convey the wave vibrate forward and backward in harmonic fashion. The locations of the particles at successive moments depend upon the period, amplitude, and phase of the vibration.

The PERIOD of a vibrating particle in a medium is the time in seconds, t, required for the particle to complete one vibration. The period is the reciprocal of the frequency, or $t=\frac{1}{f}$.

The FREQUENCY is the number of vibrations completed per second and may be expressed in cycles per second (cps). When expressed in this unit, "cycles" means vibrations per second.

The AMPLITUDE of vibration is the maximum displacement of the particle from the undisturbed, or equilibrium, position.

Two particles vibrating with the same frequency have definite phase relations. These particles are IN PHASE when they continue to pass through corresponding points of their paths at the same time. For any other condition the particles are OUT OF PHASE. The particles are in PHASE OPPOSITION when they reach their maximum displacement in opposite directions at the same instant.

The WAVELENGTH is the distance measured along the direction of propagation, between two corresponding points of equal intensity that are in phase on adjacent waves. This length can be represented by the distance between adjacent maximum compression points in the traveling sound wave.

Velocity of Sound

The velocity with which sound disturbances are transmitted through a medium is a function only of the elasticity, density, and temperature of the medium. Hence for a fixed temperature, the velocity of sound is a constant for any medium and is independent of the period, frequency, or amplitude of the disturbance. The velocity of sound in air at 0° C (32° F) is 1,087 feet per second and increases by 2 feet per second for each degree centigrade rise in temperature (1.1 feet per second for each degree Fahrenheit).

A body that is vibrating at a definite rate produces a disturbance that moves away as a wave in the surrounding medium. In any period of a vibrating body, the wave advances uniformly a distance equal to its wavelength. The velocity of the wave is the wavelength divided by the period. Because the period is the reciprocal of the frequency, the velocity of sound is

$$v = f\lambda, \tag{8-1}$$

where v is the velocity of sound in feet per second, f the frequency in cycles per second, and λ the wavelength in feet.

The wave velocity is determined entirely by the properties of the transmitting medium and is independent of the frequency of the source and of the wavelength. If the frequency changes, there must be a corresponding change in the wavelength, as shown by equation (8-1).

Properties of Wave Motion

Sound waves exhibit the usual properties of waves in that they can be reflected and refracted and can be made to interfere with each other.

Reflection.—When sound waves pass from one medium to another of different acoustic properties, some of the sound is transmitted and some is reflected at the boundary surface. A wave front, represented by line AB (fig. 8-2) is traveling toward reflecting surface MN. This wave impinges upon, but cannot penetrate, this surface. If surface MN were not present, the wave would have advanced to position CD in a certain interval of time without a change in direction. In the particular time interval, point B of the wave advances to D. Point A cannot move to C, and instead is reflected an equal distance above the surface to point H on the arc of radius AC. Any other point, E, cannot move to G, but advances to F, then is reflected an equal distance to point I on the arc of radius FG. Line DH, tangent to the arcs, is the wave front at the end of the specified time. Note that the wave is reflected back into the region above surface MN.

The angles i and r that these directions of wavefront travel

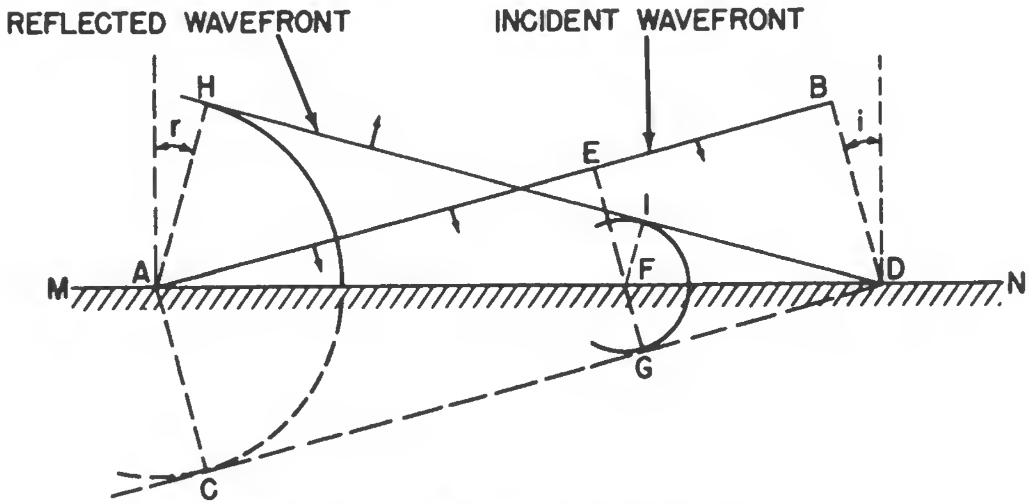


Figure 8–2.—Reflection of a sound wave.

make with the normals to the reflecting surface are respectively the angles of incidence and reflection. Because

$$AH = AC = BD,$$

the right triangles ABD and AHD are equal. Consequently angles i and r are equal.

Refraction.—When sound waves pass through a medium that does not have homogeneous acoustic properties, the direction of wave motion is changed. Such a change in direction is known as refraction.

The incident wave, BD, from wave AB (fig. 8–3) is traveling in direction BD with velocity $V1$ in medium 1. This wave encounters surface MN at an angle of incidence, i, and is partly reflected back into medium 1 and partly transmitted through medium 2. The velocity of the transmitted portion of the wave is $V2$. In the particular time interval point B of the wave advances a distance BD to surface MN at D in medium 1. Point A does not move an equal distance, AC, but moves a distance AH, or $(V2/V1)AC$, in medium 2 to some point, H, on the arc with radius AH. Any other point on wave E advances to F in medium 1 and then moves a distance FK, or $(V2/V1)FG$, in medium 2 to some point, K, on the arc with radius FK. The line DH, tangent to the arcs, is the refracted wave at the end of this time interval. Angle r that refracted wave DH makes with surface MN is the angle of refraction. It is the angle between the normal to the surface and the normal to the refracted wave.

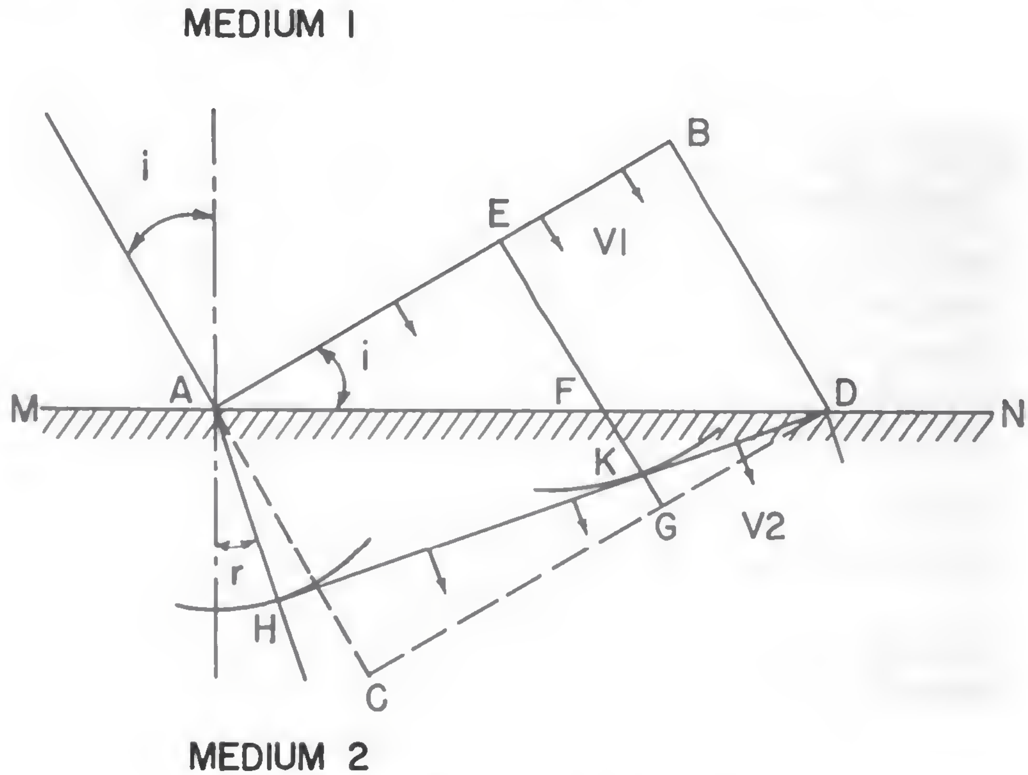


Figure 8–3.—Refraction of a sound wave.

When a wave travels obliquely from one medium into another the ratio of the sine of the angle of incidence, i, to the sine of the angle of refraction, r, is the same as the ratio of the respective wave velocities in these media and is a constant for two particular media.

INTERFERENCE.—When sound waves from more than one source meet at any point in a medium, interference between the waves results.

Two sound waves of the same frequency, in phase, and moving in the same direction, produce constructive interference. These waves produce a resultant wave that is in phase with the component waves and that has an amplitude equal to the sum of their amplitudes.

Two sound waves of the same frequency, in phase opposition, and moving in the same direction, produce destructive interference. If the frequencies are different, the disturbances at some instants are constructive and at other instants are destructive and a periodic variation in intensity results at a frequency equal to the difference between the two original frequencies. This difference frequency, referred to as the BEAT FREQUENCY, produces a type of pulsating interference that is particularly noticeable with sound waves. The effect of beat frequency, called BEATS, produces alternately loud and soft pulses or throbs. The effect is most pronounced when the individual waves have equal amplitudes.

STATIONARY WAVES.—When two sound waves of equal frequency and amplitude move in opposite directions through the same medium, they produce a STATIONARY, or STANDING, wave. Such a wave has stationary NODES, or points of zero displacement, with intermediate ANTINODES, or points of maximum amplitude at which the displacement varies between its widest limits.

Successive notes of the standing wave pattern are one-half wavelength apart and correspond to the instants at which the sound pressure is zero. Antinodes are inter-spaced one-quarter wavelength from corresponding nodes. Successive antinodes are one-half wavelength apart and correspond to the instants at which the sound pressure is maximum. Sound waves of sine waveform comprise pressures which vary with time according to a sine curve.

RESONANCE.—When a body capable of vibrating is displaced from its equilibrium position and suddenly released, it executes a series of free vibrations and finally comes to rest. The frequency of the free vibrations is determined by the properties of the body and is known as the NATURAL FREQUENCY of the body.

If periodic impulses are applied to the body so that it is repeatedly displaced from its equilibrium position the vibrations can be sustained. The frequency of this vibration may or may not be the natural frequency of the body. Such vibrations are called FORCED VIBRATIONS. When conditions are adjusted so that the period of the forced vibration is the same as that of the free vibration, the two effects reinforce each other, resulting in larger amplitudes of the vibrating body. This effect is called RESONANCE.

DOPPLER EFFECT.—Whenever there is relative motion between the source of a wave motion and a listener, the apparent frequency at the listening position differs from the frequency at the source. When a source of wave motion is moving toward a listener, more waves per second are encountered than when the source remains stationary. The effect at the listening position is an apparent increase in frequency. Conversely, when a source of wave motion is moving away from a listener, fewer waves per second are encountered than when the source remains stationary. The effect at the listening position is an apparent decrease in frequency. These apparent changes in frequency are called DOPPLER EFFECT. The amount of the change in apparent frequency depends upon the relative velocity of the listener and the source.

ACOUSTICS.—Acoustics is the science of sound, including its propagation, transmission, and effects. The performance of an announcing system or sound system when used in a room or enclosed space is dependent upon the acoustical characteristics of the enclosure. Sound originating in an enclosed space is partly reflected and partly absorbed by enclosing surfaces such as the walls, ceiling, and floor of a room. This action introduces echoes and reverberations which may seriously impair the quality or character of the sound.

An ECHO is the repetition of a sound caused by the reflections of sound waves. When a surface of a room is situated so that a reflection from it is outstanding and is heard by the listener an appreciable length of time later than the direct sound, it appears as a distinct echo, and is disturbing. If the surface is concave, it may have a focusing effect and concentrate reflected sound energy at one locality. Such a reflection may be several levels higher in intensity than the direct sound, and its arrival at a later time may be particularly disturbing. The possible remedies for this condition are to: (1) cover the offending surface with absorbing material to reduce the intensity of the reflected sound; (2) change the contour of the offending surface and thus send the reflected sound in another direction; (3) relocate the loudspeaker; or (4) vary the amplitude or pitch of the loudspeaker signal. The best method to use depends upon local conditions.

REVERBERATION is the persistence of sound due to the multiple reflection of sound waves between several surfaces of an enclosure. Excessive reverberation is one of the most common acoustic defects encountered in a large enclosure. The time that this residual sound persists varies directly with the time interval between reflections (the size of the enclosure) and inversely with the absorbing efficiency of the reflecting surfaces. The result is an overlapping of the original sound and its images. If excessive, this reverberation causes a general confusion that is detrimental to speech intelligibility. The hangar deck of an aircraft carrier is an example of an extremely reverberant area. The volume is large and the hard steel interior surfaces offer very little absorption to sound.

If a single loudspeaker is mounted in a large reverberant area, such as a hangar deck, the intelligibility directly in front of the loudspeaker is satisfactory. The intelligibility decreases rapidly as either the distance from the loudspeaker or the angle off the loudspeaker sound axis is increased. In other words, sound from a loudspeaker in a reverberant space is composed of (1) direct sound that reaches the listener directly without any reflection and (2) indirect sound that has received at least one reflection.

The direct sound intensity decreases inversely as the square of the distance from the source as it would in open air. The indirect sound intensity, on the other hand, increases because when multiple rays of sound energy leave a loudspeaker, each strikes some point on the surface of the room and is then reflected again and again, thus building up the amplitude of the sound. Each point of reflection may be considered as a new source of sound. Hence, a large number of these image sources is established so that sound distribution in a room tends to remain substantially uniform.

Intelligibility under these conditions is related to the ratio of direct to indirect sound. Thus as the listener moves away from the loudspeaker, the ratio of direct to indirect sound at the listening position decreases, and the intelligibility decreases correspondingly. Hence, in a highly reverberant space the intelligibility decreases with distance from the loudspeaker.

Characteristics of Sound

The word "sound" is used in both the subjective and the objective senses. When used subjectively it denotes the auditory sensation experienced by the ear. When used objectively it denotes the vibratory motion causing that sensation. The word "sound" is used objectively in acoustics.

Numerous terms are used to convey impressions of sounds—such as "whistle," "scream," "rumble," and "hum." Most of these are classified as noises in contrast to musical tones. The distinction is based on the regularity of the vibrations, the degree of damping, and the ability of the ear to recognize components having a musical sequence.

The ear can distinguish tones that are different in pitch, intensity, or quality. Each of these characteristics is associated with one of the properties of the vibrating source or of the waves that the source produces. Thus, pitch is determined by the number of vibrations per second or wavelength; intensity by the amplitude of the wave motion; and quality by the waveform.

PITCH.—The term "pitch" is used to describe the frequency of a sound. The outstanding recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a tone is proportional to the number of compressions and rarefactions received per second, which in turn is determined by the vibration frequency of the sounding source.

The pitch of a tone is usually measured by comparison with a standard. The standard tone may be produced by a tuning fork of known frequency or by a siren whose frequency is computed for a particular speed of rotation. By regulating the speed, the pitch of the siren is made equal to that of the tone being measured. The ear can determine this equality directly if the two sources are sounded alternately, or by the elimination of beats if the two sources are sounded together.

A sound wave can be described by either its frequency or its wavelength. Both the velocity and the wavelength change when the temperature of the air changes or when the wave enters a different medium. It is therefore preferable to specify a sound wave by its unchanging frequency.

INTENSITY.—When a bell rings, the sound waves spread out in all directions and the sound is heard in all directions. When a bell is struck lightly, the vibrations will be of small amplitude and the sound will be weak. A stronger blow will produce vibrations of greater amplitude and the sound will be louder. It is evident that the amplitude of the air vibrations is greater when the vibrations of the source are increased. Hence, the loudness of the sound heard depends on the amplitude of the vibrations comprising the waves. As the distance from the source increases, the energy in each wave spreads out and the sound is weaker. The energy that falls on the ear is less at greater distance because the amplitude is less.

The intensity of a sound wave is the time rate of transfer of vibratory energy per unit of sectional area of the sound wave. In a plane wave the energy is half kinetic and half potential—half is due to the speed of the particles, and half is due to the compression and rarefaction of the medium. These two energies are 90° out of phase at any instant. That is, when the speed of particle motion is a maximum, the pressure is normal, and when the pressure is a maximum or a minimum, the particles are at the ends of their paths and their speed is zero.

The loudness of a sound and its ease of reception depend upon the intensity, which has been defined as the flow of energy per unit time per unit area perpendicular to the direction of propagation. The intensity of a sound wave in a given medium is proportional to the (1) square of the frequency of vibration, (2) square of the amplitude, (3) density of the medium; and (4) velocity of propagation. At any distance from a point source of sound the intensity of the wave varies inversely as the square of the distance from the source.

As a sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave will be. It can be shown that the intensity is proportional to the square of the pressure variation regardless of the frequency. Thus, by measuring pressure changes, the intensities of sounds having different frequencies can be compared directly.

QUALITY.—Most sounds and musical notes are not pure tones. They are mixtures of tones of different frequencies. The tones produced by most sources can be represented by composite waves in which the sound of lowest pitch, the fundamental tone, is accompanied by several harmonics or overtones having frequencies that are 2, 3, 4, . . . times that of the fundamental frequency. The quality of a tone depends upon the number of overtones present, and upon their frequencies and intensities relative to the fundamental. It is this characteristic or difference in quality that distinguishes tones of like pitch and intensity when sounded on different types of musical instruments.

Measurement of Sound

The range of sounds that the human ear can detect varies with the individual. The average range extends from about

20 to about 20,000 vibrations per second. In the faintest audible speech sounds, the air particles vibrate with an amplitude of only 1×10^{-8} centimeter. A sound wave with an amplitude of from 1 to 2 millimeters is painful, and a wave having a pressure change of 1 percent would injure the hearing mechanism.

The human ear is a nonlinear unit that functions on a logarithmic basis. The Weber-French law in psychology, which applies within limits to all sense organs, states that "equal increments of sensation are associated with equal increments of the logarithm of the stimulus." Tests indicate this law applies in general to the hearing sensation so that loudness is closely associated with the logarithm of intensity. For example, assume the amplitude of one sound wave is 1 million times that of another, and both waves can be heard, but neither is painful to the ear. In this case, the loud sound would not seem to be 1 million times as great in amplitude as the weaker one, but only about 60 times as great.

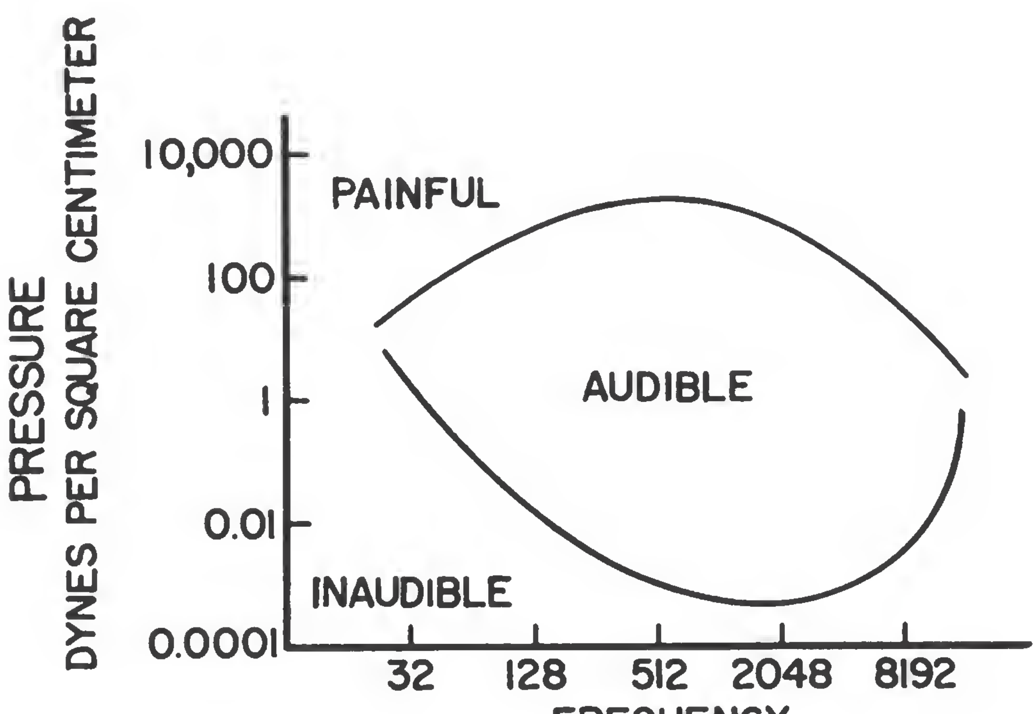


Figure 8-4.—Field of audibility.

The pressure changes that are inaudible, audible, or painful are shown by the graphs in figure 8-4. Below the lower curve the sound is too faint to be audible. Above the upper curve the sensation is one of feeling rather than of hearing—that is, the sensation of sound is masked by that of pain. At its low point the graph shows the frequency to which the ear is most sensitive and at its high point, the frequency that is least painful. Note that the scales of frequency and pressure are logarithmic. One space horizontally quadruples the frequency and one space vertically increases the pressure tenfold.

BEL.—The loudness of sound is not measured by an arbitrary scale such as measures of length. Units of sound measurement are used that vary logarithmically with the amplitude of the sound variations. These units are the BEL and DECIBEL, which refer to the difference between sounds of unequal intensity or sound levels. The decibel, which is one-tenth of a bel, is the least change of sound level that is perceptible to the human ear. Hence, the decibel merely describes the ratio of two sound levels. A sound for which the power is 10 times as great as that of another sound level differs in power level by 1 bel, or 10 decibels. For example, 5 decibels may represent almost any volume of sound, depending upon the intensity of the reference level or the sound level on which the ratio is based.

In sound system engineering, decibels are used to express the ratio between electrical powers or between acoustical powers. If the amounts of power to be compared are P_1 and P_2, the ratio in decibels (db) is

$$db = 10 \log_{10} \frac{P_1}{P_2}. \qquad (8\text{-}2)$$

If P_1 is greater than P_2 the decibel value is positive and represents a gain in power. If P_1 is less than P_2 the decibel value is negative and represents a loss in power.

SOUND-INTENSITY LEVEL.—An arbitrary zero reference level is used to accurately describe the loudness of various sounds. This zero reference level is the sound produced by 10^{-16} watts per square centimeter of surface area facing the source. This level approximates the least sound perceptible to the ear and is usually called the THRESHOLD OF AUDIBILITY. Thus, the sensation experienced by the ear when subjected to a noise of 30 decibels would be 30 times as great as when subjected to a sound that is barely perceptible.

ACOUSTICAL PRESSURE.—The loudness of sound is sometimes expressed in acoustical pressure instead of sound-intensity level. When expressed in acoustical pressure, the reference value that corresponds to the standard reference sound intensity of 10^{-16} watts per square centimeter is 0.0002 dyne per square centimeter.

Typical values of sound levels in decibles and the corresponding intensity levels and acoustical pressures are summarized in table 2. The values in this table are based upon an arbitrary zero reference level. Note that for each tenfold increase in power, the intensity of the sound increases 10 decibels. The power intensity doubles for each 3-decibel rise in sound intensity.

TABLE 2.—VALUES OF SOUND LEVELS

Sound level (decibels)	Intensity level (watts/cm²)	Acoustical pressure (dynes/cm²)
0	10^{-16}	0. 0002
60	10^{-10}	0. 2
80	10^{-8}	2. 0
100	10^{-6}	20. 0
110	10^{-5}	63. 0
120	10^{-4}	200. 0
130	10^{-3}	632. 0

POWER RATIO.—The decibel is used to express an ELECTRICAL POWER RATIO, such as the gain of an amplifier, the output of a microphone, or the power in a circuit compared to an arbitrary reference power level. The value of decibels is often computed from the voltage ratio squared or the current ratio squared, since these are proportional to the power ratio for equal values of resistance. If the resistances are not equal a correction must be made.

To find the number of decibels from the voltage ratio, assuming that the resistances are equal, substitute $\frac{E_1^2}{R}$ for P_1 and $\frac{E_2^2}{R}$ for P_2 in equation (8–2)—

$$db = 10 \log_{10} \frac{(E_1)^2/R}{(E_2)^2/R} = 20 \log \frac{E_1}{E_2}.$$

To find the number of decibels from the current ratio, assuming that the resistances are equal, $(I_1)^2R$ is substituted for P_1 and $(I_2)^2R$ for P_2 in equation (8–2)—

$$db = 10 \log_{10} \frac{(I_1)^2R}{(I_2)^2R} = 20 \log \frac{I_1}{I_2}.$$

The decibel is also used to express the ratio of ACOUSTICAL POWER to an arbitrary reference power level. The acoustical power ratio is proportional to the corresponding pressure ratio squared. Because power (P) is proportional to the square of the pressure, substitute (pressure 1)^2 for P_1 and (pressure 2)^2 for P_2 in equation (8–2)—

$$db = 10 \log_{10} \frac{(\text{pressure } 1)^2}{(\text{pressure } 2)^2} = 20 \log \frac{\text{pressure } 1}{\text{pressure } 2}.$$

ELECTRICAL LEVELS.—The power level of an electrical signal is often expressed in decibels above or below an arbitrary power level of 0.001 watt (1 milliwatt), as,

$$\text{dbm} = 10 \log_{10} \frac{P}{0.001},$$

where dbm is the power level above one milliwatt in decibels and P is the power in watts.

The VOLUME LEVEL of an electrical signal comprising speech, music, or other complex tones is measured by means of a specially calibrated voltmeter called a VOLUME INDICATOR.

The volume levels read with this indicator are expressed in "vu units," the number being numerically equal to the number of decibels above or below the reference volume level. Zero vu represents a power of 1 milliwatt dissipated in an arbitrary load resistance of 600 ohms (corresponds to a voltage of 0.7746 volt). Thus, when the vu meter is connected to a 600-ohm load, vu readings in decibels can be used as a direct measure of power above or below 1 milliwatt. For any other value of resistance the following correction must be added to the vu reading to obtain the correct vu value:

$$\text{vu}=\text{vu reading}+10\log\frac{600}{R},$$

where vu is the actual volume level, and R is the actual load, or resistance, across which the vu measurement is made. If the volume levels are indicated in other than vu units, the meter calibration, or reference level, must be stated with the decibel value.

SOUND EQUIPMENT

All sound and announcing systems consist basically of an amplifier, a microphone, and a loudspeaker. The microphone converts the sound energy into electrical energy having the same waveform as the sound energy. The output from the microphone is applied as a signal voltage to the amplifier. The output power from the amplifier has the same waveform as the sound energy that is applied to the microphone. The loudspeaker reconverts the electrical energy from the amplifier into sound energy at a higher volume level than the original sound. In shipboard installations many loudspeakers are operated from the same amplifier. Each loudspeaker produces sound having the same waveform as the original sound applied to the microphone.

Types of Microphones

A microphone is a device that converts sound energy into electrical energy. All types of microphones have a metal

317993 O—55——19

diaphragm that responds to the vibrations of the sound waves, and some means of changing this mechanical vibration into corresponding electrical signals. The most widely used types of microphones are the (1) magnetic, (2) dynamic, (3) crystal, and (4) carbon types.

MAGNETIC MICROPHONE.—The magnetic, or moving-armature, microphone (fig. 8–5) consists of a permanent magnet

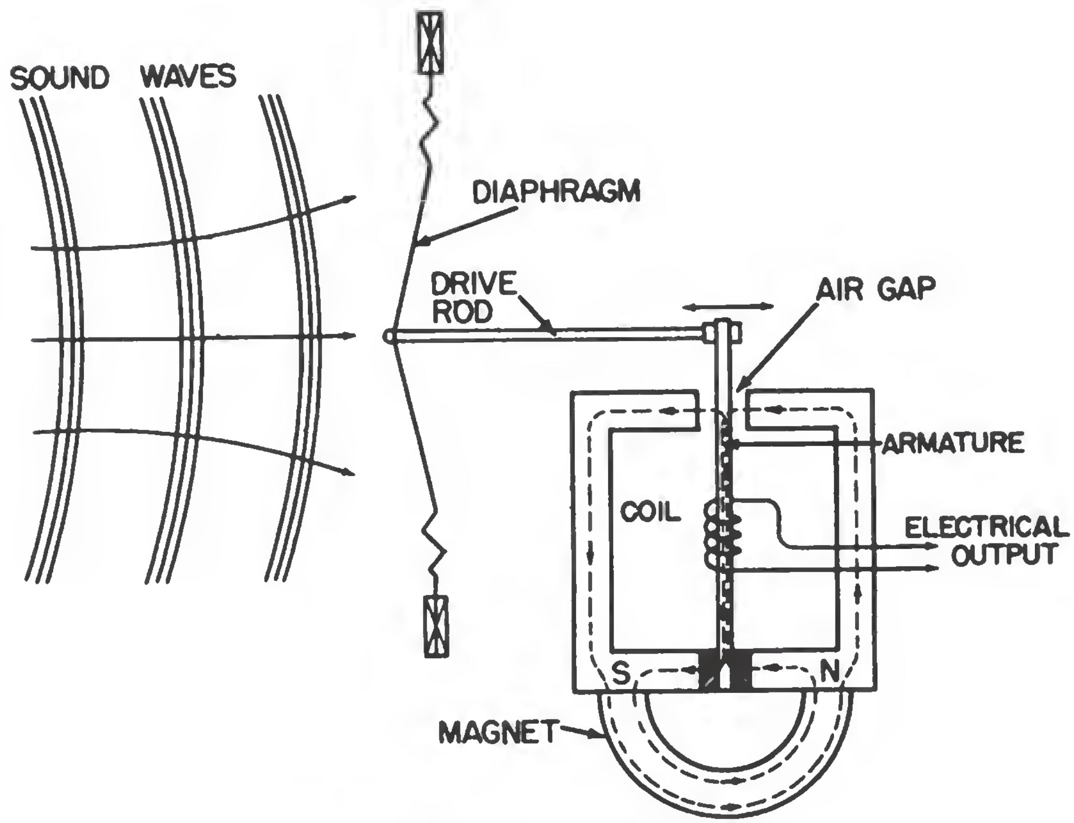


Figure 8–5.—Magnetic microphone.

and a coil of wire inside of which is a small armature. Sound waves impinging on the diaphragm cause the diaphragm to vibrate. This vibration is transmitted through the drive rod to the armature which vibrates in a magnetic field, thus changing the magnetic flux through the armature.

When the armature is in its normal position midway between the two poles, the magnetic flux is established across the air gap with no resultant flux in the armature.

When a compression wave strikes the diaphragm, the armature is deflected to the right. The flux path is directed from the north pole of the magnet across the reduced gap at the upper right, down through the armature, and around to the south pole of the magnet.

When a rarefaction wave strikes the diaphragm, the armature is deflected to the left. The flux path now is directed from the north pole of the magnet, up through the armature through the reduced gap at the upper left, and back to the south pole.

Thus, the vibrations of the diaphragm cause an alternating flux in the armature. The alternating flux cuts the stationary coil wound around the armature and induces an alternating voltage in it. This voltage has the same waveform as the sound waves striking the diaphragm.

The magnetic microphone is the type most widely used in shipboard announcing and intercommunicating systems because it is more resistant to vibration, shock, and rough handling.

DYNAMIC MICROPHONE.—The dynamic, or moving-coil, microphone (fig. 8–6) consists of a coil of wire attached to a diaphragm, and a radial magnetic field in which the coil is free to vibrate. Sound waves impinging on the diaphragm

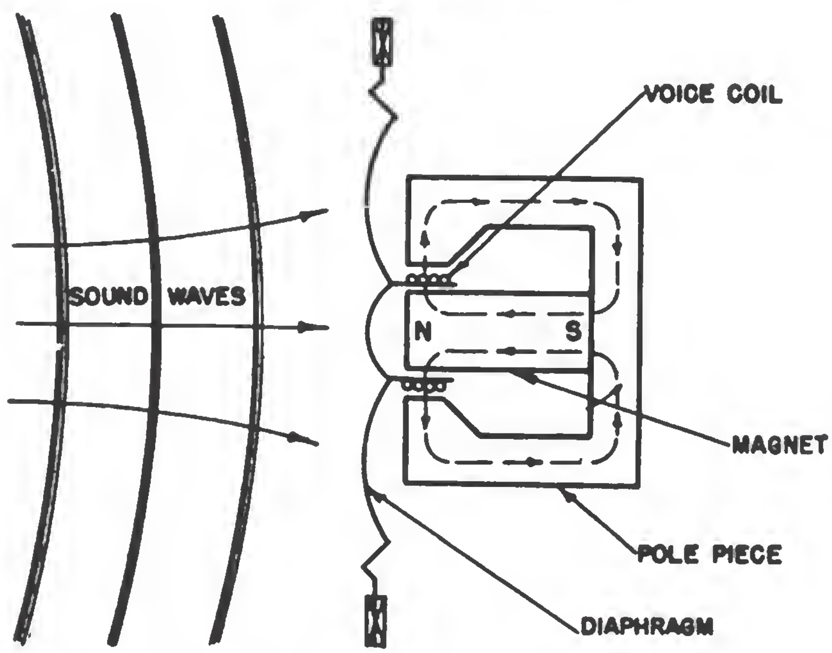


Figure 8–6.—Dynamic microphone.

cause the diaphragm to vibrate. This vibration moves the voice coil through the magnetic field so that the turns cut the lines of force in the field. This action generates a voltage in the coil that has the same waveform as the sound waves striking the diaphragm.

The dynamic microphone requires no external voltage source, has good fidelity, and produces an output voltage of about 0.05 volt when spoken into in a normal tone within a few inches of the diaphragm.

CRYSTAL MICROPHONE.—The crystal microphone utilizes a property of certain crystals—such as quartz, Rochelle salt, sugar, or coal—known as the PIEZOELECTRIC EFFECT. The bending of the crystal resulting from the pressure of the sound wave produces an emf across the faces of the crystal. This emf is applied to the input of an amplifier.

The crystal microphone consists of a diaphragm that is cemented to one surface of the crystal. Metal plates, or electrodes, are attached to the other surface of the crystal. When sound waves strike the diaphragm, the vibration of the diaphragm produces a varying pressure on the surface of the crystal and induces an emf across the electrodes. This emf has the same waveform as the sound waves striking the diaphragm.

Rochelle salt is most commonly used in crystal microphones because of its relatively high voltage output. The crystal microphone can produce an output voltage of from 0.01 to 0.03 volt into a load of 1 megohm or more, when subjected to a sound pressure of a normal tone within a few inches of the crystal. However, this crystal microphone is seldom used in naval announcing and intercommunicating systems because of the sensitivity of the crystal element to high temperature, humidity, and rough handling.

CARBON MICROPHONE.—The carbon microphone is the most common type of microphone. It operates on the principle that a changing pressure of a diaphragm applied to a small volume of carbon granules changes its electrical resistance in accordance with the vibrations of the sound waves striking the diaphragm.

The carbon microphone consists of a diaphragm mounted against a mass of carbon granules which are contained in a small cup. In order to produce an output voltage, this microphone is connected in a series circuit containing a battery and the primary of a transformer.

When a direct current flows through the carbon granules, the varying resistance changes the amplitude of the current and produces an alternating voltage in the secondary of the transformer. This voltage has the same waveform as the sound waves striking the diaphragm. The current through this microphone may be as great as 0.1 ampere. The resistance may vary from about 50 to 90 ohms. The voltage developed across the secondary depends upon the ratio of the transformer primary and secondary turns and also upon the change in primary current. Normal output voltage of a typical circuit is from 3 to 10 volts peak at the secondary terminals.

The carbon microphone is not used in shipboard announcing equipment because it requires a polarizing current and has a tendency to amplify certain frequencies more than others.

Characteristics of Microphones

Microphones are rated according to their (1) frequency response, (2) impedance, and (3) sensitivity.

FREQUENCY RESPONSE.—Shipboard announcing and intercommunicating systems are designed to produce maximum speech intelligibility under conditions of high background noise. To achieve this objective the overall frequency response characteristic of the system is altered by cutting off the system response at some lower limit, such as 500 cycles, and by employing an EMPHASIZED frequency response characteristic which rises with increasing frequency at a rate of approximately 6 decibels per octave. The output sound pressure is doubled each time the frequency is doubled for a constant level input to the system. The emphasized speech tends to sound thin and sometimes harsh, but when the masking due to background noise is almost as high as the speech level, the speech appears to cut through the noise.

For good quality, a microphone must convert sound waves into electrical waves that have the same relative magnitude and frequency, without introducing any new frequencies. The frequency range of the microphone must be at least as wide as the desired overall response limits of the system with which it is used.

Except in the case of the emphasized system in which it may be desirable for the microphone to have a rising frequency-response characteristic, the microphone response should be uniform or flat, within its frequency range and free from sharp peaks or dips such as those caused by mechanical resonances.

Impedance.—Crystal microphones have impedances of several hundred thousand ohms whereas the magnetic and dynamic microphones have impedances that range from 20 to 600 ohms. The impedance of a microphone is usually measured between its terminals at some arbitrary frequency within the useful range such as 1,000 cycles.

The impedance of magnetic and dynamic microphones varies with frequency in much the same manner as that of any coil or inductance—that is, the impedance rises with increasing frequency. The actual impedance of the microphone in shipboard applications is of importance only as it is related to the input load impedance into which the microphone is designed to operate. If the microphone is mismatched with the input impedance, the microphone input is reduced and distortion occurs. All specifications and acceptability tests for naval microphones are based on the designed input load impedance.

Sensitivity.—The sensitivity or efficiency of a microphone is usually expresed in terms of the electrical power level that the microphone delivers to a terminating load the impedance of which is equal to the rated impedance of the microphone, compared to the acoustical intensity level or pressure of the sound field that is being picked up.

Most systems rate the microphone in the electrical power level (in decibels below 1 milliwatt) produced by an acoustical pressure of 1 dyne per square centimeter. For example, a crystal microphone rated at −80 decibels means that for an input acoustical pressure of 1 dyne per square centimeter, the electrical output is 80 decibels below one milliwatt, or 10^{-8} milliwatt. Other systems rate the microphone in terms of the voltage delivered to a specified terminating load impedance for an acoustical pressure input of 1 dyne per square centimeter.

It is important to have the sensitivity of the microphone as high as possible. High sensitivity means a high electrical power output level for a given input sound level. High microphone output levels require less gains in the amplifiers used with them and thus provide a greater margin over thermal noise, amplifier hum, and noise pick-up in the line between the microphone and amplifier.

When a microphone must be used in a noisy location, an additional desirable characteristic is the ability of the microphone to favor sounds coming from a nearby source over random sounds coming from a relatively greater distance. Microphones of this type tend to cancel out random sounds and to pick up only those sounds originating a short distance away. When talking into this type of microphone the lips must be held as close as possible to the diaphragm. Directional characteristics that favor sound coming from one direction only, also aid a microphone in discriminating against background noise.

Types of Loudspeakers

A loudspeaker is a device that converts electrical energy into sound energy and radiates this energy into the air in the form of waves. All loudspeakers consist essentially of a driving mechanism for changing electrical waves into mechanical vibrations that are transmitted to a diaphragm or other vibrating source. This vibrating source is coupled, either directly or by means of a horn, to the air and causes sound to be radiated. The loudspeakers in general use in the Navy are the (1) direct radiator type which radiates sound directly from a vibrating member into the air and (2) horn type which consists of a driving unit combined with a horn to couple the unit to the air.

DRIVING MECHANISMS.—The driving mechanism changes the electrical vibrations into mechanical vibrations. The dynamic, or moving-coil, driving mechanism is the basic type used in Navy loudspeakers. The design of this unit is similar to that of the dynamic microphone (fig. 8–6.). However, the principle of operation is the reverse of that of the dynamic microphone.

A coil of wire is attached to a diaphragm and rests in a magnetic field. When a varying electric current flows through the coil, a force is exerted on the coil causing it to move back and forth in the magnetic field. The consequent motion of the diaphragm causes the radiation of sound waves which correspond to the variations in the electric current. The electrodynamic and the permanent-magnet types are the two variations in the dynamic loudspeaker. These types differ only in the method employed for obtaining the magnetic field.

In the ELECTRODYNAMIC LOUDSPEAKER the magnetic field is established by passing a direct current through a field coil that is wound on an iron core. This type requires a source of filtered direct voltage and two additional conductors to carry the field current to the loudspeaker.

In the PERMANENT-MAGNET DYNAMIC LOUDSPEAKER the magnetic field is established by a permanent magnet. All loudspeakers used by the Navy are of the permanent-magnet dynamic type.

DIRECT RADIATOR LOUDSPEAKER.—The direct radiator loudspeaker, sometimes called a CONE LOUDSPEAKER, is the simplest form of sound loudspeaker. In this type of loudspeaker (fig. 8–7), the diaphragm acts directly on the medium, which is air. Both sides of the diaphragm are open to the air so that sound is radiated behind as well as in front of the loudspeaker. At the instant the diaphragm is moving in an outward direction, a compression wave is produced by the front surface of the diaphragm and a rarefaction wave is produced by the back surface of the diaphragm.

At low frequencies, where the wavelength is large com-

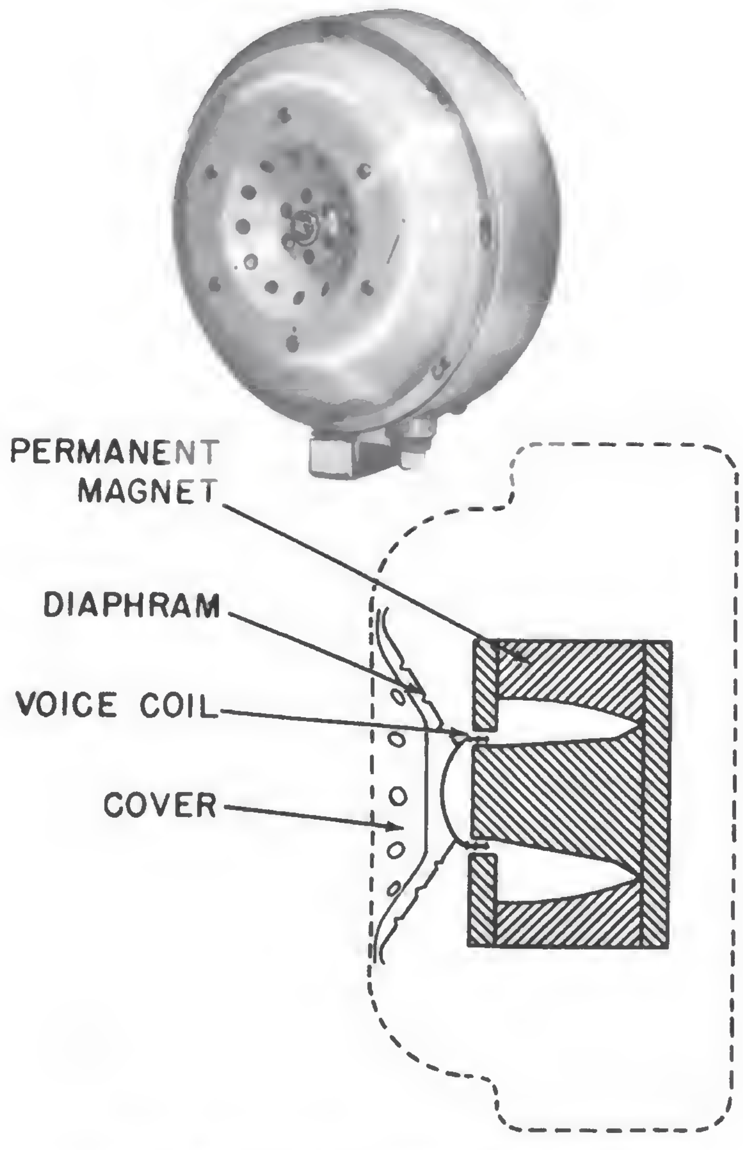


Figure 8–7.—Direct radiator loudspeaker.

pared with the dimensions of the loudspeaker, the rarefaction wave from the back of the diaphragm meets the compression wave from the front of the diaphragm and neutralizes it because the waves are in opposite phase relation. Thus low frequencies are not reproduced from this type of direct radiator.

At higher frequencies, where the wavelength of the sound is small compared with the dimensions of the loudspeaker, the sound waves from the front of the diaphragm have time to travel an appreciable distance away from the loudspeaker (in terms of wavelength) and the phase of vibration of the diaphragm changes before the interfering wave from behind can traverse the distance around the diaphragm. Hence, a BAFFLE is necessary only to reproduce low frequencies from a direct radiator. The purpose of the baffle is to delay the meeting of the front and back waves by artifically increasing the distance of the sound-wave path from the front to the back of the diaphragm.

The simplest form of baffle is a flat board with a hole in the center to accommodate the loudspeaker. This type of baffle is effective down to a frequency the wavelength of which is approximately four times the diameter of the baffle. If the loudspeaker is mounted in a wall or is completely enclosed, the baffle is called an INFINITE BAFFLE. When a cabinet is used as a baffle, it is desirable to line the inside with a sound-absorbing material to minimize the effect of cabinet resonances produced by standing waves within the enclosure.

HORN LOUDSPEAKER.—The use of the direct radiator loudspeaker is limited because of its low radiation efficiency. When it is necessary to produce high sound intensities or to cover large areas with sound, the radiation efficiency of the loudspeaker must be increased to keep the size of the amplifier within reasonable limits. Horns with appropriate driver units provide a practical solution to the problem. A horn may be considered as an impedance matching device for coupling a relatively heavy vibrating surface at the horn throat to a relatively light medium (the air), at the mouth of the horn. A STRAIGHT-HORN LOUDSPEAKER is shown in figure 8–8.

For a horn to operate effectively, the mouth must be sufficiently large in comparison with the longest wavelength (lowest frequency) of sound that is to be transmitted. Low-frequency horns often are considered to be useful at frequencies above that for which the mouth diameter is about one-third wavelength. The performance of a horn loudspeaker near the low-frequency cutoff point depends to a great extent

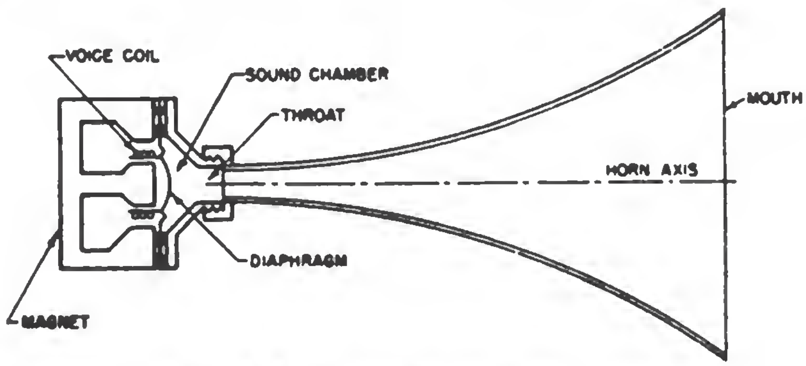


Figure 8–8.—Straight-horn loudspeaker.

upon the flare or shape of the horn. The function of the horn contour is to produce a smooth and continuous increase in cross-sectional area in progressing from the small throat to the large mouth. The shape most commonly employed is the exponential horn in which the diameter increases progressively by a fixed percentage for each equal-distance in-

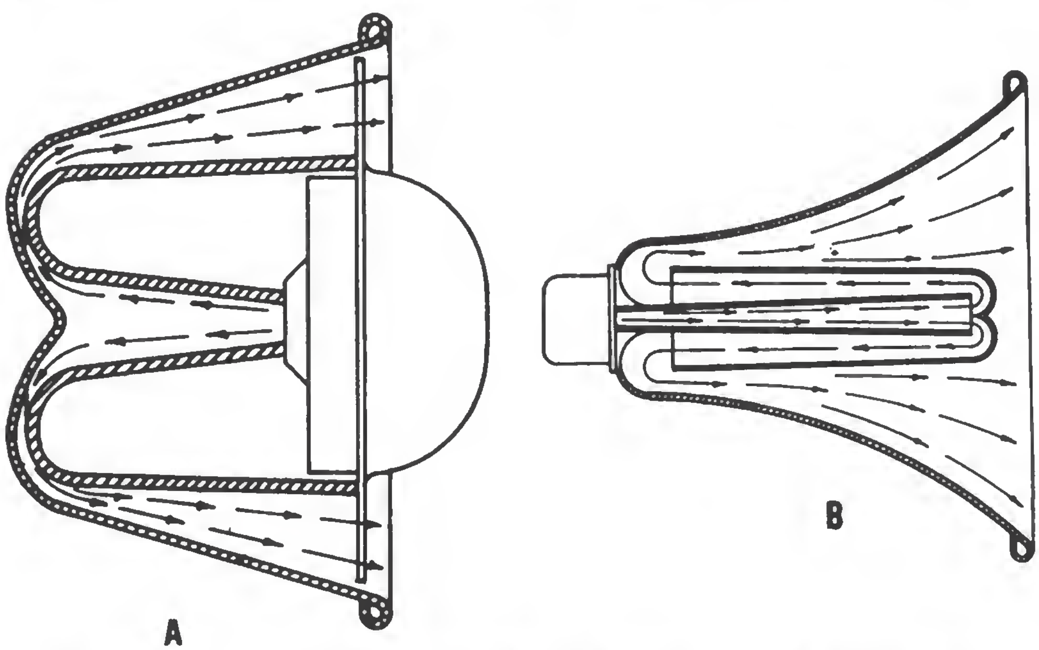


Figure 8–9.—Folded-horn loudspeaker. A, Single fold; B, double fold.

crement along the horn axis. In order for the horn to be of a practical size and shape, a FOLDED-HORN LOUDSPEAKER is employed (fig. 8-9) in preference to a straight horn (fig. 8-8). There is a practical limit to the amount of power that can be handled by a conventional driver unit. When extremely high sound intensities must be produced, multiunit loudspeakers are employed in which the units are coupled to individual horn sections that are combined mechanically into a common loudspeaker assembly. Examples of this type are the Navy superpower loudspeakers and beachmaster announcing loudspeakers.

Characteristics of Loudspeakers

FREQUENCY RESPONSE.—In the majority of cases the frequency response of the loudspeaker is the limiting factor in the over-all response of a sound system. For direct radiators the low frequency response is influenced by the (1) baffle or enclosure, (2) diameter of the cone, (3) ability of the cone and voice coil to execute large amplitudes of vibration, and (4) strength of the magnetic field in the air gap. This high-frequency response is limited by the mass of the voice coil and diaphragm.

For horn loudspeakers, the low frequency response is influenced principally by the (1) basic horn formula employed, (2) flare, and (3) mouth dimensions. The high frequency response is limited by the (1) mass of the voice coil and the diaphragm, (2) phase effects caused by differences in path lengths due to bends, and (3) impedance irregularities caused by sudden changes in cross-sectional areas at folds or joints in the horn. Vibrations of the horn walls must be sufficiently damped to avoid introducing irregularities into the response as well as transient effects.

DIRECTIVITY.—The directivity of a loudspeaker is an important factor in determining the efficiency of the sound radiation over the listening area. All practical forms of sound radiators exhibit some directional effects. If a radiator is placed in free space where the results are not affected by interfering reflections, the sound pressure at a given distance is not the same in all directions. The directivity of a loudspeaker is a function of both frequency and the size of the horn mouth of the loudspeaker. Thus, a loudspeaker becomes more directional with increasing frequency because of the shorter wavelength and a direct radiator or horn mouth of large size is more directional than one of smaller size. These factors of frequency and size are interrelated in that the size becomes a factor relative to the wavelength of the sound being transmitted. Thus the directional pattern of a small loudspeaker transmitting a high-frequency signal (short wavelength) is similar to that of a large loudspeaker transmitting a low-frequency signal (long wavelength). In general a horn loudspeaker of a given mouth diameter is more directional than a direct radiator of the same diameter, particularly at the lower frequencies.

The directivity of a horn loudspeaker is also dependent upon the rate of flare—that is, the directivity increases as the flare is made more gradual (longer horn). If a rectangular horn having a long narrow mouth (in terms of wavelength) is mounted with the long dimension of the mouth vertical, the radiation in the horizontal plane corresponds to that of a small radiator with a broad distribution pattern. The radiation in the vertical plane acts as a large radiator with a relatively narrow beam. In other words, the horn is made relatively much less directional in the horizontal plane than in the vertical plane. It is obvious that the reverse is true if the horn is turned so that the long dimension of the mouth is horizontal. Thus the sound energy is flattened out in a plane at right angles to the long dimension of the loudspeaker mouth. This principle is used to obtain the required directional characteristics for efficient high-intensity reproduction on the flight decks of aircraft carriers.

Capacity.—The load-carrying capacity of a loudspeaker is usually expressed in terms of the maximum electrical power that would be applied to it. This power is limited by heating, mechanical strength, and the production of nonlinear distortion which is caused by excessive diaphragm amplitudes or excessive acoustical pressures in the sound passages. Excessive power causes the diaphragm to strike portions of the magnet or supporting frame and may produce buzzing or rattling.

Efficiency.—The loudness of the sound obtainable from a loudspeaker at any particular listening point is not a factor of load-carrying capacity alone. Other important factors are the efficiency and the amount that the sound is spread out. The definition of absolute efficiency of a loudspeaker is not subject to simple practical interpretation. However, for specification purposes and for checking the performance of naval loudspeakers, a specified voltage is applied to the input terminals and the output sound pressure is measured at a given distance from the loudspeaker on the loudspeaker axis using various test frequency signals. These measurements are combined with off-axis sound pressure measurements to evaluate the relative loudspeaker efficiency.

When satisfactory frequency in a loudspeaker is limited to a small angle about the axis, the absolute efficiency at high frequencies is considerably lower than at low frequencies. The use of diffusing arrangements with these loudspeakers to spread out the high frequencies usually results in spreading out the small amounts of available high-frequency energy to such an extent that the response is unsatisfactory at all locations.

Impedance.—The impedance of a loudspeaker is usually measured between the voice coil terminals at some average frequency, such as 1,000 cycles, in the usable range. This impedance varies with the frequency, rising with increasing frequency. The usual value of voice coil impedance varies from 3 to 15 ohms.

In shipboard announcing and public-address systems, a matching transformer is built into each loudspeaker to transform the low voice-coil impedance to a higher value suitable for connection to loudspeaker distribution lines. Because loudspeakers in a system are connected and operated in parallel, the combined impedance of a large number of low-impedance voice coils without matching transformers would be so low compared with the resistance of the connecting cables that an appreciable portion of the amplifier output power would be dissipated in the cables. Thus matching transformers are provided to reduce this loss. These transformers have several taps in order to vary the loudspeaker impedance. Changing the loudspeaker impedance changes the power absorbed by the loudspeaker from the lines and thus provides a means of varying the loudness of the loudspeaker.

QUIZ

1. What condition must exist in a body for sound to be produced?
2. Name two classes of waves.
3. In what direction do the particles of the medium vibrate in a transverse wave?
4. In what direction do the particles of the medium vibrate in a longitudinal wave?
5. Why are sound waves in a gas or liquid considered as longitudinal waves?
6. What is the nature of a sound wave produced by a loudspeaker diaphragm?
7. What is the period of a vibrating particle in a medium?
8. What is the frequency of vibration?
9. What is the amplitude of vibration?
10. When are two vibrating particles in phase?
11. When are two vibrating particles in phase opposition?
12. What is the wavelength of a sound wave?
13. What three qualities of a medium affect the velocity with which sound disturbances are transmitted through the medium?
14. What happens when sound waves from more than one source meet at any point in a medium?
15. What kind of interference is produced when two sound waves, of the same frequency and in phase, moving in the same direction meet at a point?

16. What kind of interference is produced when two sound waves, of the same frequency and in phase opposition, moving in the same direction meet at a point?

17. What is the name given to the periodic variations in intensity resulting from constructive and destructive disturbances produced when two sound waves of different frequencies meet at a point?

18. What is the effect of beat frequency?

19. What are the apparent changes in pitch called when there is relative motion between the sound source and the listener?

20. What is the science of sound including its propagation, transmission, and effects called?

21. What is the repetition of a sound called that is caused by the reflections of sound waves?

22. What is the persistence of sound called that is due to the multiple reflection of sound waves between several surfaces of an enclosure?

23. What three terms are used to describe the characteristics of sound?

24. What determines the pitch of a sound, or tone?

25. What determines the intensity of a sound?

26. What is the sound of lowest pitch called?

27. Upon what does the quality of a tone depend?

28. What unit is used to describe the ratio of the power of two sound levels?

29. What is the meaning of the expression "threshold of audibility?"

30. What is the function of a microphone?

31. Name four principal types of microphones.

32. What type of microphone is used most widely aboard ship?

33. What mechanism comprises the magnetic microphone?

34. What three factors determine the rating of microphones?

35. How is the over-all frequency response characteristic of shipboard announcing and intercommunicating systems altered to achieve maximum speech intelligibility under conditions of high-background noise?

36. In what way is the impedance of a microphone important?

37. Why is it important to have the sensitivity of the microphone as high as possible?

38. Name the two kinds of loudspeakers used in the Navy.

39. What is the basic type of driving mechanism used in Navy loudspeakers?

40. How does the principle of operation of this driving mechanism differ from that of the dynamic microphone?

41. Why is it desirable in the direct radiator loudspeaker to increase the length of the sound path from the back to the front of the diaphragm?

42. What means is provided in the direct radiator loudspeaker to increase the distance of the sound path from the front to the back of the diaphragm?

43. What is the function of the horn contour?

44. How are extremely high sound intensities produced?

45. What is the limiting factor in the overall response in the majority of sound systems?

46. What two factors influence the directivity of a loudspeaker?

47. For a given loudspeaker, how is the directivity related to the frequency?

48. What three factors limit the capacity of a loudspeaker?

49. How are the voice coils of loudspeakers matched to audio transmission lines?

317993 O—55——20

CHAPTER 9

ANNOUNCING AND INTERCOMMUNICATING SYSTEMS

Shipboard announcing and intercommunicating systems, circuits 1MC to 31MC inclusive, serve the general purpose of transmitting orders and information between stations within the ship by means of amplified voice communications. This function is accomplished by either (1) a CENTRAL AMPLIFIER SYSTEM or (2) an INTERCOMMUNICATING SYSTEM. A central amplifier system is employed when it is desired primarily to broadcast the orders or information simultaneously to a number of stations. An intercommunicating system is employed when it is desired primarily to provide two-way transmission of the orders or information.

Each announcing and intercommunicating system installed aboard ship is assigned an I. C. circuit designation in the MC series. The Chief of Naval Operations authorizes these MC circuits for each class of vessel, based on size, complement, function, and operational equipment. All authorized I. C. announcing circuits are listed in table 3, according to type, importance, and readiness. These systems, however, are not all installed in any one ship. A more detailed description of these circuits is contained in chapter 65 of the *Bureau of Ships Manual.*

TABLE 3.—ANNOUNCING SYSTEMS

Announcing system	Circuit	Type	Importance and readiness
General	1MC	Central amplifier	SV–1.
Engineers	2MC	do	Do.
Aviators	3MC	do	Do.
Damage control	4MC	Central amplifier (early designs); Intercom (recent designs).	SV–2.
Flight deck	5MC	Central amplifier	Do.
Intership	6MC	do	Do.
Submarine control	7MC	Central amplifier (early designs); Intercom (recent designs).	V–1.
Docking control	10MC	Central amplifier	SV–1.
Turret	11MC–16MC	do	SV–3.
Double purpose battery	17MC	do	Do.
Bridge	18MC	do	NV–2.
Ready room	19MC	Intercom	SV–2.
Combat information	20MC	Central amplifier (early designs); Intercom (recent designs).	SV–1.
Captain's command	21MC	Intercom	Do.
Radio room	22MC	do	NV–1.
Distribution control	23MC	do	SV–1.
Flag officers command	24MC	do	Do.
Wardroom	25MC	Central amplifier	NV–4.
Machinery operation control.	26MC	Intercom	SV–1.
Sonar control	27MC	do	Do.
Squadron	28MC	Central amplifier	NV–4.
Sonar information	29MC	do	SV–2.
Bomb shop	30MC	Intercom	Do.
Escape trunk	31MC	Central amplifier	Do.

CENTRAL AMPLIFIER SYSTEM

A central amplifier system is designed to provide amplified voice and alarm signal communications to the various loudspeaker groups aboard ship. The equipment used in a central amplifier system consists of (1) microphone components, (2) amplifier components, and (3) loudspeaker components.

Microphone Components

Microphone components include all portable microphones, transmitter control stations, control boxes, talk-back switches, and microphone jack boxes.

PORTABLE MICROPHONE.—A portable microphone, sometimes called a portable transmitter, comprises a magnetic microphone with a "talk" push switch incorporated in the same case, and mounted in a transmitter arm or yoke that forms the upper part of a chest and bracket assembly. The complete assembly is supported on the user by means of a neckband or strap. This unit is provided with a length of portable cable that terminates in a plug. The speech or audible signal originates at this unit and its output is the audio input to the amplifier.

TRANSMITTER CONTROL STATION.—Transmitter control stations are classified as type A and F.

A type-A transmitter control station installed in an aircraft carrier is shown in figure 9-1. This station is contained in a watertight case provided with a hinged cover. Under the cover is a magnetic microphone enclosed in a watertight case and mounted on an adjustable bracket. The front panel contains the loudspeaker selector switches, required indicator lamps, volume indicator meter, and press-to-talk switch. A microphone input receptacle for a portable transmitter is located on the right-hand side of the case and is provided with a watertight cap. The type-A transmitter control station is used in circuits 1MC, 2MC, and 3MC.

The type-F transmitter control station is identical to the

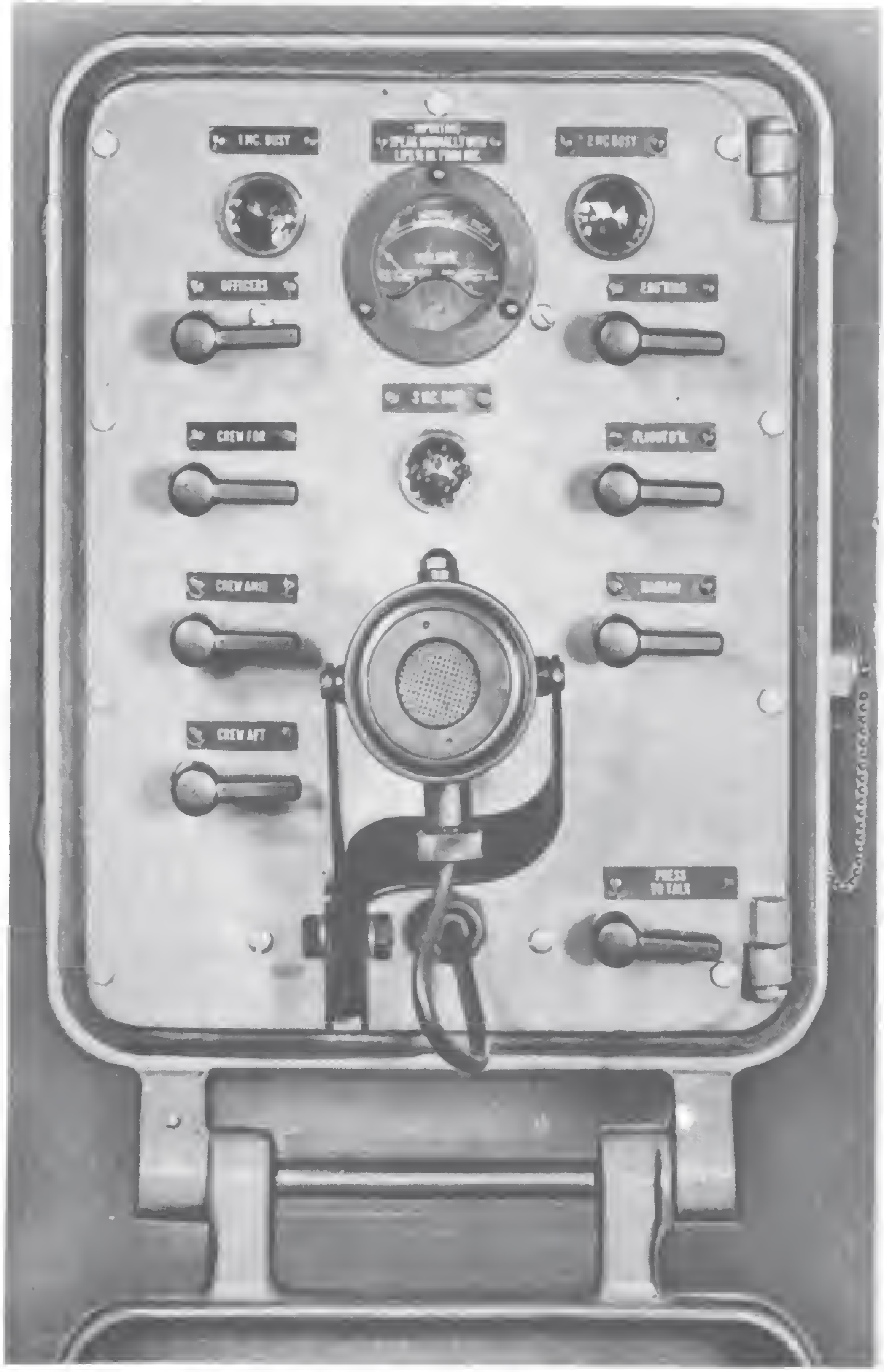


Figure 9–1.—Type-A transmitter control station.

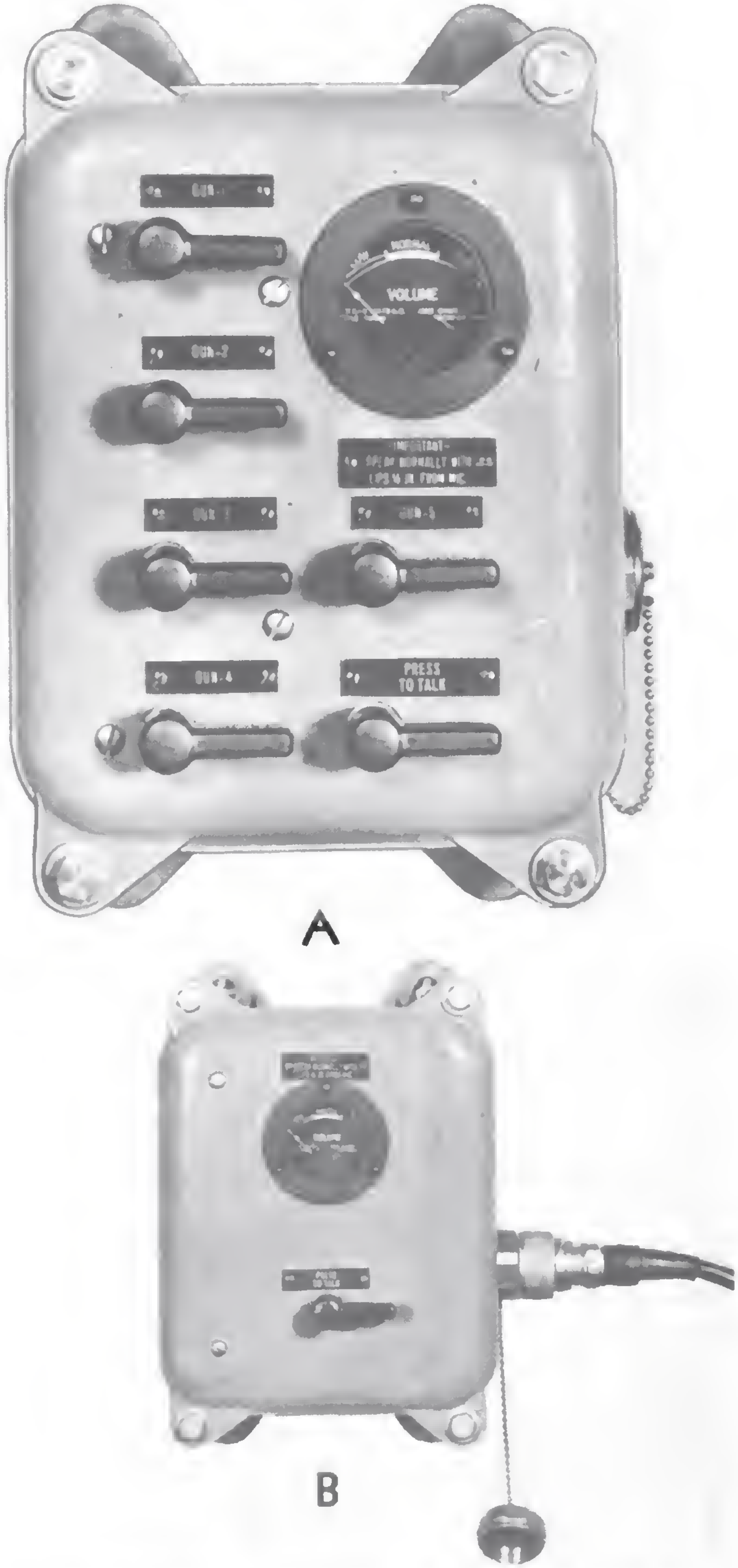


Figure 9–2.—Control box. A, Type D; B, Type E.

type-A station except that the type-F station is used in circuit 5MC and, on seaplane tenders, in circuit 6MC.

Transmitter control stations convert speech into electrical impulses and connect these impulses to the voltage amplifier in the amplifier rack.

Control box.—Control boxes are classified as type D, type E, and type MCT.

A type-D control box is shown in figure 9–2, A. This box consists of a watertight case without a cover. The front panel contains loudspeaker group selector switches, a volume indicator meter, and a press-to-talk switch. A portable transmitter is connected to the microphone input receptacle on the side of the box. The type-D control box is used primarily in circuit 17MC where the system design provides for individual gun-communications circuit selections at the control box.

A type-E control box is shown in figure 9–2, B. This box is similar to the type-D box except that it is not provided with loudspeaker group selector switches. The type-E control box is used primarily in circuit 17MC where communications-circuit selection is accomplished on the fire control switchboard.

The type-MCT control box is a splashproof box. It contains loudspeaker group selector switches; a pilot light to indicate that power has to be made available to the system; a volume indicator meter; talk-back disconnect switches to permit disconnecting the individual talk-back lines from the amplifier in case of a circuit fault; a tie-in switch to permit connecting the 1MC circuit to the loudspeakers; fuses for the power supply to the associated amplifier; and a microphone input receptacle for a portable transmitter. The type-MCT control box is used as the master station in circuits 11MC to 16MC inclusive. It contains the necessary controls and circuit relays because these controls are not included with the associated amplifier.

Talk-back switch.—A talk-back switch consists of a watertight box without a cover, as shown in figure 9–3. The

Figure 9–3.—Talk-back switch.

front panel contains an indicator lamp to indicate when the master control box is in use; a press-to-talk switch; and a microphone input receptacle for a portable transmitter. The portable transmitter is used for talking back when the background noise level is too high for satisfactory operation of the loudspeaker as a microphone. This talk-back switch is used at remote stations in circuits 11MC-16MC for the purpose of talking back to the master station.

Microphone jack box.—A microphone jack box consists of a watertight box without a cover, as shown in figure 9–4. The front panel contains two indicator lamps and a microphone input receptacle for a portable transmitter. The microphone jack box is used in various announcing circuits.

Amplifier Components

Amplifier components include all amplifiers, amplifier racks, and control racks. The incoming low-level speech or signals from the microphones are amplified in these components to a sufficiently high level for the proper operation

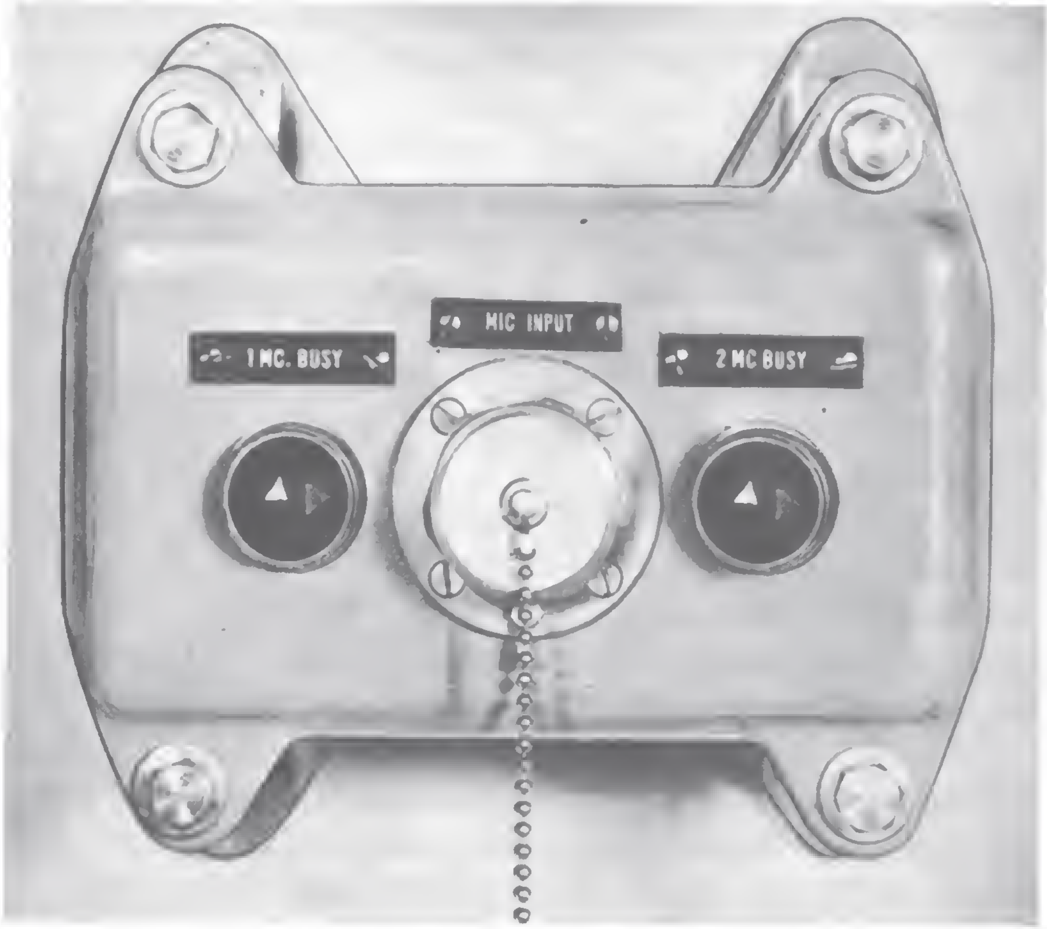


Figure 9–4.—Microphone jack box.

of the loudspeakers. The amplifiers include the (1) requisite audio signal generators that serve as the source for alarm signals; (2) necessary relays, switches, and control circuits which permit amplifier and signal generator transfer, microphone and loudspeaker circuit disconnects, establishment of circuit priorities, and proper functioning of indicator lights; and (3) test facilities for checking equipment performance and for making system adjustments.

TYPE-MCG AMPLIFIER.—The type-MCG amplifier is used for the combined 1MC, 2MC, and 3MC circuits. Each MC circuit is provided with a separate amplifier channel with facilities for combining any two or three circuits on a single amplifier channel in case of failure of any channel. Two amplifier channels are provided in ships that have circuit 1MC only, with one channel serving as a standby for the other. General alarm and chemical attack alarm signals are incorporated in this amplifier. Dual signal generators are provided for these alarm signals.

Type-MCF amplifier.—The type-MCF amplifier is used for circuit 5MC. A separate amplifier channel is provided for each superpower loudspeaker with facilities for combining any two loudspeakers on a common amplifier channel in case of failure of the other channel of a pair. Flight deck warning and flight crash alarm signals are incorporated in this amplifier. Dual signal generators are provided for these alarm signals.

Type-MCT amplifier.—The type-MCT amplifier is used for circuits 11MC to 16MC inclusive. Operating controls are not provided because all necessary circuit controls are incorporated in the associated type-MCT control box previously described under microphone components.

Type-MCA amplifier.—The type-MCA amplifier is used for circuit 17MC. A separate amplifier channel is provided for each gun director. A signal generator is provided for each amplifier channel for salvo and cease firing signals.

Loudspeaker Components

Loudspeakers convert the electrical output from the amplifier back into audible sound. Loudspeakers are classified as low (L), standard (S), medium (M), and high (H), depending on the power output. The power output depends on the size of the space to be covered and the noise level in that space.

Types L and S loudspeakers.—The type-L and type-S loudspeakers are of the direct radiator design (fig. 8–7). The line impedance is matched to the voice-coil impedance of the loudspeaker by shifting the line leads to different taps on the input transformer.

Type M and H loudspeakers.—The type-M and type-H loudspeakers are of the folded-horn design (fig. 8–9). As in the types L and S loudspeakers, the connection of the line leads and the voice-coil leads to the input transformer determines whether the loudspeaker is classified as type M or type H.

MCG General Announcing System

The MCG general announcing system, formerly called the battle announcing system, is the principal announcing system in naval vessels. It consists of circuits 1MC, 2MC, and 6MC and is designed to provide amplified voice and alarm signal communications to the various loudspeaker groups aboard ship.

A complete general announcing system provides means for (1) transmitting the spoken word or signal at any one of several stations; (2) amplifying this signal at a central amplifier; and (3) radiating the signal from many loudspeakers. A large ship has six or eight transmitting stations, two or more amplifiers, and several hundred loudspeakers.

All Navy general announcing systems have, as part of the amplifier circuit, one or more signal generators which produce various alarm signals that are amplified and then radiated by the loudspeakers. The types of signals generated by these generators are (1) general alarm, (2) chemical attack alarm, (3) salvo, and (4) cease firing signals. The first two signals are transmitted throughout the ship. The salvo and cease firing signals are transmitted only to the gun stations.

A block diagram of the MCG general announcing system installed in a cruiser of the Worcester class is shown in figure 9–5. This system consists of two interconnected circuits, the general announcing system (circuit IMC), and the engineers announcing system (circuit 2MC), which use two amplifier channels designated *A* and *B*. Normally, the 1MC circuit operates through channel *A* and the 2MC circuit operates through channel *B*. In an emergency, however, both circuits can use one amplifier channel. Two signal generators in the control rack generate alarm signals. One signal generator is in regular use while the other signal generator is in emergency standby service. This announcing system uses 115-volt a-c power from the I. C. switchboard.

The 1MC CIRCUIT is for general announcing purposes and provides communication from the 1MC transmitter control stations to loudspeakers of the 1MC and 2MC circuits. Cir-

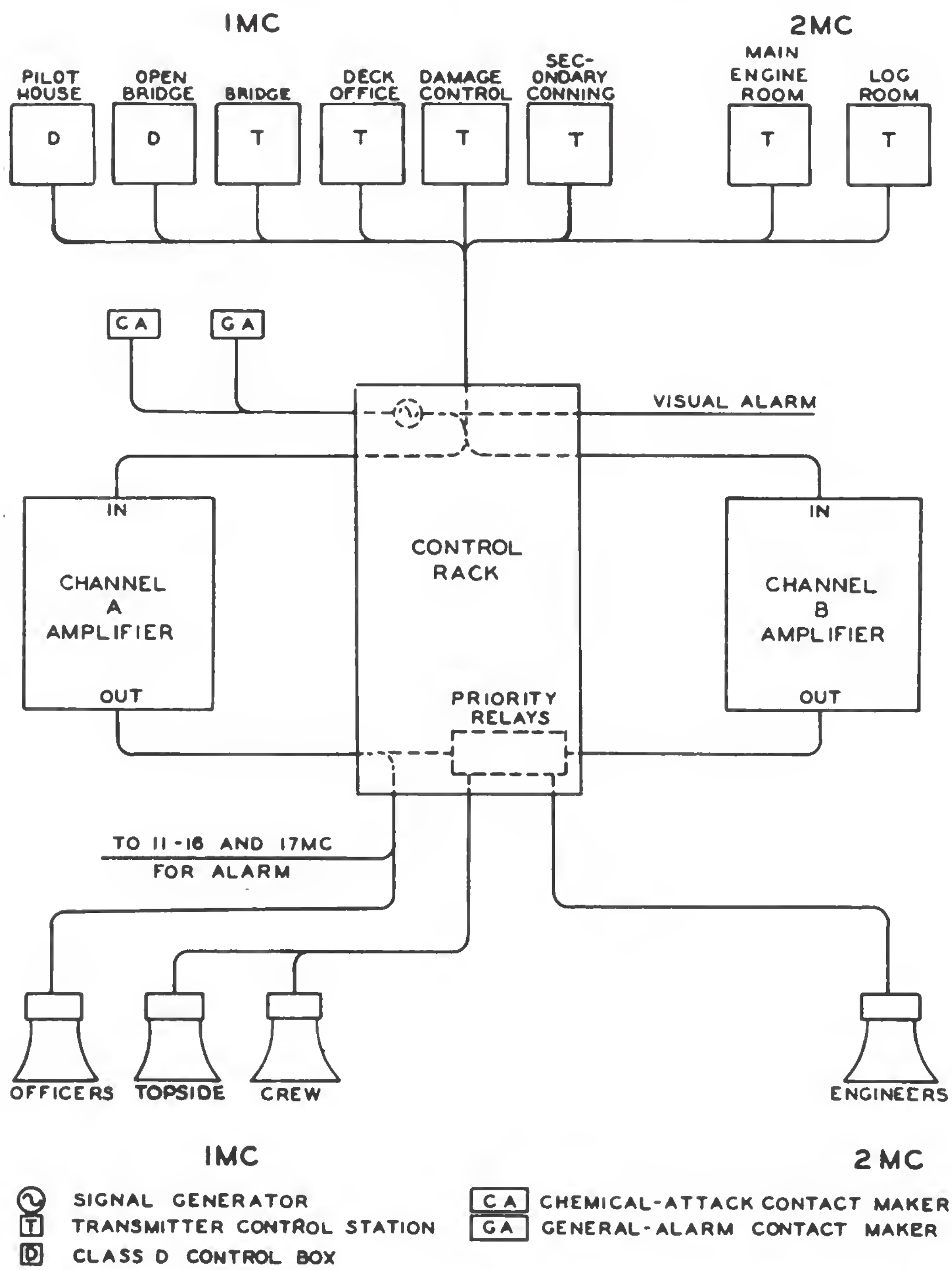


Figure 9–5.—Block diagram of an MCG general announcing system.

cuit 1MC has four transmitting stations and two class-D control boxes. The transmitting stations are located at the (1) bridge, (2) deck office, (3) damage control central, and (4) secondary conning station. One of two class-D control boxes that are used with portable microphones only is located in the pilot house and the other is located on the bridge. The 1MC loudspeakers are located (1) in the officers' country, (2) in the crew's spaces, and (3) topside.

Manual switches for energizing the signal generator and for sounding either the chemical attack or general alarm are located at the pilot house, open bridge, deck office, and forward air defense. Closing an alarm switch energizes one of the signal generators and relays, and automatically connects the alarm signal generator output to the 1MC amplifier input. At the same time, relays operate to place all loudspeakers of the 1MC and 2MC circuits on the 1MC amplifier output. In addition, loudspeakers in the MCA system (17MC circuit) are connected to the 1MC amplifier output to receive the alarm signal. The alarm signals have priority over all other functions of the 1MC, 2MC, and 6MC circuits.

The 2MC CIRCUIT provides communication from the 2MC transmitter control stations to loudspeakers of the 2MC circuit. This circuit has two transmitting stations which are located in the (1) main engine room and (2) log room. The 2MC loudspeakers are located in the engineering spaces. The signal from the 2MC transmitter stations can be reproduced by the 1MC topside and crew loudspeaker groups. The 1MC transmitter stations, however, have priority over the 2MC transmitter stations in communicating with any loudspeaker groups.

The 6MC CIRCUIT provides voice communication from the bridge transmitter station to the topside bull horn. This circuit operates from the bridge only and the 1MC and 2MC circuits have priority over the 6MC circuit at all times.

AMPLIFIER RACK.—The amplifier rack provides facilities for housing two voltage amplifiers and two 500-watt power amplifiers. One voltage amplifier with compressor and one

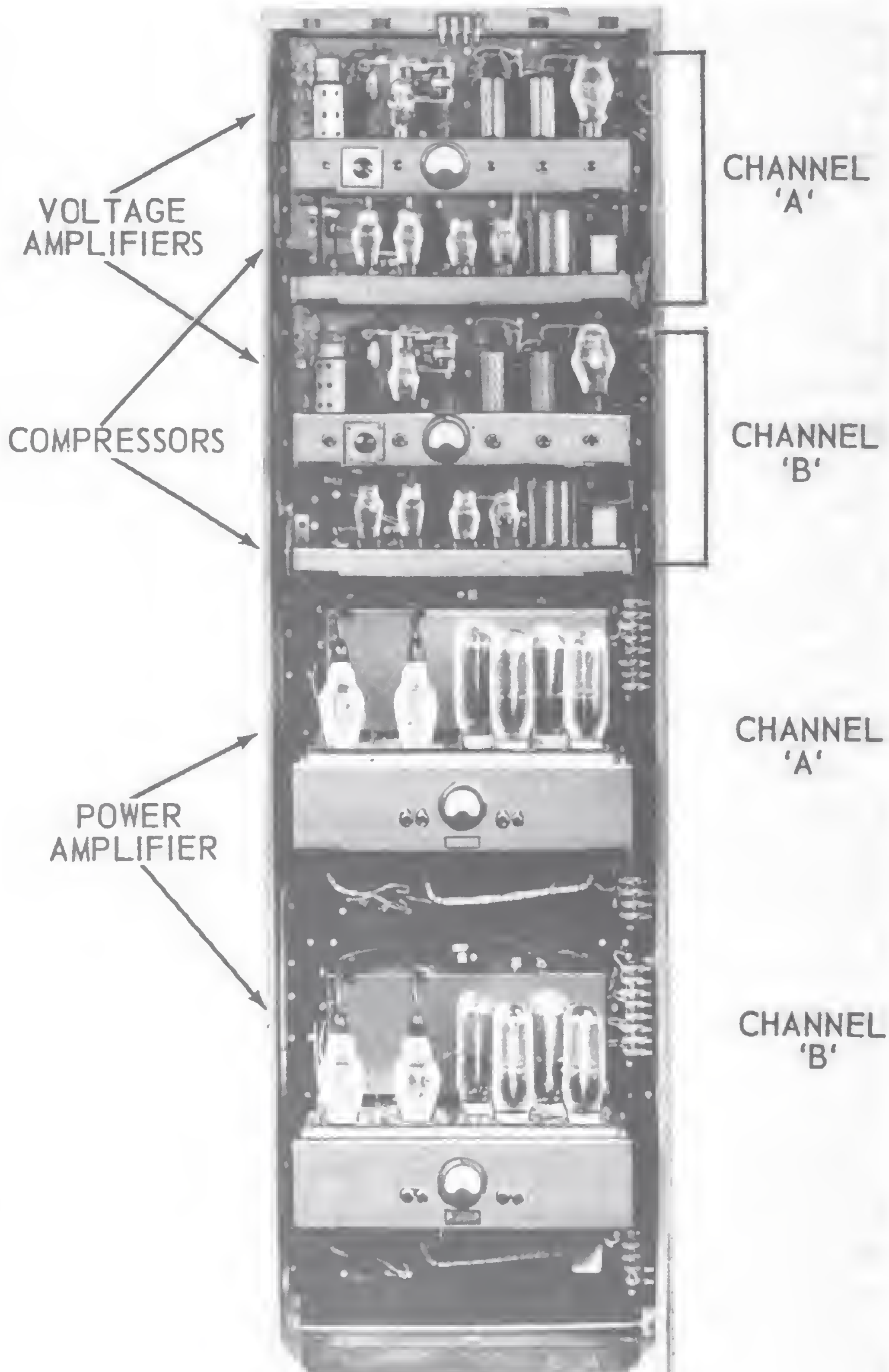


Figure 9-6.—Amplifier rack.

500-watt power amplifier constitute a channel, as shown in figure 9–6. All tubes in the amplifier rack are paralleled with a duplicate tube as a protection against interruption caused by tube failure. Thus, a failure of one tube does not make the amplifier inoperative.

The voltage amplifier with compressor consists of two chassis fastened on a subpanel mounted in the amplifier rack. The voltage amplifier (upper chassis) consists of three stages of amplification together with rectifier tubes that supply d-c plate power for the voltage amplifier and compressor. The compressor (lower chassis) consists of one stage of amplification and two separate signal rectifier stages. The voltage amplifier amplifies voice, command, and alarm signals and drives the power amplifier.

A schematic diagram of a voltage amplifier is shown in figure 9–7. The circuit consists of two stages of voltage amplification and an output stage. Incoming signals from the microphone are fed to the primary of the input transformer, *T*1. The secondary of the input transformer is connected through the normally closed contacts on relay *RL*1 to the grids of the parallel-connected pentodes *V*1 and *V*2. *R*1 is a grid leak resistor. It prevents the grids from acquiring a negative charge when relay *RL*1 is operated and the normally closed contacts are open. *V*1 and *V*2 are cathode biased by resistor *R*2 which is bypassed by capacitor *C*1. These tubes are biased to operate as a class-A amplifier. The screen-grid voltage is obtained through series-dropping resistor *R*3. The screen grid is bypassed by capacitor *C*2. *R*4 is the plate-load resistor.

The amplified signal from the plates of pentodes *V*1 and *V*2 is fed through coupling capacitor *C*3 to volume control potentiometer V_c. From the volume control the signal goes to the volume-compressor switch, *SW*1. When this switch is in the OFF position, the signal is applied directly to the grids of triodes *V*3 and *V*4. These tubes drive the output beam power tetrodes *V*5, *V*6, *V*7, and *V*8. When the compressor switch is in the ON position, the plates of *V*1 and *V*2

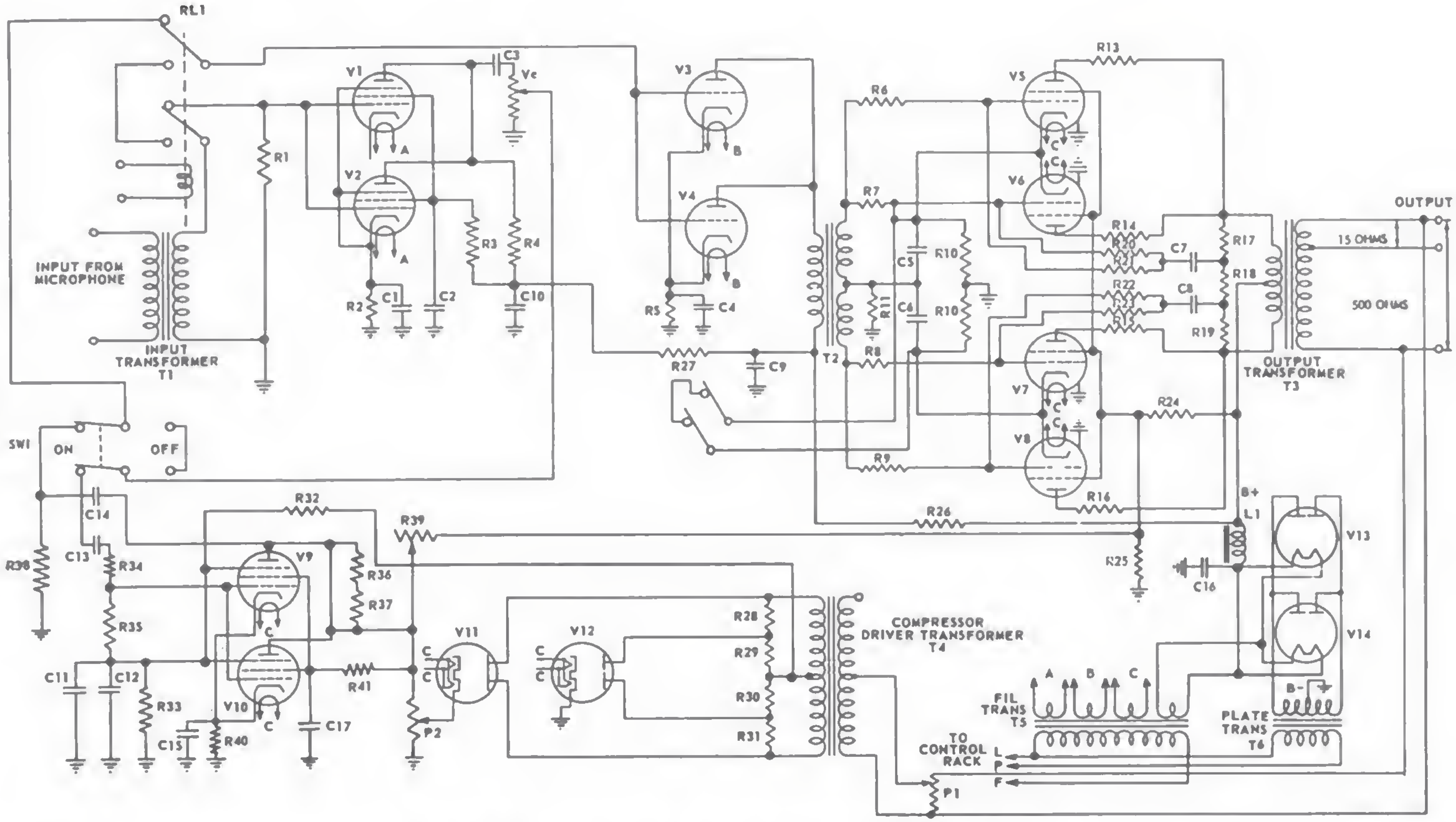


Figure 9–7.—Schematic diagram of a voltage amplifier.

are *R-C* coupled through resistor *R*34 and capacitor *C*13 to the grids of *V*9 and *V*10 in the compressor limiter. The signal at the plates of these tubes is coupled through capacitor *C*14, switch *SW*1, and relay *RL*1 to the grids of the driver stage, *V*3 and *V*4. The plate potential of *V*9 and *V*10 in the compressor-limiter unit is controlled by means of voltage-control rheostat *R*39. Cathode bias for *V*9 and *V*10 is supplied by resistor *R*40. Capacitor *C*15 is a bypass capacitor for resistor *R*40. The screen grid voltage is obtained through series dropping resistor *R*41 from a voltage-divider network composed of *P*2, *R*39, *R*25, and *R*24. The screen grid is bypassed by capacitor *C*17. *V*3 and *V*4 are transformer coupled to the parallel push-pull output stage *V*5, *V*6, *V*7, and *V*8 and are cathode biased by means of resistor *R*5 which is bypassed by capacitor *C*4.

The signal is fed from one end of the center-tapped secondary of transformer *T*2 to the grids of the upper output tubes *V*5 and *V*6 and from the other end of the secondary to the grids of the lower output tubes *V*7 and *V*8. Thus the signal at the grids of the upper pair of tubes is 180° out-of-phase with the signal at the grids of the lower pair. This action results in push-pull operation for the output stage. The output tubes are biased for class-B operation. Upper output tubes *V*5 and *V*6 are biased by one-half of resistor *R*10, and lower output tubes *V*7 and *V*8 are biased by the other half of this resistor. Capacitors *C*5 and *C*6 stabilize the cathode bias voltage across *R*10 and bypass the signal around it.

Series grid-resistors *R*6, *R*7, *R*8, and *R*9 decouple the grids of the four output tubes and provide a circuit across which a feedback voltage is fed from the plates of these tubes. In other words, these resistors suppress parasitic oscillations. These resistors also limit grid current on the peak positive swing of grid voltage.

The output signal from the plate of each of the output tubes is fed through resistors *R*13, *R*14, *R*15, and *R*16 to output transformer *T*3. Although these resistors serve no purpose under normal operating conditions, they reduce the tendency of the output tubes to oscillate when the two push-pull sections are unbalanced. Part of the voltage developed across the output transformer winding is applied to the grid circuits of the output tubes as degenerative feedback. The plate-to-plate voltage of the output tube is applied to a voltage divider that consists of resistors *R*17, *R*18, and *R*19. A portion of this output voltage from these resistors is coupled through capacitors *C*7 and *C*8 and through series resistors *R*20, *R*21, *R*22, and *R*23 to the grids of the output tubes. This feedback signal provides the desired degenerative feedback.

The B+ power for the plates of all of the tubes in the voltage amplifier is supplied by a full-wave rectifier (*V*13 and *V*14 in parallel). The alternating voltage supplied to the plates of these rectifiers is taken from plate transformer *T*6. Note that this transformer, unlike most power transformers, is separate from the transformer that supplies the heater current for the tubes in the amplifier. This use of two transformers permits filament transformer *T*5 to be energized whenever the amplifier is in a standby condition. Plate transformer *T*6 is energized only when the amplifier is in actual operation or in a ready condition. The midpoint on the plate transformer secondary is grounded. Therefore the B− voltage is at ground potential. The B+ voltage is obtained from the filament side of the tube circuit and is filtered by the capacitor input filter which is composed of inductor *L*1 and capacitor *C*16.

Screen-grid voltage for the tubes in the output stage is obtained from the power supply through series screen-grid resistor *R*24. Bleeder resistor *R*25 is connected from the screen grid of the output tubes to ground. The screen-grid dropping resistor, therefore, carries screen-grid current plus a bleeder current. The bleeder current is constant and therefore tends to stabilize the screen-grid voltage.

Plate voltage for the driver tubes *V*3 and *V*4 is taken from the B+ output of the rectifier through a decoupling filter that consists of resistor *R*26 and capacitor *C*9. The plate voltage for the pentodes *V*1 and *V*2 is taken from the plate-voltage supply for the driver tubes through a second decoupling filter that consists of resistor *R*27 and capacitor *C*10. Screen-grid voltage is applied to the pentodes through series resistor *R*3.

Output impedances of either 15 or 500 ohms are available at the output terminals of the amplifier. This arrangement permits the output from the amplifier to be applied to a load of either 15 or 500 ohms.

The COMPRESSOR-LIMITER CIRCUIT, which consists of a compressor and a limiter, is used to make speech more intelligible when there is high background noise at the loudspeaker.

The COMPRESSOR CIRCUIT acts like an automatic volume control. It varies the output of the voltage amplifier by changing the gain of the amplifier with changes in the input-signal level. When the input signal is large, the circuit reduces the gain and when the input signal is small, the circuit increases the gain. This action keeps the output signal of the amplifier at a constant level.

The output signal of the voltage amplifier is taken from output transformer *T*3 and is connected across potentiometer *P*1. The setting of the potentiometer determines the voltage across the primary of compressor-driver transformer *T*4. The secondary voltage of this transformer is connected across a voltage divider that consists of resistors *R*28, *R*29, *R*30, and *R*31. Both the secondary of *T*4 and the center point of the voltage-divider network are grounded through resistors *R*32 and *R*33.

Approximately 15 percent of the total voltage across the voltage divider is applied to the plates of the right-hand duodiode signal-rectifier tube *V*12. The cathodes of this tube are connected directly to ground. On each half cycle of the a-c voice signal, first one and then the other of the plates of the signal-rectifier tube conducts. The current flows from the cathodes to the plates and then through resistors *R*29 (or *R*30), *R*32, and *R*33 to ground. This current charges capacitors $C11$ and $C12$ to a negative potential, the magnitude of which is proportional to the magnitude of the voice signal. The negative charge on these capacitors biases both the suppressor and control grids of the variable-mu pentodes $V9$ and $V10$. Because the bias voltage is directly proportional to the output signal of the voltage amplifier, and because the gain of the amplifier varies with this bias, the gain of tubes $V9$ and $V10$ decreases when the output signal increases. This action is called COMPRESSION. The amount of compression is determined by the setting of compressor potentiometer $P1$. When the compressor is used, the triodes $V3$ and $V4$ receive their input signal from the plates of tubes $V9$ and $V10$ and not directly from the volume control V_c.

The LIMITER CIRCUIT keeps the signal from exceeding any desired level. It clips off sudden noise impulses and reduces the effect of noise. This circuit uses $V9$, $V10$, and $V11$. The entire secondary vòltage of compressor-driver transformer $T4$ is applied directly to the plates of $V11$. The voltage applied to this tube is more than six times as great as the voltage applied to the plates of $V12$. The cathodes of the left-hand tube $V11$ are made positive with respect to ground by a voltage that is determined by the setting of limiter potentiometer $P2$. Consequently, the tube does not conduct until the peak signal voltage applied to its plates exceeds the cathode voltage as set by the limiter potentiometer. However, when the peak signal exceeds the cathode voltage, current flows through this tube, through resistors $R32$ and $R33$, and charges capacitors $C11$ and $C12$. This action biases $V9$ and $V10$ as described in the compressor circuit. The amplification of this stage is decreased as much as the input signal is increased whenever the limiter conducts. Thus, the output of the amplifier does not rise appreciably above the value set by the limiter potentiometer. This action cuts off sudden noise impulses, such as static noises.

The POWER AMPLIFIER unit is mounted on a hinged shelf in the amplifier rack. It consists of a single stage audio amplifier with its associated power supply. The input signal voltage is obtained from the output of the voltage amplifier. The output feeds into a coupling transformer or resistance network in the CONTROL RACK for distribution to the various groups of loudspeakers.

A schematic diagram of a 500-watt power amplifier is shown in figure 9–8. The input signal from the voltage amplifier is fed to the primary of input transformer T1. The secondary of this transformer is connected to the grids of *V*1, *V*2, *V*3, and *V*4 operating in parallel push-pull. The plates of these tubes are connected to the primary of the output transformer. The B+ power for the four amplifier triodes is supplied by a separate plate transformer and rectifier tubes *V*5 and *V*6 that comprise a full-wave rectifier. The output of the rectifier circuit is filtered and fed to the amplifier tubes. The output transformer drives a coupling transformer in the control rack which distributes the signal to the various groups of loudspeakers.

The SIGNAL GENERATOR comprises a chassis on which are mounted the components to produce the bell-tone signal for general alarm, and the various audio frequencies for alarm or command signals aboard ship. These signals can be used also for test purposes.

The signal generator circuit consists of (1) a rectifier section that uses two rectifier tubes in parallel and (2) an oscillator and amplifier section containing two twin triode tubes. One triode unit of each tube has an associated *R-C* network. These triode units with their associated *R-C* networks are connected in parallel to generate the composite signal for the general alarm bell tone. The other triode units of these tubes are connected either in parallel as an amplifier to amplify the composite signal generated for the general alarm bell tone, or as an oscillator to generate the various audio frequencies for alarm or command signals.

A motor, which runs when any contactor or test button is depressed, drives the interrupter used in the generation of the general alarm bell-tone signal and in "coding" various

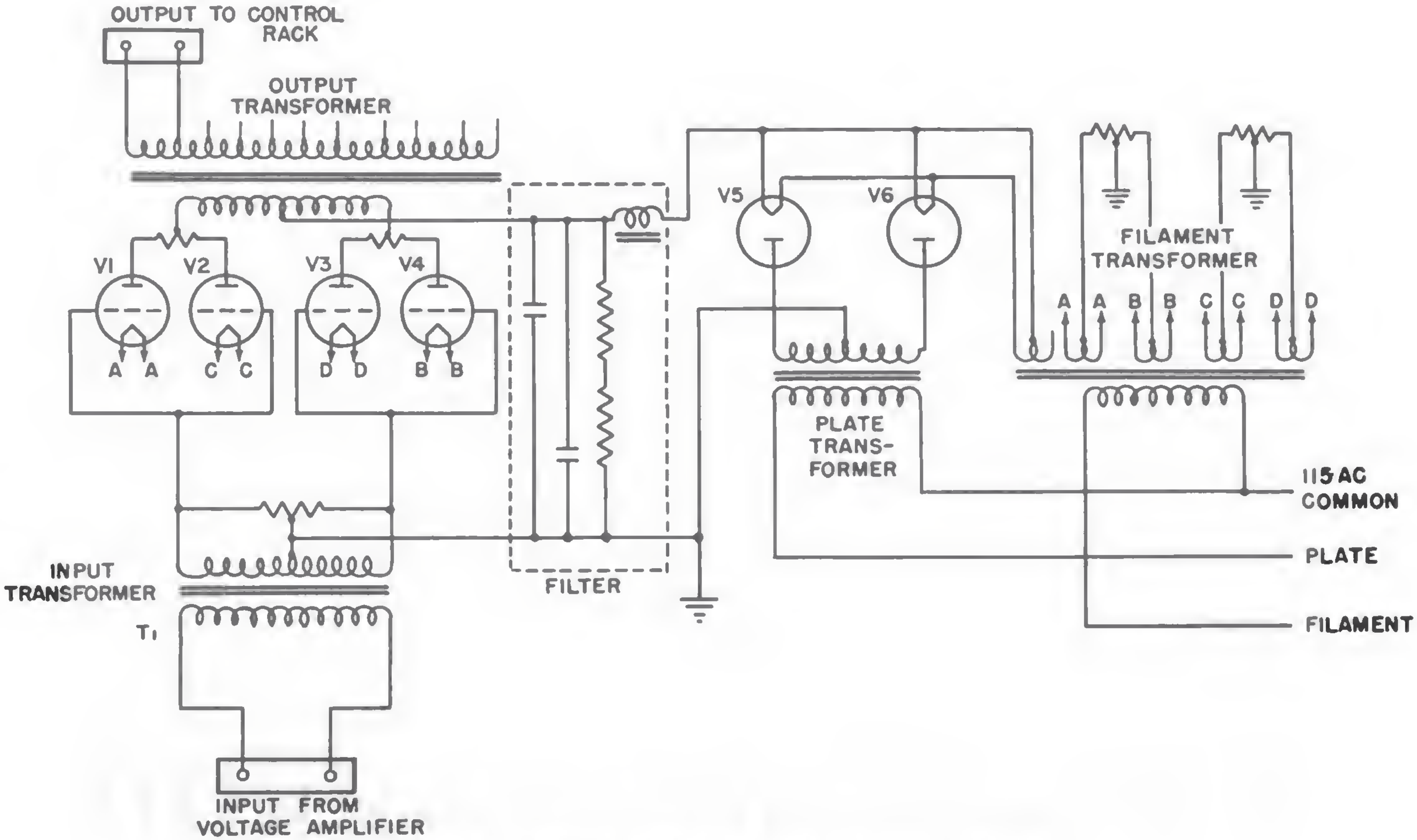


Figure 9–8.—Schematic diagram of a 500-watt power amplifier.

alarm or command signals. The interrupter is so constructed that the connection for the bell tone is a momentary contact, and the connection for the jump-frequency signal is a contact lasting for one-half revolution of the contactor.

The general alarm signal is an interupted bell tone. When the external general alarm switch is closed momentarily, the motor operates. The bell tone then is sounded over all loudspeakers for a period of 15 seconds.

The chemical attack alarm signal is a steady 1,000-cycle tone generated by the signal generator and sounded as long as the external alarm contact maker is depressed.

In general announcing systems that have a 17MC circuit as well as the 1MC and 2MC circuits, the signal generator produces two additional signals. These are the salvo and cease firing signals that are connected to the 17MC circuit only and sounded at the gun stations. The salvo signal is a steady 600-cycle tone. The cease firing signal consists of two tones sounded alternately for one-third second each. This signal is a jump-frequency tone composed of a 600-cycle tone and a 1,500-cycle tone.

Control rack.—The control rack provides a mounting for the necessary switches, meters, relays, and associated equipment for the control and testing of the circuits in which it is used. The rack also contains the signal generators that produce alarm signals aboard ship. The control rack is a steel cabinet with two hinged doors, as shown in figure 9–9. The doors provide access to the equipment inside for routine testing, adjusting, and maintenance. Mounted on the front doors of the cabinet are the (1) type JR rotary switches for selecting the various amplifier channels; (2) toggle switches for connecting various loudspeaker groups to the amplifier; and (3) amplifier-channel, signal-generator, and test switches.

Mounted on a panel above the doors are two meters and four rotary switches. The meters are used in testing the amplifier channels and signal generators. The switches select the unit to be tested.

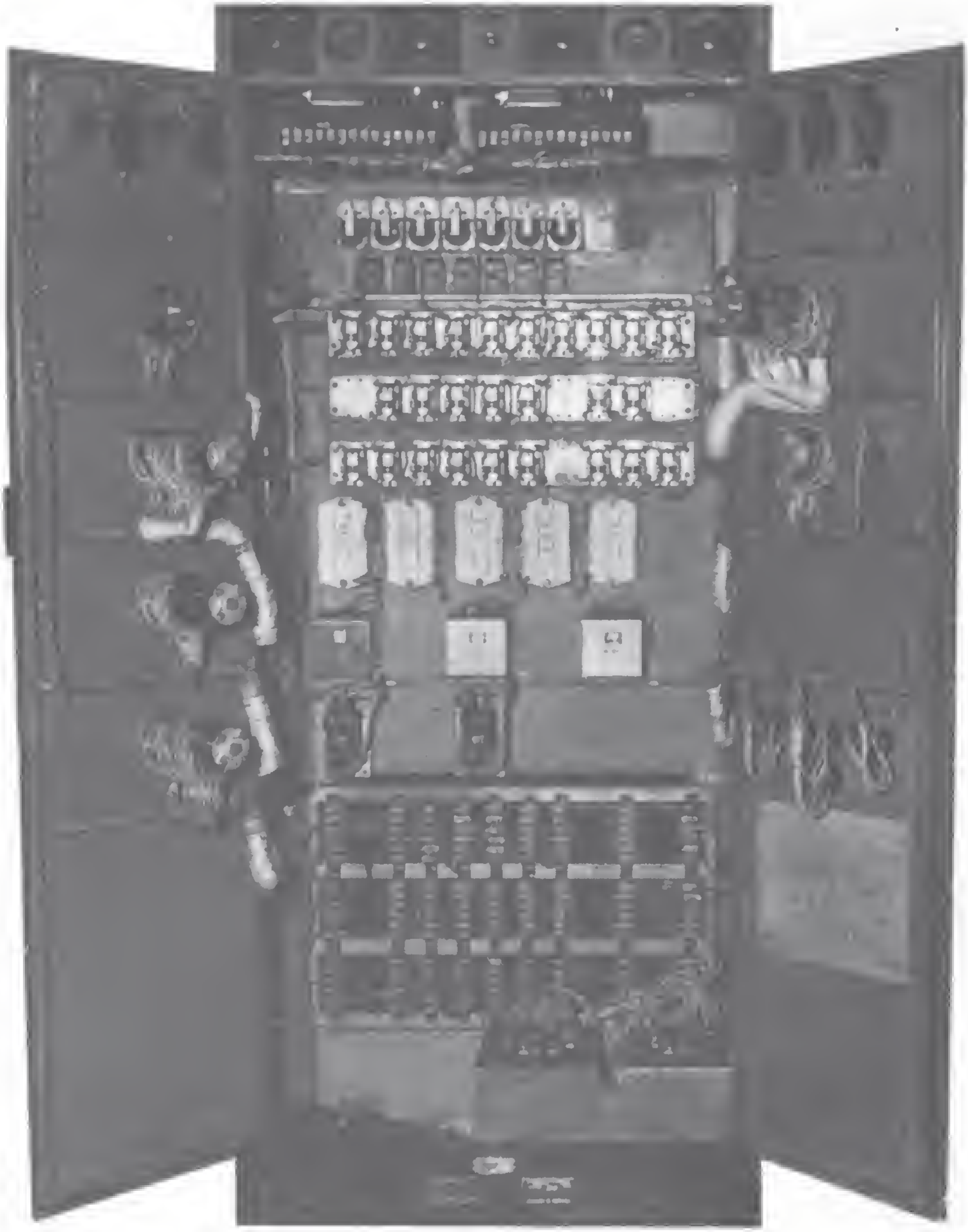


Figure 9–9.—Control rack.

Mounted inside the control rack from top to bottom are two signal generators; one row of seven low-level relays; one row of seven capacitors; three rows of high-level relays; one row of five groups of resistors; one row of three time-delay relays; one row of two contactors; three rows of terminal boards; and two output transformers on the bottom of the rack.

The rotary selector switches on the cabinet doors connect the 1MC and 2MC circuits to either of the two amplifier channels individually, or both circuits to the same channel. Separate switches select the amplifier input and amplifier output. Three switches connect the transmitting control stations to the 1MC circuit and one switch connects the transmitting control stations to the 2MC circuit. These transmitter selector switches are of the either-or-both type—that is, they connect either one of their two transmitter stations to the system individually or to both at the same time, as desired. Eight toggle switches are used to connect the loudspeaker groups and are used also to disconnect faulty lines that impair the operation of the amplifier.

The signal generator selector switch places either one of the two signal generators in operation. Four test push switches mounted alongside the signal generator selector switch test the general alarm and chemical attack alarm on both signal generators.

Five snap switches are mounted at the top of the two doors. These switches control the power to the amplifier channels, to the relays in the control rack, and to the two signal generators. Also at the top of the doors are two toggle switches for testing the amplifier channels.

The two line-matching transformers are located at the bottom of the cabinet. The primary windings of these transformers are connected to the output of the power amplifier. Each amplifier channel has its associated line-matching transformer. The use of the line-matching transformer simplifies impedance matching, power distribution, and the switching arrangement. The lines to the loudspeaker groups are connected to the line-matching transformer through the group relay. Variable-impedance taps are provided on both the primary and secondary of the transformers so that the impedance of the amplifier and its load can be matched.

Whenever a group or groups of loudspeakers are disconnected from the audio transmission circuits, the group relay automatically inserts a resistor in place of the speakers.

Thus the amplifier output is always "looking into" the same impedance irrespective of the number of loudspeaker groups being used at any time.

Details such as the complex wiring of the control rack are beyond the scope of this training course. For more complete details, refer to the applicable instruction book provided with the general announcing system installed in your ship.

TRANSMITTER CONTROL STATION.—The microphone on the transmitter control station functions like the cantilever type sound-powered telephone transmitter. It converts sound waves into a fluctuating electric current that is transmitted to the control rack. The press-to-talk switch operates a relay in the control rack that completes the circuit between the microphone and the voltage amplifier. The loudspeaker group selector switches also operate relays in the control rack. When closed, these selector switches connect the selected loudspeaker groups to the amplifier output.

When using a type-A transmitter control station:

1. Open the hinged cover.
2. Close the loudspeaker group selector switches for the desired groups.
3. Depress the press-to-talk switch.
4. Speak into the microphone in a normal tone of voice and hold the microphone approximately one-half inch from the lips.

At the completion of the message:

1. Release the press-to-talk switch.
2. Turn off the loudspeaker group selector switches.
3. Close the cover of the transmitter control station.

CONTROL BOX.—When using a type-D control box:

1. Remove the screw cover from the microphone input jack located on the right-hand side of the box.
2. Insert a chest plate microphone into the jack.
3. Close the loudspeaker group selector switches for the desired groups.

4. Depress the press-to-talk switch.
5. Speak into the microphone in a normal tone of voice.
6. Release the press-to-talk switch when the message is completed.

LOUDSPEAKERS.—As previously explained, a permanent magnet in the loudspeaker produces a magnetic field. A 6.4-ohm voice coil in this field is connected to the low impedance winding of the transformer associated with that loudspeaker. The transformer causes currents to flow in the voice coil. The fluctuating currents cause the voice coil to move within the magnet. The diaphragm of the loudspeaker is connected to the voice coil so that motion of the voice coil causes motion of the diaphragm. The diaphragm sets up sound waves that reproduce the original spoken words.

Approximately 163 loudspeakers are used in the general announcing system installed in the *Worcester* class cruiser. These loudspeakers are divided into four groups which serve the following areas: Group 1, officers' country; group 2, engineering spaces; group 3, topside; and group 4, crew's spaces. These groups have about 22, 21, 22, and 98 loudspeakers respectively.

SYSTEM OPERATION.—When a loudspeaker group selector switch at the control station is closed, a circuit is set up that energizes the relay associated with that switch. When the press-to-talk switch at the control station is depressed, the loudspeaker group relay is energized and closes. This action connects the loudspeaker group to the output of the amplifier. The press-to-talk switch also connects the microphone, through the microphone relay, to the input of the voltage amplifier. Also the press-to-talk switch, when depressed, energizes a relay that lights the indicator (busy) lamp for that circuit at all transmitter stations and turns on plate current to the amplifier rack, thus putting the amplifier in a ready condition.

When sound waves strike the microphone, they are changed into electrical impulses. These impulses are fed into the amplifier rack and are amplified first by the voltage ampli-

Figure 9–10.—Sound-powered telephone loudspeaker and amplifier.

fier and then by the power amplifier. The signals are transmitted to the various loudspeaker groups, the relays of which have been closed by the loudspeaker group selector switches at the control station. At the loudspeakers, the amplified electrical impulses are changed back into sound waves that are identical to those striking the microphone of the transmitting unit.

Sound-Powered Telephone Amplifier System

Navy telephone amplifier systems receive, amplify, and reproduce speech from a sound-powered telephone line using a sound-powered telephone headset. The system is designed to reproduce voice signals that are clear and understandable at locations aboard ship where the noise level is high, such as gun mounts and machinery spaces.

The equipment used in a telephone amplifier system consists of (1) a loudspeaker and (2) an amplifier, as shown in figure 9–10. The other components that comprise the overall system—such as sound-powered telephone headsets, jackboxes, telephone line, and ship's power supply—are not furnished with this equipment.

A block diagram of a sound-powered telephone amplifier system is shown in figure 9–11. This diagram shows the telephone circuit, the two telephone amplifiers, sound-powered telephone headsets, and two loudspeakers. The

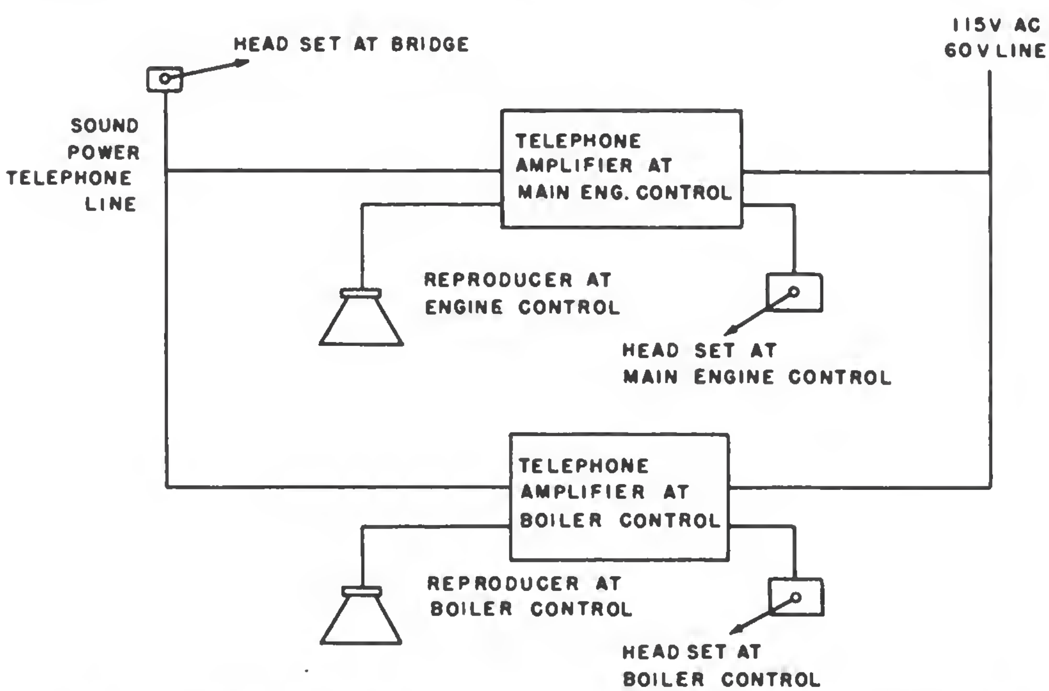


Figure 9–11.—Block diagram of a sound-powered telephone amplifier system.

telephone amplifiers amplify the signal from sound-powered telephones and feed this amplified signal both to a locally installed sound-powered telephone and to an external loudspeaker.

The telephone amplifier is energized from the ship's 115-volt a-c supply and has an input impedance of 500 ohms. Sound-powered telephone headsets used as microphones are produced by four different manufacturers and consequently have different output characteristics. Therefore, a filter is connected to the input circuit of the system to compensate for the difference in output characteristics of these four types. A switch in the filter makes it possible to adjust the filter for the particular type of headset used with the amplifier.

LOUDSPEAKER.—The loudspeaker is of the permanent-magnet, folded-horn type. A matching transformer is an integral part of the unit. The loudspeaker horn, base, and transformer compartment comprise a single aluminum casting. Input connections to the unit are made on a terminal board inside the transformer compartment.

A diaphragm-and-support assembly, carrying the voice coil, is mounted on the magnet and pole-piece assembly. Locating pins are provided in the field structure so that, if the diaphragm-and-support assembly is removed, the voice coil is automaticaly centered when replacement is made.

A blast valve is mounted in the throat of the loudspeaker. Any sound wave that has sufficient force to damage the diaphragm, such as a blast due to gunfire, moves the blast valve so that it closes the opening to the diaphragm chamber, thus protecting the diaphragm.

AMPLIFIER.—The telephone amplifier is contained in a watertight aluminum case designed for bulkhead mounting. The front of the case is a hinged metal panel. The chassis is mounted on the back of this panel and the operating controls are mounted on the front. To prevent damage, the controls are mounted in a recessed section of the front panel which contains the volume control, an on-off switch, two indicating fuse holders, and an indicator lamp. The panel and chassis assembly is easily removable for replacement of parts and for servicing.

A schematic diagram of a telephone amplifier is shown in figure 9–12. The amplifier is a two-stage *R-C* coupled unit. Each stage operates in push-pull. The signal received from the sound-powered telephone line passes through the compensating filter to the primary of the input transformer, *T*1. The secondary of the input transformer is connected to the grids of *V*1 and *V*2, which are the first amplifier stages. The grids of *V*1 and *V*2 operate in push-pull because they connect to the opposite ends of the secondary of *T*1 and the cathodes are returned to the center tap. The bias for these tubes is obtained across resistors *R*1 and *R*2. The positive potential for the screen grids and plates of these tubes, is obtained through the voltage-dropping resistors *R*3, *R*4, *R*5, and *R*6. These resistors are connected to relay *K*1 which is closed when the amplifier is energized.

The output of the first stage is capacitance coupled to the grids of *V*3 and *V*4 of the second stage. These tubes also operate in push-pull. They are biased by common cathode resistor *R*9. The screen grids of these tubes obtain their positive potential through resistor *R*10 which is connected to the center tap of the output transformer, *T*2. This B+ voltage passes through the primary winding of the output transformer to the plates of *V*3 and *V*4. The amplified signals at the plates of these tubes drive the primary of the output transformer. The secondary of the output transformer is connected to the external loudspeakers.

Potentials for the plates and grids of all the tubes are obtained from two paralleled rectifier tubes *V*5 and *V*6 connected as a full-wave rectifier. The pulsating d-c output of the rectifiers is filtered by the capacitor input filter composed of capacitors *C*3 and *C*4 in parallel, inductor *L*1, and capacitors *C*5 and *C*6 also in parallel. The B+ potential is fed to the center tap of the output transformer for the output tubes and through the voltage-dropping resistors *R*11 and *R*12 to contact relay *K*1 for the first stage.

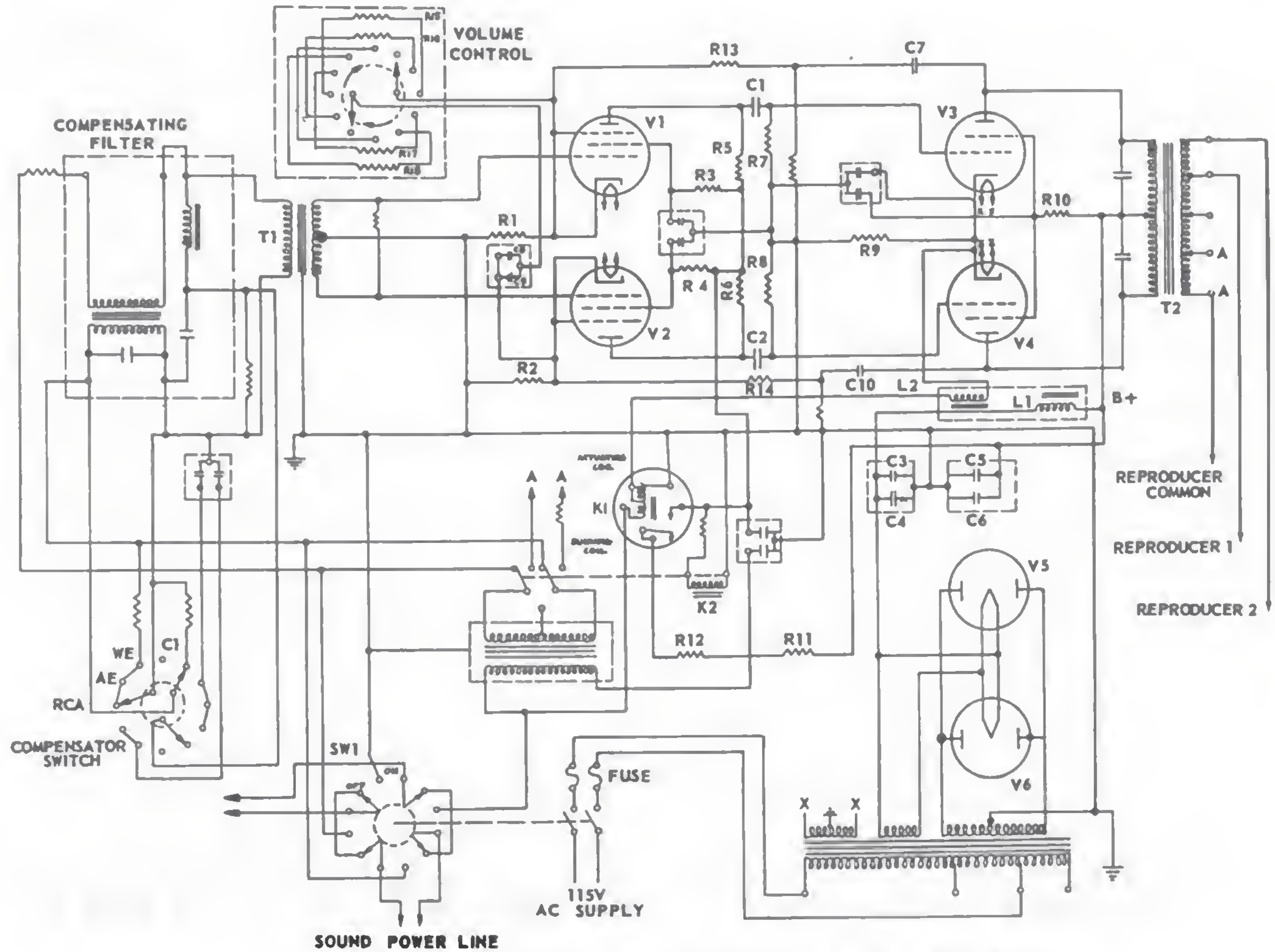


Figure 9–12.—Schematic diagram of a telephone amplifier.

The gain of the amplifier is varied by means of a noise-compensating volume control in which a portion of the output voltage of $V3$ and $V4$ is fed back through the feedback network composed of $C7$, $R13$, $C10$, and $R14$ into the cathodes of $V1$ and $V2$. Because the feedback voltage is 180° out-of-phase with the input signal, it tends to reduce the output of $V1$ and $V2$ and maintain the amplifier output at a minimum level.

The volume control consists of resistors $R15$, $R16$, $R17$, and $R18$ in series with capacitors $C8$ and $C9$. This volume-control network is connected across the cathodes of $V1$ and $V2$. When the volume-control switch is open, the entire feedback voltage is fed directly to the cathodes of the tubes and the volume is a minimum. When the volume-control switch is rotated, one of the two resistors is connected in series with the capacitors and both are connected between the two cathodes. Under this condition, the two cathode resistors $R1$ and $R2$ are shunted by the volume-control resistance and capacitance and a portion of the feedback voltage is bypassed through this shunt circuit between the two cathodes. This action reduces the effect of the feedback voltage on the signal input and increases the output of the amplifier.

As the volume control is rotated, it places successively smaller values of resistance across the cathodes of $V1$ and $V2$, more and more of the feedback voltage is bypassed, and the amplifier output increases. In the final position of the volume-control switch, all the resistance is shunted out and the two cathodes are connected together through the capacitors. The capacitive reactance of these capacitors is low at the audio frequencies and offers little opposition to the feedback signal. For all practical purposes the cathodes of the tubes are connected directly together. When this occurs all the feed-back voltage is bypassed and the amplifier has maximum volume.

Sensitive relay $K1$ contains the (1) bucking coil which is in series with the local headset and (2) activating coil which is in parallel with the local headset. When the amplifier is energized by turning switch $SW1$ to the ON position, a small amount of current flows between the cathodes of $V3$ and $V4$ and ground through the actuating coil. A smaller amount of current flows between the cathodes and ground through the bucking coil and the local headset that is in series with it. The current through the actuating coil is sufficient to operate the relay and to close the normally open contact. This action completes the circuit and provides B+ voltage to the plates of tubes $V1$ and $V2$.

SYSTEM OPERATION.—To transmit over the local headset, depress the press-to-talk button on the transmitter. This button places the transmitter unit in parallel with the receiver units of the headset. Because the transmitter unit has a much lower resistance than the receiver units, it reduces the total d-c resistance of the headset. This decrease in resistance allows an increased amount of current to flow through the headset and the bucking coil, which is in series with the headset. This increase in current through the bucking coil, along with a decrease in the current through the actuating coil, causes the bucking coil to neutralize the actuating coil, and the relay opens.

When the relay opens, B+ voltage is removed from the plates of the first stage tubes. This action silences the loudspeaker connected to the amplifier. Because relay $K2$ is energized by the plate current to the first stage, the removal of this plate current also causes relay $K2$ to open. The opening of this relay shifts the local headset from the output transformer of the amplifier to the sound-powered telephone line so that speech from the local headset is transmitted directly to the telephone line and does not appear at the local loudspeaker.

Both relays $K1$ and $K2$ are deenergized in case a fuse blows or the a-c power supply fails. This action automatically switches the local headset to the telephone line. When the amplifier switch is in the OFF position, the local headset is connected to the telephone line through this switch. The local headset then functions as a normal sound-powered headset.

The local headset can transmit and receive either with the amplifier ON or OFF by means of switch *SW*1 and relays *K*1 and *K*2. The amplifier does not amplify the speech transmitted over the local headset; it amplifies only the incoming signal received from the telephone line.

Portable Announcing Systems

Portable announcing systems for voice projectors serve to transmit orders and information conveniently by means of direct amplified voice communications. The applications of these systems are (1) to direct amphibious operations and (2) for topside and intership communications.

Amphibious groups are provided with a high-level audio sound system, such as the BEACHMASTER ANNOUNCING SYSTEM which is used by the beachmaster during amphibious landings to direct the movement of personnel and vehicles on the beach. The high output of the beachmaster announcing system can be heard above background noises caused by planes, tanks, trucks, and gunfire.

Aboard ship the voice-projection system includes the various portable announcing systems for special purposes. These systems are used within the ship or between ships when (1) high noise levels are encountered or (2) the power supply to the installed announcing system fails. All ships are equipped with at least one of these systems, usually the portable electric megaphone which is used to communicate between ships fueling at sea and to control small boats.

Portable announcing systems are designed and packaged to suit a particular application according to portability, power output, and effective range. All of these systems are self-powered and require no external source of power supply.

TYPE PAE–1 ELECTRIC MEGAPHONE.—The type PAE–1 electric megaphone has a variety of applications because it amplifies the voice to many times normal strength. It is particularly useful for (1) issuing commands from the bridge to personnel at topside stations, (2) communicating between

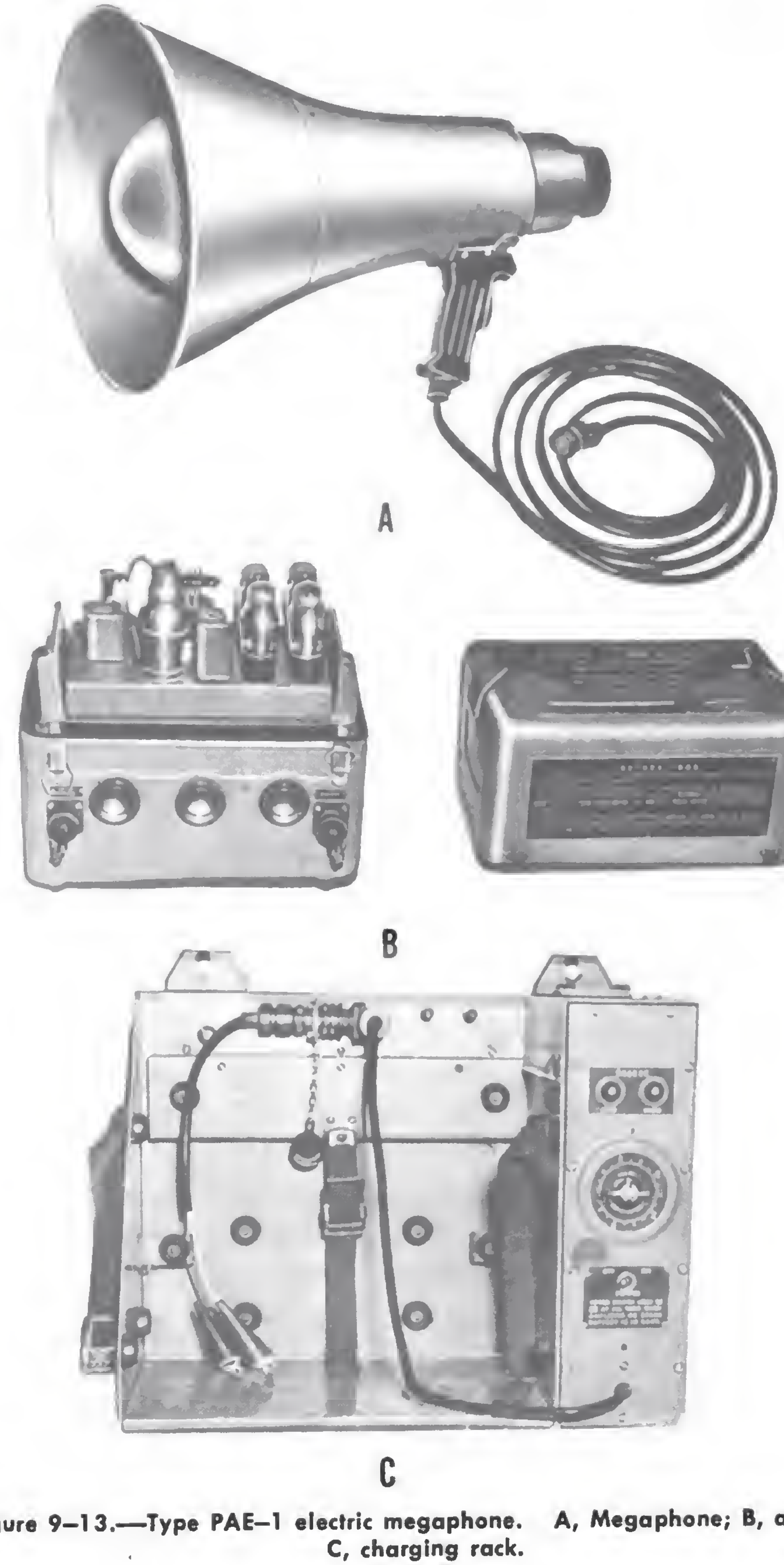


Figure 9–13.—Type PAE–1 electric megaphone. A, Megaphone; B, amplifier; C, charging rack.

ships while fueling or taking on stores at sea, and (3) communicating to and from tugs while maneuvering and docking.

The type PAE–1 electric megaphone is shown in figure 9–13. It is a portable announcing system consisting of the megaphone unit, amplifier, and charging rack.

The MEGAPHONE UNIT (fig. 9–13, A) is a hand-held assembly with the microphone mounted in the small end and the loudspeaker horn forming the large end. It consists of a straight-horn type of assembly for directing loud sounds. The horn assembly contains the (1) permanent-magnet dynamic type of loudspeaker and (2) dynamic type of microphone mounted on the rear of the horn. A pistol-grip handle is attached at the bottom of the horn at approximately the center of gravity of the unit. A trigger switch located in the handle energizes the system. A multiconductor cable extends from the pistol-grip handle and connects the megaphone unit to the portable amplifier.

The AMPLIFIER (fig. 9–13, B) is housed in a watertight aluminum case. It consists of a 3-stage amplifier, a 6-volt storage battery, and a vibrator-type power supply to furnish high voltage for the plate circuit. Two jacks are provided, one to accommodate the microphone plug and the other to accommodate the charging rack plug.

A schematic diagram of an electric megaphone amplifier is shown in figure 9–14. The signal from the microphone is fed into the primary of input transformer *T*1. The output from this transformer is connected to the grid of the first-stage tube, *V*1. The ouput of *V*1 is *R-C* coupled to the grid of *V*2 in the driver stage. The plate of *V*2 is coupled through transformer *T*2 to the grids of *V*3, *V*4, *V*5, and *V*6 which are the power output stages. These tubes are connected in parallel push-pull. The ouput of these power-stage tubes is connected to output transformer *T*3. Bias voltage for the grids of the three stages is obtained from the dry-disk rectifier and the voltage divided network made up of choke *L*1 and resistors *R*9 and *R*10.

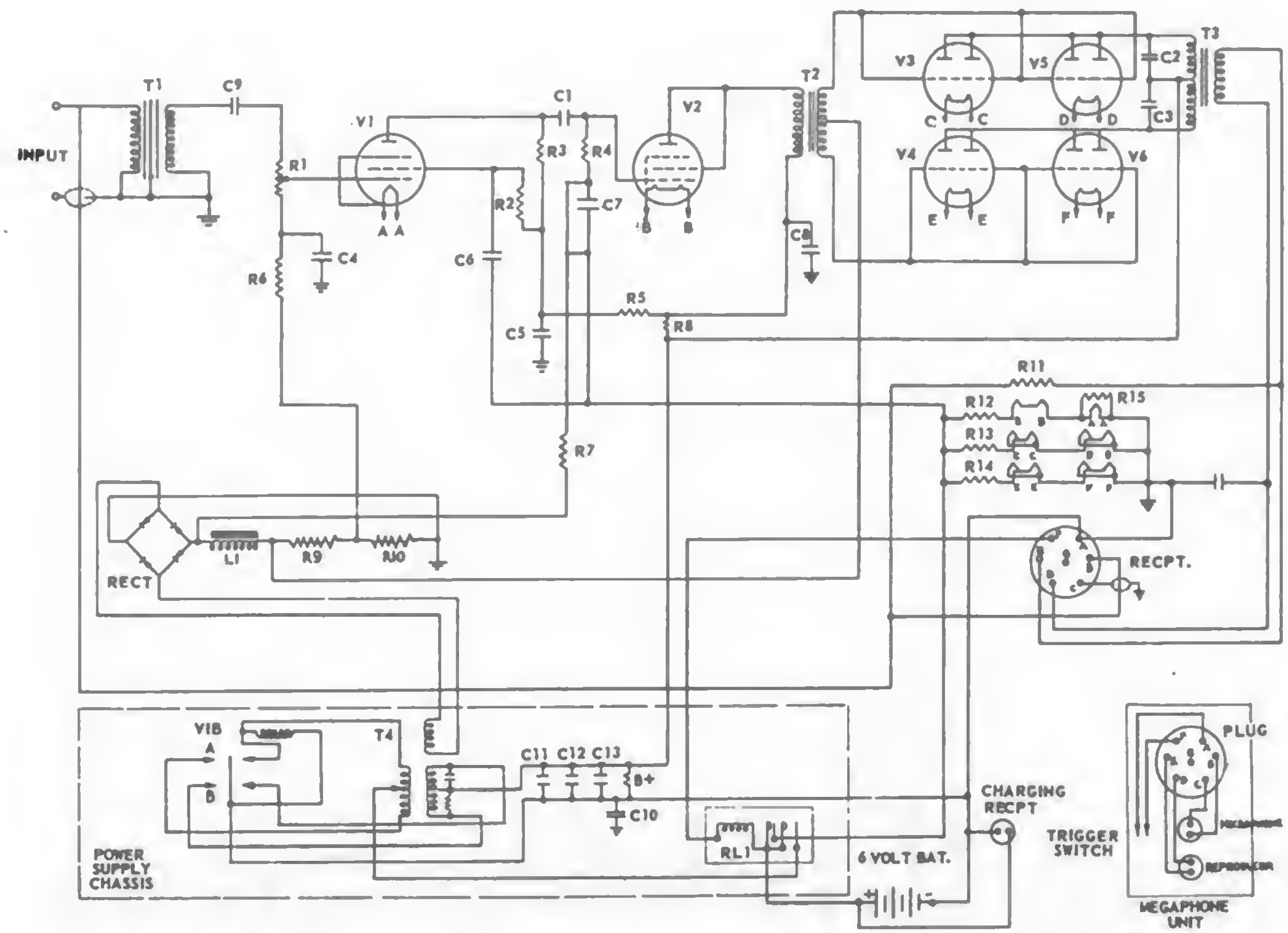


Figure 9–14.—Schematic diagram of an electric megaphone amplifier.

A portion of the output voltage on the secondary of output transformer *T*3 is fed back through the feedback network which consists of resistor *R*11 into the input of transformer *T*1 as a negative feedback. Resistor *R*1 functions as a volume control. This control requires only infrequent adjustment once it is set properly.

The primary source of power for operating the amplifier tubes is a 6-volt storage battery contained in the lower half of the amplifier case. Heater current for filaments is obtained directly from the 6-volt battery through voltage-dropping resistors *R*12, *R*13, and *R*14. These resistors adjust the potential to the correct value for the tubes in use. The filament of tube *V*1 has resistor *R*15 in parallel with it. A portion of the feedback voltage is developed across this resistor.

A vibrator rectifier and power transformer in the power pack step up the direct voltage obtained from the storage battery to approximately 385 volts d-c for the plates of the amplifier tubes. A secondary winding on power transformer *T*4 supplies about 28 volts a-c which is fed to the dry-disk rectifier. The 28-volt power is rectified, filtered, and fed to the voltage-divider network, where it is used to provide the correct bias voltages for the tubes.

The vibrator type of power supply consists of step-up transformer *T*4 combined with vibrating synchronous type of interrupter *VIB*. When the trigger switch on the megaphone unit is closed, relay *RL*1 is energized and closes its contacts. One set of contacts completes the circuit between the battery and the filaments of the tubes. The other set of contacts completes the circuit from the battery through the vibrator and power transformer, thereby providing the plate current for the tubes. The synchronous vibrator power supply changes the 6-volt d-c input to a 385-volt d-c output for the plates and screens of the tubes.

The CHARGING RACK (fig. 9–13, C) consists of a battery charger with a time switch and a storage rack to house the portable amplifier. A cable plugs into the amplifier case and connects the charging rack with the batteries within the case for charging. The timing switch is inserted into the charging circuit and controls the length of the charge. The charging rack can be connected to a 120-volt a-c supply or to d-c supplies of 120, 96, 48, 24, or 12 volts. A resistor in the rear of the rack adjusts the charging circuit for any of the d-c line voltages. A transformer steps down the alternating voltage to the correct value. This stepped-down alternating voltage is rectified by a set of selenium dry-disk rectifiers and is fed to the batteries to be charged. Under normal conditions, the amplifier always is stowed in the charging rack when it is not in use. While in the rack, the amplifier receives a constant trickle charge.

When a heavier charge is required, the charging timer switch is set for the number of hours that the charge is to be run. This period may be up to 4½ hours. When the timer is started, the battery is placed on charge at the highest rate. At the end of this set period, the high charging rate is discontinued automatically and the battery is again placed on trickle charge.

The SYSTEM OPERATION consists of voice sound waves that strike the microphone located in the small end of the megaphone unit. These sound waves are converted into a pulsating current that is fed to the primary of the input transformer *T*1. The output of this transformer is amplified by the three stages of the amplifier and is fed to the output transformer *T*3. The amplified signal returns to the loudspeaker in the megaphone unit from the output transformer. The amplified signal power energizes the loudspeaker which produces greatly amplified voice sound waves. These sound waves are projected through the highly directional horn of the loudspeaker. When not in use the complete unit is housed in a watertight steel cabinet from which the amplifier chassis and front panel can be removed. The front panel contains the loudspeaker with the necessary controls, switches, and indicator lamps.

INTERCOMMUNICATING SYSTEM

An intercommunicating system contains all the necessary components to provide two-way amplified voice communications, supplemented by signal lamps, between any two stations or from one station to any number of other stations in the system. The system consists of a number of identical permanently located units that are entirely independent of one another and of the general announcing system.

Standard intercommunicating equipment consists of the wired audio reproducing type of unit. These units include components having type designations 1–A, 1–AT, 1–AS, 1A–TW, and 2–A. The first numeral "1" indicates that the equipment is designed for use in an 11-station system, and is fitted with 10 selector switches. The first numeral "2" indicates the equipment is designed for use in a 21-station system, and is fitted with 20 selector switches.

The first letter "A" indicates that the equipment is of standard Navy circuit design and can be interconnected in any system consisting of other 1–A or 2–A types, irrespective of the equipment manufacturer.

The second letter "T" indicates that the telephone jack receptacle is provided on the equipment so that a sound-powered telephone handset can be used instead of the loudspeaker for either talking or listening in locations where the background noise level is excessively high.

The second letter "S" indicates that, although a telephone jack receptacle is not built into the unit, switching facilities and terminals for connection to a standard external telephone jack box are provided in the equipment so that a telephone handset can be used.

The third letter "W" indicates that the unit is watertight and can be installed in exposed or unprotected locations.

An intercommunicating, or intercom, system is more flexible and more reliable than a central amplifier system. The flexibility is evidenced by the fact that up to five independent conversations can be carried on simultaneously. The reliability is evidenced by the fact that if one amplifier becomes inoperative, all the other stations in the system can continue to transmit and receive. Even the station having the defective amplifier can receive, although it cannot transmit.

The components used in an intercommunicating unit consist of (1) talk-back loudspeaker, (2) amplifier, and (3) control section.

1A–TW Intercommunicating Unit

The 1A–TW intercommunicating unit shown in figure 9–15 is the latest standard intercom design and is more widely installed than any other standard types. The operation of the components of the unit applies in general to other standard units.

TALK-BACK LOUDSPEAKER.—The talk-back loudspeaker serves as a microphone to transmit sound from this unit to others in the system and as a loudspeaker to reproduce sound transmitted to this unit by any other unit. It has a perma-

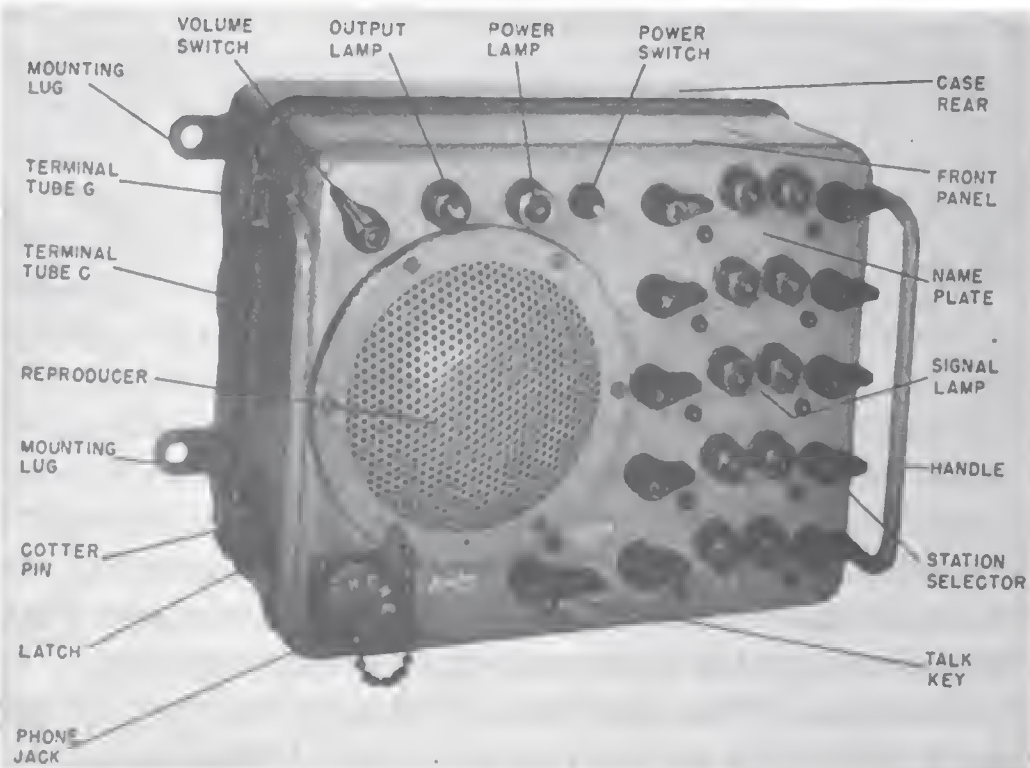


Figure 9–15.—1A–TW intercommunicating unit.

nent magnet that provides a strong magnetic field within the air gap between the poles of the magnet. A voice coil is rigidly attached to the center of a molded phenolic diaphragm that is mounted in a circular frame in front of the magnet. An incoming call can be heard through the loudspeaker with no power applied to the unit because amplification is accomplished by the amplifier of the calling unit.

A schematic diagram of a talk-back loudspeaker is shown in figure 9–16. Normally, the loudspeaker is connected to

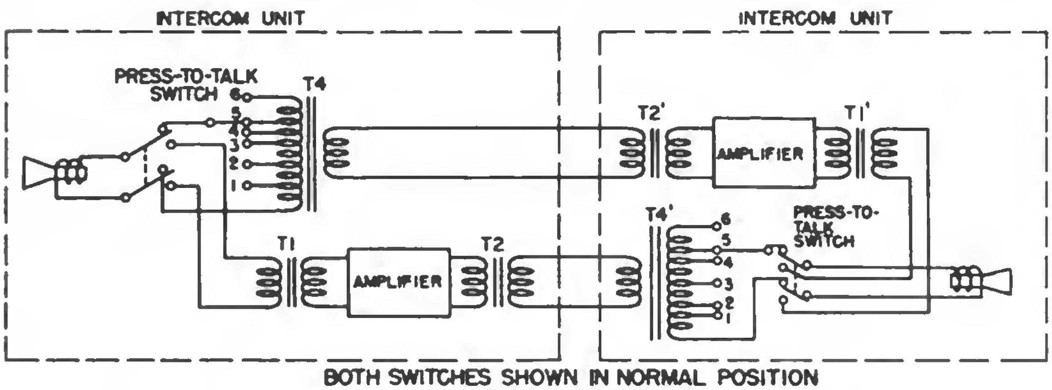


Figure 9–16.—Schematic diagram of a talk-back loudspeaker.

line-matching transformer *T*4 that receives the signal from the other station. When the loudspeaker operates as a microphone, depressing the press-to-talk switch shifts the voice-coil leads of the loudspeaker from the line-matching transformer to input transformer *T*1 of the amplifier. The sound waves produced by the speaking voice cause the diaphragm with its attached voice coil to vibrate. The movement of the voice coil between the poles of the magnet produces alternating currents in the voice coil and thus the sound energy is converted into electrical energy. This electrical energy is too small to operate the loudspeakers of the receiving station. Hence, this signal is fed to the input transformer of the audio amplifier for amplification.

AMPLIFIER.—The amplifier is mounted on four rubber shock mountings attached to brackets. A detachable connector plug joins the amplifier circuits to the front panel assembly. The complete amplifier is assembled and wired on a steel chassis that can be removed as a unit.

A schematic diagram of an amplifier for an intercom unit is shown in figure 9–17. The amplifier consists of a 3-stage audio amplifier with its associated power supply. All tubes are arranged so that if one tube fails, the circuit is not interrupted.

The amplifier power circuit consists of power transformer *T*3 having a 115-volt primary. The 650-volt secondary winding is center-tapped for the plate supply. The center tap is grounded through the press-to-talk switch. The two ends of the 650-volt secondary winding are fed to rectifier tubes *V*5 and *V*6 to provide full-wave rectification. The full-wave rectified current is filtered by a capacitor input filter. The first section of the filter, which consists of capacitors *C*5 and *C*6 and resistor *R*9, filters the B+ voltage to the plates and screen grids of *V*3 and *V*4. The second filter section, which consists of resistor *R*10 and capacitor *C*7, also filters the B + voltage to the plates of *V*1 and *V*2.

The center tap of the secondary of input transformer *T*1 is connected to ground and provides the signal return from the cathodes of the first amplifier stage. Therefore, the a-c signals at the ends of the secondary are 180° out-of-phase with each other. One of the secondary terminals is connected to the grid of *V*1 and the other secondary terminal is connected to the grid of *V*2.

Twin triodes *V*1 and *V*2 provide two stages of voltage amplification. One triode section works as the first amplifier stage and the other triode section works as the second stage. The plates of the first stages are *R-C* coupled to the grids of the second stages. *V*1 drives beam power pentode *V*3 and *V*2 drives beam power pentode *V*4.

*V*3 and *V*4 amplify the signals received from the second stage of the voltage amplifier. The output of these tubes, which are also operated in push-pull, is fed directly to output transformer *T*2. The cathodes of *V*3 and *V*4 are biased through common resistor *R*15. The screen grids of the power tubes obtain their B+ voltage from the filter and are

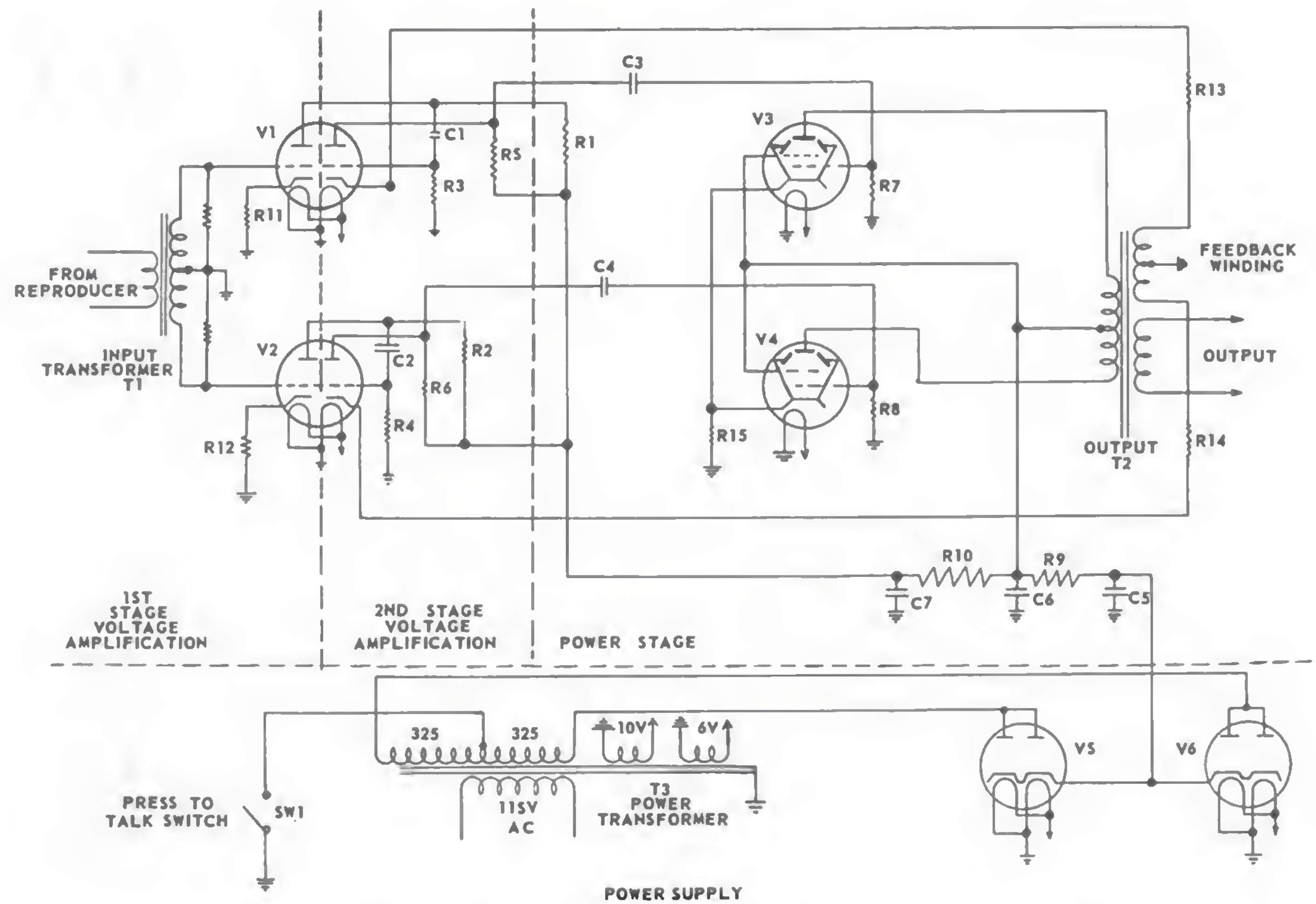


Figure 9–17.—Schematic diagram of an amplifier for an intercom unit.

operated at the same potential as the plates. The plates obtain their B+ voltage from the same filter connection as the screens. Because all the stages are in push-pull, failure of any one tube does not result in a loss of the signal but simply in a reduction of power output.

The bias voltage for the upper first stage voltage amplifier is developed across resistor *R*11. The bias for the lower first stage voltage amplifier is developed across resistor *R*12. Cathode bypass capacitors are omitted in order to develop negative feedback.

Another negative feedback circuit is incorporated in the amplifier to stabilize the output voltage under extreme varying load conditions of from 1 to 10 loudspeakers and to minimize distortion and hum. The source of the feedback voltage is the tertiary winding of output transformer *T*2, the center tap of which is grounded. The feedback voltage is returned to the cathodes of the second audio stage through cathode resistors *R*13 and *R*14 which develop the grid bias for this stage.

Control section.—The control section of the intercom unit (fig. 9–15) consists of (1) a power switch with indicator lamp; (2) a volume control; (3) an output lamp; (4) a press-to-talk switch; and (5) station selector switches with associated indicator lamps.

The power switch is a 2-pole double-throw toggle switch mounted on the front panel. When the switch is in the center position power is off. When the switch is in the down position the unit is connected to the normal ship's 115-volt a-c supply. When the switch is in the up position the unit is connected to the ship's emergency supply. The pilot lamp indicates that power is available at the unit or that a faulty condition exists.

The volume control is used to control the amplitude of all incoming signals which originate at other units. As the knob is rotated clockwise from 1 to 6, the electrical energy passing through variable-impedance transformer *T*4 (fig. 9–16) to the loudspeaker is increased and the volume of sound output to the loudspeaker is correspondingly increased. This control has no effect on the volume of outgoing sound from the unit. Thus each unit in the system can control the incoming volume to the desired level.

The OUTPUT LAMP consists of a neon lamp connected to the output of the amplifier. The purpose of this indicator is to immediately show any electrical defect that might interfere with proper operation of the unit as a sound transmitter. This indicator lamp flickers irregularly when the unit is spoken into with the press-to-talk switch depressed. This flickering denotes that the unit is functioning satisfactorily. However, if the indicator lamp remains dark, it denotes that the amplifier is defective and speech is not being properly transmitted.

The PRESS-TO-TALK SWITCH is mounted on the front panel and serves to select the function of the loudspeaker. When the key is depressed the unit functions as a microphone. When the key is released the unit functions as a loudspeaker. When the key is raised the hand telephone is connected as a microphone. The key has a spring self-return that brings it back to the listen, or standby, position when finger pressure is released.

To carry on a conversation without using the telephone, the talk key is held down while speaking and is released while listening.

To carry on a conversation using the telephone, the talk key is held up while speaking and released while listening. When the talk key is in the standby position an incoming call from any other unit in the system is heard through both the loudspeaker and the hand telephone.

Two of the contacts on the press-to-talk switch are arranged to cut off the high voltage supply from the amplifier tubes when the unit is in the standby position. When the knob is raised or depressed, this voltage supply is connected and the amplifier functions.

The STATION SELECTOR SWITCHES are mounted on the front of the panel. There are 10 unit, or station, selector switches each of which is controlled by a lever knob. To call a particular station in the system, the selector switch corresponding to the desired station is pressed down. If a station is used to transmit to several other stations at one time, the selector switches on the transmitting station corresponding to those of the respective stations called are depressed. When a selector switch is depressed to call a particular station and the talk key is depressed, the output of the amplifier becomes electrically connected to the loudspeaker of the station called. After a conversation is completed the selector switches must be moved up. When a station is called by another station, the selector switch corresponding to that of the calling station is depressed before replying.

A signal lamp is associated with the selector switch corresponding to each unit in the system. When an incoming call is received, a signal lamp illuminates with a steady light to identify the calling unit. Before a reply is made, the selector switch adjacent to the lighted signal lamp must be pressed down. The signal lamp now begins to flash on and off to indicate that this station and the calling station are engaged in conversation. When the conversation is finished, the selector switch must be raised to the upward position. These signal lamps also serve as busy signals. If, when a selector switch is depressed to call another unit, the adjoining lamp instantly begins to blink, the station being called is busy.

System operation.—When the unit is used as a transmitter, depress the press-to-talk switch that connects the loudspeakers to the input transformer *T*1 (fig. 9–16). The loudspeaker converts the sound energy into electrical energy which is fed to the input transformer *T*1 (fig. 9–17) that drives tubes *V*1 and *V*2 connected in push-pull. The first and second stages of amplification take place in these two tubes which are *R-C* coupled. The output of these tubes is *R-C* coupled to power tubes *V*3 and *V*4. The output of the power tubes is coupled through the output transformer to the voice transmission line. The output signal developed in the secondary winding of the output transformer is fed first to the voice transmission line and then to the stations selected to receive the signal. At the receiving stations the signal passes through the line-matching transformer *T*4 (fig. 9–16) and then through normally closed contacts on the press-to-talk switch to the loudspeaker which reproduces the spoken words that originated at the sending station.

QUIZ

1. What two general-purpose systems are used to transmit orders and information between stations within a ship?
2. What kind of communication is provided by each of these systems?
3. How is each announcing and intercom system designated?
4. Name the three basic components that comprise a central amplifier system.
5. Name the five devices that comprise microphone components.
6. Name the four classifications of loudspeakers.
7. What two factors determine the power level at which a loudspeaker must be operated?
8. The L and S types of loudspeakers are of what design?
9. The M and H types of loudspeakers are of what design?
10. What three circuits comprise the MCG general announcing system?
11. Name the four types of alarm signals generated in an MCG announcing system.
12. What components comprise an amplifier channel in the amplifier rack of the MCG announcing system?
13. What is the purpose of the compressor-limiter circuit in the voltage amplifier?
14. What is the function of a sound-powered telephone amplifier system?
15. Where aboard ship is the sound-powered telephone amplifier system used?
16. Name three applications of portable announcing systems.
17. What kind of communications is provided by an intercommunicating system?
18. Which is more flexible and reliable—the central amplifier or the intercom system?
19. Name the two functions of a talk-back loudspeaker.
20. Why can an incoming call be heard through the loudspeaker of an intercom unit with no power applied to the unit?

317993 O—55——23

CHAPTER 10

SOUND RECORDING AND REPRODUCING SYSTEMS

METHODS OF SOUND RECORDING

Sound recording and reproducing systems, circuit VR, are used aboard ship for monitoring radio and sound-powered telephone circuits, training personnel, dictation, and many other purposes. The basic methods of recording and reproducing sound are (1) mechanical, (2) magnetic, and (3) photographic.

Mechanical Recording

Mechanical recorders are used in the Navy to record voice or other signals on disks or films. This recording is accomplished by means of a stylus, or cutting needle, that engraves or embosses the sound pattern on the recording medium which is driven past the stationary stylus. The sound pattern can be engraved on disks and embosed on disks or films. Engraving disks are 6½, 8, 10, 12, and 16 inches in diameter. Embossing disks are 7½ and 16 inches in diameter. Embossing films are 60-foot continuous loops that are 35 millimeters wide.

The components necessary to mechanically record and reproduce sound are (1) a microphone, (2) an audio amplifier, (3) a recording head, (4) a cutting stylus, and (5) a recording medium.

The microphone converts the sound waves produced by the voice into electrical currents that are amplified by a conventional audio amplifier. The output of this amplifier is fed into the magnetic recording head. The recording head converts the electrical signal into mechanical energy which causes a lateral movement of the stylus within the record groove.

DISK RECORDING.—In disk recording a vinylite disk is rotated at a constant speed and a cutting stylus forms a spiral groove in the disk. A RECORDING HEAD which contains the stylus is driven radially across the disk by a positive drive like the lead screw in a lathe. The lead screw is geared to the disk drive so that as the disk rotates, the stylus advances radially at a constant rate. In most cases the recording spiral groove begins at the circumference of the disk and ends near the center.

The electric signal received by the recording head causes the stylus to swing from side to side. This lateral motion cuts or deforms the sound pattern on the walls of the groove. Thus, the stylus produces a spiral groove that has small lateral variations which correspond to the audio signals.

The frequency of the sound being recorded determines the frequency of the lateral swings of the stylus and the volume of the sound determines the amplitude of the swings. High notes cause shallow engravings whereas low notes cause deep engravings—that is, the action becomes more pronounced as the notes become lower. Bass notes usually have greater amplitude than high notes and cause a greater lateral swing of the stylus.

A second head known as the PICK-UP HEAD is used to play back this type of recording. The pick-up head has a standard phonograph needle. The disk is rotated at the same speed as that at which the recording is made. As the disk is rotated, the needle of the pick-up head rests in the groove and follows the pattern of the sound groove. In the magnetic type of pick-up this mechanical movement causes an armature inside the pick-up head to move. This movement varies the air gap between soft-iron pole pieces which are polarized by a permanent magnet. The principle is similar to that of the magnetic microphone (fig. 8–5). The varying air gap causes the flux to expand and contract through the coil and thus an a-c signal is induced in the coil. The signal is amplified by an audio amplifier and converted into sound waves by the loudspeaker. This type of recorder-reproducer is seldom found aboard ship, but is used occasionally for office dictation in shore establishments.

FILM RECORDING.—The operation of a film recorder is similar to that of the mechanical-disk recorder except the film recorder uses a 60-foot endless loop of specially treated 35-mm cellulose acetate film. The recording stylus embosses a groove along the film in the same manner in which sound grooves are embossed on the vinylite disk in mechanical-disk recording. An automatic tracking device shifts the recording head sideways across the film at the end of each complete loop of film so that each loop has many independent sound grooves. A tracking counter near the recording head shows which of the available 120 tracks on the film is being used.

The film recorder has a separate playback head which has its own stylus. When a film-recorded program is played back, the tracking counter is set for the track that contains the desired recording. A log sheet with each length of film lists a record of the contents of each track. The film moves under the pick-up head and the pick-up stylus is moved from side to side by the sound groove in which it rests. This lateral movement of the stylus induces a signal voltage in the coils of the pick-up head. This voltage is increased by the audio amplifier and reproduced as sound waves by the loudspeaker. As in mechanical-disk recording, sound recorded on film forms a permanent record and cannot be erased.

Magnetic Recording

Magnetic recording is similar to mechanical recording in that the sound waves are picked up by a microphone, converted into an alternating current, and amplified. Unlike mechanical recording, magnetic recording is based on the orientation of magnetic particles in a tape or wire by an electromagnet. The recording head consists of coils wound on an iron core similar to the electromagnet shown in figure 10–1. One half cycle of signal current is indicated. When current flows through the coils in the direction corresponding to this half cycle, the iron core becomes magnetized and

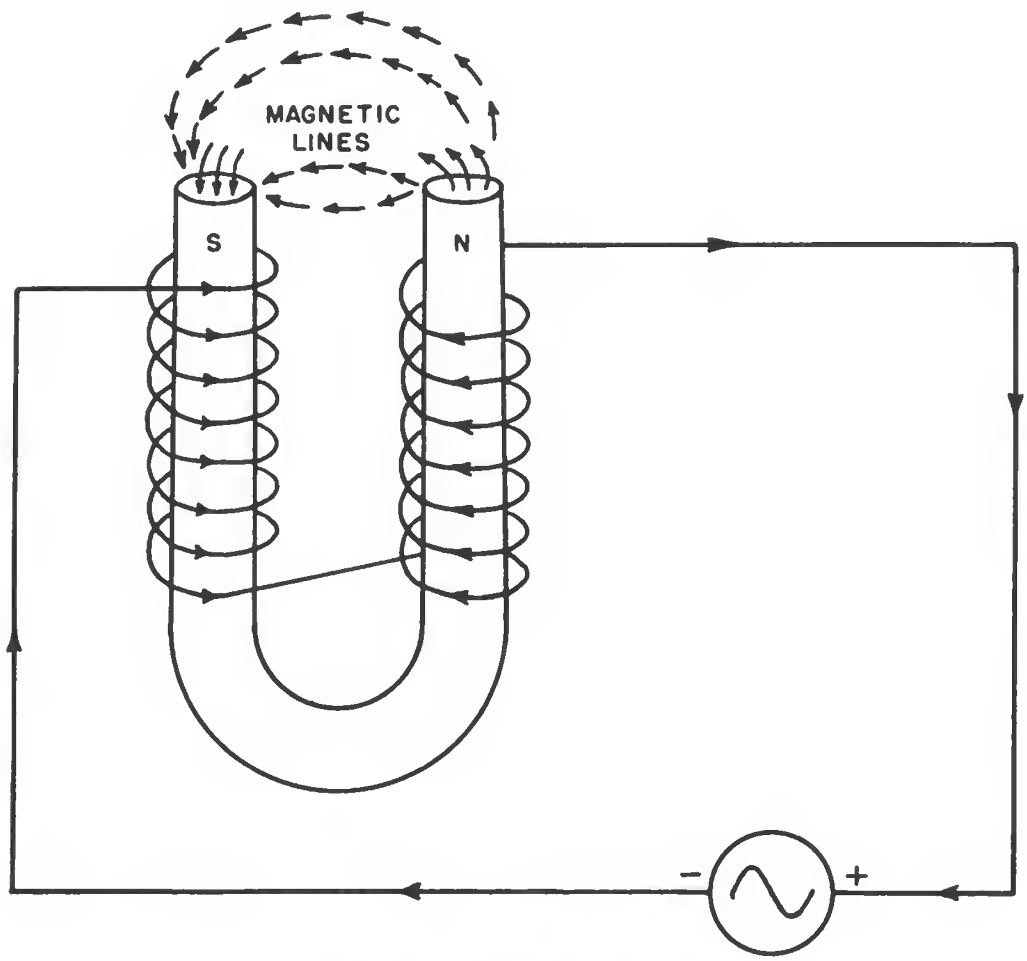


Figure 10–1.—Electromagnet.

establishes a north and a south pole at the ends of the U-shaped electromagnet. A magnetic field exists in the air gap between the poles. When the direction of the current through the coils is reversed, the direction of the lines of force across the air gap is reversed. If a steel bar were placed across the gap of the magnet, most of the lines of force would be confined within the bar and it would become magnetized.

WIRE RECORDING.—In magnetic wire recording (fig. 10–2) the output signal from the audio amplifier causes an alternating current to flow through the coils of an electromagnet in the recording head. This current sets up an a-c field of signal frequency across the gap between the pole pieces. A

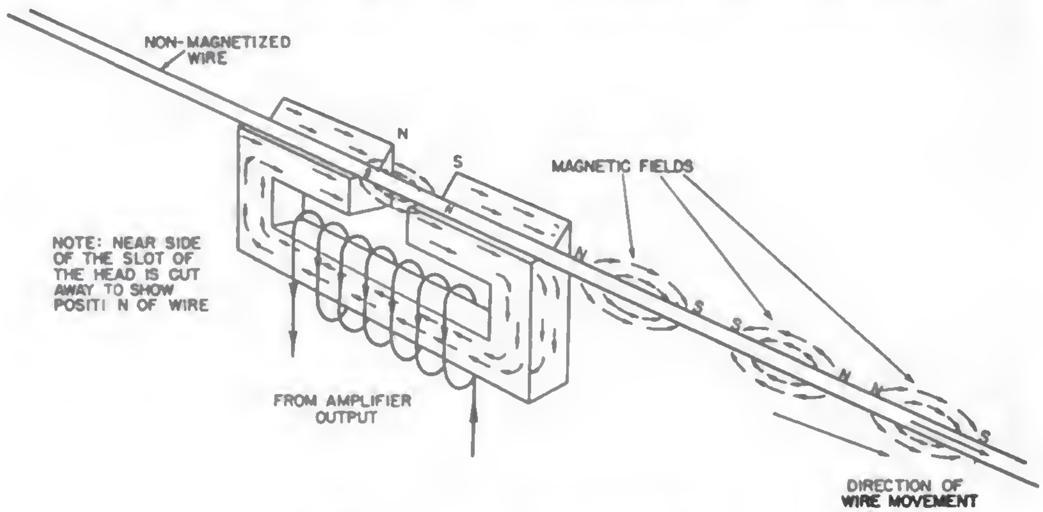


Figure 10–2.—Wire recording.

stainless steel wire 4 mils in diameter is drawn axially through the gap at constant speed. The signal constitutes a varying mmf which orients the molecules in the wire according to the signal pattern. The degree of orientation is proportional to the magnitude of the signal current. Thus more energy is stored in the magnetic field of the wire with a strong signal than with a weak one. After recording, a succession of magnetic field patterns, differing from each other in length, intensity, and direction (polarity), exists throughout the length of the wire.

When a magnetically recorded program is played back, the wire or tape is run through a playback head in the same direction and at the same speed as it was during recording. In Navy types of wire and tape recorders the recording head also functions as the playback head. There is a series of magnetic fields along the length of the recorded wire, as shown in figure 10–3. Each field has a north- and a south-pole region. The lines of force extend externally from a north pole to a corresponding south pole for that region. The intensity of these magnetic fields is in proportion to the number of lines representing them.

One of the magnetic fields is shown lying immediately across the gap between the pole pieces of the playback head. Note that only a part of the magnetic lines of force extend out into the space surrounding the recording wire. Most of

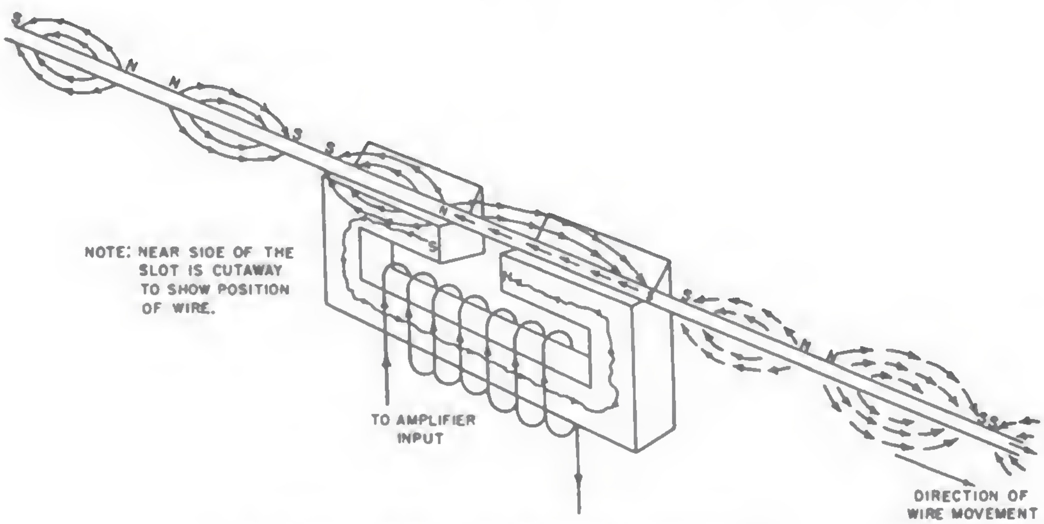


Figure 10–3.—Wire recording playback.

them are directed through the iron core of the head, as indicated in figure 10–3. As the wire moves, these varying lines of force induce an emf of signal frequency in the coil. Thus, as the recording wire is drawn across the slot of the playback head, a succession of emf's is induced in the coil. These emf's differ from one another in direction, duration, and intensity and represent the electrical equivalent of the signal on the wire. They are amplified by the audio amplifier and converted into sound waves by the loudspeaker.

Tape recording.—In magnetic tape recording a flat paper or plastic tape is used as the recording medium. The magnetic fields that comprise the sound pattern are established on the tape which either contains, or is coated with, very fine steel particles. The principles involved are the same as those for wire recording, but tape recording has the advantage of being easier to handle and less expensive.

A-c biasing.—In almost all magnetic recording an a-c bias is used upon which the audio signal is superimposed and applied to the recording head. This bias is a relatively high-frequency a-c signal that is above the audio range and therefore cannot be heard during playback. A-c biasing is used to obtain a substantially linear relationship between the flux density in the recording medium and the magnetizing force. Thus the induced signal voltages are related linearly to the recording fields.

Erasing.—The recorded sound track on a magnetic recording medium can be erased and the medium used again for further recording. This erasing may be accomplished by means of a special erase head. This head is located so that the wire or tape must pass through it before reaching the recording head. A high-frequency a-c signal is fed to the erase head and thus cancels magnetic fields from a previous recording by completely disorienting the magnetic particles in the wire or tape.

Photographic Recording

In photographic recording the sound is recorded by exposing a moving photosensitive film to a beam of light that is modulated by the sound pattern being recorded. When the film is developed, it can be reproduced by passing the sound track, which contains light and dark areas, through a beam of light focused upon a photoelectric cell. The output of the cell is fed first to an amplifier to increase the signal and then to a loudspeaker. The methods of photographically recording sound are (1) variable-density recording and (2) variable-area recording.

Variable-density recording.—In variable-density recording the sound pattern comprises varying density images that are produced by light passing through a special type of light valve. The light valve consists of a duralumin ribbon loop suspended between the two pole pieces of a powerful electromagnet. The two halves of the ribbon loop form a light shutter. The signal from the amplifier is applied to the two ends of the loop and causes the shutter to open and close. This action allows varying amounts of light to pass through to the film. This type of sound track has a varying density and a constant width along one edge of the film.

Variable-area recording.—In variable-area recording the sound pattern is recorded by a small mirror mounted on a mechanical oscillograph type of movement. The mirror suspension is vibrated by the signal from the amplifier acting on the movement. A beam of light falling on the mirror is reflected to the film and exposes it in accordance with the movement of the mirror, and thus in accordance with the sound pattern. This type of sound track has a constant density and a varying width along one edge of the film.

Designations

Circuit.—Sound recording and reproducing circuits are designated by the letters "VR." The individual circuits are further identified by numerals prefixed to the circuit designation, such as 1VR, 2VR. . . .

Equipment.—Record players used in the Navy include all 33⅓- and 78-rpm reproducers that use commercial disks. This equipment is designated by the letters "RP." A third letter "M" or "A" is added to the equipment designation to denote manual or automatic operation respectively. A numeral is also added to identify the model. For example, RPA–1 denotes a model 1 automatic record player.

Sound recorders and reproducers other than record players are based on the VR designation. One of the following designations is added as a third letter to identify the type of equipment:

D—Disk recorders and reproducers
F—Film recorders and reproducers
G—Tone warning generator for telephone recording
K—Modification kit
R—Recorder rack
S—Remote station

T—Tape recorders and reproducers
W—Wire recorders and reproducers

A numeral is also added to identify the model. The letters "IC" precede these designations to denote interior communications equipment. For example, IC/VRT-5 denotes an interior communications model 5 sound tape recorder-reproducer.

In April 1952 new designations for sound recording and reproducing equipment became effective. These designations, which are in accordance with the joint nomenclature (AN) system for communications-electronic equipment, are as follows:

RD—Recorders and reproducers
U—General utility (airborne, shipboard, and ground)
N—Sound in air

A number following the letters "RD" denotes the number of the equipment. For example, RD-115/UN denotes sound recorder-reproducer No. 115 for general utility use.

RD-115/UN SOUND RECORDER-REPRODUCER

The RD-115/UN sound recorder-reproducer is designed to magnetically record and play back audio signals. It is used aboard ship for continuous recording applications such as recording ship-to-shore and plane-to-control-tower conversations.

This recorder-reproducer is a portable device (fig. 10-4) contained in an aluminum cabinet. It uses a wide slow-speed magnetic tape and a rotating turntable of recording heads. Recordings can be made from two audio sources at the same time.

Mechanical Components

The mechanical components of the recorder-reproducer drive the magnetic tape and the magnetic head recording turntable. These components consist of: (1) synchronous motor; (2) recording medium; (3) magnetic head turntable;

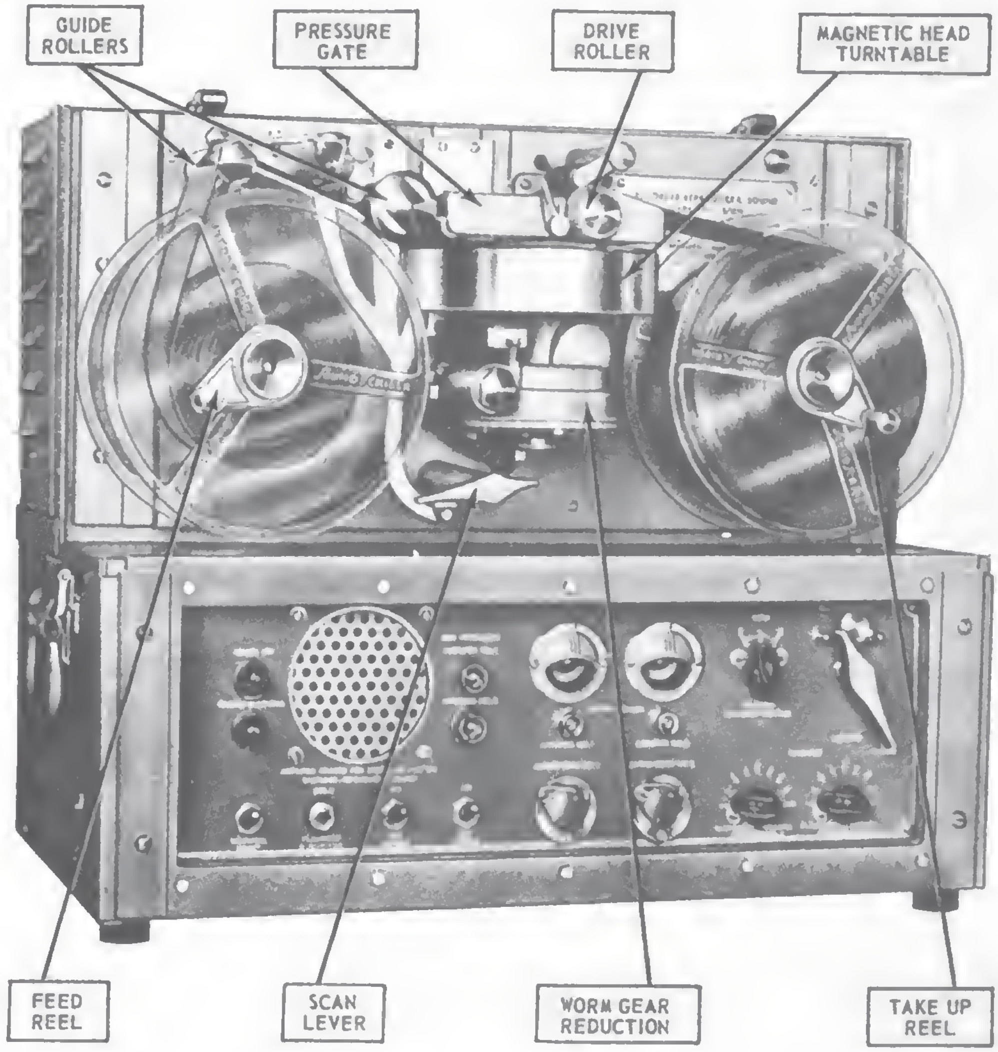


Figure 10-4.—RD-115/UN recorder-reproducer.

(4) worm gear reduction; (5) drive roller; (6) takeup reel; (7) end-of-tape contacts; (8) pressure gate; (9) guide rollers; (10) scan lever; (11) load lever; and (12) tone generator.

SYNCHRONOUS MOTOR.—A synchronous motor drives the magnetic tape and the magnetic head turntable. This motor has a starting winding that is cut in and out of the circuit by means of a current relay. The relay coil is in series with the running winding. When the motor reaches synchronous speed, the running winding draws less current and causes the relay to open. This action disconnects the starting winding from the circuit.

RECORDING MEDIUM.—The recording medium is a magnetically coated paper tape, 3 inches wide and 1,136 feet long, capable of holding 24¼ hours of continuous two-channel recording. The magnetic tape travels at a slow rate of speed, making it possible to change the reel of tape without stopping the machine. The tape is wound on a plastic reel 7 inches in diameter with the red oxide magnetic coating toward the inside. Magnetic SOUND TRACKS are recorded laterally across the width of the magnetic tape, as shown in figure 10–5. Each sound track is a 90° arc, the diameter of

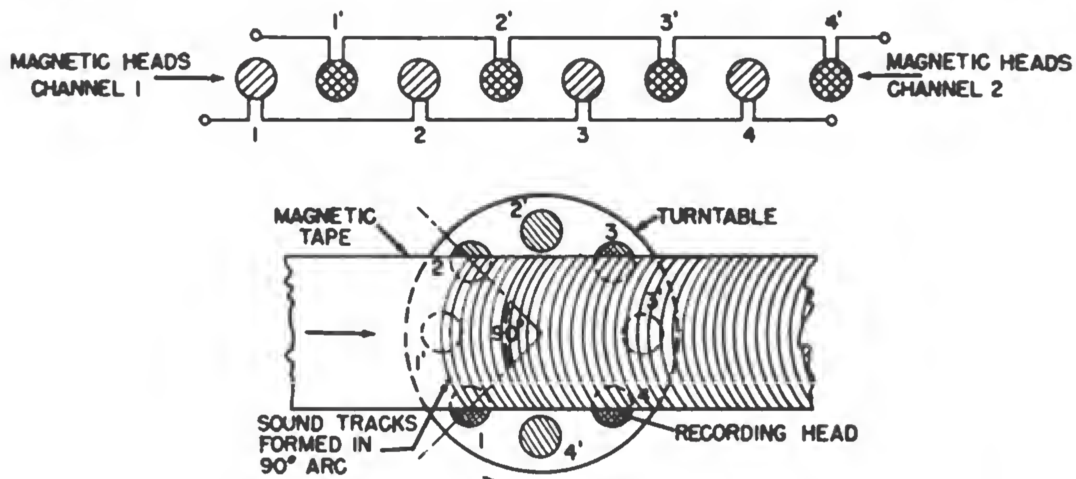


Figure 10–5.—Schematic arrangement of magnetic tape, sound track, and recording heads.

which is the same as the diameter of the circle in which the magnetic heads are mounted.

MAGNETIC HEAD TURNTABLE.—The magnetic head turntable consists of eight magnetic heads mounted equidistantly on a circular turntable, as shown in figure 10–5. The magnetic tape travels over the top of these heads. The turntable rotates as the magnetic tape moves and sound tracks are formed. The magnetic heads are connected so that there are two sets of four heads, each set connected in series. One set of four heads is for amplifier channel 1 and the other set is for amplifier channel 2. They are connected so that every other head in the direction of rotation is for channel 1, and the other four alternate heads are for channel 2.

The four magnetic heads of each channel are mounted 90°

apart. The first sound track is made with the first magnetic head of channel 1; the second sound track is made with the first magnetic head of channel 2; the third sound track is made with the second magnetic head of channel 1; the fourth sound track is made with the second magnetic head of channel 2; and so forth. Thus, every other sound track is the recording of one channel. Every eighth sound track is made with the same magnetic head.

The magnetic heads used for recording are also used for PLAYBACK. When the air gap of the magnetic head is in contact with the moving tape, the magnetically recorded variations are induced in the poles of the magnetic head. The induced magnetism in the poles of the magnetic head appears as an induced voltage across the coils that are wound on these poles. This voltage is then fed to the amplifier which increases the signal sufficiently to operate the loudspeaker.

WORM GEAR REDUCTION.—The magnetic head turntable is rotated by a worm gear reduction connected to the motor shaft through a flexible coupling. The flexible coupling reduces the motor vibration to the turntable and automatically aligns the motor shaft.

DRIVE ROLLER.—The drive roller moves the magnetic tape across the magnetic heads. This roller is rotated by a gear train from the turntable spindle.

TAKEUP REEL.—The takeup reel for the magnetic tape is rotated by a belt-driven pulley through a friction clutch from the drive roller shaft. The clutch exerts sufficient friction so that the magnetic tape is wound tightly on the takeup reel without forcing the tape to slip at the drive roller. The takeup reel runs faster when the reel is empty than when it is nearly full. Thus the reel slips more and more on the friction clutch as the takeup reel becomes full of tape.

END-OF-TAPE CONTACTS.—The end-of-tape contacts are silver contacts that slide along the top side of the magnetic tape. At each end of the magnetic tape, 5 minutes before the end of the 24-hour period, an aluminum strip provides connection across the silver contacts. These contacts operate the reload warning lamp and buzzer to indicate that only 20 minutes of recording time remain on the magnetic tape.

PRESSURE GATE.—The pressure gate consists of a spring-pressure hinged plate that holds the magnetic tape against the magnetic heads. The pressure gate has three guide rollers, one of which is mounted off-center. A tuning lever, attached to this off-center guide roller, provides a means of shifting the position of the magnetic tape relative to the magnetic heads in order to line up the sound tracks on the tape with the heads during playback.

GUIDE ROLLERS.—A system of guide rollers from the feed reel guide the magnetic tape over the magnetic heads to the takeup reel. As the tape leaves the reel, the first guide roller has a metallic tape shoe under the spring pressure that holds the tape firmly against its surface. The next drive roller is a tapered roller that takes up the slack in the variations in the width of the tape. The third guide roller positions the tape before it goes under the pressure gate.

SCAN LEVER.—The idler pulley and pressure rollers are mechanically linked to the scan lever. Rotating the scan lever clockwise raises the pressure rollers and disengages the idler pulley. Rotating the scan lever counterclockwise lowers the pressure rollers and engages the idler pulley. The pressure gate, tape shoe, and tapered roller are mechanically linked to the load lever.

LOAD LEVER.—Rotating the load lever clockwise raises the pressure gate tape shoe and the tapered roller and turns the scan lever clockwise. Rotating the load lever counterclockwise lowers the pressure gate, tape shoe, and tapered roller.

TONE GENERATOR.—The tone generator develops a low-level periodic tone that is applied to recording amplifier channel 2 to distinguish it from channel 1. The tone generator consists of a coil located in a permanent-magnetic field. A reed armature located in an air gap containing the field generates a voltage as the magnetic flux is changed by mechanically vibrating the reed. The armature is moved by a ratchet attached to a rotating shaft. The shaft is driven by a belt interconnecting the drive roller and the takeup reel spindle. The voltage developed by the generator is applied to the output stage of the recording amplifier of channel 2.

Electronic Components

The electronic components of the recorder-reproducer apply the signal to be recorded to the magnetic tape and transmit the sound from the recorded tape to the loudspeaker. These components consist of (1) a conventional audio amplifier, (2) an oscillator, (3) an amplifier for the oscillator, and (4) a power supply. These circuits are interconnected to permit two-channel recording or two-channel playback.

A block diagram of recording and monitoring circuits of the type RD–115/UN sound recorder-reproducer is shown in figure 10–6. During RECORDING, the input signal to the line terminals or to the microphone input plug of either amplifier channel is applied to the first voltage amplifier stage through input transformer *T*100. The signal is amplified by two resistance-coupled voltage amplifier stages, *V*100 and *V*101, and applied to output tube *V*102 and magnetic heads *E*100 and *E*200. A biasing voltage of 20 kc is simultaneously applied to the magnetic heads. This high-frequency biasing voltage is obtained from the oscillator circuit containing tube *V*301. This tube provides for biasing both amplifier channels. The a-c bias is amplified by tube *V*300. One half of this tube, *V*300*A*, is used for amplifier channel 1 and the other half, *V*300*B*, is used for amplifier channel 2. The combined outputs from channel 1 and the oscillator produce a modulated signal which is applied to the magnetic tape by the recording heads.

The signal from *V*102 is applied also to electron ray tube *V*103 to provide a visual indication of the recording level.

RECORDING.—The a-c bias from tube *V*300*A* and *V*300*B* is applied to the magnetic heads of the corresponding channel. The signal for monitoring is taken from the second recording

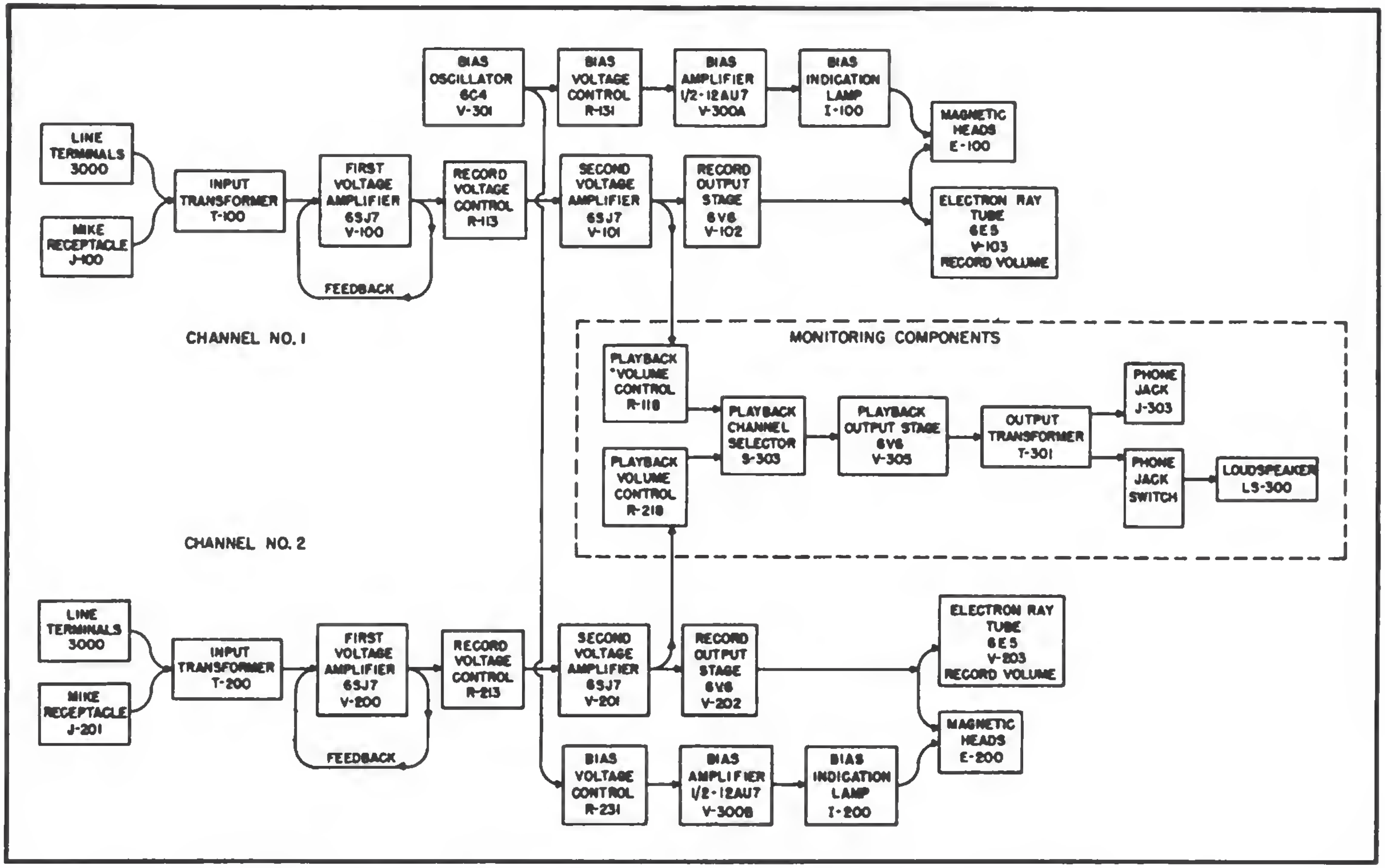


Figure 10–6.—Block diagram of recording and monitoring circuits.

voltage amplifier stage, *V*101 or *V*201, through playback volume controls *R*118 or *R*218. The monitoring signal from the desired channel is selected by playback channel selector switch *S*303. The signal is fed to output tube V305. This output tube is connected to output transformer *T*301. The signal from this transformer is fed to the phone jack and loudspeaker.

PLAYING BACK.—A block diagram of the playback circuits is shown in figure 10–7. During playback, the signal of either channel on the magnetic tape is picked up by the magnetic heads and applied as a signal voltage to input transformers *T*100 and *T*200. This signal is then amplified by the first and second voltage amplifiers of the channel. Amplifier channels 1 and 2 have playback volume controls *R*118 and *R*218 respectively. Playback channel selector *S*303 permits playback from either or both amplifier channels. The signal from the first two amplifier stages of either channel is amplified by a third voltage amplifier, *V*304. This signal is then applied to output tube *V*305 and to output transformer *T*301. The output from this transformer is fed to the phone jack and loudspeaker. A feedback voltage is also taken from the output transformer and applied to the amplifier stage preceding the output stage.

Relay *K*301 is actuated by the end-of-tape contacts and operates a warning lamp and buzzer to indicate that only 5 minutes recording remains on the tape. Relay *K*302 operates the warning lamp and buzzer to indicate a power failure in the equipment.

Power supply transformer *T*300 and parallel rectifier tubes, *V*302 and *V*303, comprise the rectifier.

DEMAGNETIZER.—The demagnetizer is furnished as a separate unit. The unit consists of two coils wound on a U-shaped iron core. The coils are in series with a capacitor across the incoming power line to provide a series-resonant circuit. The resonant condition develops a high current through the coils, which in turn develops an intense a-c field across two pole pieces. The pole pieces protrude from the

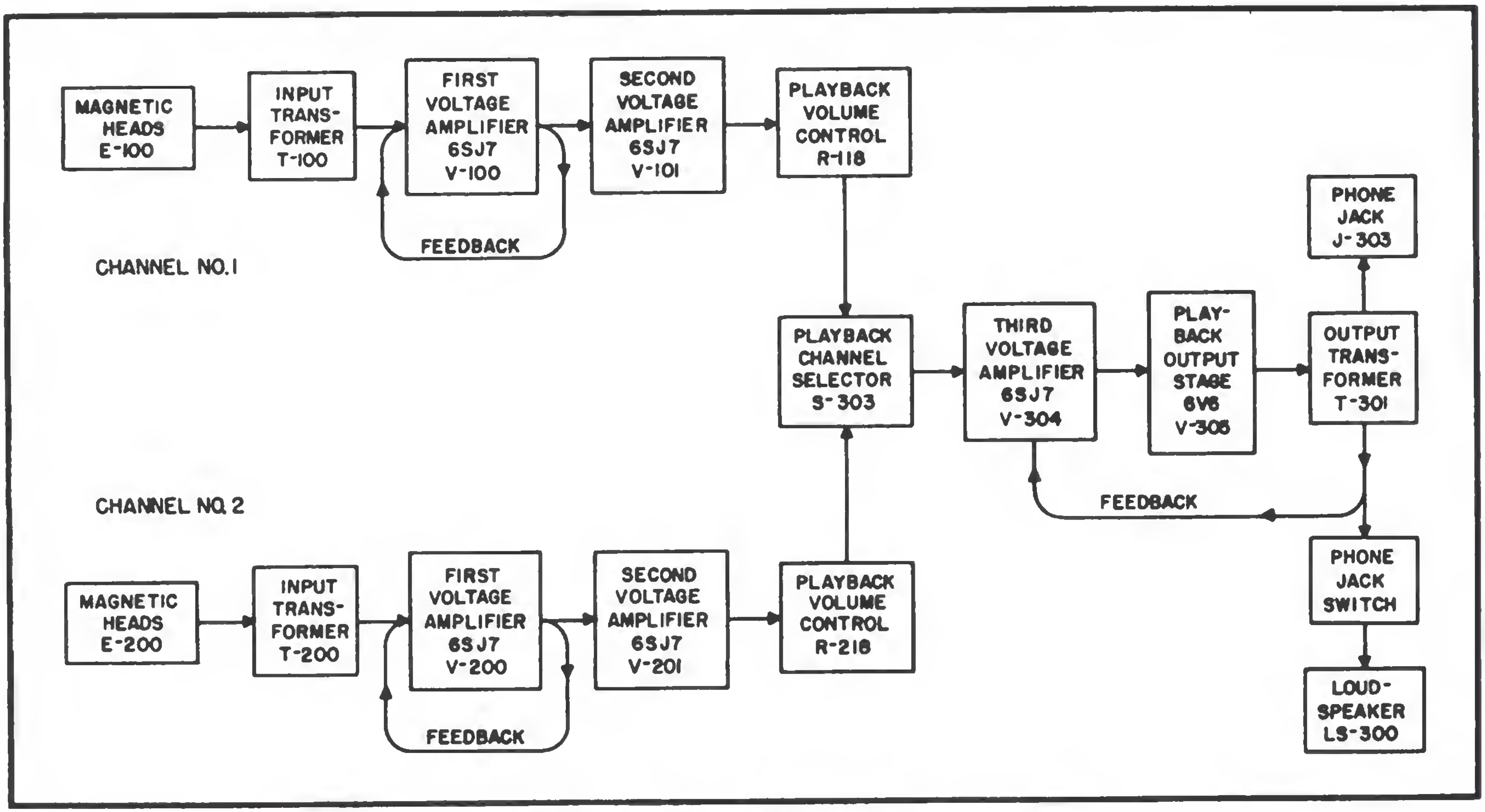


Figure 10–7.—Block diagram of playback circuits.

top panel. The reel of magnetic tape to be erased is placed between the pole pieces and the a-c field demagnetizes the entire reel. The reel rests on two rollers that permit easy rotation of the reel during the process. The demagnetizer has a momentary on-off switch that automatically returns to the off position in a short time interval.

CONTROL SECTION.—The control section for the electronic components is mounted on the amplifier panel. This panel contains: (1) on-off power switch; (2) power-on indicator lamp; (3) on-off motor switch; (4) playback and monitor phone jack; (5) loudspeaker; (6) reload warning lamp; (7) warning reset switch; (8) amplifier 1 bias indicator lamp; (9) amplifier 2 bias indicator lamp; (10) amplifier 1 record volume control; (11) amplifier 2 record volume control; (12) microphone 1 input plug; (13) microphone 2 input plug; (14) playback channel selector; (15) playback record selector; (16) channel 1 playback volume; and (17) channel 2 playback volume.

When in the RECORD position, the playback-record selector simultaneously selects the components used in recording for both amplifier channels. The playback channel selector provides switching between channel 1 and channel 2, making it possible to listen to or monitor either channel during recording. This switching does not affect the recording channels that remain independent.

When in the PLAYBACK position, this selector selects simultaneously the components used in playing back for both amplifier channels. The playback channel selector provides switching between channel 1 and channel 2, or provides mixing of both channels. Thus during playback it is possible to listen to either channel or to both channels at the same time.

MAINTENANCE

In locating troubles in the sound recorder-reproducer or demagnetizer, the first step is to sectionalize the fault into a general location. Then locate the defective part responsible for the abnormal condition. Some mechanical and electrical faults can be located by sight or smell. Other faults must be located by taking measurements with test meters.

Faults that occur in the second recorder-reproducer and demagnetizer can be located by resistance and voltage measurements and ground and sensitivity tests.

A volt-ohmmeter having a sensitivity of 20,000 ohms per volt is used for all voltage and resistance measurements except the magnetic bias voltage. This measurement requires a vacuum-tube voltmeter for accurate readings. However, the biasing voltage is not critical. A neon lamp in the circuit of each bias amplifier stage glows when sufficient voltage is applied. Test meters should be capable of measuring alternating voltages from 0 to 1,000 volts, direct voltages from 0 to 500 volts, and resistances from 0 to 1 megohm.

Ground Tests

Ground tests are conducted to trace hum troubles. If hum occurs in one of the amplifiers, short-circuit the grids of the tubes one at a time to B−, while listening to determine into which stage the hum is being introduced. Start with the grid of the first stage, then test the second stage, and so forth. When the hum stops, the trouble is in the stage immediately preceding the first grounded grid that stops the hum.

Sensitivity Tests

Sensitivity tests are conducted to locate a dead stage. Test the grids of each stage by touching the grid terminal of the tube socket with a screw driver until a grid is located that does not produce a hum or click. The dead stage is the one immediately preceding the first grid that is sensitive. The volume controls are turned on full when this test is conducted.

Amplifier Troubles

When faults occur in the amplifier, test all tubes with a tube tester or install new tubes to eliminate possible tube trouble.

If both recording amplifier channels operate properly and it is not possible to monitor or play back, the trouble is in the components that are common to both monitoring and playing back. These common components are in the output stage which contains tube *V*305 and the output circuit to loudspeaker *LS*300 and phone jack *J*303.

If both recording and monitoring amplifier channels operate properly and it is not possible to play back, the trouble is in the components used for playback. These components are in the third voltage amplifier stage, which contains tube *V*304.

If one amplifier channel records properly and both amplifier channels monitor and play back properly but the second amplifier channel does not record properly, the trouble is in either (1) the output stage containing tube *V*102 and bias amplifier stage containing tube *V*300*A*, or (2) the output stage containing tube *V*202 and bias amplifier stage containing tube *V*300*B*—depending upon which amplifier channel is defective.

If both amplifier channels monitor and play back properly but both recording amplifier channels do not record, the trouble is in the bias oscillator stage containing tube *V*301 or the bias amplifier stage containing tube *V*300.

If one amplifier channel records, monitors, and plays back properly but the second amplifier channel does not record, monitor, or play back, the fault is in the input circuit including the magnetic heads or in the first two amplifier stages of the defective amplifier.

If neither amplifier channel records, monitors, or plays back, the fault is in the power supply that is common to both amplifiers.

An open cathode bypass capacitor causes hum and decreases the amplification of the stage, resulting in a weak signal. The best method is to shunt another capacitor across the suspected capacitor and note the effect.

Low screen or plate voltage, which causes the amplifier to be weak, can result from positive voltage on the grid or from no cathode bias voltage. This fault can be localized by taking voltage and resistance measurements.

When a coupling capacitor between the plate of one stage and the grid of the next stage opens, the amplifier is blocked or does not produce any sound. This fault can be localized by taking a sensitivity test. Check the suspected capacitor by shunting another capacitor across it and note the effect.

When a coupling capacitor between the plate of one stage and the grid of the next stage shorts out or leaks, it causes hum and makes the amplifier weak. This fault can be localized by a direct voltage reading on the grid.

An open grid resistor or grid circuit causes hum. An open grid circuit can be localized by taking a ground test and checked by making resistance measurements.

An open or shorted transformer winding causes the amplifier to be weak or inoperative. This fault can be localized by taking resistance measurements.

All naval vessels have at least one sound recorder-reproducer on the ship's allowance list. For more detailed information concerning the operation, maintenance, and repair of this equipment, refer to chapter 65 of the *Bureau of Ships Manual* and to the appropriate manufacturer's instruction book.

QUIZ

1. Name three basic methods of recording and reproducing sound.
2. Mechanical recorders use what two kinds of mediums to record the sound pattern?
3. Name five components necessary to mechanically record and reproduce sound.
4. What device is used to play back mechanical disk recordings?
5. The principle of operation of a pick-up head is similar to that of what type of microphone?
6. Can sound recorded on disks or films by mechanical recorders be erased?
7. Magnetic recorders use what two kinds of mediums to record the sound pattern?

8. What is the principle of magnetic recording?

9. After recording, in what three ways do the succession of magnetic field patterns existing throughout the length of wire differ from each other?

10. What device is used to play back magnetic wire and tape recordings?

11. How is erasing of the sound pattern accomplished on a magnetic recording medium?

12. How is photographic sound recording accomplished?

13. Name two methods of photographically recording sound on film.

14. What kind of recording medium is used with the RD–115/UN recorder-reproducer?

15. How many amplifier channels are provided in the RD–115/UN recorder-reproducer?

16. How are the four magnetic heads of each channel mounted?

17. What means is provided for playback in the RD–115/UN recorder-reproducer?

18. What is the purpose of the tone generator associated with recording amplifier channel 2?

19. Name four principal electronic components of the RD–115/UN sound recorder-reproducer.

20. Name four tests for locating faults that occur in the sound recorder-reproducer and demagnetizer.

21. What kind of tests are conducted to trace hum troubles in amplifiers?

22. What tests are conducted to locate dead stages in amplifiers?

CHAPTER 11

SOUND MOTION PICTURE SYSTEM

A knowledge of light and lenses, in addition to sound, is essential for a clear understanding of the theory involved in sound motion picture projection.

LIGHT

Light is radiant energy that is capable of affecting the eye to produce vision. Light is also defined as a form of energy that results when minute particles of a body are set into extremely rapid vibration. This vibration is usually caused by intense heat and is accompanied by extremely high temperature.

The sun and stars are natural sources of direct radiation, both visible and invisible; whereas the moon and planets are natural sources of indirect radiation by reflection. The incandescent electric lamp is an artificial source of direct radiation that gives off light because of the high temperature of its filament, which is heated by an electric current.

Nature of Light

Light is a form of wave motion that is propagated through uniform isotropic media or through empty space with an exceedingly great, but finite and measurable, velocity. A light wave is a TRANVERSE WAVE the vibrations of which are perpendicular to the direction of propagation, as shown in figure 11–1. The amplitude of a light wave, like that of a water wave, is the height of the crest or the depth of the trough. The intensity of the wave depends upon the amplitude.

The WAVELENGTH, λ, is the distance between successive points in identical stages of motion of a light wave. Wave-

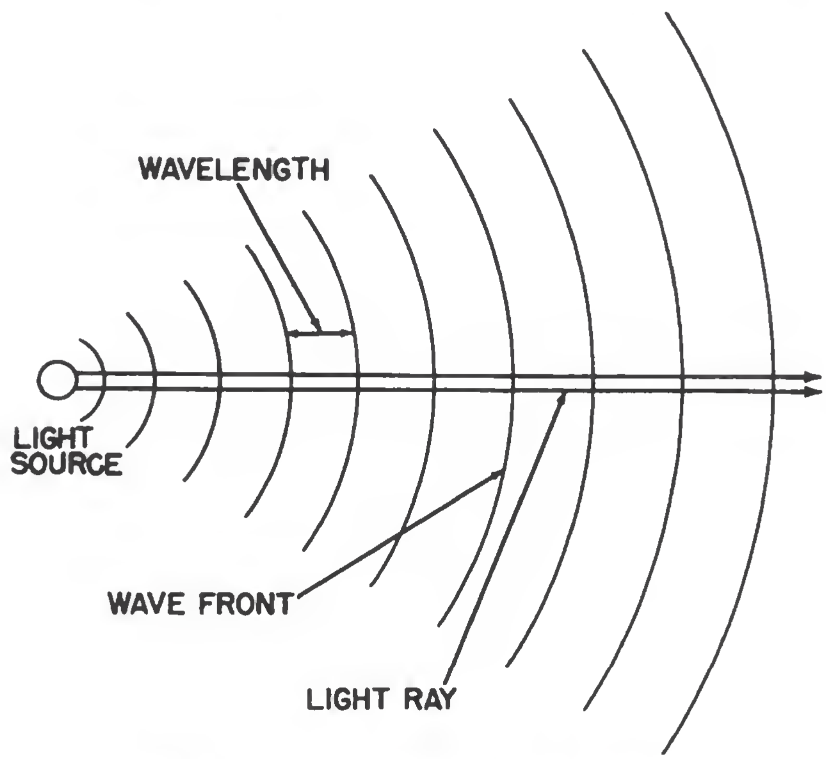


Figure 11–1.—Propagation of light waves.

lengths are indicated in figure 11–1 as the distance from the crest of one wave to the crest of the next wave.

The WAVEFRONT is a line connecting particles of the medium over which the disturbance is momentarily uniform. Wavefronts are indicated in figure 11–1 by the concentric circles. Thus a wave emitted from a point source, S, with equal velocity in all directions would have a succession of expanding spherical wavefronts.

A light RAY is a line drawn in the direction of propagation from the light source. The term "ray" can be used to refer to the light itself or to the lines that represent its path. A wavefront moving outward is assumed to be perpendicular to the ray a short distance from the light source.

A BEAM of light is a bundle of parallel rays; a CONE of light is a narrow bundle of diverging rays; and a PENCIL of light is a narrow bundle of converging rays.

The rays of light from a large source such as the sun diverge very little and for practical purposes are considered to be parallel. On the other hand, the rays of light from artificial sources such as incandescent and arc lamps spread out as they are propagated through space and diverge as they move farther from the source. For practical purposes these rays are considered as originating from a point source.

Velocity of Light

Light travels at a definite speed in any one medium. The speed of light is approximately 186,000 miles per second in a vacuum and is slightly lower in air, and appreciably lower in water, glass, and other media. The velocity of light is determined by the same method used to determine the velocity of sound (equation 8–1)—

$$v = f\lambda.$$

Characteristics of Light

Each ray must cover a greater area as it moves farther from the source because the light from a point source spreads out in all directions. Thus, the intensity (brightness) of light decreases with distance. The inverse-square law applies to this decrease in intensity with an increase in distance—that is, the light intensity is inversely proportional to the square of the distance from the source. The eye cannot form a quantitative estimate of the degree of brightness because the pupil opens or closes to receive more or less light according to the intensity of illumination.

Certain kinds of light produce the sensation of color. The color of light is produced by the different light frequencies which have different effects on the optic nerve. The color is determined by the frequency of vibration and the associated wavelength of the light wave.

The solar spectrum contains the following colors in the order of their wavelength:

*1. Infrared
2. Red
3. Orange
4. Yellow
5. Green
6. Blue
7. Violet
*8. Ultraviolet
*9. X-rays
*10. Gamma rays
*11. Cosmic rays

At one extreme, red is produced by the longest waves (lower frequency). At the other extreme, violet is produced by the shortest waves (higher frequency).

An object reflects the light associated with its own color. Thus an object is red if it reflects red light, or blue if it reflects blue light.

Sunlight contains all the colors of the visible spectrum. Thus colored objects look natural in sunlight because each reflects that part of the spectrum associated with its own color.

A brilliant red object in sunlight looks gray when illuminated by a sodium vapor light because there are no red rays in sodium vapor. The object loses its brilliant color because it absorbs the yellow light of the sodium vapor lamp and cannot reflect its natural color in the absence of the red rays.

Properties of Wave Motion

REFLECTION.—Light waves, like sound waves, can be reflected and refracted. When a light ray strikes the surface of an opaque object, some of the light is absorbed and converted into heat, and the remainder is reflected. If the surface of the object reflecting the light is flat and polished, such as a plane mirror, the light is reflected without changing the relative arrangement of the rays, as shown in figure 11–2.

The ray from the source to the mirror is the INCIDENT RAY.

---

*Not visible to the naked eye.

The point at which the ray strikes the mirror surface is the POINT OF INCIDENCE. The ray that comes from the point of incidence is the REFLECTED RAY. The line perpendicular to the surface of the mirror at the point of incidence is called the NORMAL to the surface. The angle between the incident ray and the normal to the surface is the ANGLE OF INCIDENCE, *i*.

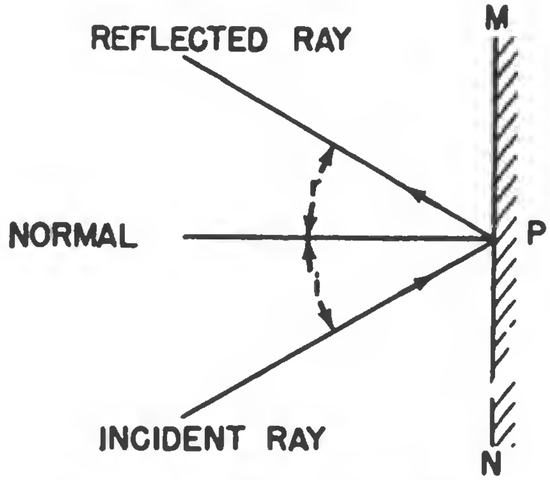


Figure 11–2.—Reflection of a light ray.

The angle between the reflected ray and the normal to the surface is the ANGLE OF REFLECTION, *r*.

In accordance with the law of reflection angle *i* equals angle *r*. In other words, the incident ray, the reflected ray, and the normal to the surface at the point of incidence are all in the same plane, and the angle of reflection equals the angle of incidence. This statement is true for both plane and curved mirror surfaces because the incident and reflected rays travel in the same medium with the same velocity.

Light rays reflected from a concave mirror are concentrated into a very small area and are called CONVERGING RAYS over the distance from the mirror to the point of maximum concentration. Beyond the point of maximum concentration they are DIVERGING RAYS.

REFRACTION.—When light travels in one medium and encounters a second medium of different optical density, part of it is reflected and part continues into the second medium, as shown in figure 11–3. Unless the angle of incidence is zero, the light that enters the second medium undergoes a change of direction. The ray that enters the second medium is the REFRACTED RAY. The angle of refraction, r, is the angle between the refracted ray and the normal to the surface of

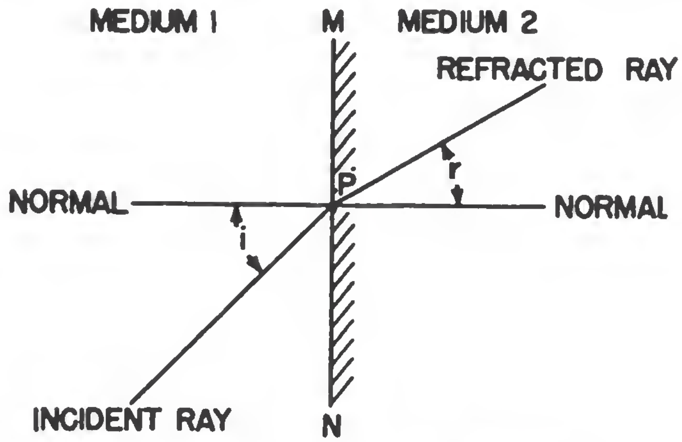


Figure 11–3.—Refraction of a light ray.

the second medium. Reflection and refraction both occur at the boundary surface between the two media. Thus the boundary serves as a plane surface for one ray and as a refracting surface for the other ray.

LENSES

A LENS is a piece of glass that is ground with curved surfaces for the purpose of directing light rays.

If light rays pass from one medium to a denser medium having parallel faces, such as plate glass, the rays emerge from the denser medium and travel in the same direction in which they traveled prior to entering the denser medium, as shown in figure 11–4, A. Thus, light rays are offset slightly when passing through an ordinary window pane, but are not changed in direction.

If the faces of the denser medium are not parallel, the rays are permanently bent and emerge from the denser medium and travel in a direction different from that traveled before they entered the denser medium (fig. 11–4, B). Thus the light rays are bent in passing through a prism with flat surfaces. If the entering rays are parallel, the emerging rays are also parallel.

If parallel light rays pass from one medium to a denser medium having curved surfaces, such as a lens, the emerging rays are not parallel but are concentrated, or focused, to a

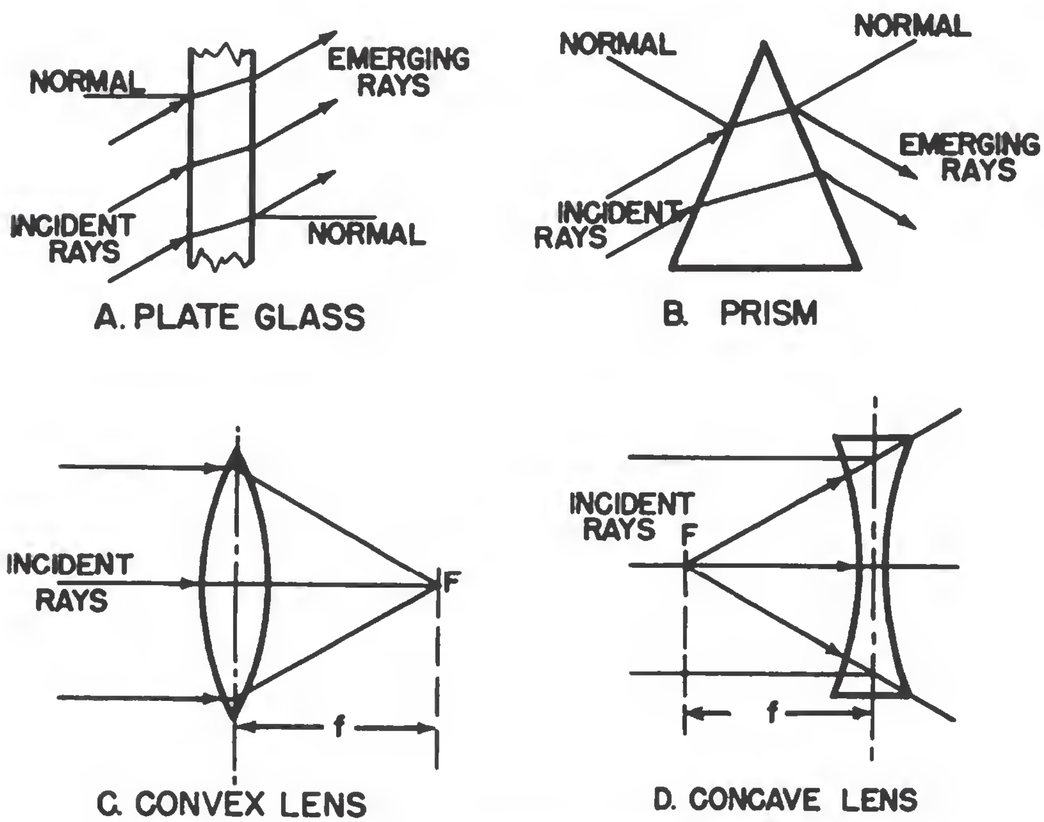


Figure 11–4.—Refraction of light rays.

small point. The PRINCIPAL FOCUS, F, of the lens is the point of convergence or of divergence of the light rays.

A double-convex and a double-concave lens are shown in figure 11–4, C and D, respectively. The rays converge to point F in the convex lens and diverge from point F in the concave lens. The distance from the principal focus, F, to the lens is called the FOCAL LENGTH, f. Thus it is possible to concentrate, or to control, light rays by passing them through a dense transparent substance such as glass.

The projection of motion pictures on a screen is based on the principle of the formation of an image by a convex lens. A lens can be used to form an image of an object on a screen if all the light radiated from each point on the object and incident upon the lens can be brought to a focus at corresponding points on the screen.

The formation by a convex lens of image $A'B'$ of the object AB is shown in figure 11–5. Some of the rays of light

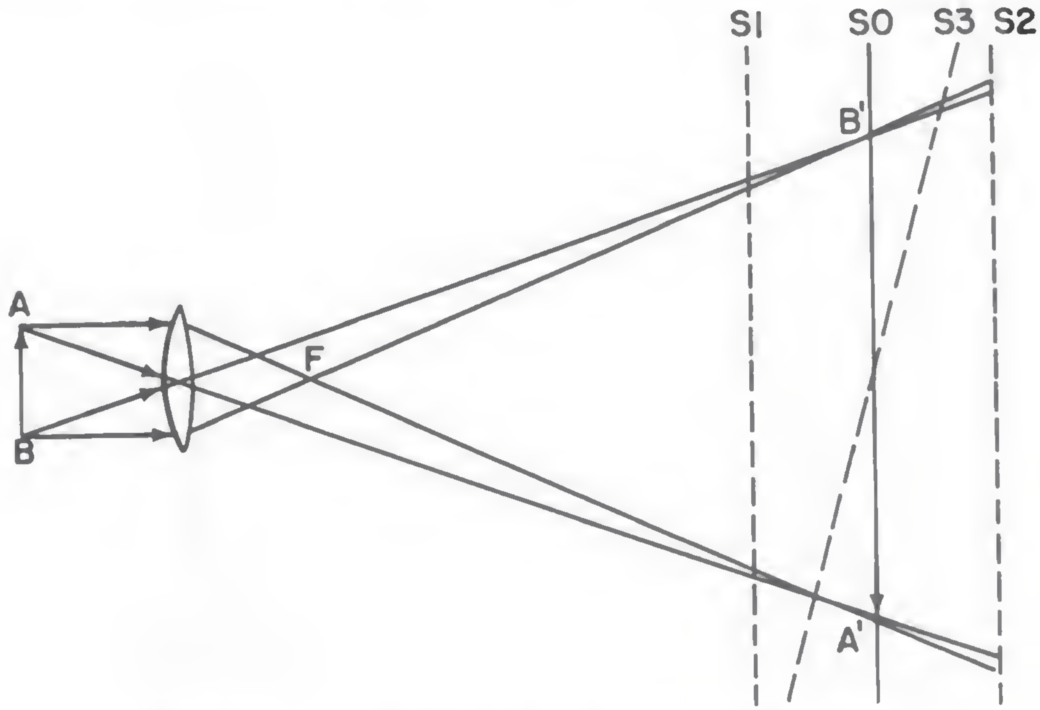


Figure 11–5.—Formation of an image by a convex lens.

from A are intercepted by the lens and are brought together at point A' on the opposite side of the lens. For simplicity, only two rays are shown. One of the rays from point A in the object passes through the optical center of the lens and strikes the screen at A'. Another ray from point A parallel to the axis of the lens is refracted by the lens and also strikes the screen at point A'. Any other ray from A, incident upon the lens, also strikes the screen at point A'. Point A' is the image of point A in the object. Similarly, all the light rays from point B in the object strike the screen at point B'. Point B' is the image of point B in the object. Every other point in the object is represented by a corresponding point in the image.

For a given distance between the lens and object, there is only one distance between the lens and the screen at which the image will be sharp on the screen. Light rays from a point in the object meet at a point on the screen in the plane $S0$. If the screen is either nearer to the lens, as $S1$, or farther from the lens, as $S2$, the rays produce a blur because not all of them strike the same point. For any screen distance there is a corresponding object-to-lens distance that produces a sharp picture. It is usual practice to select the screen distance to provide the desired image size and then adjust the distance between the object and lens until the image is the sharpest. This adjustment, which moves the lens closer to or farther from the object, is called FOCUSING. To obtain a larger or smaller image for a fixed projection distance, it is necessary to use a lens of a different focal length.

The screen should be at right angles to the axis of the lens. Tipping the screen as shown at $S3$, in figure 11-5, results in an image that is out of focus at the top and at the bottom, although it may be sharp at the middle. Note that the rays cross as they pass through the lens. The image on the screen is therefore inverted with respect to the object. Hence, when motion pictures are projected, the images on the film must be upside down.

PRINCIPLES OF SOUND MOTION PICTURE PROJECTION

Motion picture projection is the presentation on a screen of a series of images taken in very rapid succession by a motion picture camera. Such a presentation produces an illusion of moving images. This illusion results from viewing, in very rapid succession, a series of images each of which differs slightly from the preceding one. The eye retains an impression of the preceding image, blends it with the succeeding image, and creates an illusion of motion. In motion picture terminology an image is known as a FRAME.

Film

A sound motion picture film (fig. 11–6) contains two types of records—(1) a series of photographs taken in rapid suc-

Figure 11–6.—Section of a 16mm sound motion picture film.

cession of moving objects by a motion picture camera, and (2) a record of the sounds associated with or appropriate to the scenes recorded.

When such a film is shown on a screen the pictures are projected in the same order in which they were taken. The sound reproduced through the amplifier and loudspeaker is synchronized with the action of the picture.

Sound motion picture film is available in standard 35mm and 16mm sizes. The 35mm sound film travels through a 35mm projector at the rate of 90 feet per minute and is the standard size for theatrical projection. The 16mm sound film travels through a 16mm projector at the rate of 36 feet per minute and is the standard size used in the Navy. The 16mm film is a strip of cellulose acetate, one surface of which is coated with photographic emulsion. A row of perforated sprocket holes is one side of the film, with one hole to a frame. These sprocket holes provide a positive feed for the film through the camera and projector.

Sound Recording on Film

Sound is recorded on film as a continuous photographic image along a narrow strip at one side of the film called the SOUND TRACK. As previously mentioned, the two methods of recording sound on film are (1) VARIABLE-AREA recording (fig. 11–7, A) and (2) VARIABLE-DENSITY recording (fig. 11–7, B). Variable-area recording is denoted by zig-zag waves, whereas variable-density recording is denoted by parallel lines that vary in spacing and intensity.

In variable area recording the black areas on the sound track are opaque and the white areas are transparent. The width of the transparent area can vary from nothing to the limits of the opaque band, depending upon the instantaneous strength of the sound being recorded. When there is no variation in the width of the transparent area, no sound is recorded on the film and no sound is produced from it. In variable density recording the variation of density between successive dark and light bands determines the amplitude of the recorded sound.

When the subject is being recorded by the motion picture camera, the sound is picked up by a microphone that converts the audible sound waves into equivalent variations in electric current. This electric current is amplified and then photographed on film by a camera sound recorder. This recorder, equipped with a light modulator, converts the electric

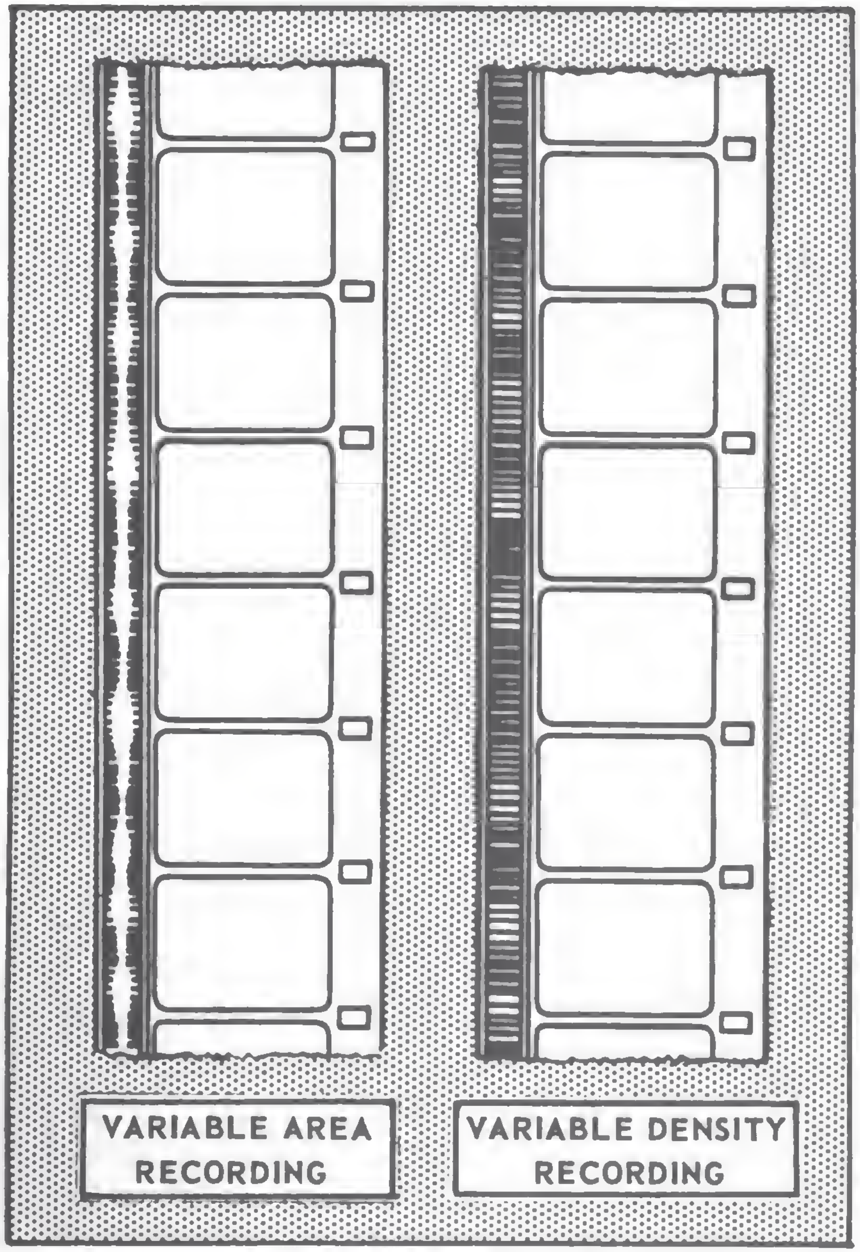


Figure 11–7.—Sound on film.

current from the amplifier into equivalent light variations and photographs these variations onto film. The sound and the picture are reproduced separately. The two films are then synchronized so that when they are printed together, the reproduced sound corresponds to the action of the picture.

The sound associated with an individual frame is not recorded on the sound track directly opposite that frame, but at a point 26 frames farther ahead. This displacement of the sound track relative to the picture is necessary because, for proper synchronization of sound and picture, the sound track must pass the scanning beam when the picture is at the aperture. When the sound track is scanned by the light beam the motion of the film is smooth and continuous. A loop of film interposed between the aperture and the point at which the light beam scans the sound track isolates the intermittent motion from the continuous motion. A LOOP SETTER ROLLER is used in some sound projectors to form the proper size of film to produce 26 frames between the picture in front of the aperture and the scanning beam.

Projector Image Formation

A motion picture projector projects each frame of the film on the screen for a small fraction of a second. Each frame is immediately followed by the next frame, which is shown for an equally brief interval. In sound motion picture projection, 24 frames are shown every second. However, this does not mean that each frame is held on the screen for one twenty-fourth of a second. The actual time is about one-half of this interval because the screen is darkened twice during each frame, once while the film is moving forward and again while a frame is being held stationary in the projector. If the light is not cut off while the film is in motion, the picture on the screen is blurred and streaked. If the light is not cut off at least once while each frame is still, a flicker results. The light is cut off by means of a 2- or 3-segment barrel-type shutter placed between the source of light and the film aperture. This shutter revolves once for each frame,

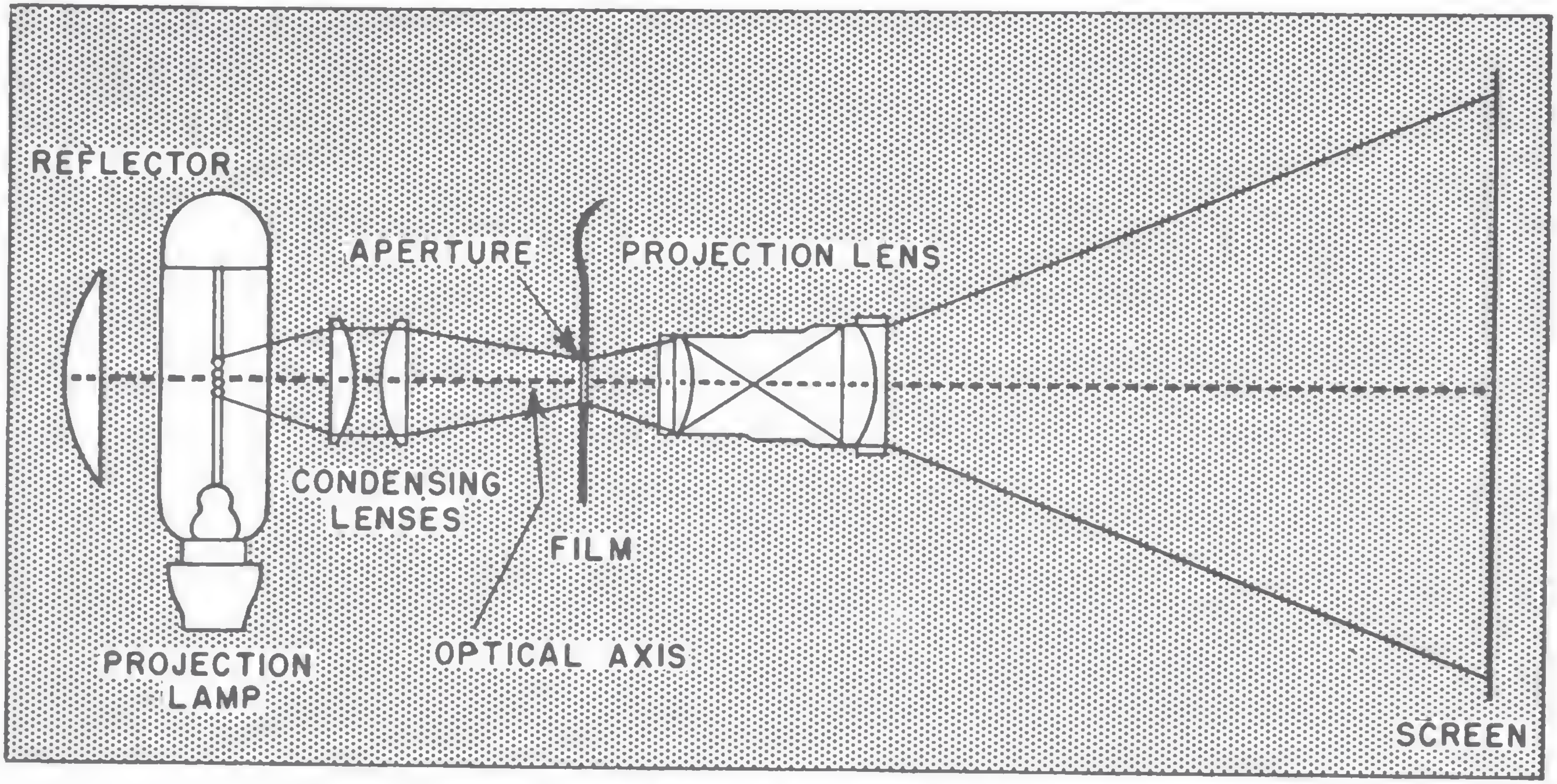


Figure 11–8.—Projection optical system.

or for each complete cycle of the intermittent mechanism. The segment that interrupts the light beam while the film is in motion is called the PULL-DOWN BLADE and the other segment is called the ANTIFLICKER BLADE.

Projection Optical System

The sound motion picture projector is provided with an optical system to project the picture on the screen, as shown in figure 11–8. This system consists of a 750- or 1,000-watt concentrated-filament projection lamp located behind the film. This lamp provides the light beam for projecting the film image on the screen. The condensing lenses concentrate the light from the projection lamp on the picture area. A reflector placed behind the projector lamp recovers the light emanating to the rear and directs it forward through the optical system. To obtain maximum brilliance in the projected picture, an aperture plate masks the beam of projected light and screens it off from all film frames except the frame positioned in front of the aperture. The projection lens placed in front of the film focuses the image of the film frame on the screen.

Sound Optical System

The sound motion picture projector is provided also with a sound optical system (fig. 11–9). The purpose of the sound optical system is to convert the variations in the sound track of the film into sound waves. When the film sound track is run through the projector, it passes in front of the sound optical unit, which focuses a beam of light from the exciter lamp on the sound track. This beam of light, called the SCANNING BEAM, passes through the film to the anode of the photocell by way of a mirror or prism not shown in the figure. In variable-area recording the wave images on the sound track vary the amplitude of the scanning beam as it passes through the sound track. These variations in the scanning beam produce corresponding variations in the electron emission through the photocell. These corresponding variations are converted into voltage variations across a resistor and fed to an amplifier. The output of the amplifier is converted into sound waves at the loudspeaker.

The greater the width of the sound waves, or the greater the density of the sound bands on the film (depending on the type of recording used), the greater are the variations in

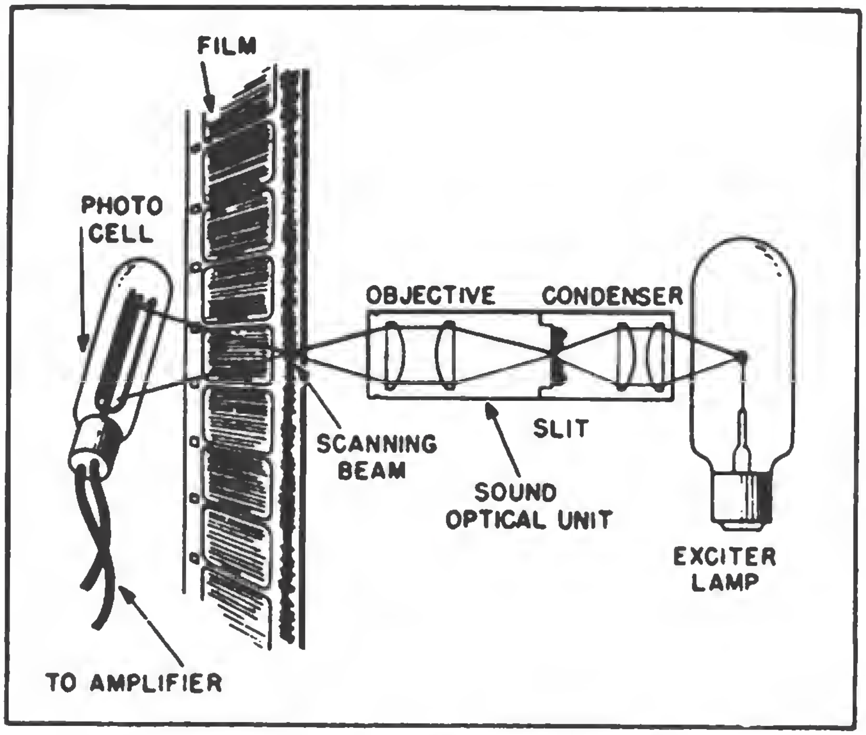


Figure 11–9.—Sound optical system.

the amount of light that reach the photocell. The recorded sound track interposed between the light source and the photocell determines the variation in the intensity of light transmitted to the photocell and the rapidity with which the variations in light intensity occur. The variations in light intensity thus control the magnitude and frequency of the electric impulses to the amplifier.

IC/QEB–1D EQUIPMENT

The sound motion picture system, circuit MP, is designed for use in training, briefing, and entertaining naval personnel. The IC/QEB–1D motion picture projector and ampli-

Figure 11—10.—IC/QEB—1D projector and amplifier.

fier are shown in figure 11–10. This equipment can be used in an average size room, in an auditorium, topside aboard ship, or in any projection area where a single-phase 115-volt power supply is available. This equipment consists of (1) IC/QPB–1D 16mm sound motion picture projector, (2) IC/QAF–1D 20-watt amplifier, and (3) IC/QDM–1D 25-watt loudspeaker.

Projector

The IC/QPB–1D projector (fig. 11–11) is a portable device contained in an aluminum case. The right side of the case is fitted with a hinged cover to provide access to the front operating side of the projector. The front of the case

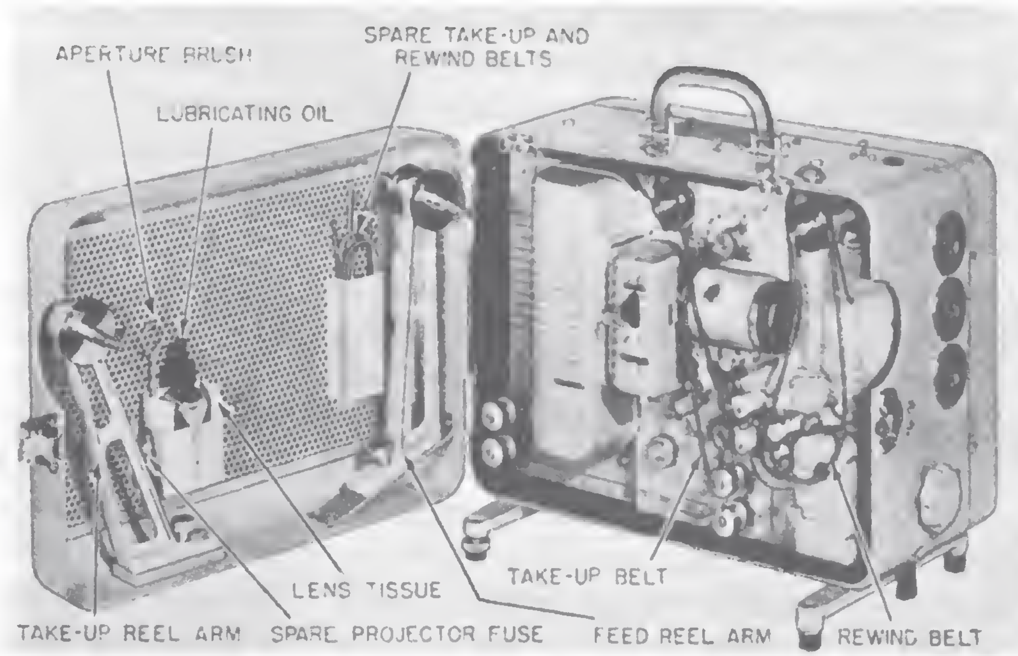


Figure 11–11.—IC/QPB–1D projector.

contains the power-changeover and sound-output receptacles. The left side is fitted with a removable cover to provide access to the back of the projector mechanism. The rear of the case contains the control panel. The major divisions of the projector are the mechanical components and the electrical components.

Mechanical components.—The mechanical components of the projector consist of: (1) cooling system; (2) feed reel arm assembly and take up reel arm assembly; (3) film sprockets; (4) aperture plate assembly; (5) intermittent mechanism; (6) light optical system; (7) condensing lens; (8) reflector; (9) projection lens; (10) loop setter roller; (11) sound lens; and (12) optical light pipe prism.

The COOLING SYSTEM consists of the ventilating motor with its blower. This system operates at all times when the projector is operating. The blower circulates cool air around the projection lamp, the condensing lens, the aperture, and the film. Intake vents are located in the switch panel, under the lamp house, in the changeover shutter cover, and in the left side cover. Exhaust vents are located in the rear of the case.

The FEED REEL ARM ASSEMBLY and the TAKEUP REEL ARM ASSEMBLY are each provided with a spindle and a lock latch for holding the reels. Friction is applied to the spindle on the feed reel arm to maintain tension on the film being run off the reel. The pulley attached to this spindle is used for rewinding film. Friction is applied to the takeup spindle to maintain tension on the film takeup. The pulley attached to this spindle is used to take up the film after it runs through the projector. A rewind spring belt drives the film reel on the feed reel arm when the film is rewound. A takeup spring belt drives the takeup reel on the takeup reel arm so that film that has been projected winds up properly on the takeup reel.

Three FILM SPROCKETS that turn with a uniform velocity help move the film at a constant speed. The upper, or feed, sprocket unwinds the film from the feed reel and maintains a loop of film above the film channel. The center, or sound, sprocket feeds the film to the sound head and maintains a loop of film below the film channel. The lower, or takeup, sprocket moves the film away from the sound head to the takeup reel.

The APERTURE PLATE ASSEMBLY is the channel through which the film is moved in front of the aperture, one frame at a time, by the action of the intermittent mechanism. The aperture is the rectangular opening in the aperture plate that limits the illumination from the light optical system to that portion of the film that is occupied by the picture. The PRESSURE PLATE contains a rectangular opening slightly larger than the aperture. It maintains proper tension to hold the film flat against the aperture and in a plane of exact focus at all times.

The INTERMITTENT MECHANISM consists of a shuttle with three teeth, a front shaft, and a rear shaft. As the shuttle moves toward the film, the teeth engage the film perforations. The shuttle then moves down to advance the film one frame and back to disengage the teeth from the perforations. The front shaft actuates the vertical motion of the shuttle and the rear shaft actuates the horizontal motion. The 2-segment barrel shutter rotates at a speed of 24 rpm to provide 48 interruptions per second.

The LIGHT OPTICAL SYSTEM produces a screen illumination in excess of 320 lumens with a new 750-watt Mazda lamp and in excess of 475 lumens with a new 1,000-watt Mazda lamp.

The projection light CONDENSING LENS ASSEMBLY consists of an aspheric condensing lens and a plane-convex condensing lens. The aspheric condensing lens collects the greatest amount of light emitted by the projection lamp. The plane-convex condensing lens converges and concentrates this light upon the picture frame in the aperture.

The REFLECTOR is positioned behind the projection lamp to increase the utilization of light by reflecting most of the light radiation forward to the condensing lens and in the direction of the film.

The PROJECTION LENS forms on the screen an enlarged image of the illuminated film frame at the picture aperture.

The LOOP SETTER ROLLER controls the size of the lower loop of film to maintain synchronism between the picture and the sound. The lever arm attached to the loop setter roller can be directly depressed or operated by a push switch located on top of the case. The distance that the lever arm can be depressed is limited to avoid forming a larger loop which would result in a loss of synchronism between the picture and the sound.

The SOUND LENS (sound optical unit) focuses a beam of light from the exciter lamp on the sound track.

The OPTICAL LIGHT PIPE PRISM is mounted on the sound stabilizer assembly. This quadrangular shaped prism (1) gathers both the directly reflected and the scattered sound light beam that is received through the film; (2) concentrates all of the sound light beam into a small area; and (3) transmits this concentrated sound light beam to the photoconductive cell without loss.

ELECTRICAL COMPONENTS.—A schematic wiring diagram of an IC/QPB-1D projector is shown in figure 11-12. The

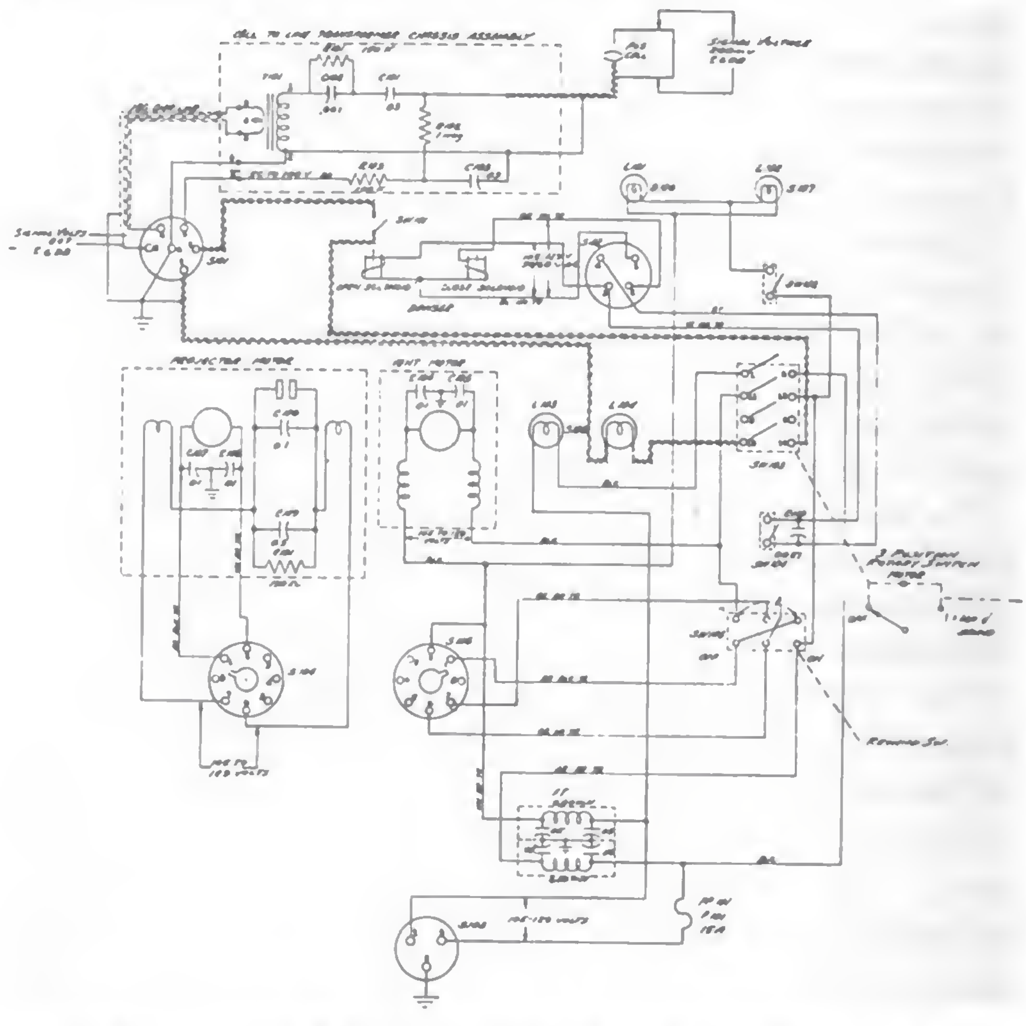


Figure 11–12.—Schematic wiring diagram of an IC/QPB–1D projector.

electrical components of the projector include: (1) photoconductive cell; (2) exciter lamp; (3) projector drive motor; (4) ventilation motor; (5) projection lamp; (6) two threading lamps; and (7) changeover mechanism.

The lead sulfide PHOTOCONDUCTIVE CELL converts the light variations that impinge on its surface, into corresponding variations in voltage across a resistor. The photocell develops a maximum signal intensity of 0.2 volt directly from the film signal. The output of the photocell is transmitted to the amplifier through an audio transformer.

Direct voltage for the photocell is supplied by the amplifier to receptacle *S*101 through decoupling filter resistor *R*103, shunt filter capacitor *C*103, and load resistor *R*102 across which the audio frequency signal is developed. Capacitor *C*101 blocks direct current from coupling transformer *T*101. The resistor-capacitor filter network, consisting of resistor *R*101 and capactor *C*102, attenuates the low frequencies and thus compensates for film scanning and cell high-frequency response losses. Coupling transformer *T*101 matches the photocell circuit impedance of 200,000 ohms to the line impedance of 150 ohms.

The EXCITER LAMP is a 6-volt double-contact prefocused incandescent lamp. This lamp supplies intense illumination for scanning the sound track. The high frequency for the filament of exciter lamp *L*104 is supplied through *SW*101 by a Hartley oscillator in the amplifier. Switch *SW*101 is actuated by the OPEN solenoid in the changeover mechanism. Contactors *SW*103 are located in the motor-lamp switch.

The PROJECTOR DRIVE MOTOR is a series-wound universal governor type of motor. It operates at constant speed with changes in voltage of from 100 to 130 volts.

The motor speed governor is a centrifugally operated switch mounted on the armature shaft of the projector drive motor, and shunted by capacitor *C*106. If the speed is low, the governor switch shorts out resistor *R*104. If the speed is high, the governor switch opens and inserts resistor *R*104 to reduce the motor speed.

The projector drive motor is supplied through plug *S*104, which is inserted in socket *S*105 and is controlled by projector rewind switch *SW*105 and motor-lamp switch *SW*103. The drive motor field windings are connected to the center blades of double-pole double-throw switch *SW*105. When switch *SW*105 is in the REWIND position the drive motor is reversed. When this switch is in the OFF position, switch *SW*103 becomes operative for the drive motor. Switch *SW*103 is the main control for normal forward projection and connects the drive motor through contacts 11 and 12 to the a-c power supply.

The power supply for the projector drive motor, ventilating motor, and projection lamp is supplied through receptacle *S*103. The r-f filter, *FT*, eliminates any radio frequency radiation in the power feed to the drive motor, ventilating motor, threading lamp, and pilot lamp. Such an r-f filter is not used in the projection lamp circuit because of the surge-current power required. Contactors 1 and 3 of contactor *SW*103 comprise the switch lamp circuit. Threading and pilot lamp sockets *S*106 and *S*107 are connected through *SW*102 to the r-f filter power output supply.

The power for the series, universal type of ventilating motor is supplied through contacts 11 and 12 on motor-lamp switch *SW*103. Capacitors *C*104 and *C*105 are connected between the motor armature brushes and ground to prevent r-f radiation. The lamp-ventilating motor is energized simultaneously with the drive motor.

The CHANGEOVER MECHANISM provides uninterrupted sound-film programs when two projectors are used with one or more amplifiers and reproducers. It is a solenoid electromagnetic changeover mounted inside the shutter cover assembly. Sound changeover is effected by breaking the exciter-lamp circuit. Picture changeover is effected by a light shield that drops between the condenser lens assembly and the picture aperture. The push switch on the switch panel controls simultaneously the sound and the picture changeover from the outgoing projector to the incoming projector.

The changeover mechanism is supplied power from the amplifier through receptacle *S*102. Interconnection between projectors is provided by the changeover power cable, which parallels the "open" solenoid of one projector with the "close" solenoid of the other projector. The changeover circuit is never used with a single projector. Depressing changeover switch *SW*104 energizes the "open" solenoid of the desired operative projector and, through the changeover interconnection cable, also energizes the "close" solenoid of the desired inoperative projector. Capacitor *C*110 is connected across switch *SW*104 to eliminate electrical noise from the switching operation.

Amplifier

The IC/QAF–1D amplifier is a portable unit contained in an aluminum case. The front side of the case is fitted with a removable cover to provide access to the amplifier control panel.

The unit includes a conventional audio amplifier with push-pull output. Also included are a power supply for the amplifier and an oscillator to supply filament power for the projector exciter lamp. The amplifier will deliver 20 watts of output power to the loudspeaker on full volume when a 6-millivolt signal is applied to the grid of the first stage.

A schematic diagram of an IC/QAF–1D amplifier is shown in figure 11–13. The 115-volt, 60-cycle, a-c power supply is fed to the amplifier through receptacle *S*10. Single-pole single-throw switch *SW*1 is in series with one side of the line that feeds the primary of power transformer *T*1 and changeover receptacle *S*13 through fuse *F*1. The changeover receptacle provides the power to operate the changeover solenoids in each of the projectors when two projectors are used. Power transformer *T*1 has three secondary windings. Winding 1 (terminals 4, 5, and 6) supplies 405 volts at 265 milliamperes to the plates of rectifier tube *V*6. Winding 2 (terminals 1, 2, and 3) supplies 6.3 volts to pilot lamp *L*1 and the filaments of all tubes except rectifier tube $V6$. Winding 3 (terminals 7 and 8) supplies 5 volts for the filament of rectifier tube $V6$.

Plate and screen currents are furnished by winding 1 (terminals 4, 5, and 6) of the power supply transformer, $T1$. Rectification of the alternating current is accomplished by tube $V6$. Terminal 2 of tube $V6$ is the positive side of the power supply output. The negative side is center tap 5 of transformer $T1$ which is grounded through resistor $R41$ to provide negative bias for the power output stage. The 5-volt filament of rectifier tube $V6$ is supplied by winding 2 (terminals 7 and 8) of power supply transformer $T1$.

The rectifier output is filtered by a pi-section filter made up of input capacitor $C27$, series choke $T3$, and output capacitor $C26$. Plate and screen voltages are supplied from the output across capacitor $C26$ through series resistors and decoupling networks. Reduced plate voltage for oscillator tube $V7$ is obtained across capacitor $C25$ by means of series dropping resistors $R40$, $R42$, and $R43$. The oscillator operates at a frequency of 112 kc. A decoupling network made up of resistors $R42$, $R43$, and capacitors $C22$, $C29A$, $C29B$, $C30$, and $C31$ prevents the 112-kc output from feeding back into the power supply and causing interference.

Plate voltage for power amplifier pentodes $V4$ and $V5$ is supplied through the primary of output transformer $T2$, by way of the center tap connection and the common connection between filter capacitor $C26$ and choke $T3$.

Plate voltage is supplied to one triode plate (pin 2 of $V3$) through the decoupling network $R33$ and $C18$. Plate voltage for the other half of $V3$ (pin 5) is supplied through the decoupling network $R28$ and $C16$. Plate voltage is supplied to one half of $V2$ (pin 2) through decoupling filter $R25$ and $C13$. Plate voltage is supplied to the other half of $V2$ (pin 5) by way of decoupling network $R20$ and $C12$. Plate and screen voltages for tube $V1$ are supplied through decoupling network $R8$ and $C4$. Positive bias voltage for the photocell is supplied through decoupling filter $R5$ and $C1$.

PAGE NOT AVAILABLE

hes 6
way
elded
fre-
fre-
bias
out-
n the

V5)
out-
The
high-
aker.
als 4
out-
nd 7)
h re-
cross
Ca-
stors
todes
sig-
R35
.
rmal
nd 3)
push-
is de-
other
utput
phase
e sig-
cond
grid
hode-
Re-

the fi
3 (te
rectil
Pl
mina
Recti
tube
powe
trans
prov
5-vol
2 (te
Th
up of
tor C
outpu
coupl
tube
dropp
ates a
up c
C29L
back
Pl
supp
way
betw
Pl
throu
age f
decou
to on
C13.
5) by
scree
netw
is su

The series-fed HARTLEY OSCILLATOR, tube *V*7, furnishes 6 watts of 112-kc, r-f power to the exciter lamp filament by way of the step-down winding of oscillator coil *T*4, and a shielded cable terminating in receptacles *S*11 and *S*12. The frequency of the oscillator is determined by the resonant frequency of the tuned tank circuit *C*24 and *T*4. Grid leak bias for the oscillator is developed across *R*39 and *C*28. The output coil of *T*4 reduces the oscillator voltage to obtain the higher output current for the exciter lamp.

The PUSH-PULL POWER AMPLIFIER (pentodes *V*4 and *V*5) is biased for class-AB operation. It has a rated power output of 20 watts with less than 2 percent distortion. The output transformer, *T*2, couples the signal from the high-impedance plate circuit to the low-impedance loudspeaker.

The secondary has two windings. Winding 1 (terminals 4 and 5) supplies a 500-ohm line for monitoring the sound output by way of receptacle *S*8. Winding 2 (terminals 6 and 7) supplies the 8-ohm voice coil of the loudspeaker through receptacle *S*9. Grid bias for this stage is developed across *R*41 and is supplied through decoupling resistor *R*36. Capacitor *C*21 acts as a cathode bypass capacitor. Resistors *R*44 and *R*45 are in series with the grids of pentodes *V*4 and *V*5 and act as parasitic suppressors. The input signal is developed across grid leak resistors *R*34 and *R*35 through the action of coupling capacitors *C*19 and *C*20.

One half of twin triode *V*3 (pins 4, 5, and 6) is a normal type of voltage amplifier. The other half (pins 1, 2, and 3) is a self-balancing PHASE-INVERTER STAGE used to drive push-pull tubes *V*4 and *V*5. One half of the output signal is developed between the plate (pin 2) and ground, and the other half appears across cathode resistor *R*30. Thus the output signal consists of two components that are 180° out of phase and have equal magnitudes. Capacitor *C*17 couples the signal from the plate (pin 5) to the grid (pin 1) of the second triode section of tube *V*3. The signal appears across grid leak resistor *R*27. Resistor *R*29 is the unbypassed cathode-bias resistor for the cathode follower section of *V*3. Resistor $R32$ is the plate-coupling resistor for one half the output signal and resistor $R30$ is the cathode-follower coupling resistor for the other half of the output signal.

NEGATIVE FEEDBACK of 12 decibels is applied to the first triode section of $V3$ from the power stage through coupling resistor $R31$. This resistor connects terminal 5 of the 500-ohm winding of ouput transformer $T2$ and the cathode (pin 6) of the first section of twin triode $V3$. The first section provides a limited amount of voltage amplification. Capacitor $C15$ is a high-frequency bypass capacitor that reduces parasitical r-f pickup generated by the exciter supply oscillator. Capacitor $C14$ is the grid coupling capacitor to the preceding tone-control stage. Resistor $R23$ is a grid leak resistor (pin 4 of $V3$); resistor $R24$ is the cathode-bias resistor (pin 6 of $V3$); and resistor $R26$ is the plate-coupling resistor (pin 5 of $V3$).

Twin triode $V2$ provides two resistance-coupled stages of voltage amplification. Potentiometer $R14$ provides volume control at the grid of the first half of the twin triode (pin 4). A voltage divider network between the output of $V1$ and the input of $V2$, consisting of coupling capacitor $C5$ in series with the parallel combination of $R10$ and $C6$ and the series combination of $R12$ and $C7$, provides a means of frequency selection.

Inverse feedback between the output (pin 2) of the second half of twin triode $V2$ and the cathode (pin 6) of the first half is provided by the parallel combination of $R11$ and $C9$ in series with $C11$ and $R18$. Additional degeneration control is provided by the series combination of cathode bypass capacitor $C8$ and variable resistor $R13$. Coupling capacitor $C36$ provides high-frequency inverse feedback from the cathode (pin 3) of the second triode section of $V2$ and the grid (pin 4) of the first section, thus reducing the sensitivity of the amplifier to parasitical pickup from the exciter supply oscillator. Adjustment of $R12$ and $R13$ provides treble frequency control and adjustment of $R10$ and $R11$ provides low frequency control.

The INPUT VOLTAGE STAGE tube, $V1$, is a resistance-coupled voltage amplifier having a gain of 80. The input signal is developed across grid leak resistor $R4$, the transformer termination resistor; resistor $R6$ is the cathode-bias resistor; capacitor $C2$ is the cathode bypass capacitor; capacitor $C3$ is the screen bypass capacitor; resistor $R7$ is the screen voltage-dropping resistor; and resistor $R9$ is the plate-coupling resistor. The primary winding of input transformer $T5$ is designed to work from either of two 150-ohm sources. The center tap is grounded to reduce radio frequency and noise pickup. The secondary is designed to work into a 150,000-ohm load.

The amplifier CONTROL PANEL (fig. 11–14) is a separate aluminum subassembly secured to the amplifier main chassis uprights by machine screws. The controls and receptacles mounted on this panel comprise: (1) power switch; (2) vol-

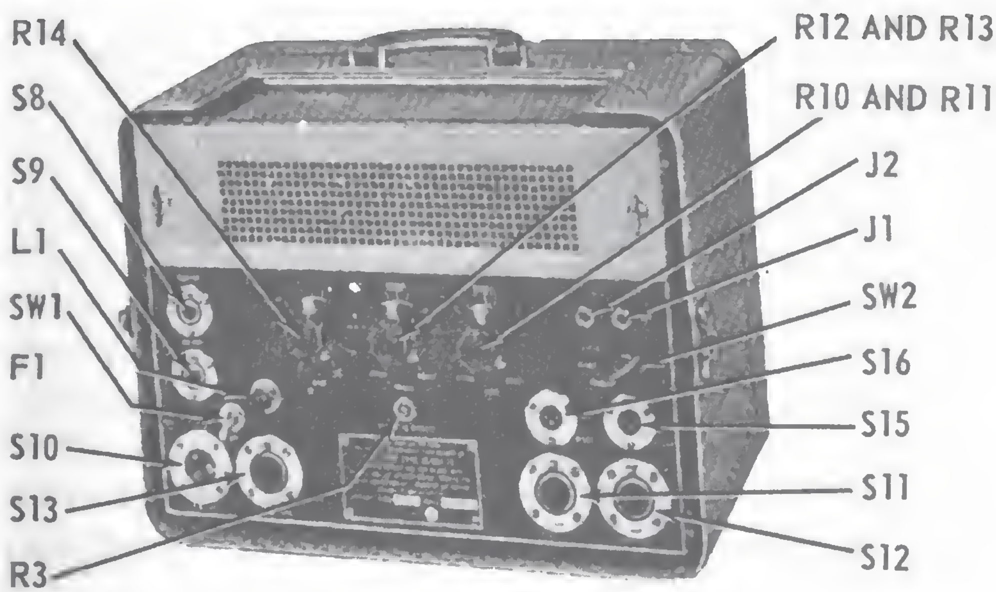


Figure 11–14.—Amplifier control panel.

ume control; (3) two tone controls (bass and treble); (4) microphone; (5) phonograph; (6) projector switch (micro-phono-proj); (7) pilot light; (8) fuse receptacle; (9) output receptacle (monitor) for connecting 500-ohm loudspeaker; (10) output receptacle for connecting 8-ohm loudspeaker;

(11) changeover cable receptacle; (12) dual projector input receptacles (projector 1 and projector 2); (13) microphone receptacle (micro); (14) record-player receptacle (phono); (15) two amplifier bridging jacks (in and out); (16) projector sound balance control (projector balance); and (17) a-c power receptacle.

The sound volume is regulated by the VOLUME CONTROL marked "gain." This control regulates the amount of power that is fed to the loudspeaker from any of the standard sources, such as the sound track on the film, microphone, or phono-record turntable.

The TREBLE CONTROL and the BASS CONTROL are provided to adjust the frequency response of the sound reproducing system. The center position of both controls is marked "normal." This position results in a response characteristic that closely approximates the design objective of the equipment.

When the TREBLE CONTROL (high-frequency) is turned counterclockwise, it provides high-frequency attenuation above 700 cycles. Normal adjustment is midway between the two extremes of the control. Adjustment of the treble control improves the intelligibility of films having poor sound-track definition and reduces background noise due to dirty or scratched film.

When the BASS CONTROL (low-frequency) is turned counterclockwise from the NORMAL position, it provides attenuation of the frequencies below 700 cycles. Normal adjustment is midway between the two extremes of the control. If the film program takes place in a large area having bare walls, a great amount of reverberation results. The over-all sound quality is improved by decreasing the low frequencies because these frequencies are most subject to reverberations.

The INPUT CIRCUIT JACK marked "in" and the MULTIPLE-CONNECTED JACK marked "out" provide for:

1. Parallel operation of two amplifiers from the input signal and permit independent adjustment of the volume and tone of the loudspeaker bank.

2. Use of an amplifier with any external sound device, such as microphones and phonographs that terminate in a telephone plug.

3. Insertion of auxiliary sound equipment into the input speech circuit—such as volume compressors, volume expanders, and special-purpose wave filters.

Jack multiple *J*1 (fig. 11–13) is connected to input switch *SW*2. Inserting a telephone plug in *J*1 parallels the plug with the input sound circuit. Inserting a telephone plug in *J*2 disconnects input switch *SW*2 from the amplifier input and transfers the amplifier input to the equipment that is connected to the telephone plug.

The INPUT SELECTOR SWITCH, *SW*2, marked "proj-micro-phono" is provided for rapid switching from projectors to phonograph or to microphones. This switch must always be set in the PROJ position when sound motion picture film is being projected.

The PROJECTOR VOLUME BALANCE CONTROL labeled "projector balance," equalizes the sound output from two projectors when dual equipment is operated. For single equipment operation, set the control in the midposition.

Turn the control, with a screwdriver, clockwise to decrease the sound output of projector 1, and to increase the sound output of projector 2. Turn the control counterclockwise to decrease the sound output of projector 2, and to increase the sound output of projector 1.

Loudspeaker

The IC/QDM–1D loudspeaker is a portable device contained in an aluminum case. The top section of the case is removable. A slot is provided on the right side of the removable top section to permit the use of the loudspeaker cable with the top in postion. A 75-foot loudspeaker cable is wound on a bracket that is mounted inside the case. The case acts as a baffle to provide the desired acoustic quality for sound output.

The IC/QDM–1D equipment is a direct radiator loudspeaker containing an 8-inch, 25-watt permanent magnet and a moving voice coil. The loudspeaker provides a means for converting the amplified audio signal from the amplifier into sound energy.

The direct radiator loudspeaker has a relatively wide angle of sound distribution and therefore is particularly fitted for use in the proximity of the screen. Direct radiator loudspeakers can perform satisfactorily up to about 100 feet from the speaker, depending upon the amount of distracting noise generated by the ship.

The horn loudspeaker has a relatively narrow angle of sound distribution and therefore is particularly suited to cover areas of 75 feet or more away from the screen. Hence, the horn type of loudspeaker should be mounted on the top of the screen frame and directed so that the focal point of its sound converges at approximately 125 feet from the screen.

The recommended combination of loudspeakers comprises two direct radiator loudspeakers (IC/QDM) and two horn loudspeakers (IC/QHE). To obtain uniformity of the sound level over the audience area, the sound level of each of these banks of loudspeakers is adjusted independently.

Both a primary and secondary amplifier (IC/QAF–1D) are required to obtain this uniform sound distribution (fig. 11–15). All input connections are made to the primary amplifier. The sound output of this amplifier feeds both the monitor speaker and the direct radiator bank of two loudspeakers.

The secondary amplifier is connected to the primary amplifier sound input circuit by means of a bridging cable. Interconnection is between the primary amplifier bridging jack labeled "out" and the secondary amplifier bridging jack labeled "in." This interconnection disconnects all the input receptacles on the secondary amplifier, making the secondary amplifier a slave to the primary amplifier input circuits. The secondary amplifier output is connected to the two horn loudspeakers.

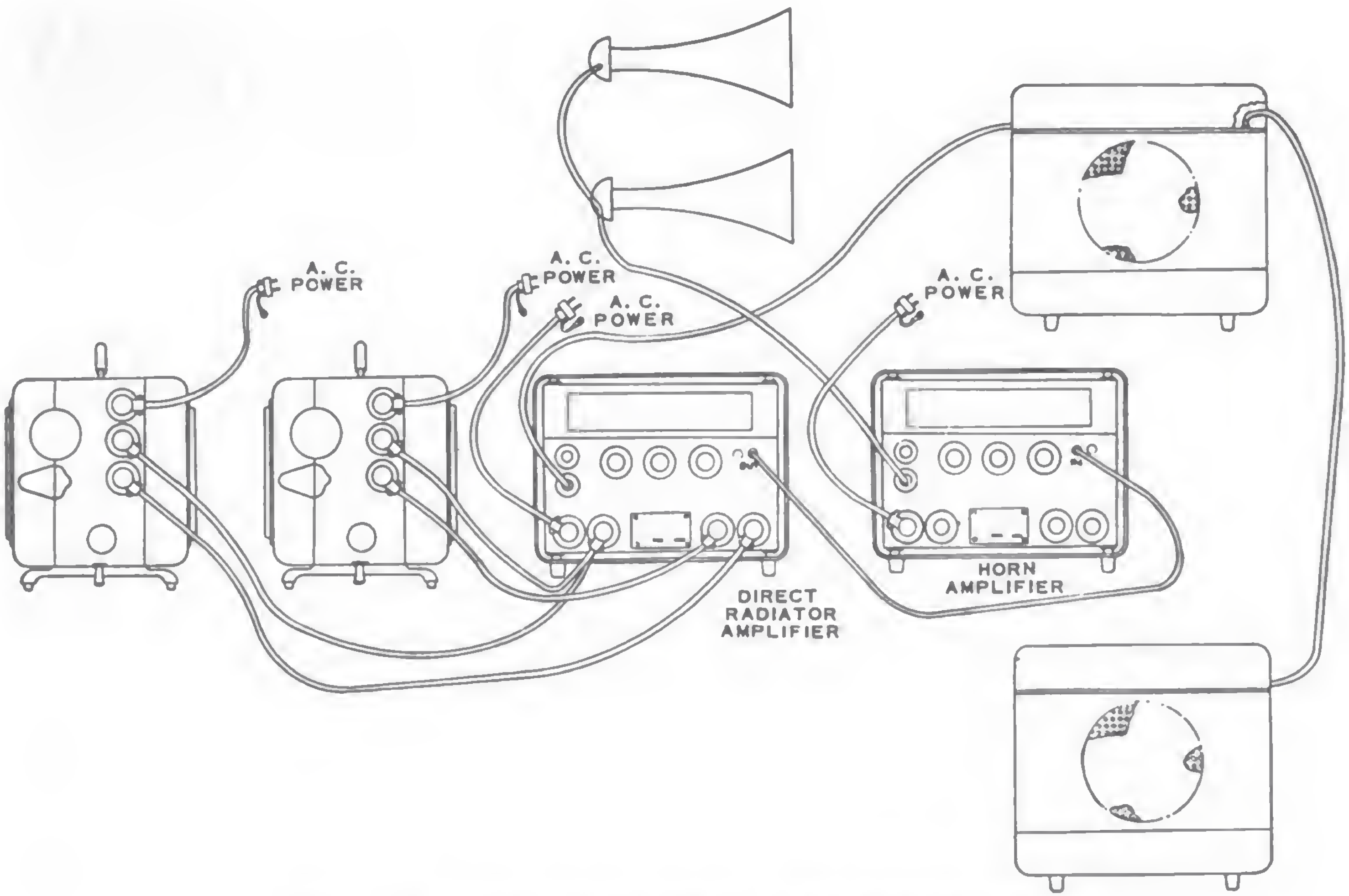


Figure 11–15.—Interconnection diagram for dual equipment operation.

Both the direct radiator loudspeakers and the horn loudspeakers have a nominal impedance of 16 ohms. The two direct radiator loudspeakers have a joint impedance of 8 ohms when connected in parallel. This 8-ohm impedance is a matching impedance for the primary amplifier. A similar condition exists for the two horn loudspeakers and the secondary amplifier.

Correct phasing of the loadspeakers is essential; otherwise, dead spots and loss of sound intensity would result. All of the loudspeakers are mounted in the same plane. Thus all of the voice coils must be CORRECTLY PHASED—that is, they must be connected so that they move back and forth identically in their air gaps. If the loudspeaker voice coils are not paralleled correctly, cancellation of the loudspeaker sound output will occur, resulting in distortion with loss of sound.

When the loudspeaker banks are correctly phased, make the following preliminary adjustments to establish the optimum amplifier volume- and tone-control settings:

1. Turn the gain control to ZERO on the amplifier that feeds the horn loudspeakers.
2. Raise the gain control to position FOUR on the amplifier that feeds the direct radiator loudspeakers.
3. Reproduce a portion of the sound film and note the gain-control setting necessary to furnish adequate volume at a distance 50 feet from the screen.
4. Energize the horn loudspeakers and establish the gain-control setting necessary to obtain the same volume level at a distance of 125 feet from the horn loudspeakers.

All film that has been run through a projector must be rewound before it can be shown again. During projection the film is wound on the takeup reel with the start of the picture at the hub of the reel. Therefore, it is necessary to rewind the film on another reel to get the start of the picture on the outside of the reel. A rewinding device can be used for this purpose, or rewinding can be accomplished quickly by the projector. With the projector it is not necessary to twist, change, or remove any belt. Rewinding is accomplished by moving the rewinding mechanism knob on the front reel arm to the IN position and turning on the REWIND toggle switch on the projector switch panel. However, rewinding the film with the projector does not permit checking the condition of the film.

Only qualified personnel are authorized to operate motion picture equipment. For detailed information concerning the operation, care, and maintenance of this equipment, refer to chapter 85 of the *Bureau of Ships Manual* and to the manufacturer's instruction book furnished with the equipment in use aboard your ship.

QUIZ

1. Why does the incandescent electric lamp produce light?
2. Name two natural sources of direct radiation.
3. Name two natural sources of indirect radiation by reflection.
4. Are light waves longitudinal?
5. What is indicated by the height of the crest or the depth of the trough of a light wave?
6. What is indicated by the distance between successive points in identical stages of motion of a light wave?
7. What is indicated by a line connecting particles of the medium over which the disturbance is momentarily uniform?
8. What is represented by a line drawn in the direction of propagation from a light source?
9. What is the relation between a wavefront and a ray?
10. What is the relation between the velocity of light, the frequency of the wave, and the wavelength?
11. What determines the sensation of color on the optic nerve?
12. Why do colored objects look natural in sunlight?
13. Can light rays be reflected and refracted?
14. What is the ray from the source to the reflecting surface, or mirror, called?
15. What is the name of the point at which the incident ray strikes a reflecting surface?

16. What is the name of the ray that comes out of the reflecting surface from the point of incidence?
17. What is the name of the line perpendicular to a reflecting surface at the point of incidence?
18. What is the angle called between the incident ray and the normal to the surface?
19. What is the angle called between the reflected ray and the normal to the surface?
20. What is the relation between the angle of incidence and the angle of reflection in accordance with the law of reflection?
21. What is the name of the ray that enters the second medium when light travels in one medium and encounters a second medium of different optical density?
22. What is the name of the point of convergence or of divergence of light rays passing through a lens?
23. What is the name of the distance from the principal focus to the lens?
24. What type of lens is used in motion picture projection systems?
25. How is a larger or smaller image obtained for a fixed projection distance?
26. What is the displacement between the sound and the picture with which it is associated?
27. What is the purpose of the condensing lenses in the projection optical system?
28. What is the purpose of the projection lens in the projection optical system?
29. What is the purpose of the sound optical unit in the sound optical system?
30. Name the three principal components of a sound motion picture equipment.

CHAPTER 12

DIAL TELEPHONE SYSTEM

The dial telephone system, circuit J, is primarily an administrative circuit that provides fully selective telephone communications throughout the ship. This system is also used to supplement other communications facilities for ship control, fire control, and damage control. The capacity of the system varies with the size and needs of the particular ship.

COMMON-BATTERY TELEPHONE SYSTEM

A common-battery telephone system consists of a group of telephones the individual lines of which are terminated at a central point so that they can operate from a common battery located at that point. The system can be manual or automatic. In the manual system, the connections between the calling telephone and the telephone being called are completed by operators; whereas, in the automatic dial system the connections are completed by remotely controlled switching mechanisms.

The switching mechanisms in automatic systems are controlled at the calling telephone by means of a calling device, or dial. The dial has 10 digits, any one of which can be dialed. When the dial is operated it causes a series of interruptions, or impulses, in the current flowing in the line circuit. The number of impulses, sent out by the dial, corresponds to the digit selected. These impulses cause the automatic switches to operate and to select the telephone being called.

The dial telephone system (fig. 12–1) consists of (1) line station equipment, (2) automatic switchboard equipment, (3) power equipment, and (4) accessory equipment.

The LINE STATION EQUIPMENT consists of various types of telephones for mounting in both protected and exposed locations. In addition, special loud-ringing, or extension, signals are provided at telephone stations located in noisy spaces.

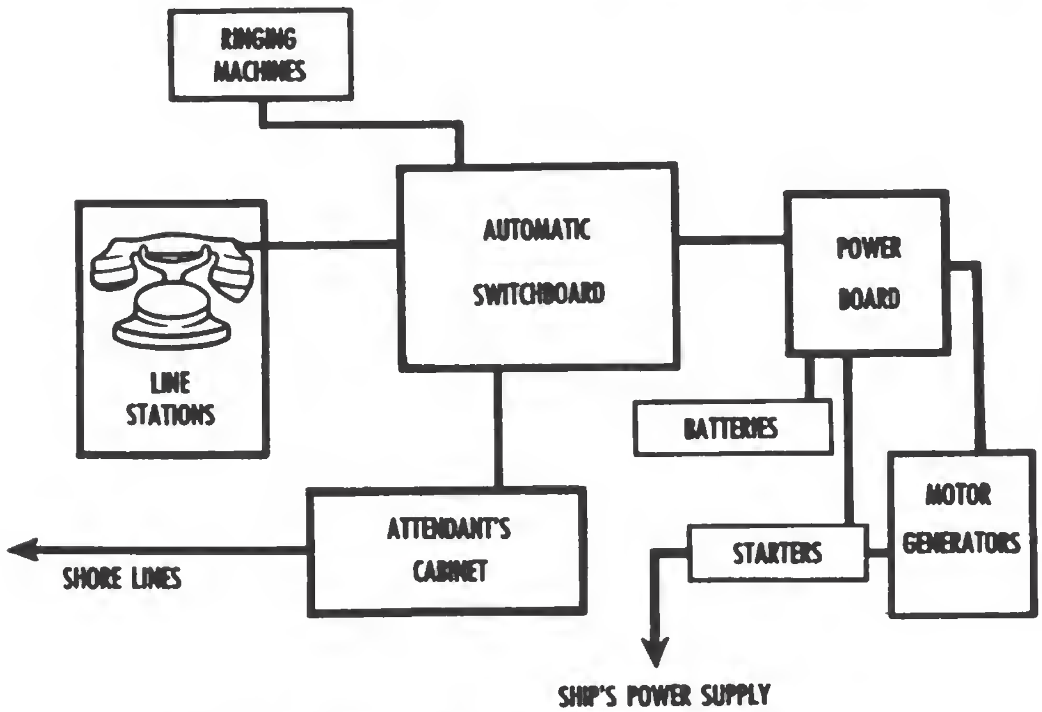


Figure 12–1.—Block diagram of a dial telephone system.

The AUTOMATIC SWITCHBOARD EQUIPMENT includes the switching mechanisms necessary for setting up automatically the connection between any two telephones, and certain miscellaneous equipment used in common by all switches.

The miscellaneous equipment includes ringing machines, alarm signals, testing equipment and control circuits for the switching mechanisms, start and stop circuits for the ringing machines, line disconnect keys, and fuses.

The POWER EQUIPMENT consists of a motor-generator set and storage battery connected across the generator. This equipment supplies d-c service at approximately 48 volts to operate the automatic switchboard equipment, including the ringing machines. Power to operate the motor-generator set is obtained from the ship's power supply via the I. C. switchboard.

The ACCESSORY EQUIPMENT includes an attendant's cabinet, which is a small manual switchboard used to establish calls to and from shore exchanges when the ship is in port.

TELEPHONE INSTRUMENT

The telephone instrument is a compact unit designed for transmitting and receiving speech, and for signaling the desired station.

The parts that comprise the telephone instrument are mounted in various enclosures to form different types of telephones. These are the type-A desk telephone, type-B bulkhead telephone, type-C watertight bulkhead telephone, type-D intercommunicating telephone, type-E compact telephone for mounting on the side of a desk, and type-F telephone for either bulkhead or side-of-desk mounting.

The component parts of a telephone instrument are (1) handset, (2) dial, (3) cradle switch, (4) ringer, (5) capacitors, and (6) induction coil.

Handset

The handset (fig. 12–2) consists of a conveniently shaped handle with two mounting cups—one for the transmitter and the other for the receiver. A mouthpiece screws onto one end of the handset handle and holds the transmitter in its mounting cup. An ear cap screws onto the other end of the handset handle and holds the receiver in its mounting cup.

The transmitter and receiver units are both of the capsule type and are constructed so that the transmitter unit cannot be inserted into the receiver mounting cup and vice versa.

Connections from the cord conductors to the transmitter and receiver units are completed by means of contact spring clips that are contained in the mounting cups of the handset.

TRANSMITTER UNIT.—The transmitter unit consists essentially of a diaphragm and a carbon microphone contained in

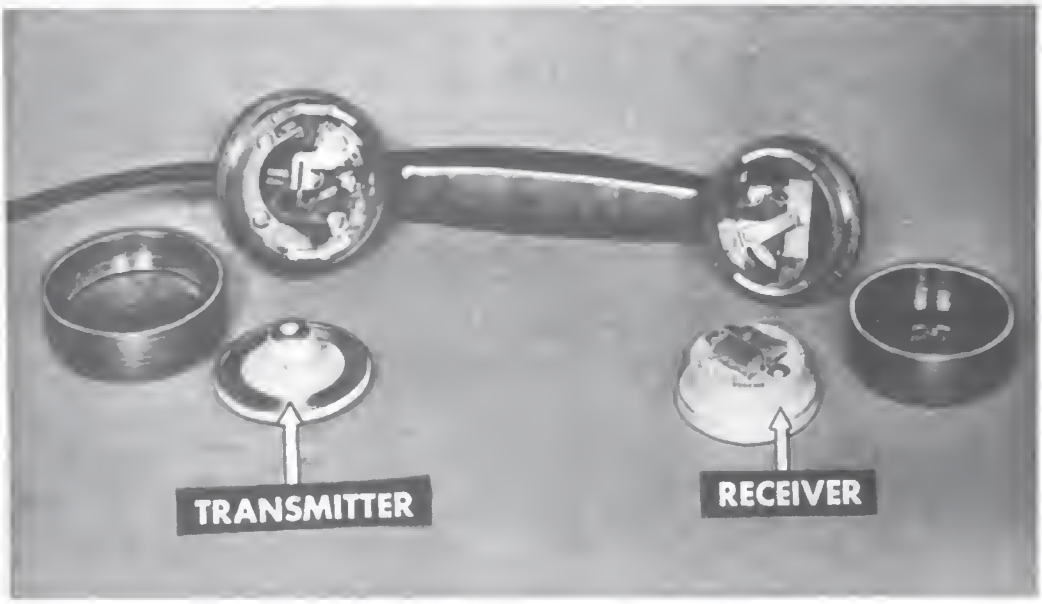


Figure 12–2.—Handset.

a protective shell. The carbon button microphone is discussed in chapter 8. The diaphragm is mechanically connected to the carbon button microphone so that sound waves striking the diaphragm cause it to vibrate. The mechanical vibrations of the diaphragm are transmitted to the carbon granules. When the carbon granules are compressed by an inward movement of the diaphragm, their resistance is lowered and more current flows through the transmitter. A steady direct current flows through the transmitter when no sound waves strike the diaphragm, and the diaphragm is at rest. This current is called TRANSMITTER CURRENT and is supplied by the common battery at the switchboard.

As long as sound waves strike the diaphragm and cause it to vibrate, the resistance of the carbon granules is constantly changing. This constant change in resistance causes the current through the transmitter to vary accordingly.

This varying current is called the VOICE CURRENT and is sent out on the line after being boosted by the action of the induction coil and talking capacitor. The receiver at the other end of the line converts the voice current back into sound waves.

RECEIVER UNIT.—The receiver unit is of the permanent-magnet type. It consists essentially of a powerful permanent magnet with two soft-iron pole pieces, two coils, and a diaphragm contained in a protective shell. The coils are mounted on the soft-iron pole pieces. The path for the magnetic flux includes the pole pieces, air gaps, and diaphragm. The diaphragm is mounted under a slight tension so that it is pulled toward the pole pieces by the permanent magnet. Voice currents, flowing through the coils around the two pole pieces, set up magnetomotive forces that alternately aid and oppose the magnetic flux of the permanent magnet. This action causes the receiver diaphragm to be attracted with alternately greater and less force. Accordingly, the diaphragm moves back and forth, reproducing the original vibrations of the transmitter.

Dial

The dial (fig. 12–3) enables the calling telephone to control the automatic switching mechanisms which establish the telephone connection. The principal functions of the dial are to (1) deliver impulses, (2) short-circuit the parts of the instrument that introduce unnecessary resistance in the dialing circuit, and (3) prevent the dialed impulses from clicking the receiver.

The principal parts of the dial are compactly mounted on a mounting plate. These parts are (1) finger plate (with 10 holes), (2) number plate, (3) speed control governor, (4) impulse cam and springs, (5) shunt cam and springs, and (6) driving mechanism. The parts are arranged so that when the dial is operated, the line is opened and closed at a rate of approximately 10 interruptions per second.

In operating the dial, the finger plate is turned in a clockwise direction. When restoring to normal under its own power in a counterclockwise direction, the speed of the dial is controlled by the main spring and the governor assembly. While being turned in a clockwise direction, the tension of the main spring is increased to give sufficient tension to provide the power required to return the dial to normal.

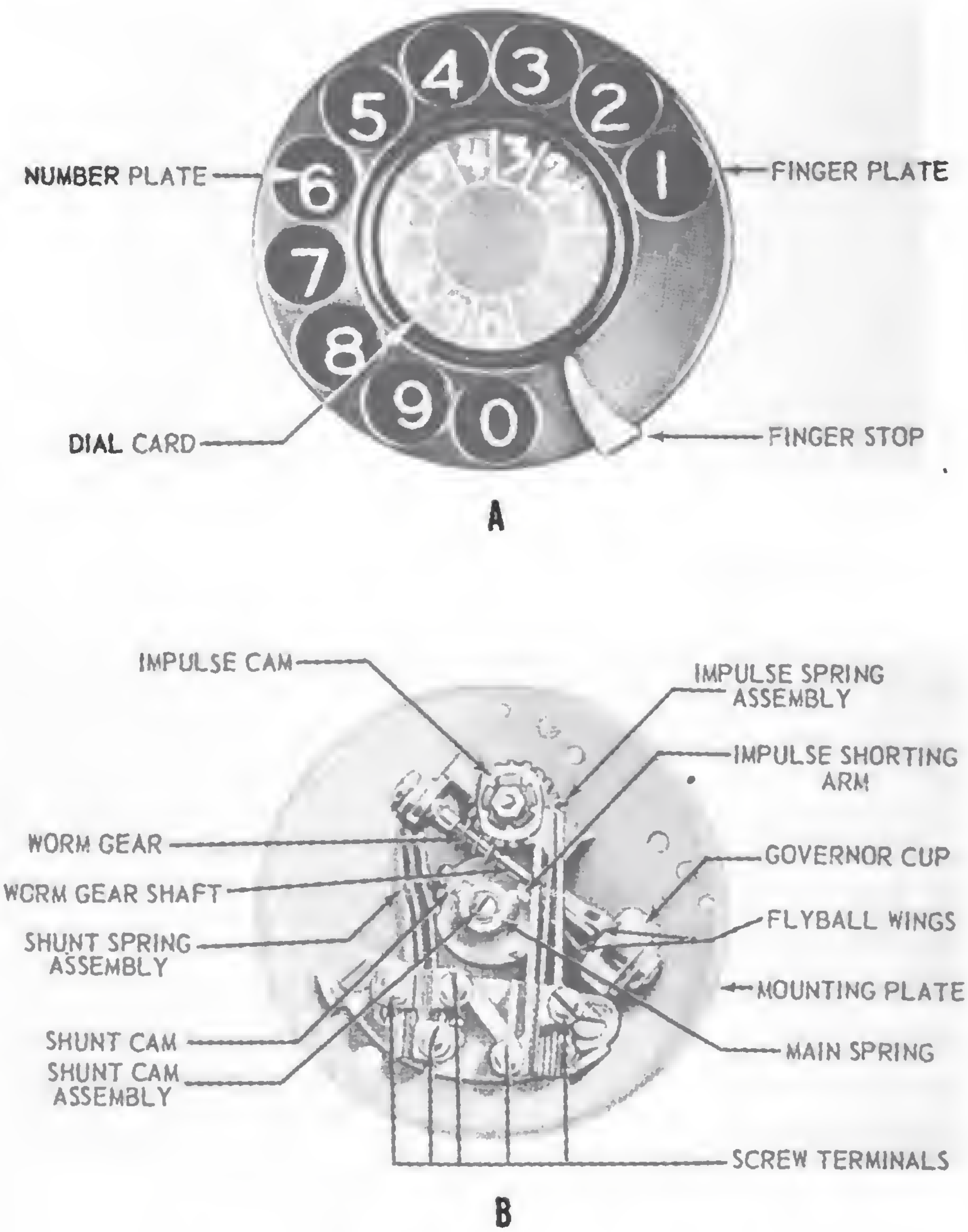


Figure 12–3.—Dial. A, Front view; B, rear view.

The main spring is a helically wound spring attached to a shaft that returns the dial main gear (not shown in figure 12–3) to normal when the dial is turned from normal and released. The main gear does not turn when the dial is turned from normal because the ratchet pawl slips over the ratchet wheel (not shown in figure 12–3) which is mounted on the same shaft with the main gear. However, the main gear does turn when the dial restores to normal, because the ratchet pawl engages the ratchet wheel and turns the main gear.

The governor assembly consists of a worm gear shaft that is mechanically connected to the main gear of the dial through a gear train. Two flyball wings are attached to the worm gear shaft. Each flyball wing has a governor weight on the end of the wing that protrudes into the governor cup. The rotary motion of the worm shaft causes the flyball wings to fly outward and, due to centrifugal force, cause friction between the governor weights and the governor cup. The speed of the dial is therefore regulated by adjusting these flyball wings to increase or decrease the amount of pressure the governor weights exert on the inside surface of the cup.

The impulse cam is geared mechanically to the main gear through a gear train. The revolutions of the impulse cam correspond to the angular displacement of the dial. The cam forces the impulse springs apart twice for each revolution of the cam shaft except for the last half revolution.

The impulse springs are normally closed. They are opened by the impulse cam only when the dial is returning to normal. An impulse is produced each time the impulse springs are opened. The travel from any off-normal position is one series of impulses. The number of impulses in the series depends on how far the dial is turned away from normal. The cam in revolving will break and make the impulse spring contacts a number of times corresponding to the digit dialed.

The shunt springs are used to shunt the receiver and transmitter circuits when the dial is in an off-normal position. The shunt springs are normally open. When the dial is at normal, these springs are forced to remain open by the shunt cam assembly pressing against them. When the dial is turned off normal, the shunt cam assembly is moved away from the shunt springs. This action causes the shunt springs to close and remain closed until the dial returns to normal. This closure shunts the transmitter and receiver circuits and prevents the impulses from being heard in the receiver during dialing, and also prevents the variable resistance of the transmitter from affecting the character of the operating impulses.

Cradle Switch

The CRADLE SWITCH, sometimes called the SWITCH HOOK OR MONOPHONE SWITCH, is an assembly of springs used in completing and opening circuits. In a telephone set it is not desirable to have both the talking apparatus and the signaling apparatus connected with the line at the same time. Therefore, when the handset is in the cradle, the signaling circuit is connected across the line and the talking circuit is open. Conversely, when the handset is removed from the cradle, the talking circuit is connected across the line and the signaling circuit is open.

An open view of the type-A desk telephone (fig. 12–4) shows the arrangement of the components contained inside the instrument enclosure. These components are the rear view of the dial assembly, monophone switch, ringer assembly, ringing and talking capacitors, and induction coil.

Ringer

The ringer (fig. 12–5) is of the polarized, untuned type commonly called the STRAIGHT-LINE ringer. It is suitable for use on both individual and party lines, and is called UNTUNED because it operates over a wide range of frequencies.

The ringer consists of a permanent hard-steel magnet, an electromagnet having two soft-iron cores, a pivoted soft-iron armature on which is attached a clapper rod and clapper, and a set of two gongs.

The armature is pivoted at its center and lies in front of the two poles of the electromagnet. The permanent magnet

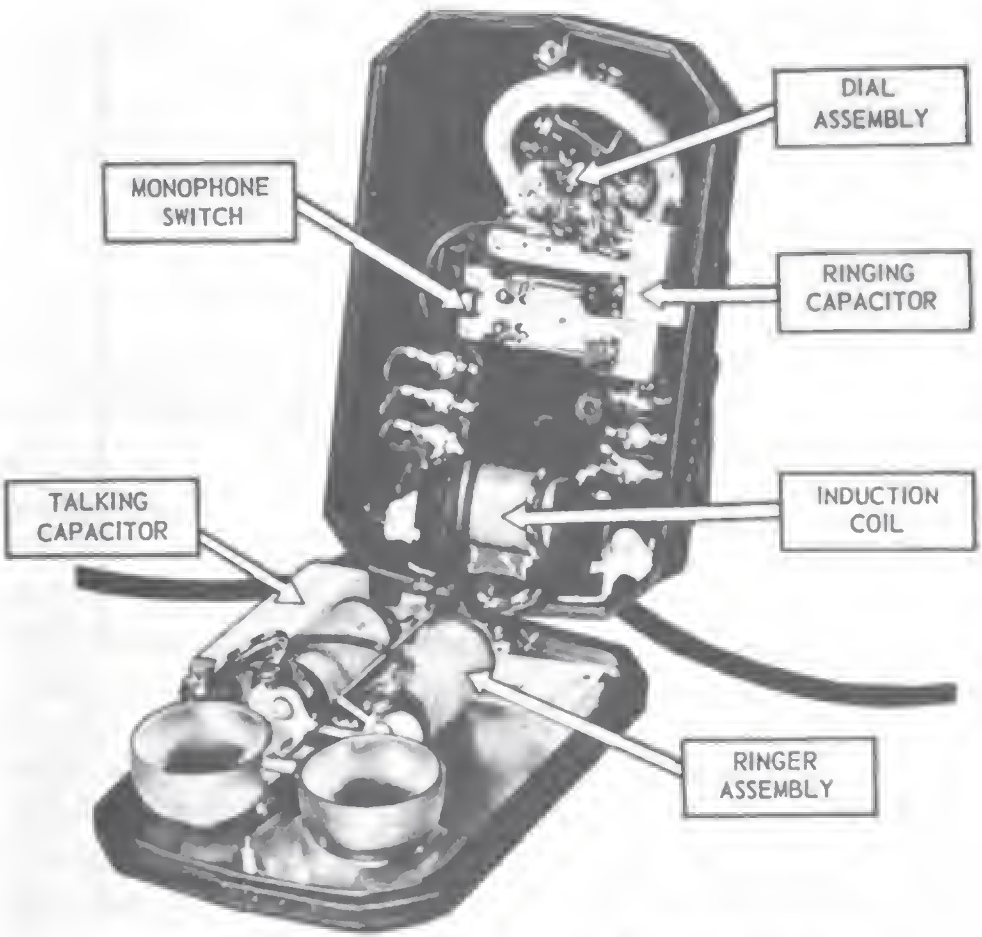


Figure 12–4.—Open view of a type-A desk telephone.

is used to polarize the armature ends of the electromagnet. The armature end of each coil has a consequent north polarity produced by the permanent magnet. The two ends of the armature have consequent south poles produced by the permanent magnet.

The coils are wound on the soft-iron pole pieces so that when current flows in one direction (fig. 12–5) the mmf of coil 1 aids the permanent-magnet flux and the mmf of coil 2 opposes it. Thus coil 1 increases the strength of the north pole at the armature end of coil 1 and coil 2 attempts to establish a south pole at the armature end of coil 2. Because like poles repel and unlike poles attract, the armature moves clockwise and the clapper strikes the gong at the right.

When the ringer current reverses, the mmf of the coils

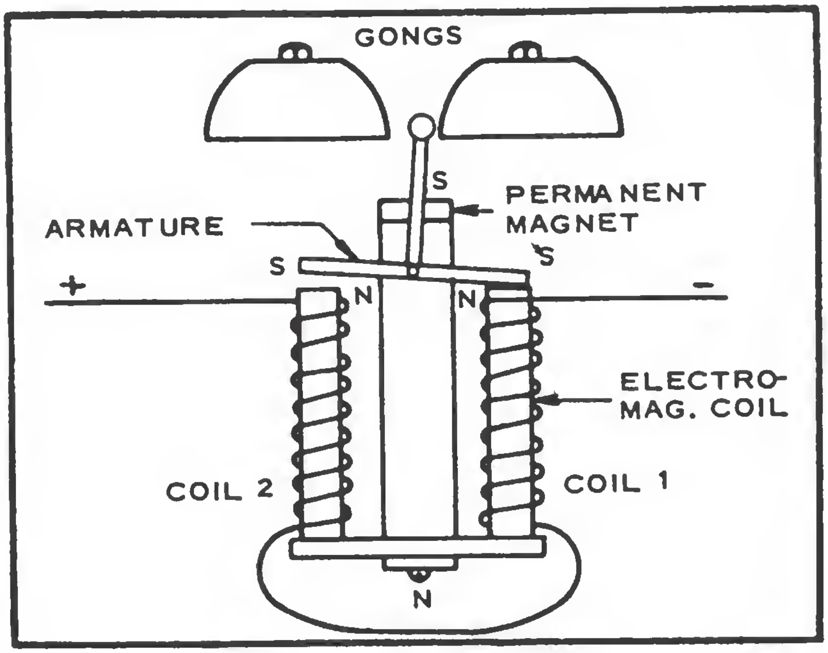


Figure 12–5.—Polarized ringer.

reverses. Thus coil 2 establishes a north pole at the armature end of coil 2 and coil 1 attempts to establish a south pole at the armature end of coil 1. The armature moves counterclockwise and the clapper strikes the gong at the left. The gongs ring once for each half cycle of ringing current. The ringing current is 20 cycles per second.

When no current flows through the coils, the armature south poles attract the north poles at the armature end of the coils and the clapper moves either to the right or left depending on which air gap is shortest. A biasing spring is provided to give the armature a definite position when the gong is silent. This spring holds the clapper against one gong and prevents the gong from tingling during the dialing period. Small pieces of nonmagnetic material are placed between the core ends and the armature to prevent actual contact and subsequent sticking due to residual magnetism.

Capacitors

Two capacitors (fig. 12–4) are used in each telephone—one in the ringing circuit and one in the transmission circuit. The capacitor in the ringing circuit allows a-c ringing current to pass through the ringer and prevents the flow of direct current. The capacitor in the transmission circuit improves the transmission output characteristics of the telephone. If a capacitor were not used, the output would be very low because of the high impedance of the telephone circuit and the line circuit.

Induction Coil

The induction coil (fig. 12–4) couples the transmitter and receiver units to the line. It also (1) increases the output volume by boosting the voice current variations developed by the transmitter; and (2) prevents or decreases SIDETONE. Sidetone occurs when a person hears his own voice in his receiver while talking into the transmitter.

The induction coil consists of three windings wound on a laminated iron core. The windings are magnetically coupled by the iron core and its armature which completes that portion of the magnetic circuit external to the core. The induction coil serves as a 3-winding autotransformer. Any change in the current in one of the windings causes a corresponding induced emf in all three. The core has a high-permeability, low-reluctance path for the magnetic flux. The magnetic flux is almost completely in iron except for a small air gap to prevent d-c core saturation.

TELEPHONE CIRCUIT

A typical telephone circuit is shown in figure 12–6. This is an antisidetone type of circuit employing a 3-winding induction coil. Windings 1 and 2 are used to increase the output volume of the transmitter. Winding 3 is the antisidetone winding. It receives an induced emf from windings 1 and 2 which opposes that part of the voltage change across

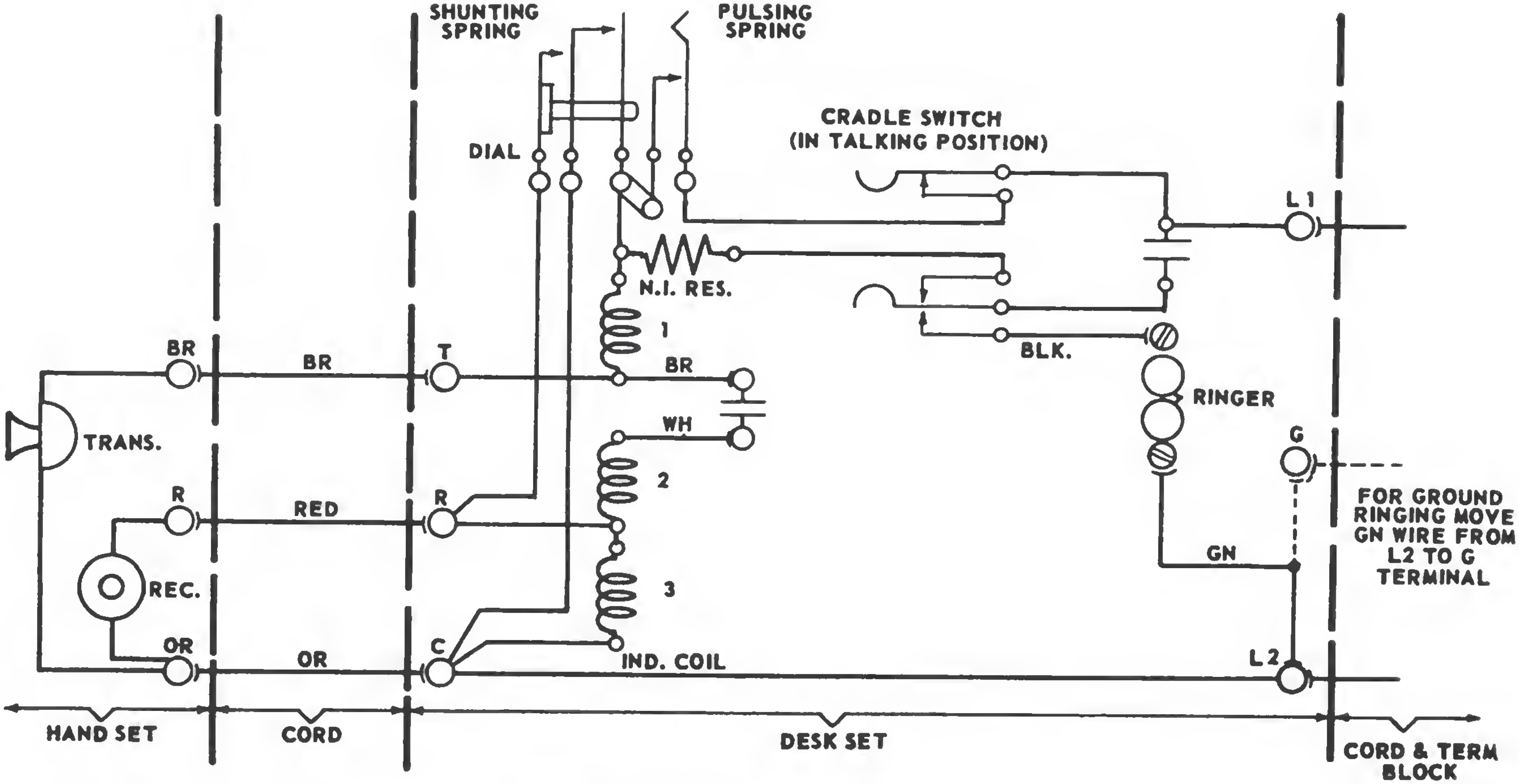


Figure 12–6.—Telephone circuit.

the line that appears across the receiver. Because the line voltage variation component and the induced emf in winding 3 are in opposition and approximately equal, the resultant voltage change across the receiver is almost zero.

This telephone circuit includes (1) dialing, (2) ringing, (3) transmission, and (4) receiving circuits. In figure 12–6 the handset is removed from the cradle and the ringing circuit is disconnected. The cradle switch is operated and the line circuit is in the dialing and talking positions.

Dialing Circuit

The dialing circuit consists of the dial impulse springs, dial shunt springs, and the line wires. When the dial is operated, the transmitter, receiver, and induction coil are shunted out so that they will not interfere with the impulses sent out by the dial.

Ringing Circuit

The ringing circuit consists of the line springs of the cradle switch, the ringing capacitor, and the ringer. As previously stated, when the handset is removed from the cradle, the ringer circuit is disconnected (fig. 12–6) and the capacitor is transferred from the ringer circuit to the dial impulse springs to prevent excessive sparking at the contacts.

Transmission Circuit

The transmission circuit (fig. 12–7) consists of the transmitter, receiver, induction coil, and capacitor. The units included in this circuit are used in both the transmission and reception of speech. When these units are used for voice transmission, the transmitter converts sound waves into corresponding current variations. When these units are used for reception, the receiver converts the electrical variations into audible sound waves. In voice transmission, windings 2 and 3 of the induction coil are used as the primary of the coil. In voice reception, winding 1 of the induction coil is used as the primary of the coil.

The booster feature is accomplished by means of the induction coil acting in conjunction with the capacitor. This action increases the magnitude of the voice current variations produced by the transmitter directly in the line.

The antisidetone feature is also accomplished by means of the induction coil. This action prevents the voice currents

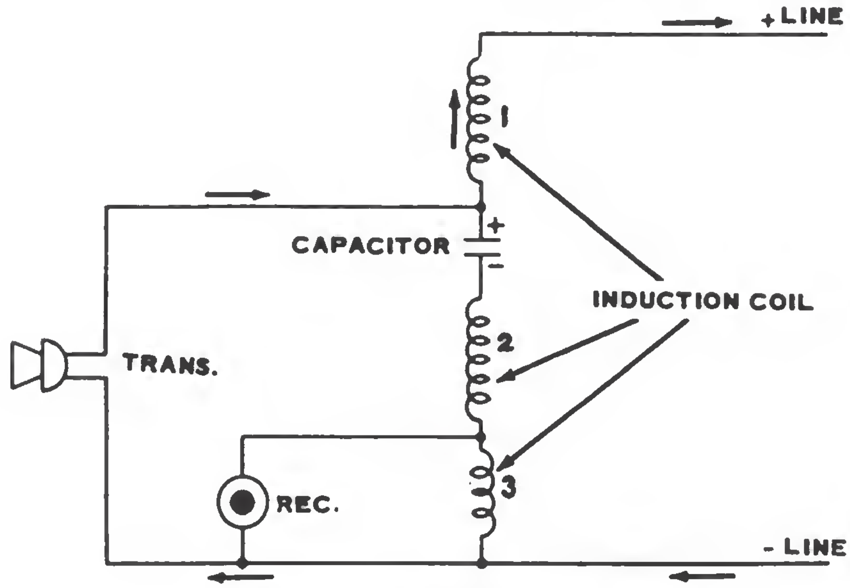


Figure 12–7.—Transmission circuit.

set up by the transmitter from flowing through the receiver of the same telephone instrument.

During speech transmission, in a circuit of this type, the two distinct circuits are the MAIN talking circuit and LOCAL talking circuit. The main talking circuit includes the positive line, winding 1 of the induction coil, the transmitter, and the negative line. The local talking circiut includes the transmitter, the capacitor, and windings 2 and 3 of the induction coil.

The d-c path through the telephone (indicated by the solid arrows in figure 12–7) is from the negative line, through the transmitter, through winding 1 of the induction coil, and to the positive line. Because the capacitor is connected across the transmitter in series with windings 2 and 3 of the induction coil, it acquires a charge and its voltage rises to a value proportional to the voltage across the transmitter.

Talking into the transmitter causes two sets of current variations to be set up—(1) those produced directly in the line because of the variations in the resistance of the transmitter; and (2) those produced in the local talking circuit by the charging and discharging of the capacitor due to the varying potential drop across the transmitter.

The current variations in the local talking circuit are best understood by keeping in mind that the capacitor is connected directly to the transmitter on one side and through windings 2 and 3 on the other side. Hence, the potential difference across the capacitor is varied by potential variations across the transmitter terminals. Alternating currents flow in the local circuit as the capacitor adjusts its charge to the varying difference of potential across its own terminals.

The resultant alternating currents flowing in windings 2 and 3 induce a voltage in winding 1 of the induction coil. This induced voltage is equal to the difference between the voltage induced by winding 2 and the voltage induced by winding 3 because the induced voltages of these two windings are in opposite directions. The induced voltage in winding 1 aids and increases the voice voltage directly delivered by the transmitter to the line. The voltage induced in winding 3 by windings 1 and 2 is of such a value and direction that it tends to make the resultant voltage across winding 3 equal to zero. Thus there is no a-c voltage across the receiver and the circuit is antisidetone.

The inductive balance required for complete neutralization of the sidetone depends on the relative impedances of the local circuit containing windings 2 and 3 of the induction coil, and of the line circuit containing winding 1 of the induction coil. Because the line conditions vary with different lengths of line, the characteristic impedance of a typical line is used as a standard, and the impedance of the local circuit is arranged to balance it. Sidetone tends to increase as the line departs from this standard characteristic impedance. However, this tendency is offset by the decreases in sidetone due to the reduction in current supply to the transmitter with increased loop resistance.

Receiving Circuit

The receiving circuit (fig. 12–7) also consists of the transmitter, receiver, induction coil, and capacitor. When the units are used for voice reception, winding 1 of the induction coil acts as the primary and windings 2 and 3 act as the secondary. The voice currents are received from the main talking circuit which includes the positive line, winding 1 of the induction coil, the transmitter, and the negative line.

The currents flowing in the main talking circuit induce currents in the local talking circuit consisting of the capacitor, winding 2 of the induction coil, the receiver, and the transmitter. Most of the current flows in winding 2. Only a small current flows in winding 3 because the voltage induced in this winding opposes the current through it.

AUTOMATIC SWITCHBOARD

The automatic switchboard is the switching center of the dial telephone system. Mounted on this switchboard are all telephone switching mechanisms, control circuits, line disconnect keys, part of the testing equipment, and most of the supervisory alarm signals. The ringing machines and the common alarm signals are mounted externally in most cases. However, some switchboard enclosures include the ringing machines. These switch mechanisms automatically perform the following functions:

1. Locate a station desiring to make a call.
2. Respond to dial impulses and extend the calling station to the called station.
3. Ring the called station and, if necessary, select between the two parties on a party line.
4. Supply various tones, such as dial tone, busy tone, and ring-back tone as required.

5. Provide "hunt-the-not-busy-line" service where required. This is a feature whereby if the lowest numbered of a consecutively numbered group of line stations is called, the switchboard will automatically connect the calling line station to the lowest numbered idle line station of such a group. A busy signal is returned only if all line stations of the group are busy.
6. Provide "executive cut-in" service to line stations as specified. This feature enables such line stations to complete their connection to any line station they may call irrespective of whether that line station is busy.
7. Disconnect the calling and called stations at the completion of the conversation.
8. Perform certain other operations in connection with telephone service.

SWITCHING

Numerous methods of switching, such as "all relay," "rotary," "panel," "crossbar," and "step-by-step" have been devised and are used commercially. The most extensively used switching equipment for shipboard installations is the Strowger automatic type. The switch mechanisms used in this type of equipment operate on a step-by-step basis—that is, the switching functions are accomplished electromagnetically in synchronism with the dial impulses.

Line Grouping and Numbering

The basic system of grouping provides for a maximum of 100 lines, as shown in figure 12–8. The horizontal dashes represent 100 pairs of metallic contacts. There are 10 horizontal levels and 10 sets of contacts in each level. Thus the tens digit of the called number represents the level whereas the units digit represents the individual pair of contacts in the level.

Numbers beginning with 1 are in the first, or bottom, level, numbers beginning with 2 are in the second level, and so on. This arrangement causes the digit "0" to be used to represent 10 steps so that the 10th, or top, level is indicated by the symbol for zero. Also, the 10th pair of contacts in each level is indicated by the symbol for zero. Groups of 10 lines

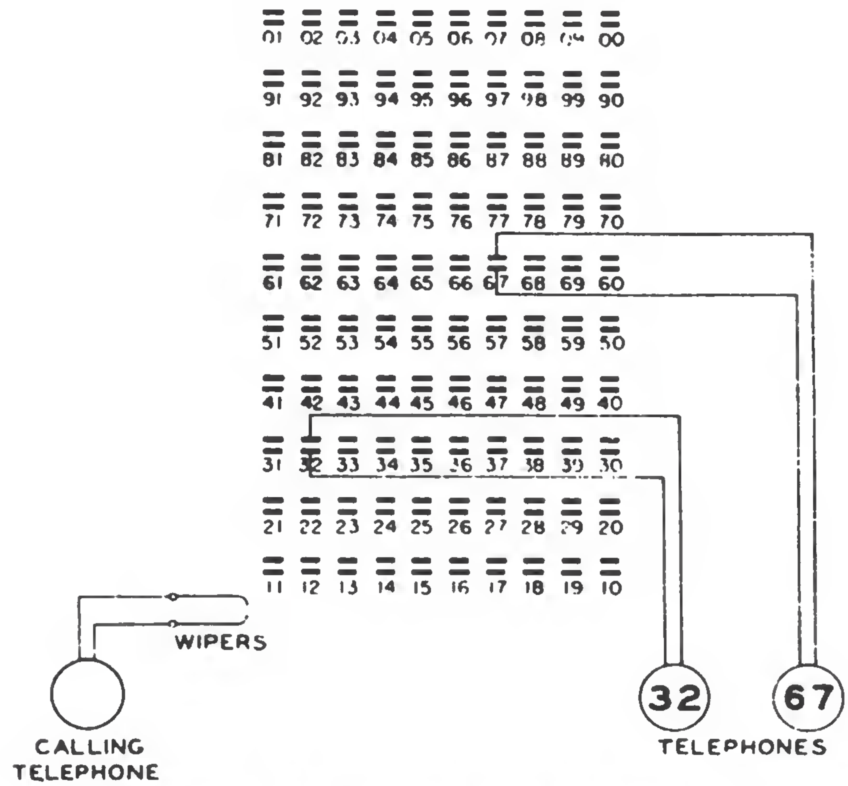


Figure 12—8.—Connector-bank numbering.

are referred to as lines 11-10, 21-20, 31-30, and so forth. Likewise, lines 11-50 mean a group of 50 lines. The first 10 lines consist of 11-10, and the last 10 consist of 51-50.

Each pair of metallic contacts is connected to a pair of wires that lead to a certain telephone. These contacts are actually contained in a Strowger switch, arranged in the arc of a circle with the vertical rows paralled to the axis of the cylinder. The entire assembly of contacts is called a CONNECTOR BANK.

A pair of metallic wipers mounted on the shaft of the Strowger switch is shown at the lower left-hand corner of the connector bank. These wipers are moved under the control of the dial on the calling telephone. For example, if the calling telephone is used to call telephone No. 32, when digit "3" is dialed the wipers step UP to the third level in the connector bank. When digit "2" is dialed the wipers rotate IN 2 steps on the third level. This action connects the calling telephone with telephone 32. Likewise, to connect the calling telephone with telephone 67, the wipers step UP 6 steps and then rotate IN 7 steps.

Basic 100-Line System

The system described with reference to figure 12–8 is not practical because only the calling telephone can originate calls. The basic 100-line system is shown in figure 12–9. Each telephone is connected to the wipers of its own connector bank. The wiper of each bank can be stepped up and rotated in, under the control of the dial of the associated telephone. One connector bank with its wipers and the mechanism necessary to step the wipers up and in constitute a CONNECTOR SWITCH. A connector switch is referred to as a NUMERICAL type of Strowger switch because it operates under the control of dial impulses.

The connector bank described with reference to figure 12–8 has only the 100 pairs of contacts required for the positive and negative lines. In practice, the connector and other switches have one or more banks, with associated wipers, contained in the same switch. However, these banks are for control and special purposes and are not considered now.

For simplicity, only 3 of the 100 telephones with these associated connector switches are shown in figure 12–9. Also, only 1 wire from each telephone is indicated, and a black dot represents 1, 2, or as many contacts as are necessary to complete the circuit.

Telephone 32 is connected to the wipers of connector 32. Telephone 32 also has an appearance in the bank of each connector—that is, it is multipled to contact 32 in all of the connector banks. Telephone 67 terminates in wiper connector 67 and is likewise multipled to its associated contact 67 in all of the connector banks. This multiple arrangement of the connector banks permits any telephone to be used to call any other telephone in the system.

For example, to call telephone 89 from telephone 32, remove the handset from the cradle at telephone 32 and dial

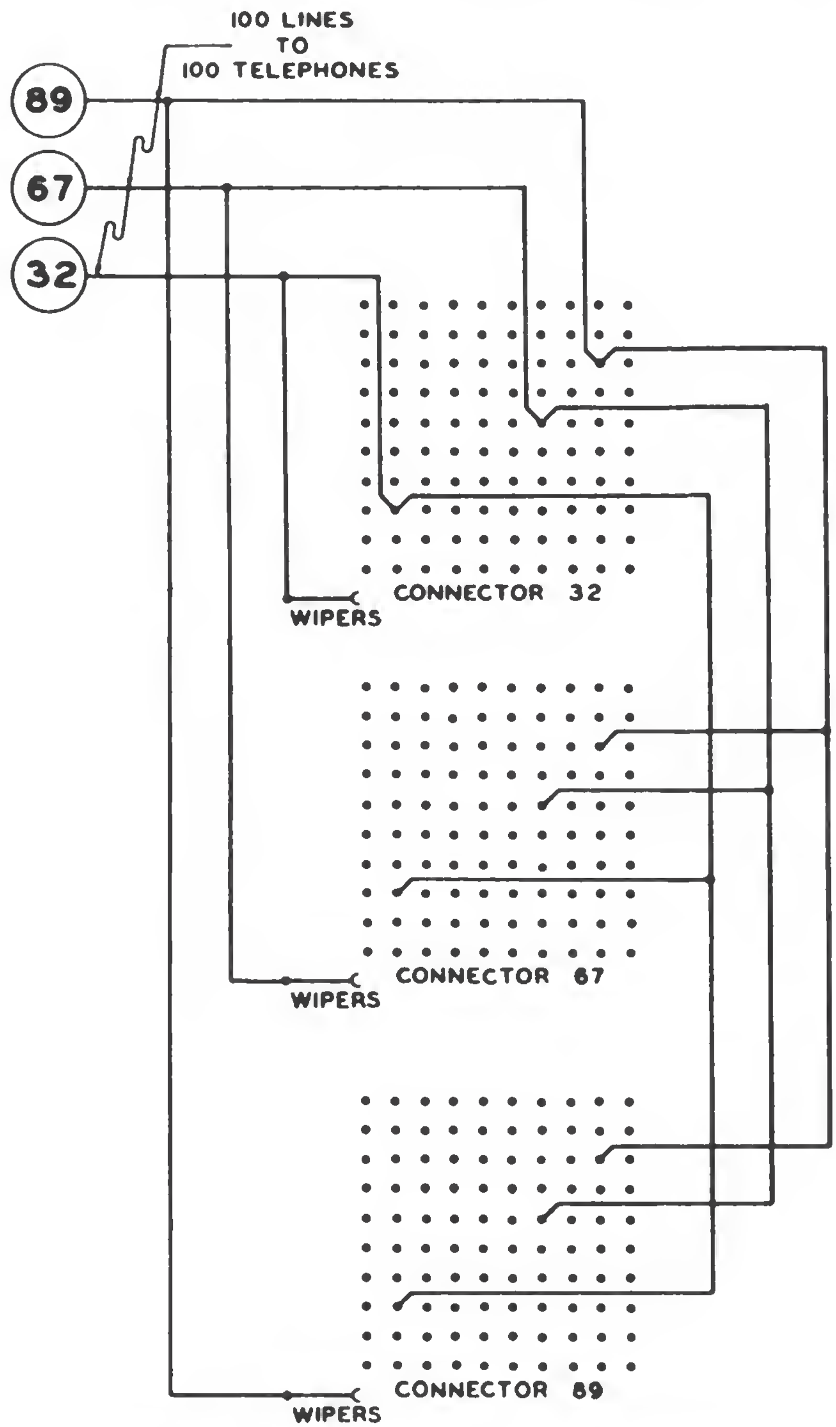


Figure 12–9.—Basic 100-line connector system.

the digits "8" and "9." When "8" is dialed, the wipers of connector switch 32 step up to the eighth level and when "9" is dialed, the wipers rotate into the bank and come to rest on the ninth contact of that level. This action completes the connection to telephone 89. Similarly, any one of the 100 telephones can cause the wipers of its associated connector switch to step up and in, and connect with any one of the other 99 telephones.

Line Finding

The 100-line connector system described with reference to figure 12–9 requires an individual connector switch for each line in this system. As the connector is a relatively expensive switch, this system is not economical because the average telephone is used for making calls only a short time each day with the result that the corresponding connector switch would remain idle during the remainder of the time.

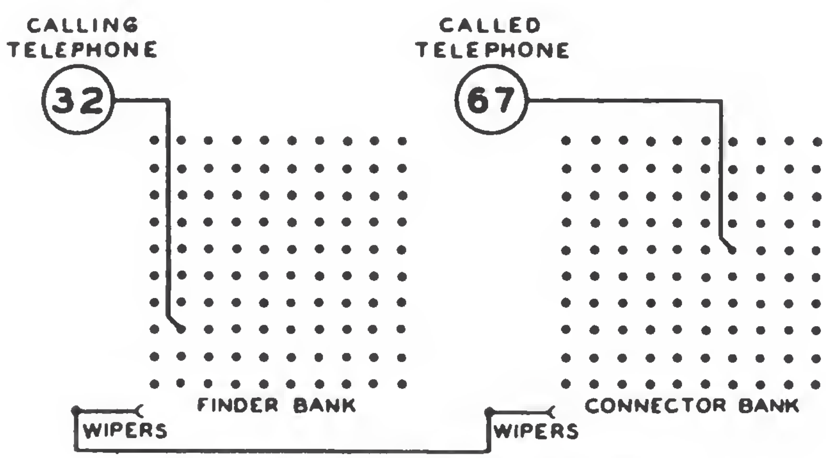


Figure 12–10.—Line-finding principle.

Line finding enables a large group of lines to be served by a smaller number of switches used in common by all lines in the group. The line-finding principle is illustrated by means of the diagram of two 100-point banks shown in figure 12–10. One is called the FINDER BANK and the other is the previously mentioned CONNECTOR BANK. The finder bank is similar to the connector bank. Although one telephone is shown, actually there are 100 telephones connected to the finder bank. One finder bank with its wipers and the mechanism necessary to step the wipers up and in constitute a FINDER SWITCH. A finder switch is referred to as a NONNUMERICAL type of Strowger switch because its operation is automatic and not under the control of dial impulses.

To call telephone 67 from telephone 32, remove the handset from the cradle at telephone 32. The finder switch (fig. 12–10) automatically steps its wipers up to the third level and rotates in 2 steps, stopping on contact 32. Thus the calling telephone is extended through to the wipers of the connector switch. When the digits "6" and "7" are dialed, the wipers of the connector switch step up to the sixth level and rotate in 7 steps, completing the connection between telephones 32 and 67.

Basic 100-Line Finder-Connector System

The system described with reference to figure 12–10 is equipped with one finder switch and one connector switch. Hence, only one conversation is possible at any one time because each conversation requires one finder and one connector to complete and hold a connection between the calling and called telephones.

The basic 100-line finder-connector system is shown in figure 12–11. Each finder switch is permanently tied "stem to stern" with a connector switch. In other words, the finder is facing backward ready to find any line that originates a call, whereas the connector is facing forward ready to connect to the dialed line. Such a combination of finder and connector is called a FINDER-CONNECTOR LINK. One finder-connector link is required for each of the conversations that are to be held simultaneously. The links are analagous to the "cord circuits" in a manual telephone system.

Each of the 100 lines is connected to each finder bank. Hence, any idle finder is capable of stepping up and rotating in to locate any one of the 100 lines that originates a call. Also, each of the 100 lines is connected to each connector bank. Hence, under control of dial impulses from the calling telephone, the connector tied to the idle finder can step up and rotate in to complete a connection to any one of the 100 telephones. The leads from the connector banks to the 100 telephone lines are called LINE NORMALS.

To call telephone 89 from telephone 32, remove the hand-

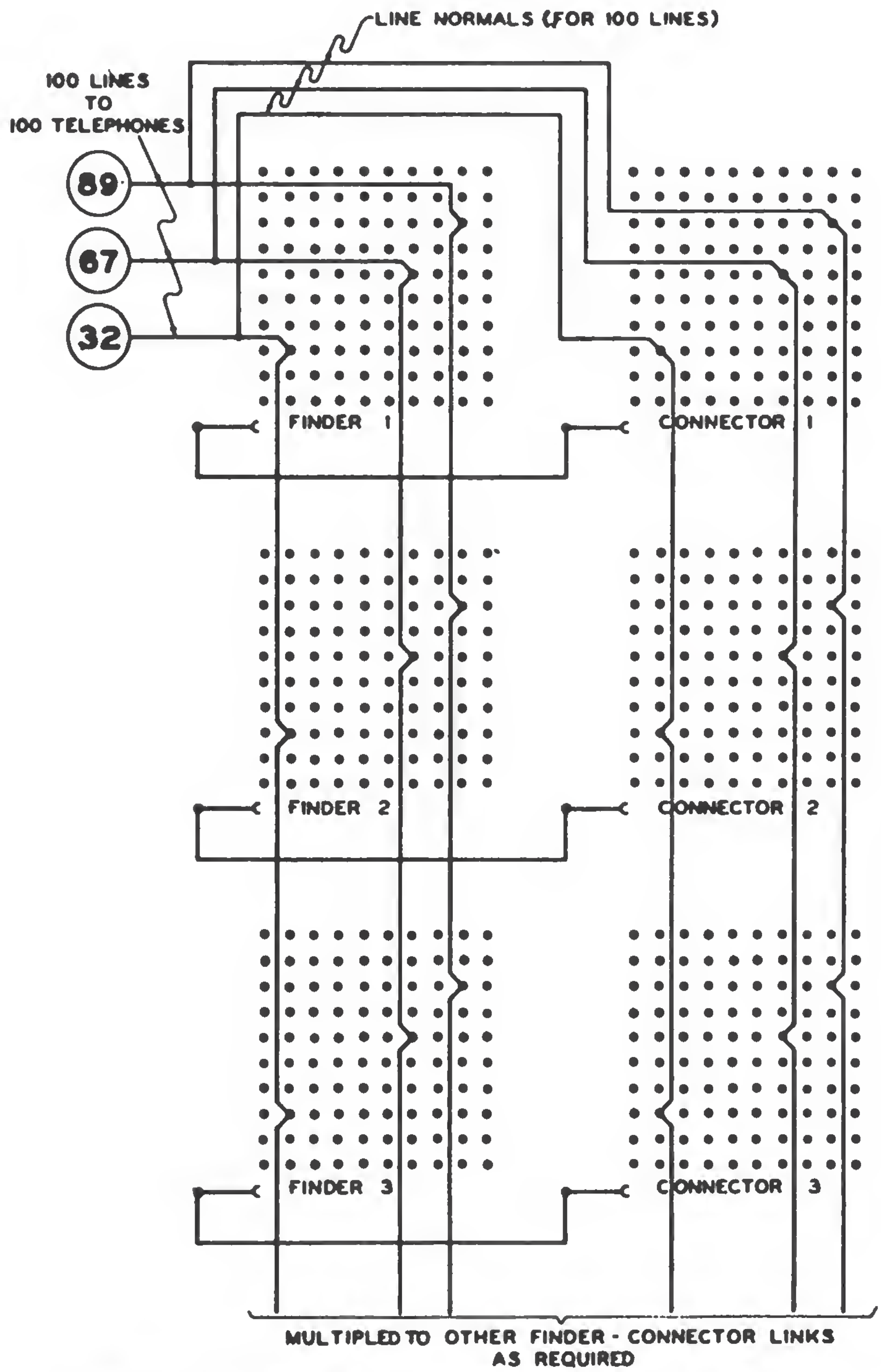


Figure 12–11.—Basic 100-line finder-connector system.

set from the cradle at telephone 32. An idle finder, such as finder 1, steps up, rotates in, and stops on contact 32. The connection is now extended through to the connector associated with the finder, in this case connector 1, and the dial tone is received by the calling telephone. The DIAL TONE is a signal for the person making the call to dial the number of the called telephone. When digits "8" and "9" are dialed, the wipers of the connector switch step up, rotate in, and stop on contact 89.

The connection is now completed from telephone 32, through finder-connector link 1, and back over the line normal of line 89 to telephone 89. The connector switch now tests telephone 89 and, if it is not in use, ringing current is sent out to operate the ringer at telephone 89. If telephone 89 is found to be in use, a busy signal is returned to the calling telephone.

A complete 100-line finder-connector system is shown in figure 12–12. The finder and connector banks are each rep-

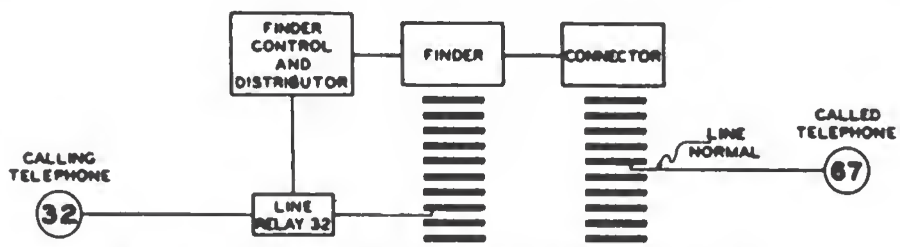


Figure 12–12.—Complete finder-connector system.

resented by 10 horizontal lines. The rectangles at the top of the finder and connector banks represent the switch mechanisms. One line relay is associated with each line whereas one finder control and distributor equipment is common to all lines. Only one finder-connector link is shown. However, there are many such links provided for each 100 lines. Older systems have 25 links.

To call telephone 67 from telephone 32, remove the handset from the cradle at telephone 32. Line relay 32 operates and marks the position of line 32 in the finder banks.

When the line relay operates it also sends a START SIGNAL to the finder control and distributor equipment.

The signal causes this equipment to start a preselected idle finder searching for the calling line.

The finder control and distributor equipment at this time automatically preselect the next idle finder to have it ready to search for the next incoming call.

The finder searching for line 32 finds it and extends the connections through to the connector switch.

At this point line 32 is made busy at the connector banks to guard against intrusion from any incoming call. Also, line relay 32, which is a 2-step relay, now operates the remainder of its contact springs, which cut off its own windings from the line. This action is called CLEARING the line of attachments. The 2-step relays are sometimes called LINE and CUTOFF RELAYS because of this dual function.

The connector switch returns a dial tone to the calling telephone and the call proceeds as previously explained.

Only one finder control and distributor is shown in figure 12–12. In practice the finder switches are divided into groups A and B, with each group equipped with its own finder control and distributor equipment.

Basic Selector System

The system described with reference to figure 12–12 has a capacity of 100 lines. It will serve any number less than

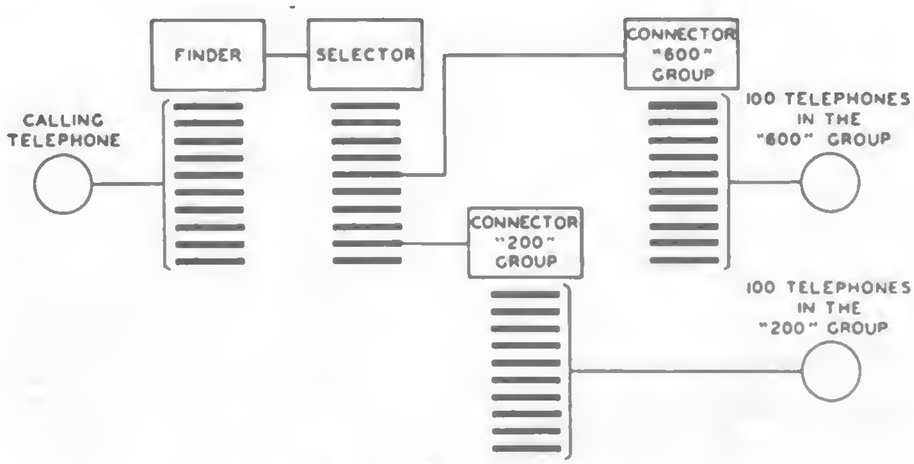


Figure 12–13.—Basic selector system.

100, such as 50 or 25. The number of lines to be served is wired to only the required finder and connector banks. For systems comprising 200 lines or more a SELECTOR is connected between the finder and connector switches, as shown in figure 12–13. The selector is similar in mechanical construction to both the finder and connector. It has the same bank, wipers, and 2-motion mechanism.

The selector faces the called line the same as does the connector. The function of the selector is to select the "hundreds" group of lines. From then on, a connector selects both the "tens" group of lines and the "units" line in that group. Note that the lines are divided into groups of 100. Two such groups are shown, the "200" group with 100 lines and the "600" group with 100 lines. Each group has a corresponding group of connectors having their banks multipled together.

A 200-line capacity system showing the trunks leading from the selector bank to the two 100-line groups of connector banks is illustrated in figure 12–14. Note that each finder

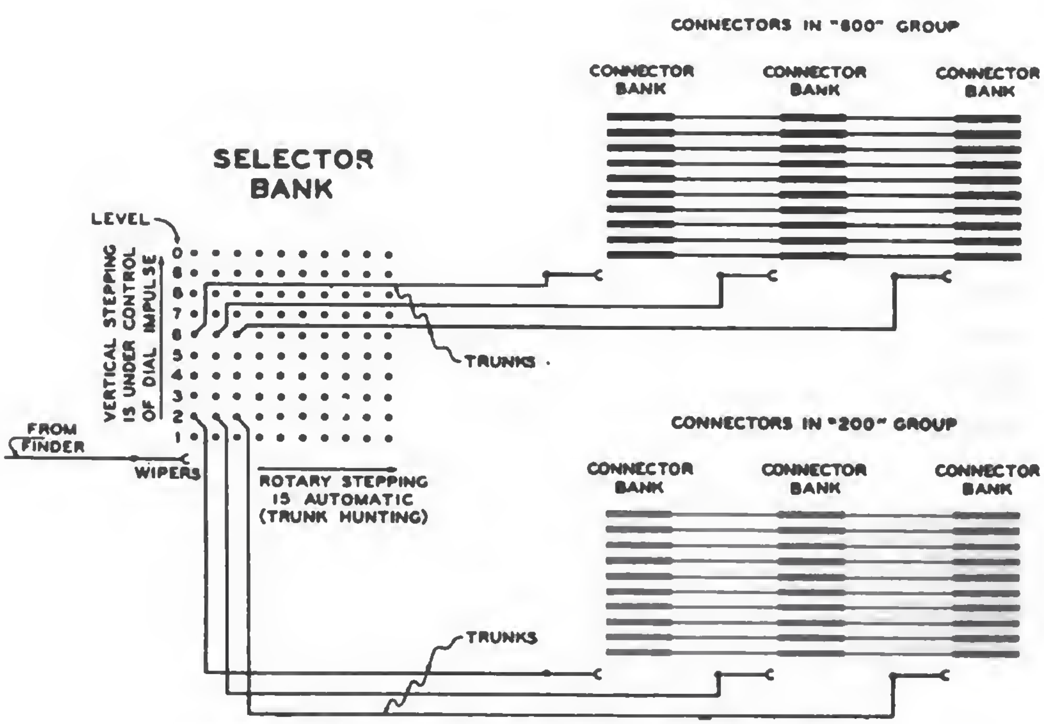


Figure 12–14.—A 200-line capacity selector system.

switch is tied "stem to stern" with a selector switch, instead of being tied to a connector switch as in the 100-line capacity system. However, one finder-selector link is required for each conversation that is to be held simultaneously. The connector switch always operates last and selects the "tens" group of lines and the "units" line within the group.

To call telephone 673, remove the handset from the cradle at the calling telephone. An idle finder searches and extends the calling line to the selector switch associated with that particular finder. The selector returns a dial tone to the calling telephone. When the "hundreds" digit, "6," is dialed, the selector wipers step up to the sixth level, and automatically rotate in on that level in search of a contact that is attached to an idle connector switch. The leads to the connectors are called TRUNKS and the automatic selection of an idle trunk is called TRUNK HUNTING.

A selector switch is capable of searching over the 10 contacts, on the dialed level, more quickly than a calling person can dial the next digit. If all 10 contacts test busy, the selector switch returns a busy signal to the calling person.

If the selector finds an idle trunk, the call is extended through to a connector. When digits "7" and "3" are dialed, the connector steps up 7 levels and rotates in 3 steps to complete the call. Because the dialed digits extend the call step by step, the Strowger automatic telephone equipment is referred to as the STEP-BY-STEP system.

QUIZ

1. How are the switching mechanisms in automatic telephone systems controlled at the calling telephone?
2. What action occurs within the dial assembly when the dial is operated?
3. Name five types of telephones classified according to the type of enclosure used.
4. Name the six component parts of a telephone instrument.
5. What are the principal parts of the transmitter unit of the handset?
6. What is the name of the steady direct current through the transmitter before this current is modulated?

7. What is the name of the varying transmitter current caused by voice modulation?
8. What is the purpose of the receiver of the handset?
9. What type of receiver is used in the handset?
10. Name the six principal parts of the dial.
11. What is the relation between the digit dialed and the number of the impulses?
12. What is the function of the shunt springs in the dial mechanism?
13. What circuit conditions exist when the handset is in the cradle?
14. What circuit conditions exist when the handset is removed from the cradle?
15. What type of ringer is used in the automatic telephone instrument?
16. What is the purpose of the capacitor in the ringing circuit?
17. What is the purpose of the talking capacitor?
18. What are the three functions of the induction coil in the telephone instrument?
19. Name the four circuits that comprise a typical telephone circuit.
20. What type of switching mechanism is used in shipboard dial telephone systems?
21. How many pairs of metallic contacts are contained in a connector bank used in the basic system?
22. How are the connector bank contacts arranged within a Strowger switch?
23. What action takes place in the connector bank when a calling telephone dials No. 32?
24. Why is a connector switch referred to as a numerical type of Strowger switch?
25. Why is a finder switch referred to as a nonnumerical type of Strowger switch?
26. How many finder-connector links are required for each of the conversations that are held simultaneously?
27. What is the name of the leads that connect the connector banks to the 100 telephone lines?
28. Where is the selector bank connected with relation to the connector bank in a 200-line capacity telephone system?
29. What is the name of the leads that connect the selector bank to the connector banks?
30. What is the automatic selection of an idle trunk called?

CHAPTER 13

GYROCOMPASS ERRORS

DISTURBANCES

The direction indicated by a compass is read from the COMPASS CARD, the outer circumference of which is graduated in degrees (fig. 13–1). The graduations start with 0°

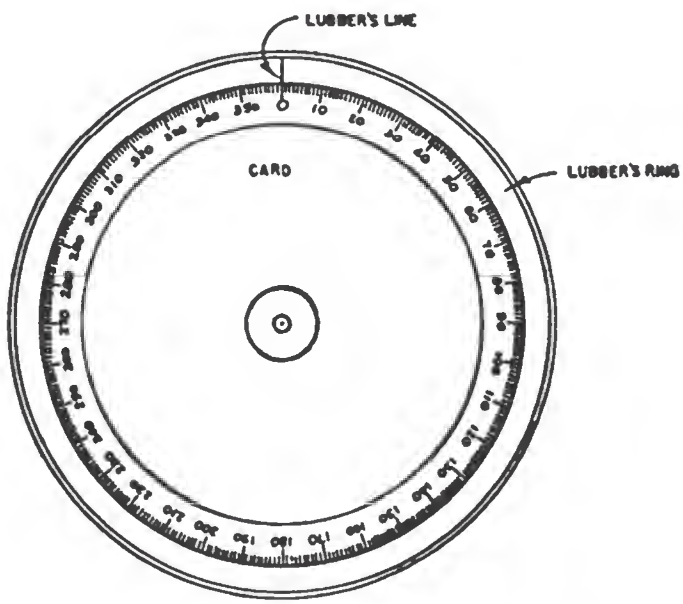


Figure 13–1.—Gyrocompass card.

at the north point and continue clockwise around the card to 360°, which coincides with the 0° point. The index line which indicates the ship's heading is called the LUBBER'S LINE. As the ship turns, the lubber's line turns with it. However, the card is controlled by the compass and remains stationary, always indicating north. The card graduation opposite the lubber's line on an errorless compass indicates the ship's heading in degrees clockwise from true north. Hence, the compass reads 90° for a true east course; 180° for a true south course; 270° for a true west course; and so forth.

If a ship is on a northerly course and turns east, the lubber's line turns clockwise around the card and the compass card reading changes to a higher number. However, if the compass is disturbed and an easterly error is introduced, the card turns clockwise an amount equal to this error and the reading changes to a lower number. Only in drydock would this minor turning of the compass card be discernible.

Assume this easterly error is 2° and the ship is on a true course of 20°. The lubber's line has turned 20° clockwise to correspond to the true course. However, the card reads only 18° instead of 20° because the card has turned 2° clockwise with the easterly error.

When an easterly error occurs, the card reading is always less than the true course. Conversely, when a westerly error occurs the card reading is always more than the true course.

To correct for an easterly error in the Sperry compass the LUBBER'S LINE is moved CLOCKWISE the amount of the error, whereas in the Arma compass the COMPASS CARD is moved COUNTERCLOCKWISE the amount of the error.

The elementary gyrocompass is described in the *I. C. Electrician 3* training course. This compass seeks and remains in the meridian as long as it is in a fixed location and is not subjected to motion relative to the earth. However, a gyrocompass aboard ship is subjected to many motions that tend to produce errors in the compass. These motions are caused by the ship's (1) linear speed over the surface of the ocean, tending to produce CONSTANT MOTION ERRORS; (2) changes in course and speed, tending to produce OSCILLATING ERRORS; and (3) roll and pitch, tending to produce QUADRANTAL ERRORS. Some errors can be eliminated by designing the compass to neutralize the influences that cause them. Other errors can be removed by calculating the amount of the error and correcting the compass to the true reading.

CONSTANT MOTION ERRORS

Constant motion errors comprise (1) tangent latitude error and (2) speed, course, latitude error.

Tangent Latitude Error

The tangent latitude error is the direct consequence of the method used in the Sperry compass to damp the horizontal oscillations of the gyro axle. At the equator the compass settles in the meridian with its axle horizontal and with equal amounts of mercury in each tank. In any other latitude a torque must be applied to the gyro to keep it continually precessing or the gyro will leave the meridian because of its rigidity of plane and the earth's rotation. For the compass to reach a settling point, the north axle must be tilted upward in northern latitudes and downward in southern latitudes.

The upward tilt of the axle in northern latitudes causes an excess amount of mercury to collect in the south tanks. As previously explained, the point of connection between the mercury ballistic and the rotor case is offset a short distance east of the vertical axis to provide damping. Therefore, the excess mercury in the south tanks exerts a force through the offset connection that applies a torque simultaneously about both the horizontal and vertical axes. This action is called COMPOUND COMPRESSION. The downward precession tending to tilt the north axle below the horizontal is offset by the earth's rotation tending to tilt the axle upward. This action just prevents the torque produced by the mercury ballistic from bringing the axle horizontal and in the meridian. The north axle lags behind the meridian just enough to keep the gyro precessing at a constant rate.

In northern latitudes the north axle assumes a settling position slightly east of the true meridian with an upward tilt. In southern latitudes the north axle assumes a settling position slightly west of the true meridian with a downward tilt. As the angle of latitude increases, the displacement of the axle from the meridian increases. Finally, a position east of the meridian in northern latitudes or west of the meridian in southern latitudes is reached and the compass settles. This position occurs when the turning and tilting of the compass, caused by the action of the mercury ballistic through the offset connection, exactly balances the turning and tilting caused by the earth's rotation. The angle between the meridian and the settling position is called the TANGENT LATITUDE ERROR.

The tangent latitude error varies from zero at the equator to a maximum at high northern and southern latitudes. In any latitude other that the equator the Sperry compass settles with a slight tilt of the north axle and east or west of the true meridian. This tilt increases as the latitude increases. The tangent latitude error is approximately proportional to the tangent of the latitude in which the compass is operating.

SPERRY COMPASS.—When the Sperry compass has settled, the north axle is at rest in a virtual meridian with an upward or downward tilt. The small angle between the virtual meridian and the true meridian represents the tangent latitude error. This error is compensated for by a speed and latitude corrector that enables the lubber's line to be moved manually the exact amount of the error and in the proper direction. The device is calibrated in degrees of north and south latitude. Setting the latitude dial to the local latitude moves the lubber's ring and the transmitters so that the compass card and the repeaters indicate the true angle between the ship's heading and geographical north.

ARMA COMPASS.—The Arma compass has no tangent latitude error because it does not use compound precession. In the Arma compass the pendulous weight is in the line of the vertical axis and there is no offset connection as in the Sperry compass. Thus, the precession is about one axis only and the damping force of the oil tanks causes the Arma compass to settle in the meridian. Therefore, the gyro units bring the sensitive element to rest in the true meridian in all latitudes. However, the gyros used in the Arma compass come to rest in the true meridian with their north axles tilted slightly upward in northern latitudes and slightly downward in southern latitudes.

Speed, Course, Latitude Error

The magnitude of the speed, course, latitude error depends upon the speed, course, and latitude of the ship. The north-seeking tendency of the gyrocompass depends upon the fact that north is at right angles to the west-to-east direction in which the earth's rotation carries the compass. The gyrocompass tends to settle with its axle at right angles to its plane of travel through space at all times.

A compass on the earth's surface is carried from west to east only when it is stationary with respect to the earth's surface, or when it is moving true east or true west. If any component of the course is north or south, the plane of motion is no longer west to east. Therefore, the compass will settle on a line at a small angle from true north. This line is called the APPARENT, OR VIRTUAL, MERIDIAN. The virtual meridian is a plane at right angles to the plane containing the path of the compass travel through space that the compass senses as the true meridian.

A ship at the equator is carried around the polar axis by the earth's rotation at a velocity of 900 knots. At any other latitude this velocity becomes 900 times the cosine of that latitude. If the ship is on a true west course its motion is opposite to that of the earth and subtracts from the speed of the earth. Conversely, if the ship is on a true east course its motion is in the same direction as that of the earth, and adds to the speed of the earth. The actual rate at which the compass is carried around the earth's polar axis thus decreases slightly on westward courses, and increases slightly on eastward courses. The ship's speed on east-west courses merely increases or decreases the directive force of the gyro rotor to cause the compass to settle with its axle in the meridian. The actual increase or decrease in the directive force is small—about 2 percent at the equator and increasing to about 4 percent at 60° latitude for a ship's speed of

20 knots. Thus, the position of the gyro axle is not disturbed by the ship's movement over the earth's surface on east-west courses. Hence, no error or change occurs in the resting position of the gyro axle.

However, if the ship travels on any other than a true east or true west course, the ship's motion and the earth's rotation combine to carry the compass in some direction other than west to east. In this case the compass seeks a new resting position away from the true meridian. This position is at right angles to the plane containing the path of the compass.

A ship at the equator is steaming true north at 20 knots (fig. 13–2). Thus, it is carrying the compass in a direction

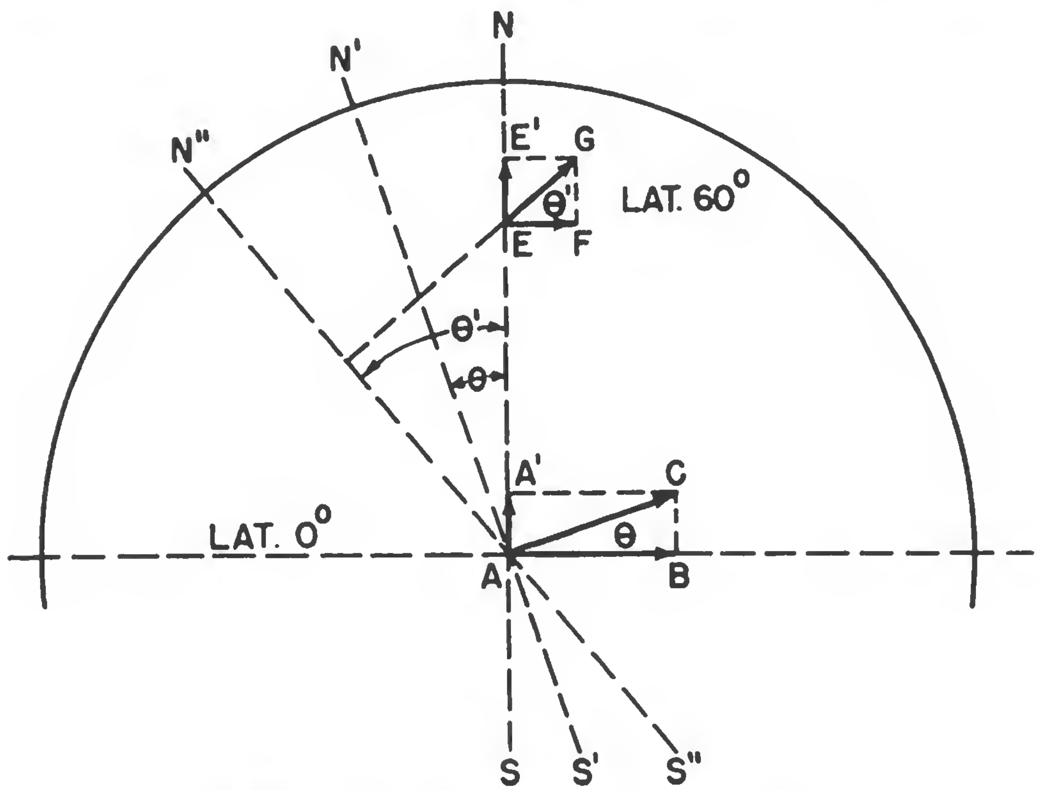


Figure 13–2.—Speed, course, latitude error.

that is at right angles to the direction of the earth's rotation. Vector AA' represents the ship's direction and speed which is 20 knots. Vector AB represents the direction and speed of the earth's surface which is 900 knots at the equator. The vectors are not drawn to scale because AA' is only about

2 percent of the length of vector AB and the resulting parallelogram would be too small to indicate clearly the individual components. Resultant vector AC represents the total absolute speed of the compass and the direction in which it is being carried in space around the earth's polar axis (earth's axis of spin).

The true meridian is along line NS which is perpendicular to vector AB. The apparent or virtual meridian is along line $N'S'$ which is perpendicular to vector AC. Vector AC lies in the plane which contains the path of the compass motion through space. The gyro axle therefore settles on the virtual meridian, $N'S'$, and not on the true meridian, NS. The true north is east of the indicated north by angle θ, where

$$\theta=\tan^{-1}\left(\frac{BC}{AB}=\frac{20}{900}=0.0222\right)=1.27°.$$

Thus, $\theta=1.27°$ for a speed of 20 knots on a true north course. Angle θ is purposely exaggerated in the figure to clearly indicate the speed, course, latitude error.

A ship at 60° north latitude is steaming true north at 20 knots (fig. 13–2). Vector EE' represents the ship's direction and speed which is 20 knots. Vector EF represents the direction and speed of the earth's surface which is 450 knots at 60° north latitude. Resultant vector EG represents the total absolute speed of the compass and the direction in which it is being carried in space around the earth's polar axis. The resultant virtual meridian for the ship's speed, course, and latitude (as indicated in figure 13–2) is at right angles to vector EG and is along line $N''S''$. The compass tends to align itself with this virtual meridian.

The true north is east of the indicated north by angle θ', where

$$\theta'=\tan^{-1}\left(\frac{FG}{EF}=\frac{20}{450}=0.0444\right)=2.56°.$$

Thus, $\theta'=2.56°$ for a speed of 20 knots on a true north course. Angle θ' is exaggerated to indicate the error. If the ship's speed is reduced, the error will be less. If the ship's speed is increased, the error will be more.

If a ship at the equator is steaming true south at 20 knots, the deviation of the compass axle is toward the opposite side of the true meridian. In other words, the true north is to the west of that indicated by the compass. However, in practice the speed, course, latitude error (SCLE) is determined from the equation—

$$\text{SCLE}=\frac{0.0637\times\text{speed in knots}\times\text{cosine of the course}}{\text{cosine of the latitude}},$$

where 0.0637 is a constant for converting the error into degrees.

The speed, course, latitude error is westerly if any component of the ship's course is north. Conversely, the speed, course, latitude error is easterly if any component of the ship's course is south. The magnitude of this error is proportional to the latitude, the speed, and the course of the ship. The direction of this error is determined by the ship's vector course and the magnitude of the ship's speed.

As a ship moves over the earth's surface on different courses at different speeds in various latitudes, the resting position of the gyro axle changes accordingly. In other words, the compass does not indicate true north when a ship is underway and steering any course other than true east or true west. The effect is similar for both the Sperry and Arma compasses. The error is not corrected in the compass itself, but a means is provided to compensate for this error so that the compass card indicates the true angle between the ship's heading and true north.

Sperry compass.—As mentioned previously, when a ship is steaming on any course other than true east or true west, the gyro axle does not point toward true north because of the combined effects of the earth's rotation and the ship's speed. Instead, the gyro axle settles in a virtual meridian that is at some angle from true north. The Sperry compass is provided with a speed and latitude corrector (fig. 13–3) to compensate for this error in addition to the tangent latitude error. This corrector consists of a stationary plate on which are engraved several speed curves and a movable plate on which are engraved various latitudes. The movable plate is controlled by means of an adjusting knob. The speed and

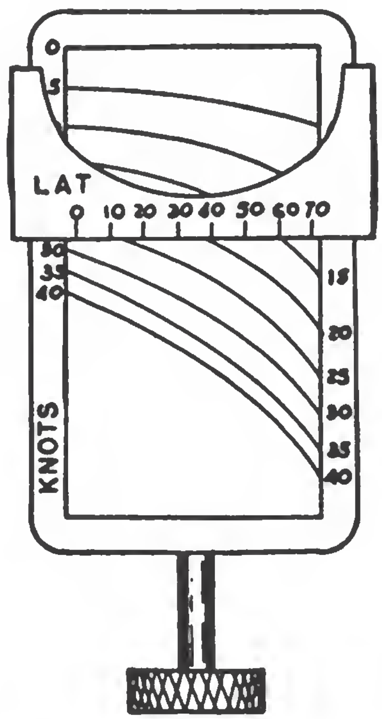


Figure 13–3.—Sperry speed and latitude corrector.

latitude corrector is set by turning this knob until the mark indicating the local latitude intersects the speed curve corresponding to the ship's speed. When set to the proper speed and latitude, the correction device automatically shifts the lubber's line in the right direction and the proper amount to compensate for this error.

The effect of the ship's course on the speed error is automatically compensated for by an eccentric groove, or COSINE RING (fig. 13–4), cut into the lower surface of the large azimuth gear which is located below the compass card. As the ship turns around the compass, the cosine ring moves a follower, or COSINE CAM, forward or aft. The movement of the cam operates a system of levers that determines the amount of the course correction for the given speed and latitude correction applied to the lubber's line.

On a northerly course, the cam is in its most forward position and the maximum correction for speed and latitude is applied to the lubber's line. On a southerly course, the cam is in its most aft position and the maximum correction is again applied but in a direction opposite to that for a northerly course.

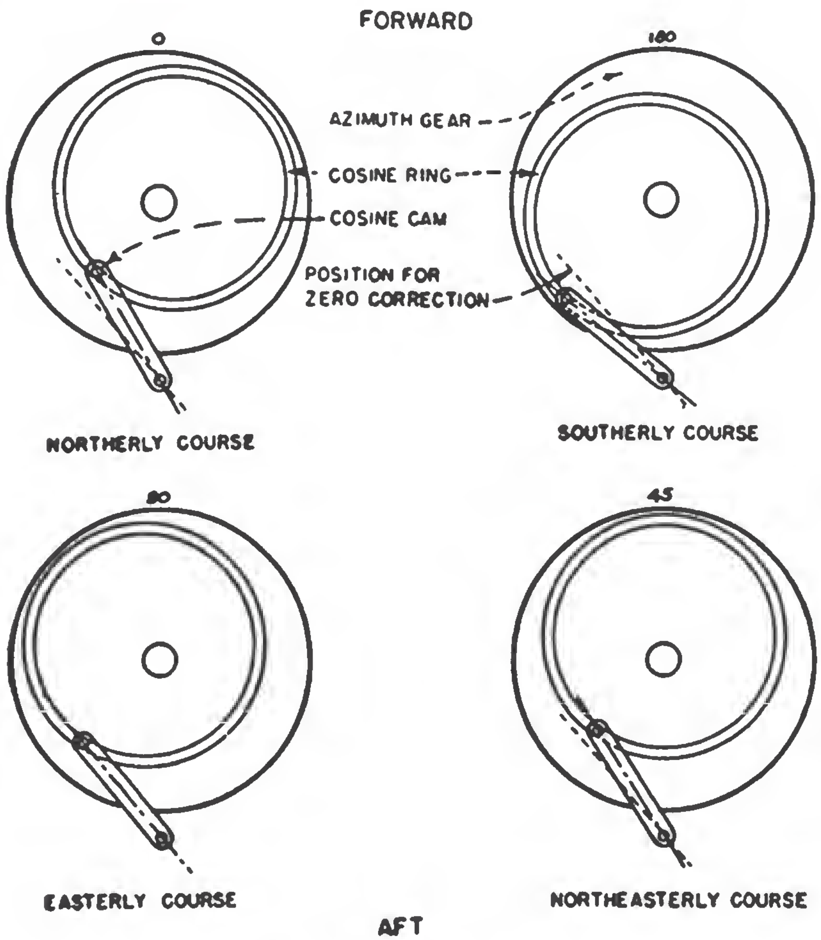


Figure 13—4.—Sperry cosine ring.

When the heading is east or west, the cam is in a position halfway between that for north or south, and no correction is applied. On an intermediate course, the cam is in a position between these extremes and the correction applied is of the proper value for the ship's heading.

The amount of correction applied for any heading is proportional to the cosine of the angle between true north or true south and the ship's course. For this reason the eccentric ring and the follower are called the cosine ring and cosine cam respectively.

When the speed and latitude corrector is set to the proper speed and latitude combined with the automatic course corrector, the total resultant correction for the tangent latitude error and the speed, course, latitude error is transmitted to the lubber's line. The lubber's line is automatically moved to port or starboard the exact amount of the resultant correction. The lubber's ring shifts the electrical zero of the transmitters so that the repeaters and the compass cards indicate the true heading on all courses.

Arma compass.—The Arma compass is equipped with a speed and latitude correction mechanism to compensate for the speed, course, latitude error. The mechanism consists of a metal plate on which is engraved the correction in degrees to be applied for any speed in any latitude. The correction for the speed and latitude is applied to the compass by means of a correction knob which carries a scale graduated in degrees. The speed correction mechanism is set by turning the knob until the scale shows the proper correction as indicated on the metal plate.

The effect of the ship's course on the speed error is automatically compensated for by the eccentric bearing and fork (fig. 13–5) which are geared to the follow-up head. When the correction due to speed and latitude is introduced by means of the correction knob, it is applied to the follow-up system through the eccentric bearing and fork which automatically corrects for the error on all headings by moving the follow-up coil arms. Movement of these arms induces a voltage in the follow-up coil, causing the follow-up motor to operate and move the compass card and repeaters to indicate the angle between the ship's heading and true north.

The fore-and-aft position of the bearing is controlled by the setting of the correction knob. On a northerly or southerly course, the motion of the eccentric bearing in a fore-and-aft direction rotates the fork about its pivot and applies the maximum correction. On an easterly or westerly course, no correction is applied because the motion of the eccentric bearing in a fore-and-aft direction does not rotate the fork. On an intermediate course, the eccentric bearing is between these extremes and the correction applied is of the proper value for the ship's heading.

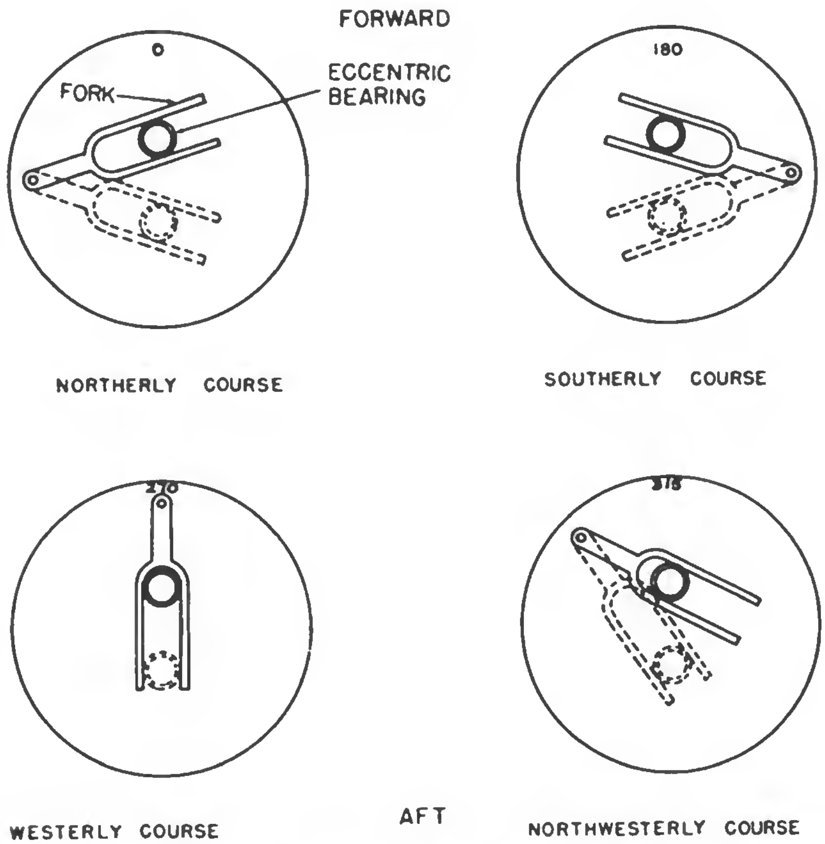


Figure 13–5.—Arma eccentric bearing and fork.

Some models of the Sperry and Arma compasses are equipped with automatic mechanisms that apply the correction for the speed error. These mechanisms are provided with synchro receivers that receive an indication of the ship's speed from the underwater log, and a follow-up motor that applies this quantity to a lever-type multiplier.

OSCILLATING ERRORS

Oscillating errors comprise (1) ballistic deflection error and (2) ballistic damping error.

Ballistic Deflection Error

The ballistic deflection error is dependent upon the rate of change of the ship's speed or course. It is a transient error that is introduced into the compass only during changes of speed or course. Because the gyrocompass is a pendulous body, it is subjected to the action of the forces of inertia when a ship changes speed or course. The inertia of an object causes it to resist any attempt to change its position if it is at rest, or to resist any attempt to change its speed or direction if it is in motion. This principle is demonstrated by the manner in which passengers on a street car or bus are thrown backward when the vehicle starts, and forward when it stops. The mercury in the Sperry mercury ballistic and the weight of the Arma compass are subjected to a similar force when the ship's speed or course is changed.

When a ship steaming north increases its speed, the mercury in the mercury ballistic is forced aft, or to the south, by the effect of its inertia. A portion of the mercury in the north container flows to the south; the south container becomes heavier and a downward force of gravity is exerted on the south end of the rotor axle. A similar force acts on the pendulous weight of an Arma compass and pushes south at the bottom of the rotor. This is equivalent to a downward force on the north end of the axle.

In either case, fortunately, the direction of the force is such as to cause the compass to precess toward its new settling position. The force is exerted during the time in which the change is being made and its strength is proportional to the rate of the change. Thus, during a rapid change of 10 knots in speed, a comparatively large force is exerted for a short time, whereas during a more gradual change of the same amount, a smaller force is exerted for a longer time. The total precession in either case is the same. The precession resulting from such a force is called BALLISTIC DEFLECTION. When the ballistic deflection is exactly equal to the change in the speed, course, latitude error for a change in speed or course, the compass settles quickly in the virtual meridian and there is no error in its indication. When the ballistic deflection is not equal to the change in the speed, course, latitude error, the resulting error is called the BALLISTIC DEFLECTION ERROR. This error consists of a series of decreasing oscillations across the normal settling point of the compass. Therefore, it cannot be corrected by shifting the lubber's line or the compass card.

The factors that control the magnitude of the speed, course, latitude error also control the amount of the ballistic deflection and the length of the undamped period of the compass. If the gyroscope is designed properly, the ballistic deflection for any change of speed or course can be made equal to the change in speed, course, latitude error. Such design results in a normal period of approximately 85 minutes. Since the period varies with the latitude, a compass that has no ballistic deflection error in one latitude will have such an error in another latitude. This condition can be corrected if one or more of the controlling factors are made variable so that the period can be adjusted to the same level for all latitudes.

The combined effect of the speed, course, latitude error and the ballistic deflection error on the accuracy of the gyrocompass is illustrated in figure 13–6. A ship steaming true north at 20 knots suddenly changes its speed to 10 knots during a 5-minute period. On a northerly course, the gyro will have a speed, course, latitude error. The gyro axle will point west of the true meridian by an amount dependent upon the ship's speed and latitude.

The angles are exaggerated in figure 13–6 to clarify the discussion. Line *ON* represents the direction of true north and line *ON′* represents the direction in which the gyro axle aligns itself when the ship's speed is 20 knots. Angle *NON′* represents the speed, course, latitude error. Line *ON″* represents the direction in which the gyro axle points when the speed has been reduced to 10 knots. Angle *NON″* is the new speed, course, latitude error.

As the speed is being reduced, the gyro axle tends to move eastward to its new resting position because of the meridian-seeking property of the compass. The ballistic deflection also causes the gyro axle to precess eastward. Assume that the ballistic action causes the gyro axle to precess to OC, overshooting ON''. When the ship has settled to its 10-knot speed, the acceleration force subsides and the gyro axle begins

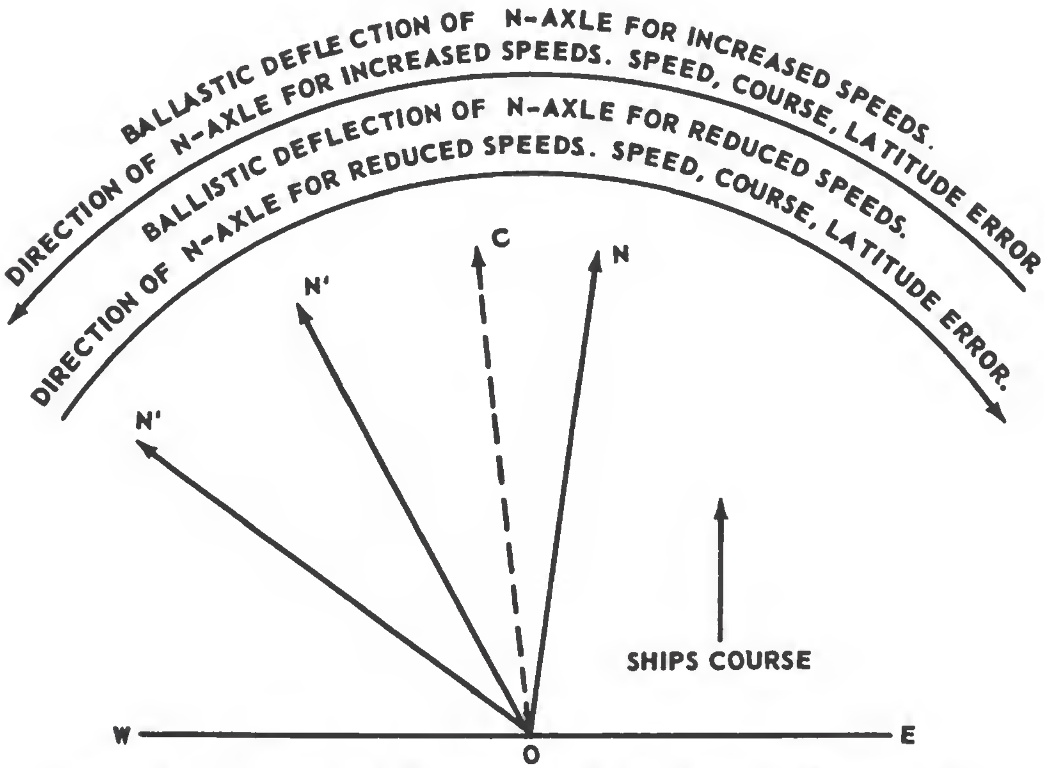


Figure 13–6.—Speed, course, latitude error and ballistic deflection error.

to precess westward and across ON''. It will continue this oscillation about ON'' with diminishing amplitude and finally come to rest along ON''. Note that the ballistic deflection is always in the same direction as the change in the speed, course, latitude error for all changes of speed on any course.

Under certain conditions, the movement caused by the ballistic deflection may cause the compass to move to its settling position at the same rate as the change in speed,. course, latitude error. If this occurs, the ballistic deflection will swing the axle to its new settling position, and there will be no tendency for the gyro axle to oscillate when the ship assumes a steady speed. The gyro axle will point in its new direction in a dead-beat manner. The effect of the ballistic deflection is then confined only to the period during which the speed is being changed.

Once the characteristics of the compass are determined, the magnitude of the ballistic deflection error is dependent upon the (1) direction of the ship's course and (2) rate of change of speed. It is not affected by the latitude. The acceleration force is the same in all latitudes for a given course and rate of change of speed. However, the magnitude of the speed, course, latitude error does vary with the latitude. If these factors are considered in the design of the compass, the period of oscillation at one particular latitude can be selected so that the ballistic deflection can be made just equal to the difference between the speed, course, latitude errors for any changes in speed or course at this latitude. If this selection is accomplished, the error due to ballistic deflection is compensated for and the period of compass oscillation maintained at the proper value for the particular latitude chosen.

Sperry compass.—Sperry compasses that are used for navigation are constructed with a fixed undamped period of about 85 minutes at 40.7° latitude. Hence, there is no ballistic deflection error at 40.7° latitude with this period. In fact, the error at any latitude is small and does not affect the accuracy of navigation to any great extent.

Compasses that are used for fire control must maintain a constant and accurate indication of the ship's heading. This condition is accomplished by maintaining a period of about 85 minutes in all latitudes. On these compasses the mercury ballistic is constructed so that the tanks can be set closer to, or farther from, the horizontal axis about which they operate. At the equator, the tanks are set in their innermost position. For north and south latitudes where the period would normally be longer, the tanks are set farther out. This adjustment provides the additional torque necessary to cause a faster rate of precession and thereby shorten the period. To set the ballistic for any latitude, a knob mounted on the ballistic frame is turned until an attached scale indicates the correct latitude.

ARMA COMPASS.—The Arma navigational compass, like the Sperry, is constructed with a fixed undamped period of about 85 minutes at 40.7° latitude.

In Arma fire control compasses the period is kept constant at about 85 minutes in all latitudes by adjusting the rotor speed. The rotors spin at their maximum speed at the equator, and at lower speeds in north or south latitudes. The gyro rigidity of plane decreases with the speed. Thus the relative force of precession caused by the pendulous weight is increased with respect to rigidity of plane as the gyro speed is decreased. The adjustment on the Arma compass is made by setting a knob on the control panel to the desired latitude. This knob adjusts the rotor speeds by varying the speed of the gyro supply motor-generator and thus the frequency of the 3-phase voltage applied to the gyro stators.

Ballistic Damping Error

Oscillations are damped in the Sperry and Arma compasses by partly suppressing the precession caused by the action of the mercury ballistic or the pendulous weight. The slight error introduced by the damping arrangement on changes in speed or course is called the BALLISTIC DAMPING ERROR. This error, like the ballistic deflection error, is oscillatory and of a temporary nature.

The Sperry compass uses a mercury ballistic connected slightly east of the true vertical axis of the gyro to damp the oscillations across the meridian, or about the vertical axis. The Arma compass uses an oil ballistic to damp the oscillations of the gyro about the vertical axis. These damping arrangements cause the gyros to reach a settling point. However, both systems produce a transient error in the compass when a ship makes a rapid change in speed or course. Changes in speed produce ACCELERATION FORCES; whereas changes in course produce CENTRIFUGAL FORCES. Both of these forces have a similar effect on the compass.

A ship steaming true west at 20 knots suddenly executes a 90° turn to the right (fig. 13–7). During the turn a centrifugal force is applied to every part of the compass, including the ballistic. In the Sperry compass this action causes an excess of mercury to collect in the south tanks of the ballistic at *A*. Because of the offset connection of the mercury ballistic, the excess mercury that has collected in the south tanks exerts a torque about the vertical axis in addition to the one taking place about the horizontal axis during the turn. This torque about the vertical axis produces a downward tilt of the north axle at *B* as a result of precession. This tilt of the gyro axle causes an oscillation to start as the centrifugal force diminishes to zero at *C*. As a result the gyro precesses

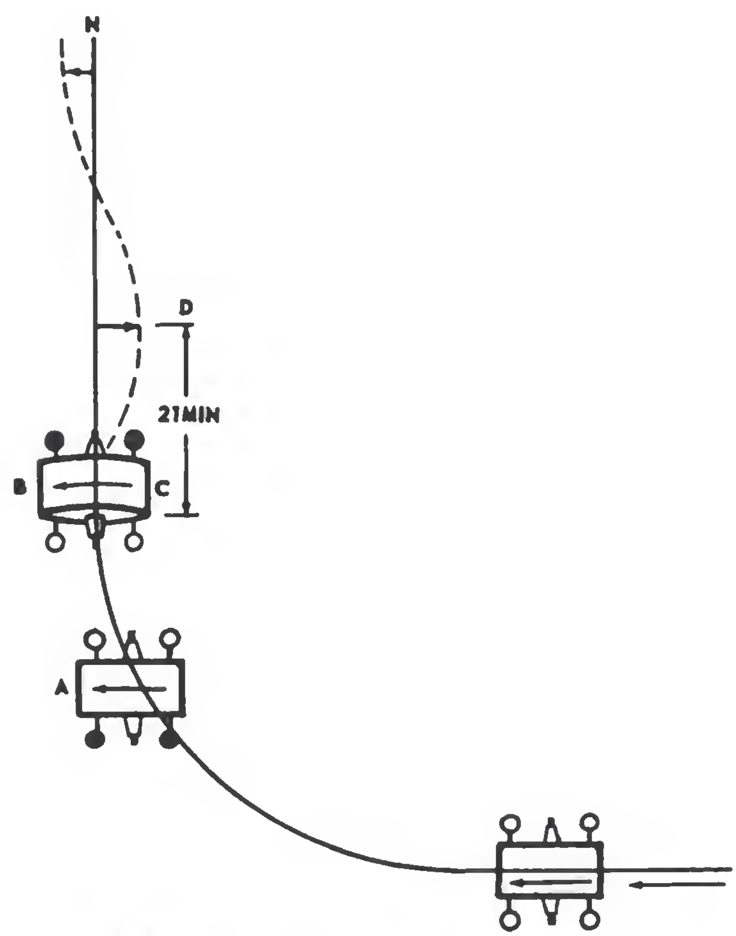


Figure 13–7.—Ballistic damping error.

and leaves the meridian. This oscillation on a compass with a damped period of about 85 minutes becomes maximum at *D*, 21 minutes after the change in course is completed, and finally comes to rest in about 2 hours.

The oil in the oil ballistic of the Arma compass is subjected to the same centrifugal force on changes in course. An excess of oil collects in one tank. This action causes a torque and a consequent movement of the gyro axle from the meridian. The magnitude of this error is small and averages not more than 1°.

SPERRY COMPASS.—The ballistic damping error is eliminated in the Sperry fire control gyrocompass by means of an automatic damping eliminator. This device automatically moves the mercury ballistic connection arm from the eccentric position to the true vertical axis of the gyro whenever a change in the ship's course is greater than 15° and faster than 40° per minute, or whenever the ship's speed changes at 2 knots per minute. Moving this eccentric connection to the true vertical axis eliminates the torque about this axis caused by the centrifugal force and prevents the compass from going through a damped oscillation.

ARMA COMPASS.—The ballistic damping error is eliminated in the Arma compass by closing a valve in the pipe line between the oil damping tanks. Electromagnetic devices called DAMPING ELIMINATORS are used for this purpose. They are automatic in their action for changes above an established minimum which is the same as that for the Sperry compass. Push buttons are provided for manual operation of the damping eliminators.

QUADRANTAL ERRORS

A gyrocompass aboard a rolling or pitching ship is subjected to acceleration forces and centrifugal forces. Accelration forces are caused by the inertia of the gyrocompass tending to oppose the change in the direction of motion at the end of a roll or pitch. Centrifugal forces tend to move the gyrocompass away from the center about which the ship is rolling or pitching.

When the gyro axle is parallel to the ship's heading (true north or true south course) or at right angles to the ship's heading (true east or true west course), the forces of rolling or pitching have no effect on the gyro axle. On all courses between the cardinal headings (true north, south, east, or west), or quadrantal courses, the forces of rolling or pitching affect the gyro axle. Hence, the resulting errors in compass indications are called QUADRANTAL, or INTERCARDINAL, ERRORS.

Acceleration Forces Due to Roll or Pitch

A gyrocompass is suspended by means of gimbal rings in its binnacle so that it is free to take almost any position with respect to the binnacle. The compass can hang vertically regardless of the ship's position and it can swing out of a vertical position when the acceleration forces caused by rolling or pitching act on it.

A pendulous gyrocompass viewed from the south is shown in figure 13–8, A. The rotor case, *R*, corresponds to the inner

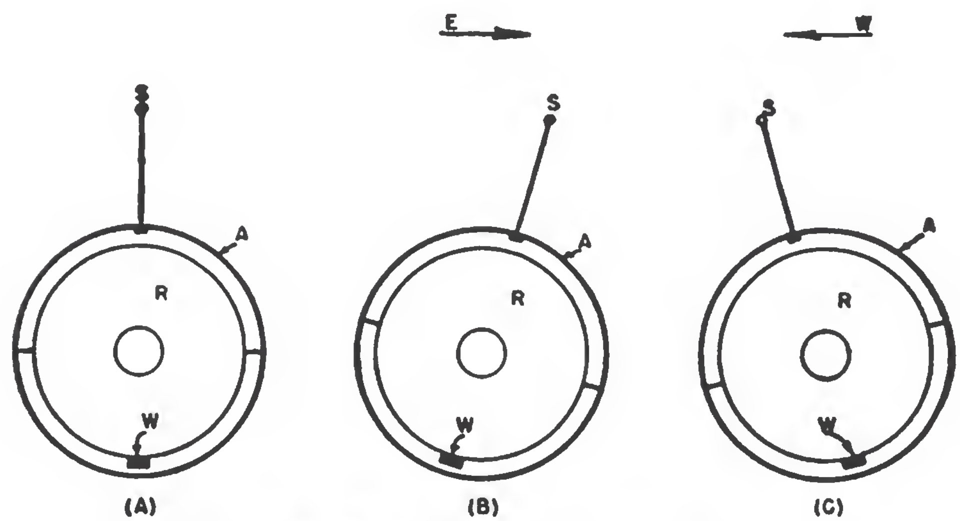


Figure 13–8.—Effect of rolling on a true north course.

ring of the gyroscope and supports the bearings on which the rotor spins. It is mounted on horizontal bearings in the vertical ring, *A*, which corresponds to the outer gimbal ring of the gyroscope. The entire assembly hangs from the support, S, with freedom to swing in any direction and to turn about a vertical axis.

When the support, S, is accelerated to the right, or east, the compass assumes the position shown in figure 13–8, B, and the weight, W, is west of the vertical. Conversely, when the support is accelerated to the left, or west, the compass assumes the position shown in figure 13–8, C, and the weight, W, is east of the vertical.

The same gyrocompass viewed from the west is shown in figure 13–9, A. When the support is accelerated to the right,

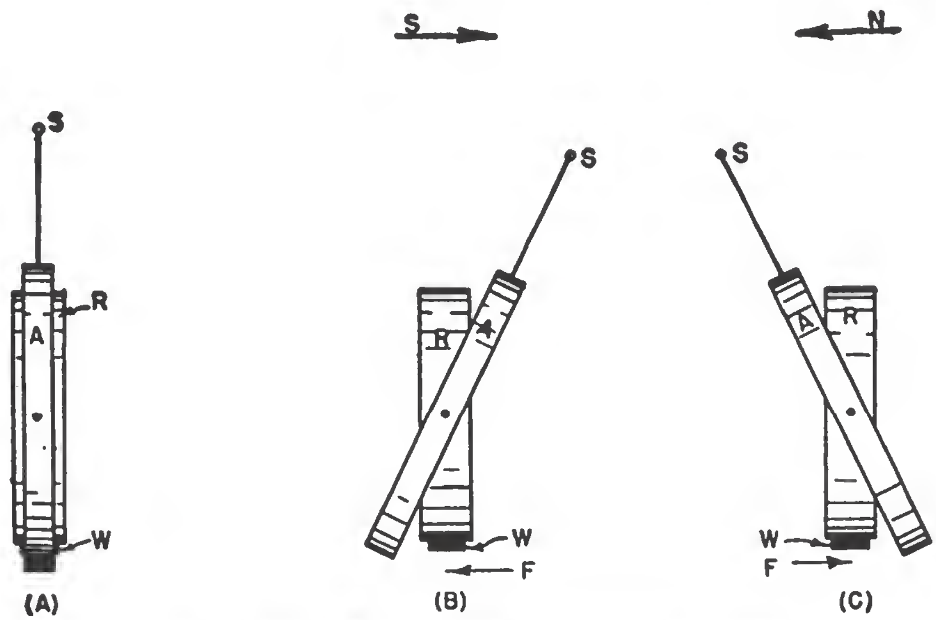


Figure 13–9.—Effect of rolling on a true east course.

or south (fig. 13–9, B), and when the support is accelerated to the left, or north (fig. 13–9, C), rigidity of plane prevents the rotor from swinging out of the vertical. However, the inertia of the weight, W, attempts to cause such a swing, and exerts acceleration forces, F, around the horizontal axis.

When the ship is rolling on a true north course, the relative positions of the rotor and vertical ring as viewed from the south are shown in figure 13–8. All swinging occurs in the plane in which the rotor is spinning. Because there is no attempt to change this plane of rotation, there is no precession. Thus, there is no error on a true north or true south course.

When the ship is rolling on a true east course, the relative positions of the rotor and vertical ring as viewed from the west are shown in figure 13–9. In this case torques are exerted about the horizontal axis, alternately clockwise and counterclockwise, by the acceleration forces, *F*. The natural period of oscillation of the compass is so large (85 minutes) in comparison to the period of the ship's roll (5 to 10 seconds), that these torques reverse and cancel each other on successive rolls. Thus, there is no error on a true east or true west course.

When the ship is rolling on a northeasterly course, the compass is subjected to a combination of the effects that occur on true north and true east courses. When the ship rolls to starboard, the acceleration is southeast. Conversely, when the ship rolls to port, the acceleration is northwest.

During the starboard roll, as viewed from the southwest, the compass assumes a position that is a combination of those shown in figures 13–8, B, and 13–9, B. The effect of the easterly component of the acceleration to the southeast is represented by the position shown in figure 13–8, B. The effect of the southerly component is represented by the position shown in figure 13–9, B. The easterly component swings the weight, *W*, out of the vertical. The southerly component causes the acceleration forces, *F*, to act at a time when the weight, *W*, is out of the vertical, and causes torques to be exerted about both the horizontal and the vertical axes.

To visualize the action of the acceleration forces, *F*, rotate the position shown in figure 13–9, B, one-quarter turn to the left about the vertical axis, so that the rotor is viewed from the south as it is in the position shown in figure 13–8, B. The forces, *F*, are then rotated through 90° and are directed away from the observer. A force acting on the weight, *W*, in a direction away from the observer will, when it is displaced from the vertical as shown in figure 13–8, B, exert a clockwise torque about the vertical. It will also exert a torque about the horizontal, tending to raise the north end of the rotor axle.

The torque developed about the horizontal axis on the starboard roll tends to raise the north end of the rotor axle, and on the port roll tends to raise the south end of the rotor axle. These effects are opposite and cancel each other on successive rolls. The torques about the vertical axis are clockwise on both the starboard and port rolls. Even if the torque produced on one roll is quite small, the successive impulses on many rolls being in the same direction, are cumulative and can cause a considerable error.

If a ship is steering a course in the northeast or southwest quadrant, the deviation is always to the east. Conversely, if a ship is steering a course in the northwest or southeast quadrant, the deviation is always to the west. The effect of pitching on quadrantal courses causes an error opposite to that produced by rolling. Thus if a ship is both rolling and pitching the quadrantal error is less than if rolling alone is present.

Sperry compass.—If a compass is improperly balanced so that it is either top-heavy or pendulous, a disturbing effect results when the ship rolls or pitches on an intercardinal heading. When the Sperry compass is properly balanced, the sensitive element is neither top-heavy nor pendulous.

The mercury ballistic is mounted with its center of gravity coincident with the horizontal axis of the gyro element. Consequently, it is in neutral equilibrium when the mercury is equally distributed in each tank. Therefore, acceleration forces resulting from the roll or pitch of the ship have no disturbing effect on the Sperry gyro when it is dynamically balanced about the horizontal axis.

Arma compass.—Acceleration errors cannot be prevented in the Arma compass by making it nonpendulous because this compass depends for its operation on the principle of a pendulous gyro. However, the acceleration forces due to roll or pitch on intercardinal courses are neutralized in the Arma compass by east-west stabilization of the sensitive element. This stabilization is accomplished by using two gyros mounted on the sensitive element frame at an angle of approximately 40° with respect to the north-south axis (fig. 13–10).

The two gyros oppose any attempt of the sensitive element to tilt in an east-west direction and a portion of the directive force of the gyros remains in the north-south plane so that the sensitive element seeks the meridian. If the sensitive element attempts to tilt in the north-south direction,

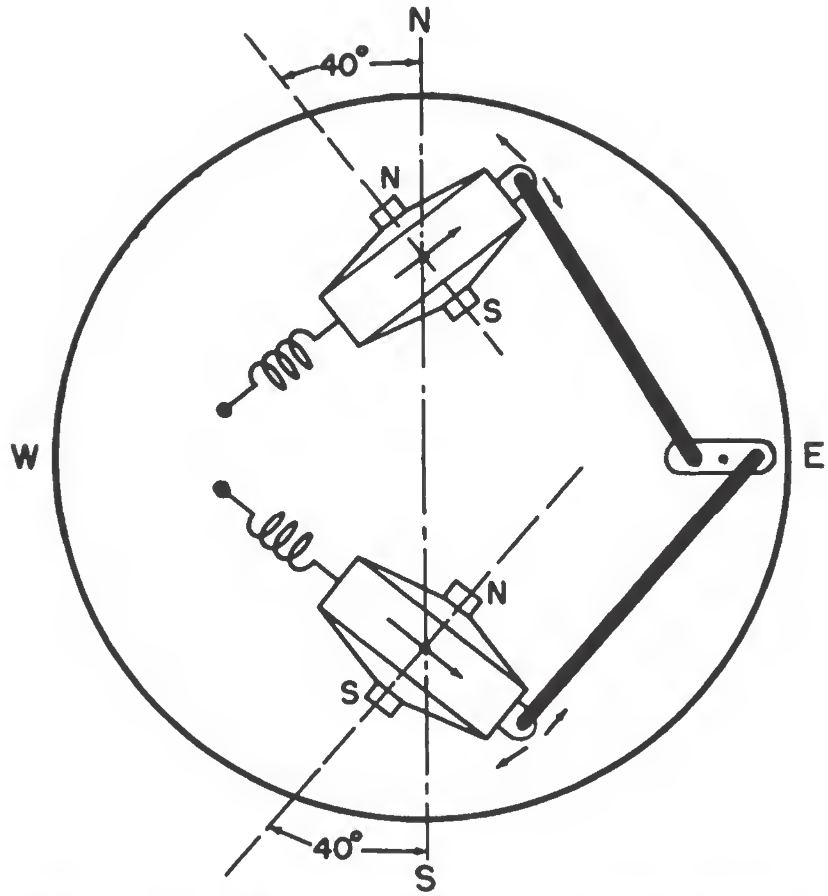


Figure 13–10.—Arma arrangement and coupling of gyro rotors.

the two gyros precess in the same direction and carry the sensitive element with them. To make certain that the sensitive element follows the gyros exactly when they precess in the same direction and to prevent the sensitive element from turning at all when the gyros precess in opposite directions, the two gyros are connected by a linkage. This linkage ensures their turning relative to the sensitive element only in equal and opposite angles. The centering springs hold the two gyros in their normal resting positions from the north-south plane when there is no disturbing force tending to deflect them.

The reason for having the gyros inclined and coupled by the linkage is to eliminate the intercardinal error by preventing the sensitive element from swinging in an east-west direction. When the frame tends to swing, the gyro units precess around their vertical axes in equal and opposite angles. As the ship rolls, the swinging tendency is first in one direction and then in the other, causing the gyros to turn back and forth through a small angle. The compass reading is not affected because this action does not turn the sensitive element as a whole.

Centrifugal Forces Due to Roll or Pitch

Intercardinal rolling or pitching resolves itself partly into centrifugal forces. These forces act upon the entire mass composing the movable element of the gyrocompass. Centrifugal forces are a maximum when the masses cross the vertical because the masses are then moving with the greatest velocity. The effect is the same for either direction of swing. If the mass is not uniformly distributed about every axis that is perpendicular to the axis of suspension, the compass tends to turn so that the axis of greatest moment of inertia is in the axis of swing. A simple demonstration of this phenomenon is to swing a watch on its chain. Regardless of the position of the watch when it starts swinging, it soon turns so that its flat surfaces are in the plane of swing.

When the axle of a gyrocompass rotor is north and south, it has much more weight in the east-west plane than in the north-south plane. When it is subjected to the centrifugal force resulting from the rolling or pitching of a ship, it attempts to align its east-west plane in the plane of roll or at right angles to the course.

The attempt of the gyro rotor to align itself in the plane of the ship's roll causes a torque about the vertical axis and can cause an error in the compass indication. On a true north or true south course, the east-west plane of the rotor is already in the plane of the roll. On a true east or true west course, the east-west plane of the rotor is at right angles to the plane of the roll and the torque attempting to turn it clockwise is the same as the torque attempting to turn it counterclockwise. These equal and opposite torques cancel each other. Thus, centrifugal forces can cause compass errors only on quadrantal courses.

Sperry compass.—The effect of centrifugal forces is neutralized in the Sperry compass by compensator weights mounted on the vertical ring at right angles to the plane of the greatest moment of inertia. These weights are mounted in brackets that support one weight opposite each end of the rotor axle. The moment of inertia is made equal about all horizontal axes in the plane of the gimbal centers by adjusting the weights to the proper position. Hence, centrifugal forces have no effect on the Sperry compass. The compensator weights are attached to the vertical ring in order that the sensitive element will be a truly hemispherical mass.

Arma compass.—The effect of centrifugal forces is eliminated in the Arma compass by maintaining a uniform distribution of the masses of the sensitive element about the vertical axis. In other words, in any plane parallel to, and including the vertical axis, the same mass is distributed on each side of the vertical axis and the centers of gravity of the masses are the same distances from the vertical axis. This even distribution of mass in conjunction with the mercury flotation prevents torque about the vertical axis. Thus, centrifugal forces have no effect on the Arma compass.

QUIZ

1. What is the name of the index line from which a ship's heading is obtained?
2. Which motions of a ship tend to produce constant motion errors in the gyrocompass?

3. Which motions of a ship tend to produce oscillating errors in the gyrocompass?

4. Which motions of a ship tend to produce quadrantal errors in the gyrocompass?

5. Name the two errors that comprise constant motion errors.

6. Name the two errors that comprise oscillating errors.

7. Name the two errors that comprise quadrantal errors.

8. What is the tangent latitude error?

9. What is the settling position with respect to the meridian of the north axle of the Sperry compass in northern latitudes?

10. What is the settling position with respect to the meridian of the north axle of the Sperry compass in southern latitudes?

11. What error is a direct consequence of the mercury ballistic in the Sperry gyrocompass?

12. What is the tangent latitude error approximately proportional to?

13. How is the tangent latitude error compensated?

14. Why does the Arma compass have no tangent latitude error?

15. What is the line called that is at a small angle from the true north, on which the compass settles when a ship is not on a true east or west course?

16. What error does the angle between the true meridian and the apparent meridian represent?

17. In what direction is the speed, course, latitude error if any component of a ship's course is north?

18. In what direction is the speed, course, latitude error if any component of a ship's course is south?

19. What devices are used to compensate for the speed, course, latitude error in the Sperry compass?

20. What devices are used to compensate for the speed, course, latitude error in the Arma compass?

21. When is the ballistic deflection error introduced into the compass?

22. What is the precession called that results from the force exerted by the Sperry mercury ballistic or Arma pendulous weight when a ship changes speed or course?

23. What is the error called that results when a ship changes speed or course and the ballistic deflection is not equal to the change in speed, course, latitude error?

24. What is the period of oscillation of a compass when the ballistic deflection for any change of speed or course is equal to the change in speed, course, latitude error?

25. During what period is the ballistic deflection effective when the ballistic deflection is made equal to the change in speed, course, latitude error?

26. How is the ballistic deflection error compensated for in the Sperry compass in all latitudes?

27. How is the ballistic deflection error compensated for in the Arma compass in all latitudes?

28. What is the error called that is introduced in the compass by the damping arrangement on rapid changes in speed or course?

29. What kind of forces are produced on the damping arrangement of Sperry and Arma compasses by rapid changes in speed?

30. What kind of forces are produced on the damping arrangement of Sperry and Arma compasses by rapid changes in course?

31. How is the ballistic damping error compensated in the Sperry compass?

32. How is the ballistic damping error compensated in the Arma compass?

33. In what direction is the deviation caused by acceleration forces when a ship is steering a course in the northeast or southwest quadrant?

34. In what direction is the deviation caused by acceleration forces when a ship is steering a course in the northwest or southeast quadrant?

35. How are quadrantal errors caused by acceleration forces compensated in the Sperry compass?

36. How are quadrantal errors caused by acceleration forces compensated in the Arma compass?

37. How are quadrantal errors caused by centrifugal forces compensated in the Sperry compass?

38. How are quadrantal errors caused by centrifugal forces compensated in the Arma compass?

CHAPTER 14

GYROCOMPASSES

The gyrocompass system, circuit *LC*, provides a means of indicating own ship's course at various stations in the ship. It also provides own-ship's-course inputs to fire control systems, electronic systems, plotting equipment, and navigational equipment.

Gyrocompasses are identified by means of the MARK-MOD system. The Mark, or Mk, number designates a major development of a compass, whereas the Modification, or Mod, number shows the modification or change to the major development. For example, the first compass of the Sperry Mk XI series was the Mod 0. The most recent compass of this series is the Mod 6. All compasses of the Sperry Mk XI series are essentially the same except for modifications.

Gyrocompass equipment consists essentially of (1) master compass, (2) control system, (3) follow-up system, (4) transmission system, and (5) alarm system.

The MASTER COMPASS is the principal unit of the gyrocompass equipment. It includes the north-seeking gyroscopic element, its housing, and a follow-up mechanism that obtains the ship's true heading from the sensitive element and transmits this heading to the various repeater compasses.

The CONTROL SYSTEM includes the control panel, battery throwover panel, and motor-generator with the necessary apparatus for the operation and control of the master compass.

The FOLLOW-UP SYSTEM includes the follow-up panel and the electrical units that drive the follow-up mechanisms of the master compass in azimuth.

The TRANSMISSION SYSTEM includes the repeater panel, relay transmitter repeater panel, and relay transmitter necessary to transmit the readings of the master compass to the remotely located repeater compasses.

The ALARM SYSTEM includes the alarm relays and indicators necessary to indicate failure of the master compass or of the ship's power supply.

SPERRY MK XI MOD 6 MASTER GYROCOMPASS

The principal components of the Sperry master gyrocompass are (1) sensitive element (gyroscopic element), (2) mercury ballistic, (3) phantom element, (4) spider, and (5) binnacle and gimbal rings. The components are identified

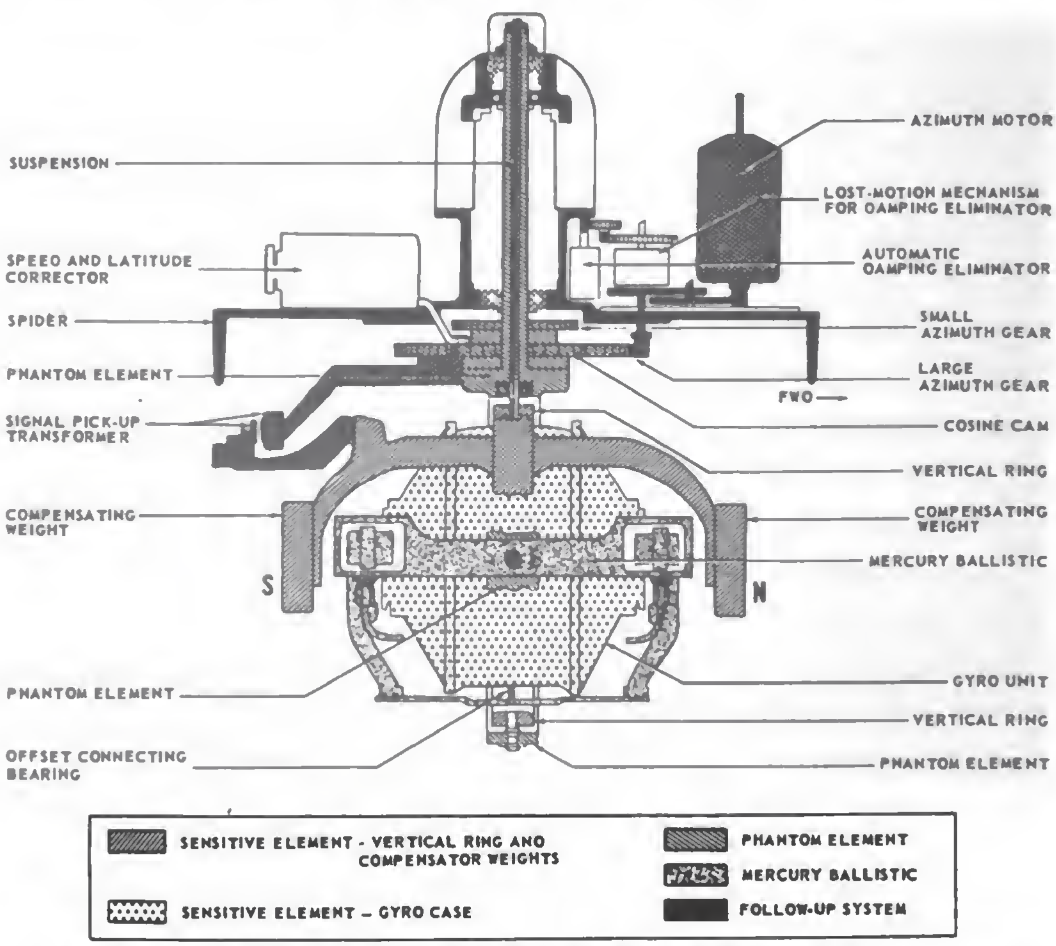


Figure 14–1.—East elevation of Sperry Mk XI Mod 6 master gyrocompass.

by the crosshatched areas in figures 14–1 and 14–2, which show the views of the Sperry Mk XI Mod 6 master compass removed from its binnacle. This compass, which is a recent fire control type, has been adapted for general compass use and is installed in most U. S. destroyers.

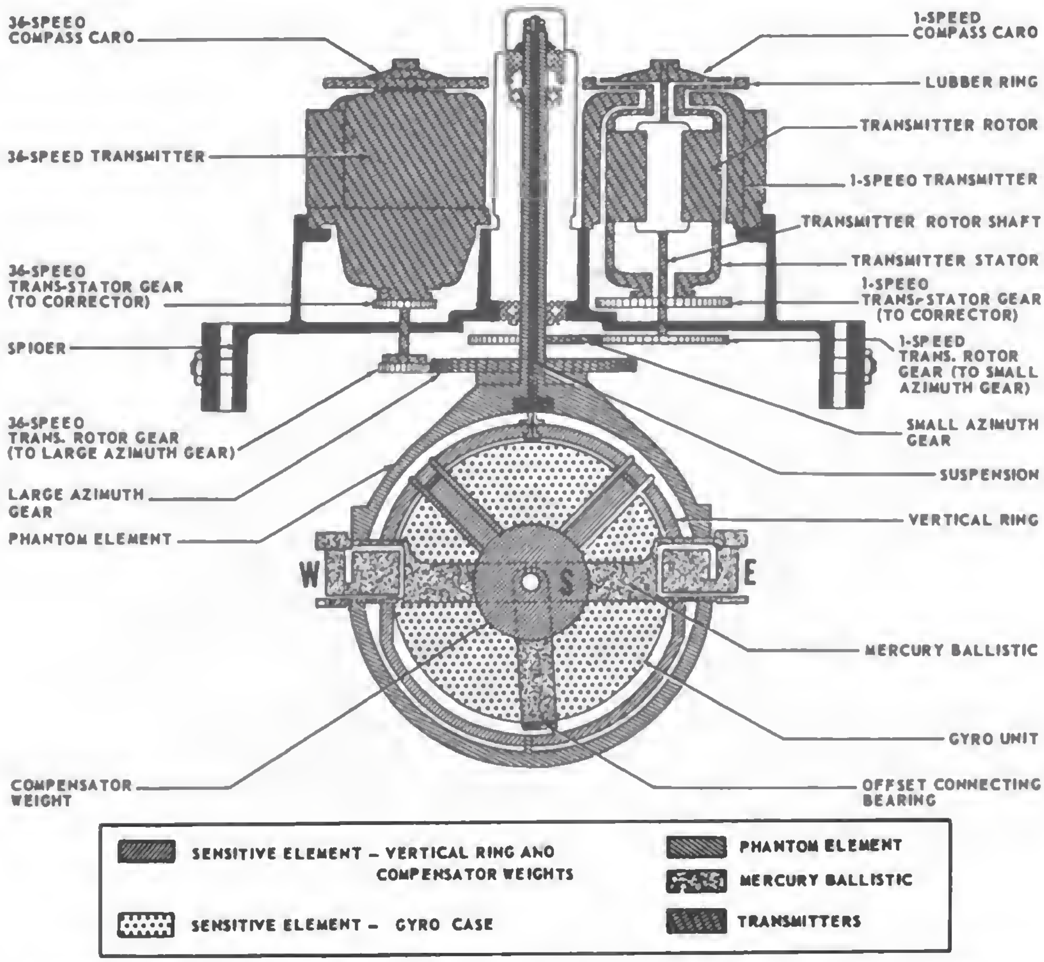


Figure 14–2.—South elevation of Sperry Mk XI Mod 6 master gyrocompass.

The principal units, excluding the binnacle, are further grouped into (1) moving, or inner, member and (2) fixed, or outer, member.

The INNER MEMBER includes the sensitive element, the mercury ballistic, and the phantom element. This member is controlled by the gyro unit (item 1 in figures 14–1 and 14–2) and maintains a north-south position under normal operating conditions.

The OUTER MEMBER includes the spider with its component parts, 1-speed and 36-speed transmitters, automatic damping eliminator switch, speed and latitude corrector, and azimuth motor.

The outer member supports the inner member and turns with the ship. The angle between the inner member and the outer member is the ship's heading, which is indicated by the compass card.

Sensitive Element

The sensitive element (fig. 14–3) is the north-seeking gyroscopic element of the master compass. It is suspended within the phantom ring of the master compass (fig. 14–1)

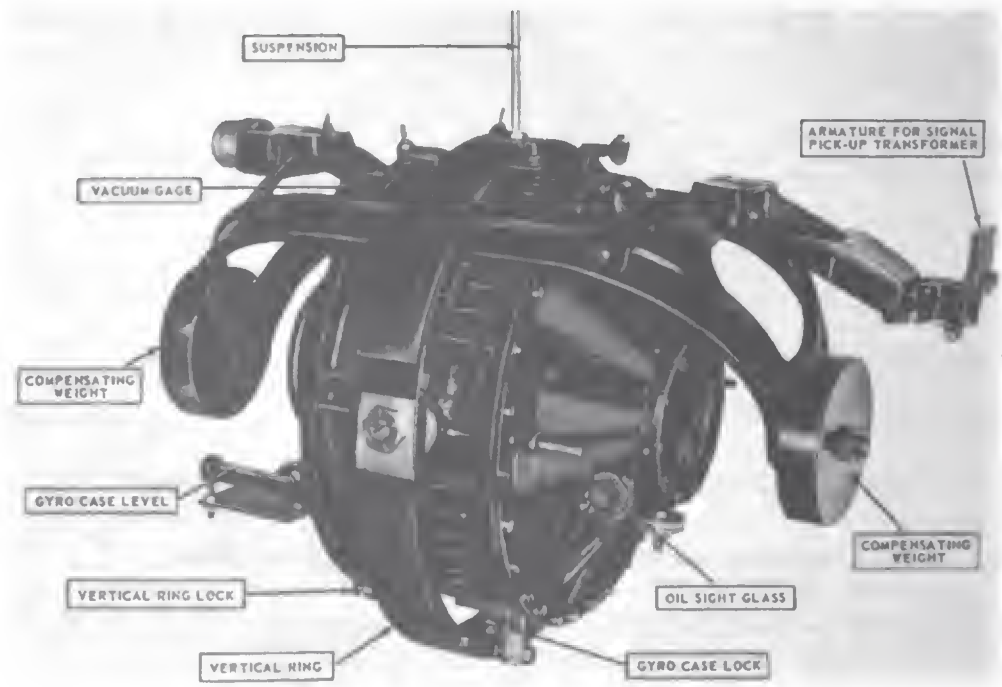


Figure 14–3.—Sperry Mk XI Mod 6 sensitive element.

and consists essentially of the gyro unit, vertical ring, compensator weights, follow-up indicator, and suspension.

GYRO UNIT.—The gyro unit provides the directive force for the sensitive element that makes the compass north-seeking. The unit consists of the rotor and case (fig. 14–4). The gyro rotor (fig. 14–4, A) is a steel forging 10 inches in diameter, 4½ inches wide, and weighing approximately 72 pounds. It is machined and balanced to rotate on special ball bearings with a minimum vibration at a normal speed of 11,000 rpm. The gyro rotor construction includes a laminated squirrel-cage rotor fitted inside the rim on both faces of the gyro wheel.

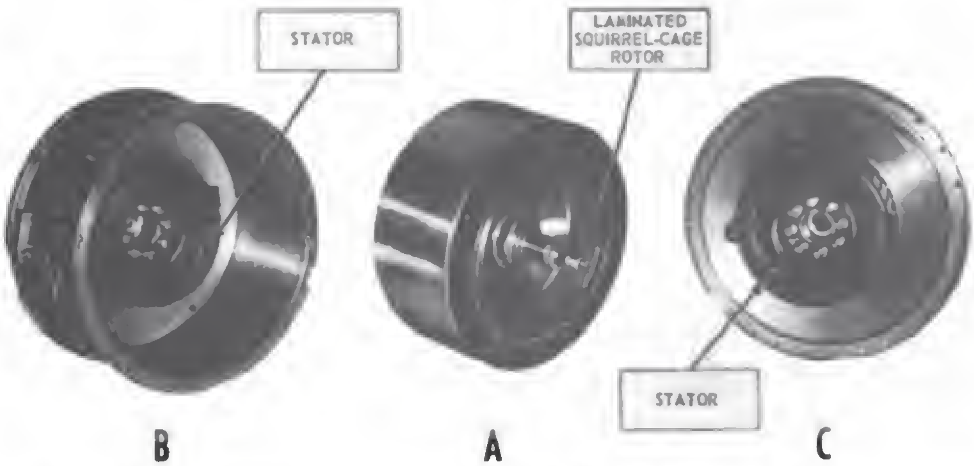


Figure 14–4.—Sperry Mk XI Mod 6 gyro unit. A, Rotor; B and C, case.

The gyro case (fig. 14–4, B and C) construction includes a 3-phase, double-stator winding, one stator being mounted in each half of the case. Horizontal ball bearings on which the rotor spins are mounted in both halves of the case. The case is supported on horizontal ball bearings by means of horizontal bearing studs mounted in the vertical ring (fig. 14–2).

The case is made airtight and the rotor operates in a vacuum of 26 to 30 inches of mercury to reduce the friction caused by air resistance. A vacuum gage is mounted near the top of the north half of the case to indicate the degree of vacuum.

A spirit level (fig. 14–3) is mounted on the lower part of the north side of the case to indicate the tilt of the rotor. This level has a graduated scale that is numbered from 30 to 70. The entire scale represents two minutes of angle.

A small window is provided in the south half of the case through which the spinning rotor can be observed. A spiral stripe painted on the rotor enables the observer to check the correct direction of rotation (counterclockwise as observed through the window).

Vertical ring.—The vertical ring (fig. 14–2) is attached to a wire suspension from the head of the phantom element. An upper and a lower guide bearing prevent the vertical ring from moving laterally within the phantom ring.

The upper guide bearing has its outer race secured in the phantom ring. The inner race is formed by the lower stud of the suspension. The lower guide bearing has its outer race secured in the bottom of the vertical ring. The inner race is formed by a vertical stud that projects upward from the bottom of the phantom ring.

A gyro case lock (fig. 14–3) is provided to prevent the gyro case from tilting about its horizontal axis when the compass is not operating. This latch should be disengaged only when the rotor is running at normal speed. It is located on the lower part of the south side of the ring.

A vertical ring lock (fig. 14–3) is provided to keep the vertical ring in line with the phantom ring when the compass is not operating. This lock prevents the wire suspension from acquiring a permanent set which would affect the settling point of the compass.

Compensator weights.—The compensator weights (fig. 14–3) are supported by two frames that are attached to the vertical ring. These frames project out beyond each end of the rotor axle. The weights are mounted concentrically on their studs, and their positions can be adjusted in the direction of the axis of the gyro rotor. The function of the weights is to provide an even distribution of the weight of the gyrocompass about the vertical axis.

The armature of the signal pick-up or follow-up transformer is attached to an arm that protrudes horizontally from the upper part of the south compensator-weight frame (fig. 14–3).

Follow-up indicator.—The follow-up indicator determines the position of the phantom element with relation to the sensitive element. This indicator consists of a scale and a pointer. The scale is attached to the phantom element below the spider table and the pointer is attached to the north compensator weight frame. The scale is calibrated in degrees with the center marked "0." Thus, a misalignment between the phantom element and sensitive element is indicated in degrees.

Suspension.—The suspension (fig. 14–2) suspends the entire sensitive element from the phantom element. It consists of a number of small steel wires secured at the upper end to a support stud and at the lower end to a guide stud. A nut and check nut are provided to secure the support stud to the phantom element. This nut is used to adjust the sensitive element vertically within the phantom ring. The guide stud passes through a hole in the upper part of the vertical ring and is clamped to the ring by a nut. This stud also serves as the inner race of the upper guide bearing of the ring.

Mercury Ballistic

The mercury ballistic (fig. 14–5) is that group of parts which applies the gravity-controlling force to the gyro unit and makes it north-seeking. It consists of a rigid frame supported on bearings in the phantom ring. These bearings are in line with the horizontal case bearings, E, in the vertical ring so that the mercury ballistic is free to tilt about the east-west axis of the sensitive element (fig. 14–1).

The frame supports a mercury reservoir in each of its four corners. The *N* and *S* reservoirs on the east side of the compass are connected by a U-shaped tube and the *N* and *S* reservoirs on the west side are similarly connected. The gravity controlling force of the mercury ballistic is applied to the bottom of the gyro case through an adjustable offset bearing stud mounted on the ballistic connection arm (fig. 14–1).

The connection bearing is offset to the east from the vertical axis by a short distance to provide the damping adjustment. When it is desired to eliminate damping, a solenoid is energized and attracts a plunger which moves the pivoted connection arm until the connection bearing is in line with the vertical axis of the gyro. In this position, the gravitational force of the mercury is applied directly about the vertical axis.

Each mercury reservoir is offset from its supporting stem

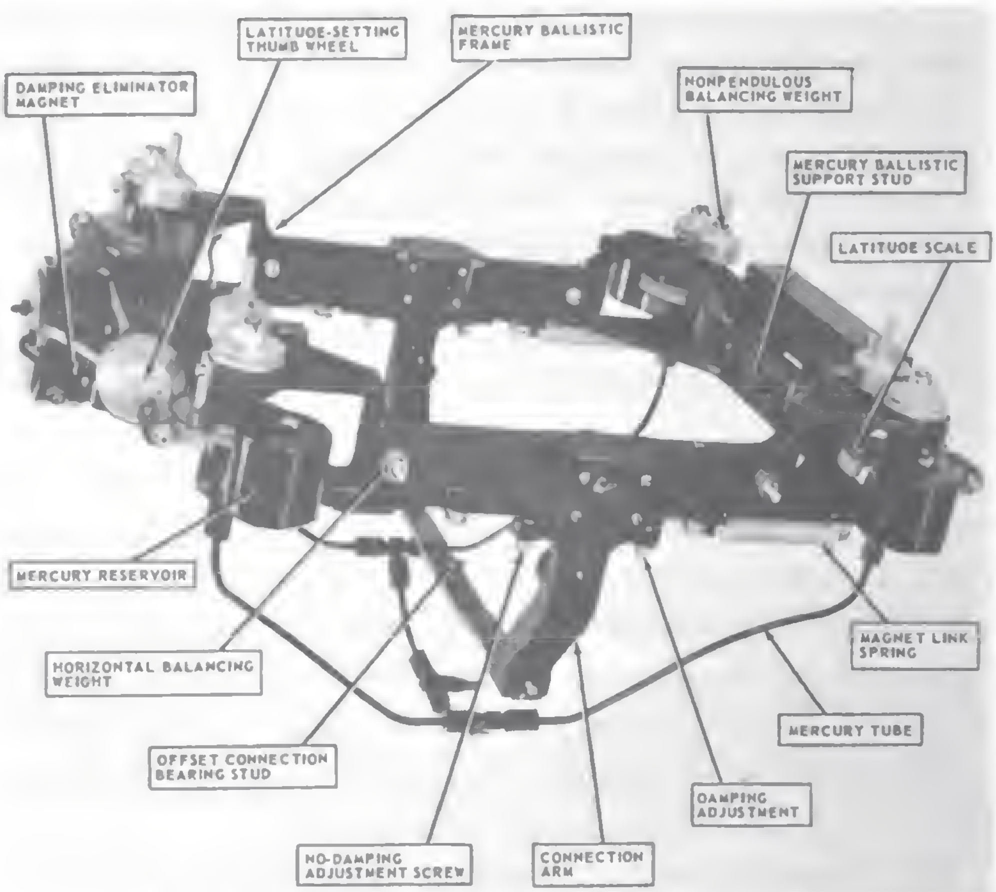


Figure 14–5.—Sperry Mk XI Mod 6 mercury ballistic.

and can be rotated about its stem in order to vary the lever arm of each tank. Thus, the period of oscillation of the gyrocompass is kept constant in all latitudes by adjustment of the mercury ballistic deflecting force on the gyro axle. The reservoirs are arranged with worm wheels and a connecting shaft so that when the shaft is turned the reservoirs are rotated simultaneously closer to, or farther from, the horizontal center line of the gyrocompass. This action varies the damping effect of the mercury ballistic by varying the effective lever arms of the respective mercury pots about the horizontal axis. A knurled thumb wheel is provided at the center of the shaft for turning the two mercury reservoirs on the east side of the ballistic. The two reservoirs on the west side are provided with a similar arrangement.

An engraved latitude scale is mounted on top of each mercury reservoir worm wheel. This scale shows the position of the reservoir with respect to an index pointer attached to the ballistic frame.

The mercury contained in the reservoir and the connecting tubes is equally distributed with respect to the four reservoirs when the spinning axis of the gyrocompass is horizontal. The tubes allow the mercury to flow from the north containers into the corresponding south containers, or vice versa, when the gyrocompass is tilted. This action applies a torque or controlling force about the horizontal axis of the gyrocompass. As mentioned previously, the gravitational force of the mercury is normally applied slightly east of the vertical axis which passes through the center of the gyro shaft. Thus, the force of the mercury ballistic is applied simultaneously about the horizontal and vertical axes and any gyroscopic oscillation about the meridian is damped out.

The mercury ballistic is so designed that it is nonpendulous when filled with mercury. Adjustable nonpendulous balancing weights are provided on the ballistic to accurately obtain this condition. Adjustable horizontal balancing weights are also provided for accurately balancing about the horizontal axis.

Phantom Element

The phantom element (fig. 14–6) is a group of parts that acts as a follow-up support for the sensitive element. It consists essentially of a hollow cylindrical stem (fig. 14–2) that projects radially from the phantom ring, which is mounted vertically below the central hub of the spider table.

The phantom element supports the vertical ring by means

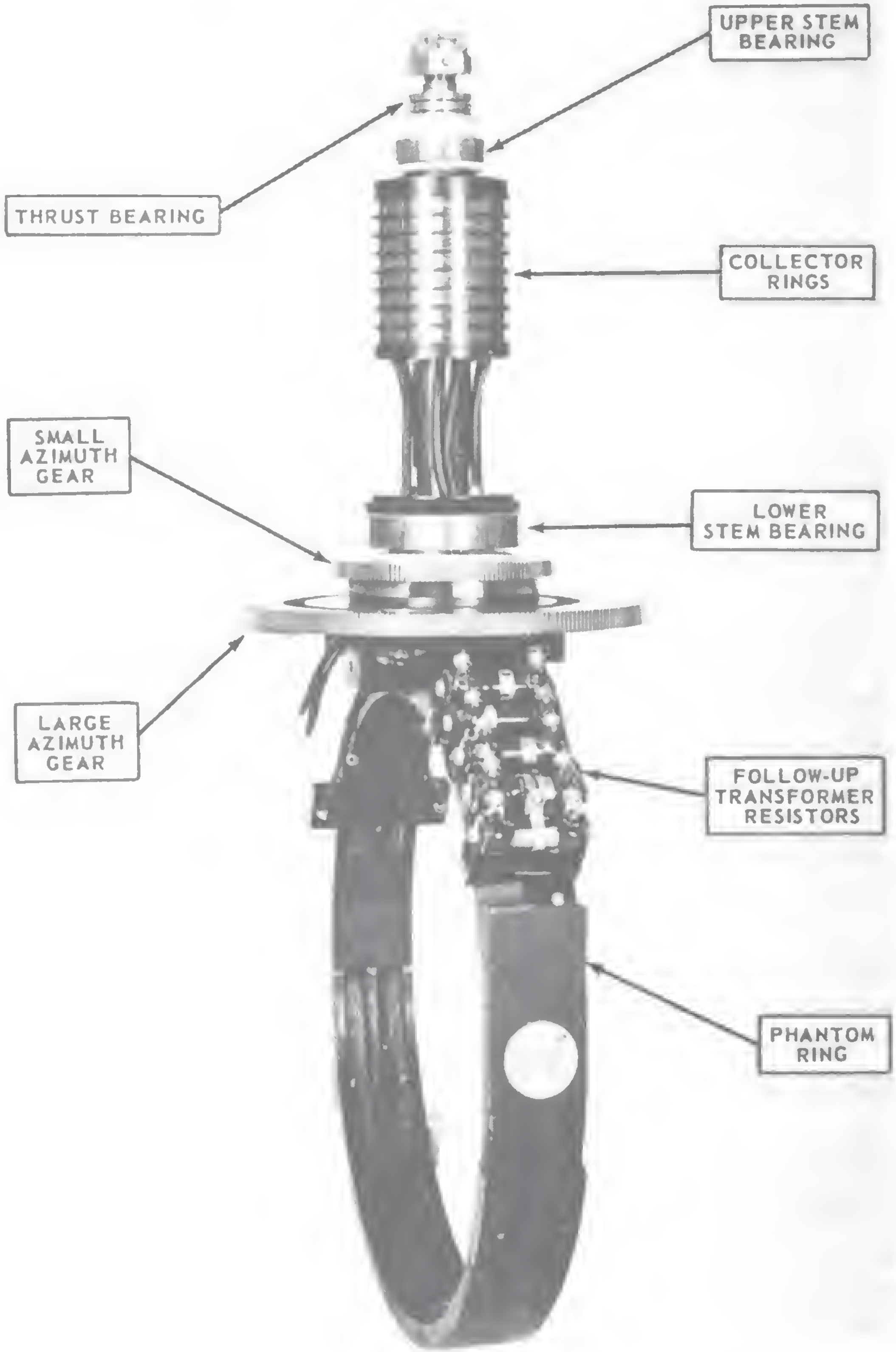


Figure 14–6.—Sperry Mk XI Mod 6 phantom element.

of the suspension. The element is free to turn about a vertical axis so that as the vertical ring turns under the control of the gyro rotor, the phantom ring can be made to follow. This arrangement prevents the suspension from becoming twisted and provides a practically frictionless support for the sensitive element.

A thrust bearing on the top of the stem rests in the hub of the spider table and supports the weight of the phantom and sensitive elements. The upper and lower stem bearings keep the stem in alignment with the vertical axis of the spider but permit the phantom element to rotate about its own vertical axis.

The phantom ring also carries bearings that support the mercury ballistic. The axis of these bearings coincides with the axis of the horizontal bearings of the gyro case when the phantom ring is aligned with the vertical ring. This relation in azimuth is maintained by the follow-up movement of the phantom element.

A large azimuth gear (fig. 14–1) is attached to the phantom ring and is concentric with the phantom stem. The azimuth motor drives the phantom element into alignment with the vertical ring by means of the azimuth gear. It also drives the automatic damping eliminator switch and the 36-speed synchro transmittter (fig. 14–2).

A small azimuth gear is secured directly above the large azimuth gear and is concentric with the large gear. This azimuth gear drives the 1-speed synchro transmitter through the rotor gear.

An eccentric groove (fig. 14–1) called the COSINE CAM is cut into the upper surface of the large azimuth gear. The cosine cam operates the speed and latitude corrector and introduces the necessary corrections for changes in course of the ship.

A follow-up transformer (fig. 14–1) is suspended from the azimuth gear frame on the south side of the phantom ring. Alarm contacts are located on the phantom ring and are so situated with respect to the vertical ring that relative displacement between the phantom and the vertical rings above a predetermined value will actuate the follow-up alarm.

The various electrical circuits are connected from the fixed to the moving members of the gyrocompass by means of a set of collector rings and brushes. The collector rings are mounted on, and are concentric to, the upper end of the phantom stem. The brushes are mounted on a base in the center of the spider.

Spider

The spider (fig. 14–7) is a circular table of cast aluminum alloy that supports the entire inner, or moving, member of the compass by means of the hub on which the thrust bearing that supports the phantom element rests. The spider is supported in the inner, or cardan, ring of the two rings that comprise the gimbal system. A boss in the center of the table supports the thrust bearing and the upper and lower stem bearings.

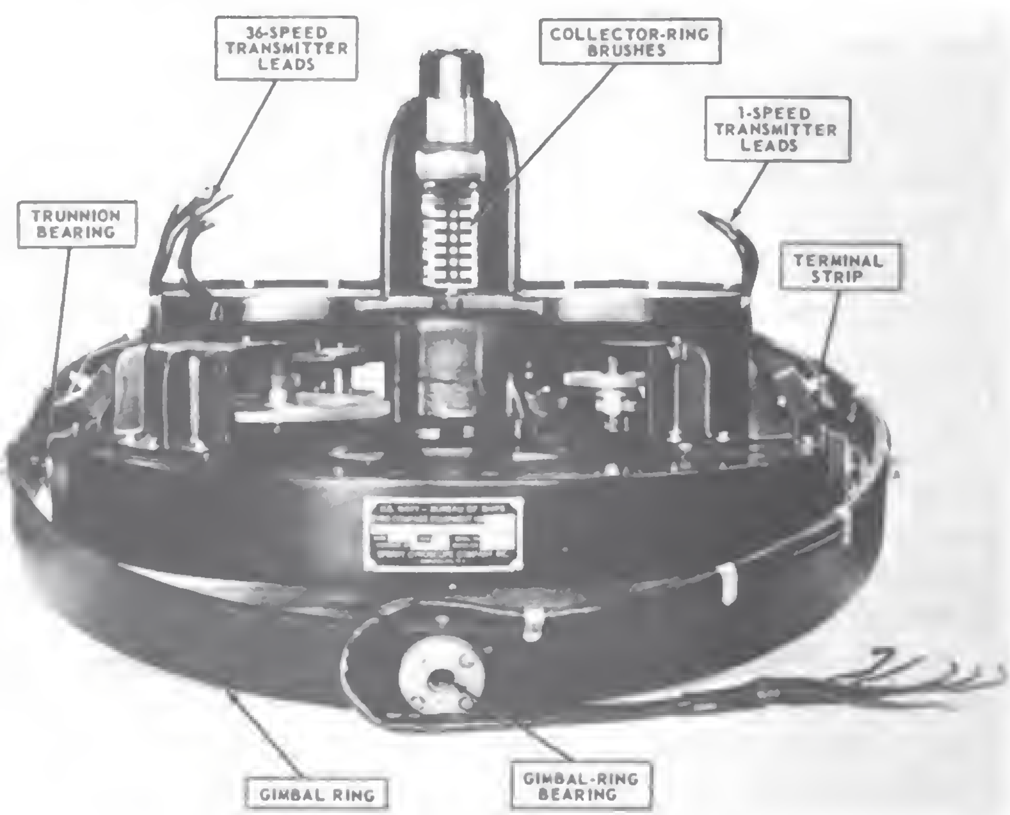


Figure 14–7.—Sperry Mk XI Mod 6 spider.

The azimuth follow-up motor (fig. 14–1) and the automatic damping eliminator switch, are mounted on the forward side of the spider table. The speed and latitude correction mechanism is mounted on the after side of the table. The 36-speed synchro transmitter (fig. 14–2) is located on the port side and the 1-speed synchro transmitter is located on the starboard side of the table.

Azimuth Follow-Up Mechanism

The azimuth follow-up mechanism is a group of units used to drive the phantom element in azimuth. The follow-up mechanism is a part of the master compass. It is distinguished from the follow-up system, which includes both the follow-up mechanism and the follow-up panel. The follow-up mechanism consists of (1) follow-up transformer, (2) azimuth follow-up motor, (3) compass cards, (4) synchro transmitters, (5) automatic damping eliminator switch, and (6) speed correction mechanism. The gearing for the azimuth follow-up mechanism is shown in figure 14–8.

FOLLOW-UP TRANSFORMER.—The follow-up transformer (fig. 14–1) controls the amplifier and the azimuth follow-up motor. It consists ot two secondary coils and one primary coil mounted on the three legs of an iron yoke. The armature, which completes the magnetic circuit of this transformer, is mounted on the sensitive element. Two small capacitors are included in the transformer mounting to tune the secondary coils to resonance. A small resistor is in series with the primary coil.

AZIMUTH FOLLOW-UP MOTOR.—The azimuth follow-up motor (fig. 14–1) is a d-c motor that drives the phantom element through a gear train. The armature is connected in the rectifier tube plate circuit on the follow-up panel. The direction of current flow in the rectifier circuit controls the direction of rotation of the armature. When the phantom element is displaced from its neutral position with respect to the sensitive element, current flows through the motor in such a direction as to drive the phantom ring (to which is attached the follow-up transformer coils) into alignment with the sensitive element.

COMPASS CARD.—The compass cards (fig. 14–2) are mounted on the synchro transmitters. The transmitters are driven by the phantom element through the azimuth gear and turn through the same angle, with respect to the lubber's line, as the sensitive and phantom elements.

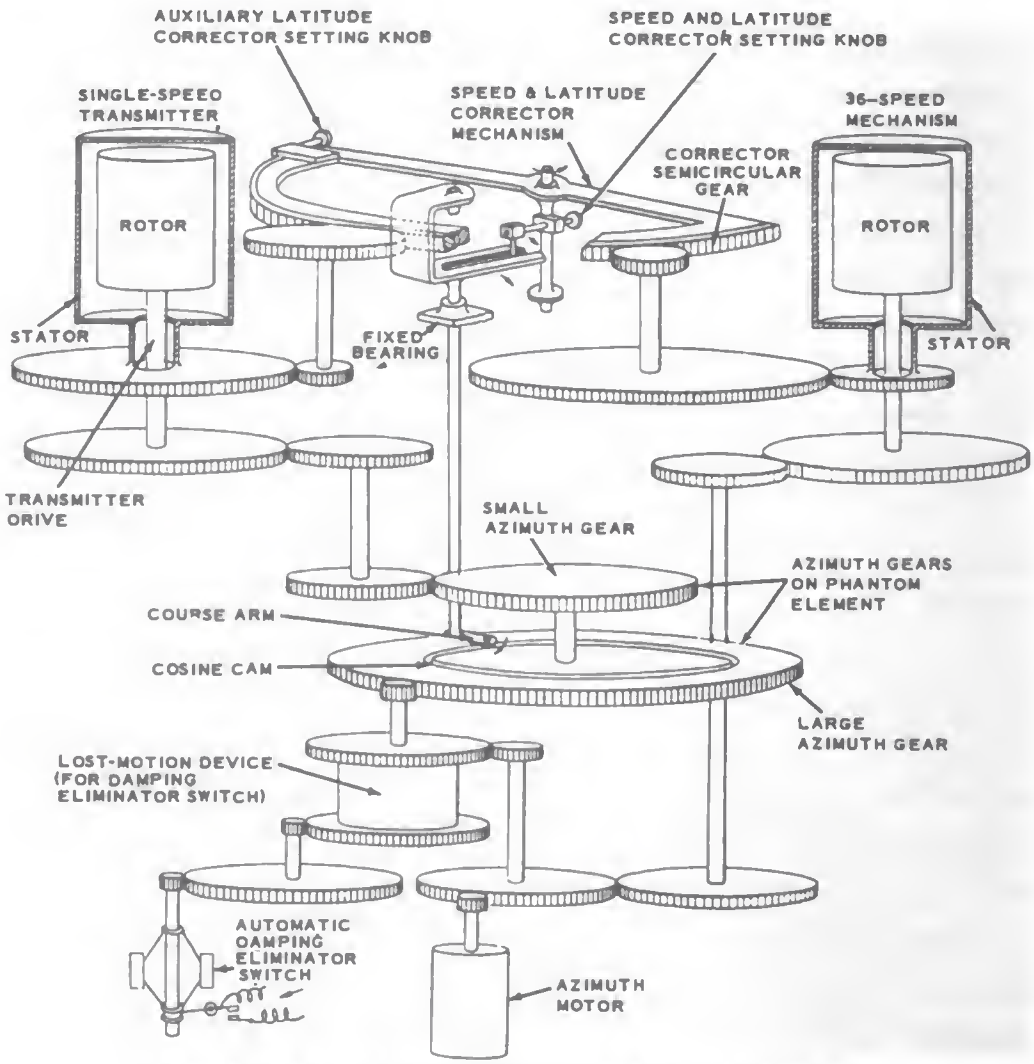


Figure 14–8.—Azimuth follow-up mechanism gearing.

The 1-speed synchro transmitter is calibrated in 10 steps from 0° to 360° and makes one revolution for one revolution of the phantom element. The 36-speed synchro transmitter is calibrated in 0.1 steps from 0° to 10° and makes 36 revolutions for one revolution of the phantom element. This arrangement permits accurate reading of the compass headings.

SYNCHRO TRANSMITTERS.—The synchro transmitters (fig. 14–8) consist of a 1-speed transmitter and a 36-speed transmitter. The stator of the 1-speed transmitter is geared to the speed and latitude corrector through the 1-speed transmitter stator gear. When the corrector gear segment is moved, either by the connector setting knobs or by the cosine cam, its motion is transmitted to the stator of the 1-speed transmitter. This action causes the stator to move a corresponding number of degrees to compensate the repeater for the speed and latitude error.

The lubber's ring, which is inscribed with the lubber's line against which the compass card is read, is attached to the stator of the 1-speed transmitter. Hence, the lubber's ring moves to compensate the reading of the master compass for the speed and latitude error.

The rotor of the 1-speed transmitter is geared to the phantom element of the compass in such a manner that it makes one complete revolution for one revolution of the compass. The 1-speed compass card is secured to the upper end of the 1-speed transmitter rotor shaft (fig. 14–2).

The 36-speed synchro transmitter (fig. 14–8) is essentially the same as the 1-speed synchro transmitter except that it is driven by the azimuth follow-up motor through a gear train that gives it a speed ratio of 36 to 1 with respect to the phantom element.

The frame of the 36-speed transmitter is provided with five roller contacts that bear on five slip rings on the stator. Leads from the two upper slip rings supply current to the single-phase rotor winding through a pair of brushes and the rotor slip rings. The voltage induced in the 3-circuit stator winding from the rotor acting as the primary is transmitted to the repeater circuit through the three lower slip rings on the stator.

The heading of the ship is determined by first reading the 1-speed card to obtain an approximate heading, and then reading the 36-speed card to obtain an accurate heading.

AUTOMATIC DAMPING ELIMINATOR SWITCH.—The automatic damping eliminator switch (fig. 14–9) cuts out the damping action of the compass by moving the offset connection of the mercury ballistic to a position under the true vertical. This action occurs when the ship makes a turn of more than 15°, at a rate in excess of 40° per minute. In other words, the

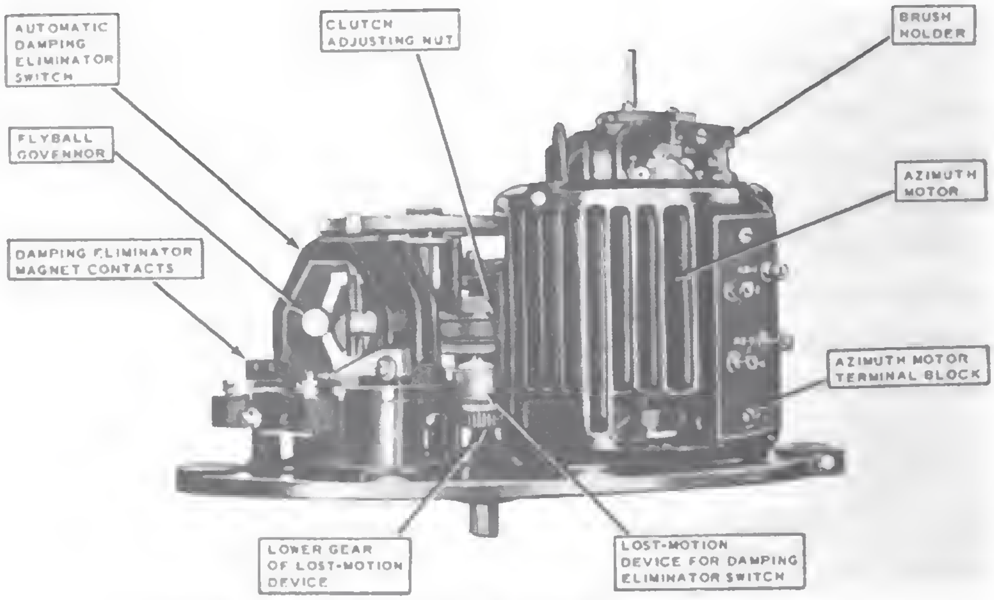


Figure 14–9.—Automatic damping eliminator switch.

automatic damping eliminator switch closes the 115-volt, d-c supply circuit which energizes the damping eliminator magnet (fig. 14–5). The magnet moves the pivoted connection arm on the mercury ballistic.

This automatic switch consists of an aluminum housing that supports a flyball governor, driving gears, and a damping eliminator magnet contact. The governor is driven from the azimuth follow-up motor through a gear train that speeds up the governor shaft to approximately 4,300 revolutions to 1 revolution of the phantom (fig. 14–8). To eliminate a constant starting and stopping of the governor when the ship is yawing, a lost-motion mechanism and a helical driving spring (fig. 14–9) are inserted between the switch driving gear in the azimuth motor train and the first gear in the train to the governor shaft. As the ship yaws, the lost-motion mechanism operates so that the motion is not transferred to the governor shaft. If the ship turns more than 15°, the helical spring is wound up in one direction or the other until there is sufficient tension in the spring to set the governor in motion. As the governor spins, the balls fly out, thus raising the sliding collar on the governor shaft and moving an arm which operates the magnet circuit contact. This action closes the 115-volt d-c supply circuit to the damping eliminator magnet. A friction brake on the governor and a spring-disk friction clutch in the gear train are provided to prevent the governor from spinning too fast when the compass is precessed by hand.

SPEED CORRECTION MECHANISM.—The speed correction mechanism (fig. 14–10) consists mainly of a large semicir-

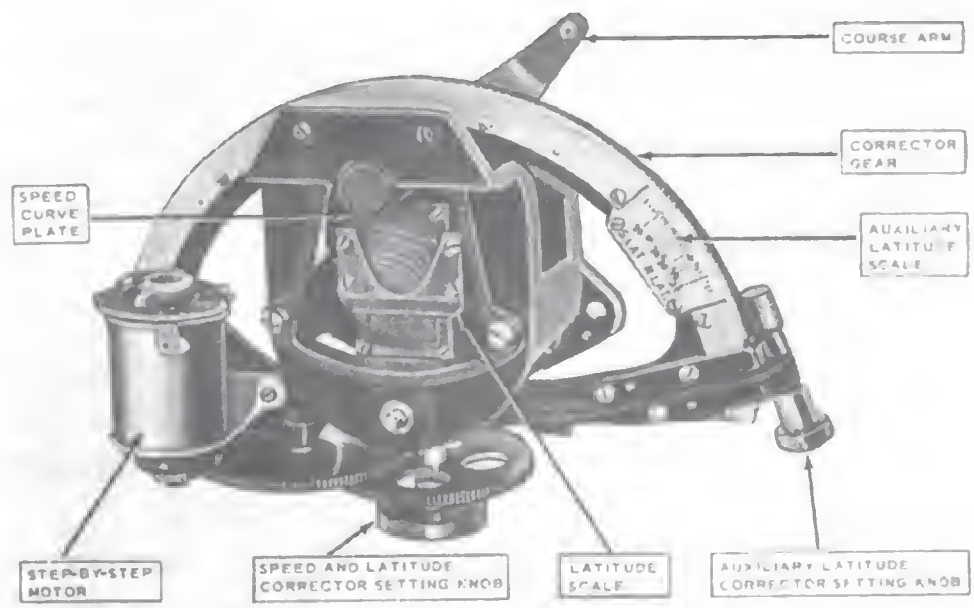


Figure 14–10.—Speed correction mechanism.

cular gear which engages, through gear trains, with two gear wheels that are fixed to the stators of the two transmitters. Any movement of the semicircular gear rotates the transmitter stators relative to their rotors and transmits a correction to the repeaters. At the same time, the master compass readings are similarly corrected because the lubber rings are fixed to the transmitter stators. The sector is turned by a series of pivoted levers operated by the course arm engaged in the eccentric groove of the cosine cam.

The amount of movement of the sector is controlled by shifting the central pivot of the mechanism which is adjustable by means of a knurled knob. Turning this knob also moves the latitude scale over the speed curve plate on which a number of speed curves are engraved. The setting is accomplished by turning the knob until the curve corresponding to the ship's speed intersects the latitude scale of the ship's latitude. This setting can be made automatically by means of the step-by-step corrector motor which receives the speed indication from the automatic speed corrector.

Binnacle and Gimbal Rings

The binnacle and gimbal rings (fig. 14–11) enclose and support the entire master compass. The compass is suspended in the binnacle by means of a system of gimbal rings. The spider is supported on the inner, or cardan, ring by ball bearings on the athwartships trunnions. This arrangement allows the compass to swing fore and aft in the binnacle.

The cardan ring is supported in the outer gimbal ring by fore-and-aft studs and bearings. This arrangement allows the compass to swing from side to side. The outer gimbal ring is suspended from the binnacle by a number of coil springs. This spring suspension helps to absorb any sudden shock to which the compass might be subjected.

The combination of the inner and the outer gimbal rings allows the compass to make any fore-and-aft and athwartship movements with respect to the binnacle and permits the compass to hang in a vertical position during rolling and pitching of the ship.

The gimbal rings are provided with roll dampers and pitch dampers to prevent violent swinging of the compass in rough weather. The ROLL DAMPERS are located in the binnacle on the forward side to reduce any swinging of the compass in its gimbals about the fore-and-aft axis when the ship is rolling. The PITCH DAMPERS are located on the port and starboard pivots of the spider to reduce any swinging of the compass in its gimbals about the athwartship axis when the ship is pitching.

The roll dampers comprise a twin dashpot assembly secured to the inner side of the outer gimbal ring. One

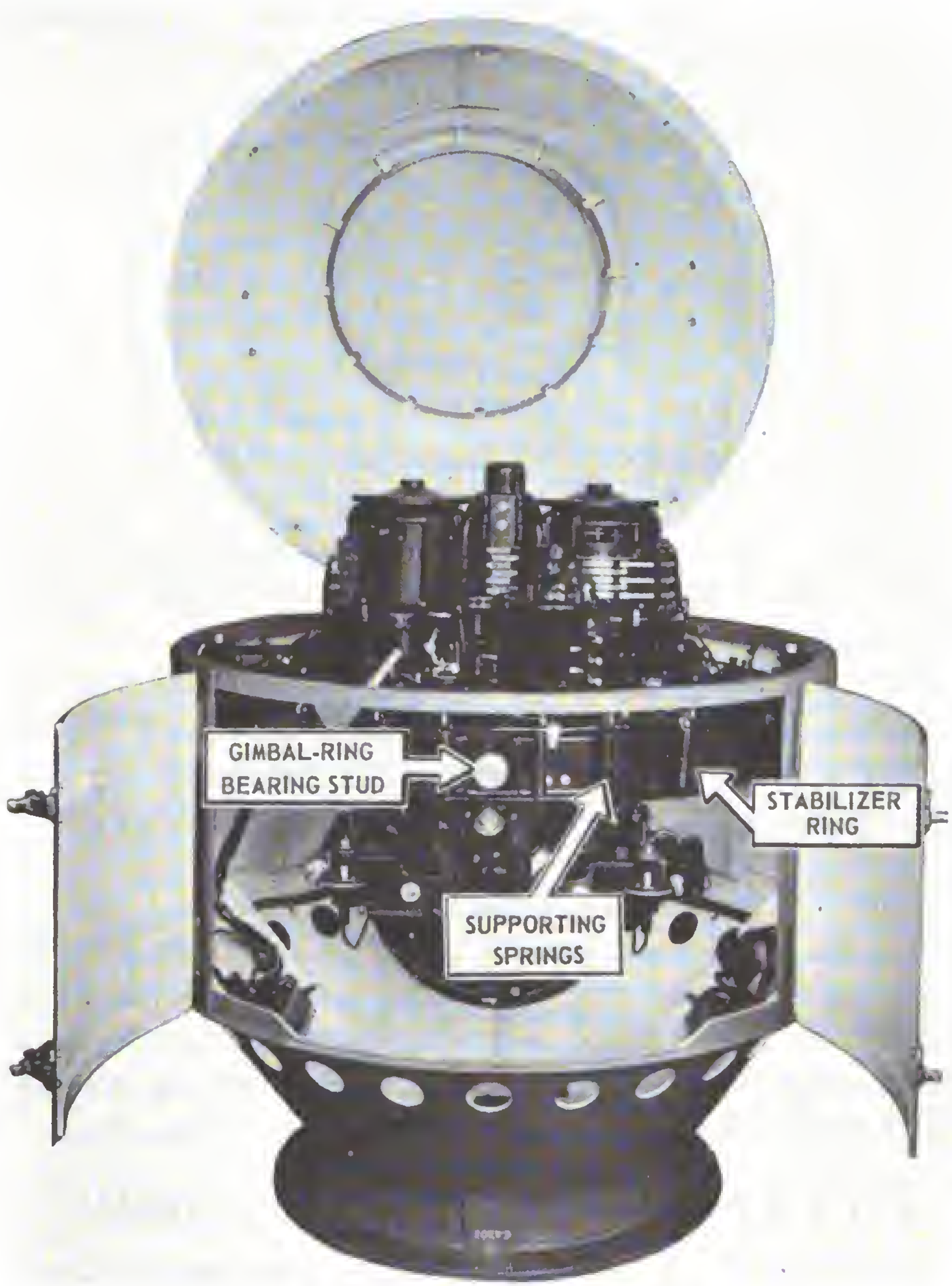


Figure 14–11.—Sperry Mk XI Mod 6 gyrocompass, showing binnacle and gimbal rings.

plunger of this assembly extends upward on the starboard side and the other plunger extends upward on the port side of the forward trunnion bearing. Each dashpot contains a piston and a quantity of oil. When the roll exceeds a certain minimum, two studs mounted on the cardan ring are alternately brought to bear against the pistons. This action forces the oil through a small opening that resists the flow of oil and restricts the movement of the pistons, thereby restricting the swinging of the compass.

The pitch dampers comprise a set of friction dampers secured to the cardan ring, These dampers operate on eccentric friction disks attached to the spider.

The binnacle consists of a circular sheet steel body bolted on a cast-aluminum base. The binnacle base is secured to a round steel mounting plate that is bolted to the deck in such a position that the compass parts, suspended within the cardan ring, swing about the athwartship axis which remains horizontal. The steel mounting plate is provided with elongated holes to allow for a $\pm 5°$ rotational movement of the binnacle to adjust the compass relative to the fore-and-aft axis of the ship.

The body is provided with two pairs of doors and a cover. Each door is hinged to the body. One door of each pair can be secured in the closed position by a latch and the other door locked to it. When the doors are open they can be lifted off their hinges and removed.

The cover consists of a sheet metal spinning provided with a flat glass top through which the compass card and lubber's ring can be observed. The cover is provided with two sets of double-hinged covers both of which can be locked with the same key. A metal protective cover is provided to protect the glass top when the compass is not in use.

ARMA MK VIII MOD 3A MASTER GYROCOMPASS

The principal components of the Arma master gyrocompass are (1) sensitive element, (2) mercury flotation, (3) spider, (4) azimuth follow-up mechanism, and (5) bin-

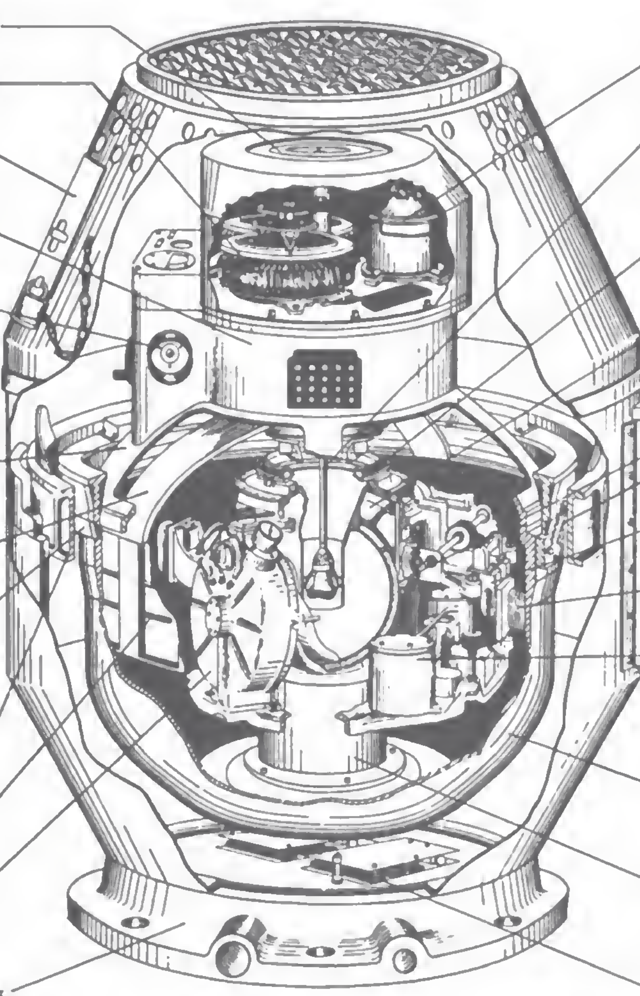


Figure 14–12.—Arma Mk VIII Mod 3A master gyrocompass.

nacle and gimbal rings. A cutaway view of the Arma Mk VIII Mod 3A master compass is shown in figure 14–12. This compass is a recent type and is used in most cruisers, battleships, and aircraft carriers.

Sensitive Element

The sensitive element (fig. 14–13) is the north-seeking gyroscopic element of the master compass. It consists essentially of a frame on which are mounted (1) two gyro units, (2) an oil damping system, (3) follow-up magnets, and (4) an emergency azimuth scale.

Gyro units.—Two gyro units (fig. 14–13) provide the directive force for the sensitive element that makes the compass north-seeking. Each unit consists of a rotor and case. The gyro rotor is an alloy steel forging 8 inches in diameter and weighing approximately 24 pounds 11 ounces. It is machined and balanced to rotate on special ball bearings at speeds up to almost 12,000 rpm, depending upon the latitude in which the compass is operating. The rotor speed is

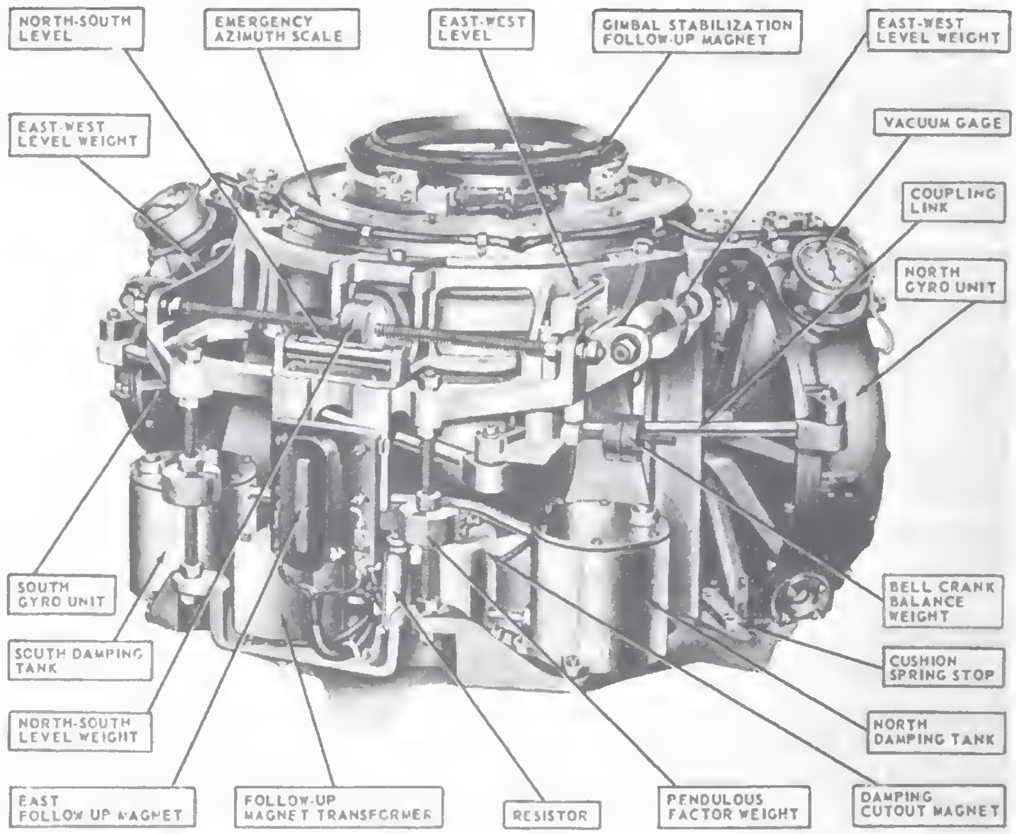


Figure 14–13.—Arma Mk VIII Mod 3A sensitive element.

adjusted to keep the period of the compass constant at all latitudes. The gyro rotor construction includes a laminated squirrel-cage rotor pressed into the gyro wheel, one side of which is machined out around the axle to accommodate the stator winding.

The gyro case construction includes a 3-phase stator winding that projects into the center of the squirrel-cage rotor. The bearings on which the rotor spins are mounted inside the case. The case is supported on upper and lower spindle bearings so that it is free to rotate about a vertical axis. The lower spindle rests on a single steel ball that supports the weight of the entire unit.

A vacuum of 26 to 30 inches of mercury is maintained within each rotor case to eliminate windage losses and thus reduce the heating effect of the high speeds of the rotors. A vacuum gage is mounted on the unit to indicate the degree of vacuum.

A sight glass is provided in the top of the case through which the spinning rotor can be observed. A spiral groove turned around the periphery of the rotor enables the observer to check the correct direction of rotation (clockwise as observed through the sight glass).

The two gyro units are mounted on the sensitive element at an angle of 40° to the north-south axis. Each gyro is pivoted on its vertical axis, and the two gyros are connected together so that they can turn only through equal and opposite angles without turning the frame. The north gyro (fig. 14–13) is coupled by a link to a bell-crank lever arm pivoted on the sensitive element frame. The south gyro is coupled by another link to the other end of the bell-crank lever arm.

The gyros are held in their normal positions by light coil springs located on the side of the gyro units opposite the links. The rotation of the gyro units is limited by cushioning springs located near the bottom of the sensitive-element frame.

The gyros are inclined and coupled by a linkage in order to eliminate the intercardinal error by preventing the sensitive element from swinging in an east-west direction. As the ship rolls, the swinging tendency is first in one direction and then in the other, causing the gyros to turn back and forth through a small angle. The compass reading is not affected because the turning back and forth of the gyros does not turn the sensitive element.

Oil damping system.—The oil damping system (fig. 14–13), consisting of two oil tanks and their connecting tubes, is mounted on the east side of the sensitive-element frame. It causes the sensitive element to settle down in its correct position instead of continually oscillating back and forth across the meridian.

The two oil tanks are totally enclosed and are aligned parallel with the meridian. The tanks, which are partly filled with oil, are connected at the bottom by an oil pipeline and at the top by an air pipeline. The proper damping is obtained by restricting the flow of oil between the two tanks by means of an obstruction inserted in the oil line.

A damping cutout valve is placed in the oil line to prevent the flow of oil due to the acceleration forces present during a turn. This valve operates whenever the ship makes a turn of more than 15° at a rate greater than 40° per minute, or when the ship's speed changes rapidly. The valve consists of a steel ball inside the oil line and an external electromagnet. The electromagnet draws the steel ball up vertically against a spherical seat to automatically stop the flow of oil. Thus, the valve is operated without disturbing the equilibrium of the sensitive element.

FOLLOW-UP MAGNETS.—Two a-c magnets are mounted on the frame for exciting the azimuth follow-up mechanism. These magnets are located at opposite extremities of the east-west axis of the sensitive element so that their fields are cut by the adjacent follow-up windings. A third circular a-c magnet is mounted on the top of the sensitive element for the gimbal stabilization system.

EMERGENCY AZIMUTH SCALE.—The emergency azimuth scale (fig. 14–13) is mounted on the top of the sensitive element. The scale can be read by opening the forward binnacle door and sighting the scale across two parallel lines on one of the upper spider covers.

Two spirit levels (fig. 14–13) are mounted on the sensitive element at right angles to each other and aligned with respect to the axes of the gyros. The north-south level is mounted on the east side of the sensitive element and is graduated in 1-minute divisions from 40 to 60 minutes. This level indicates when the gyrocompass has settled on the meridian.

The sensitive element also carries the follow-up transformer magnet and four adjustable weights for balancing the element.

Mercury Flotation

The mercury flotation (fig. 14–14) provides a practically frictionless suspension for the sensitive element. It consists essentially of a hollow steel sphere that floats in a slightly larger concentric tank containing mercury. The entire sensitive element is supported on the floating hollow steel sphere. Thus it is free to tilt and turn about its vertical and horizontal axes.

The upper part of the mercury tank is shaped to conform to the upper part of the float ball by means of a collar (fig. 14–14) which is a continuation of the spherical part of the mercury tank. The various parts of the sensitive element are arranged on the frame so that its center of gravity is slightly below the level of flotation. This arrangement makes the compass pendulous. An adjustable weight is provided for making small changes in the pendulous factor.

The vertical position of the element is governed by the quantity of mercury in the tank and is indicated by a line on the contact support tube. The flotation is correct when this line is level with the topmost machined surface of the sensitive element.

MERCURY CONTACT PARTS.—Mercury contact parts located at the center of the float ball (fig. 14–14), provide four electrical connections between the sensitive element and spider frame. One contact is through the mercury bowl. The other three contacts are through a contact pin, an outer contact ring, and an inner contact cup which dip into three concentric mercury-filled grooves that are insulated from each other. These three contacts are suspended from the contact support tube that extends vertically downward from the center of the follow-up coil support. Hence, these contacts remain in the same relative position with respect to the sensitive element except for the very small angle of lag in the follow-up system.

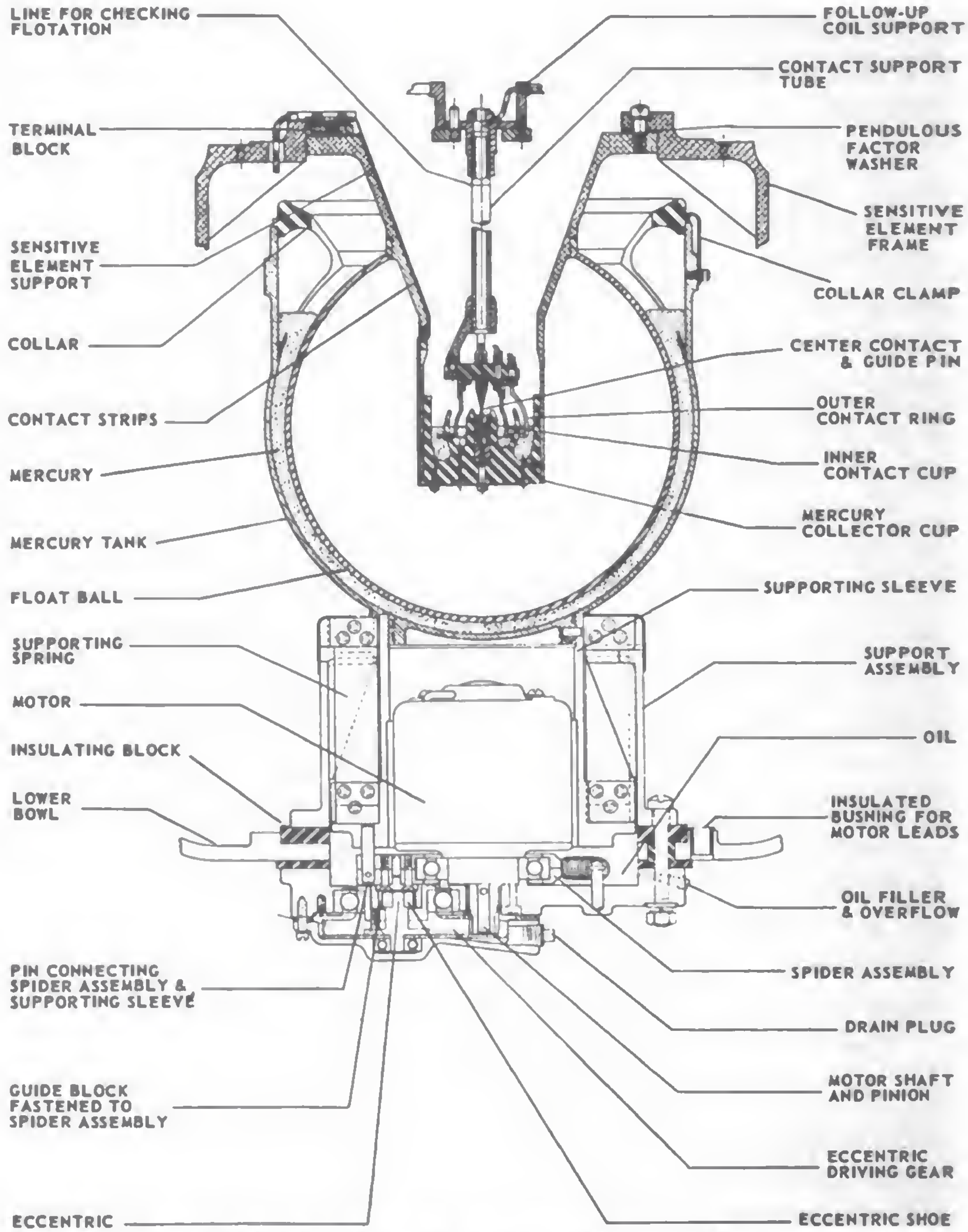


Figure 14–14.—Arma Mk VIII Mod 3A mercury flotation.

Electrical connections to the contact pin, outer ring, and inner cup are made by wires that pass up through the contact support tube to brushes that bear on slip rings on the lower side of the spider casting. These contacts supply power to the damping cutout magnet, follow-up magnets and transformer, and the gyro units on the sensitive element.

The center contact pin, which fits loosely into a guide at the center of the float ball, prevents the sensitive element from drifting laterally. The contact support tube is held vertical by a spring that allows a slight lateral movement to protect the retaining pin.

Oscillating mechanism.—The oscillating mechanism causes the mercury tank to oscillate continuously through a small angle several times per second. These oscillations eliminate any possible static friction in the mercury that might tend to reduce the freedom of the sensitive element. This oscillator assembly is located below the mercury tank (fig. 14–14) which is suspended from leaf springs. It consists of a single-phase induction motor driving an eccentric and a connecting linkage.

The motor is of the shaded-pole type having a squirrel-cage rotor and a 4-pole, series-connected field. It is located in the circular space within the supporting sleeve for the mercury tank. It is geared to a small eccentric carrying an eccentric sliding block. A guide member engages with this block and transmits the oscillating motion to a pair of spiders pinned to the lower part of the suspension sleeve. The complete mechanism below the motor windings is submerged in oil to ensure quiet and dependable operation.

Spider and Bowl

The spider (fig. 14–15) and bowl form a supporting frame for the sensitive element, mercury flotation, and components that comprise the azimuth follow-up mechanism.

The bowl surrounds and supports the sensitive element and mercury flotation. It is suspended from the inner gimbal ring (fig. 14–12) by 24 helical springs. The supporting springs are divided into 12 sets of 2 springs each. One end of each spring is attached to the inner gimbal ring and the other ends are attached to the bowl to form a **V**. Small damping felts are inserted in the springs to damp out any oscillations of the suspended system.

The SPIDER supports the components of the azimuth follow-up mechanism and the speed-course correction mechanism. It is attached to the upper surface of the bowl and completes the top of the enclosure formed by the bowl on the bottom.

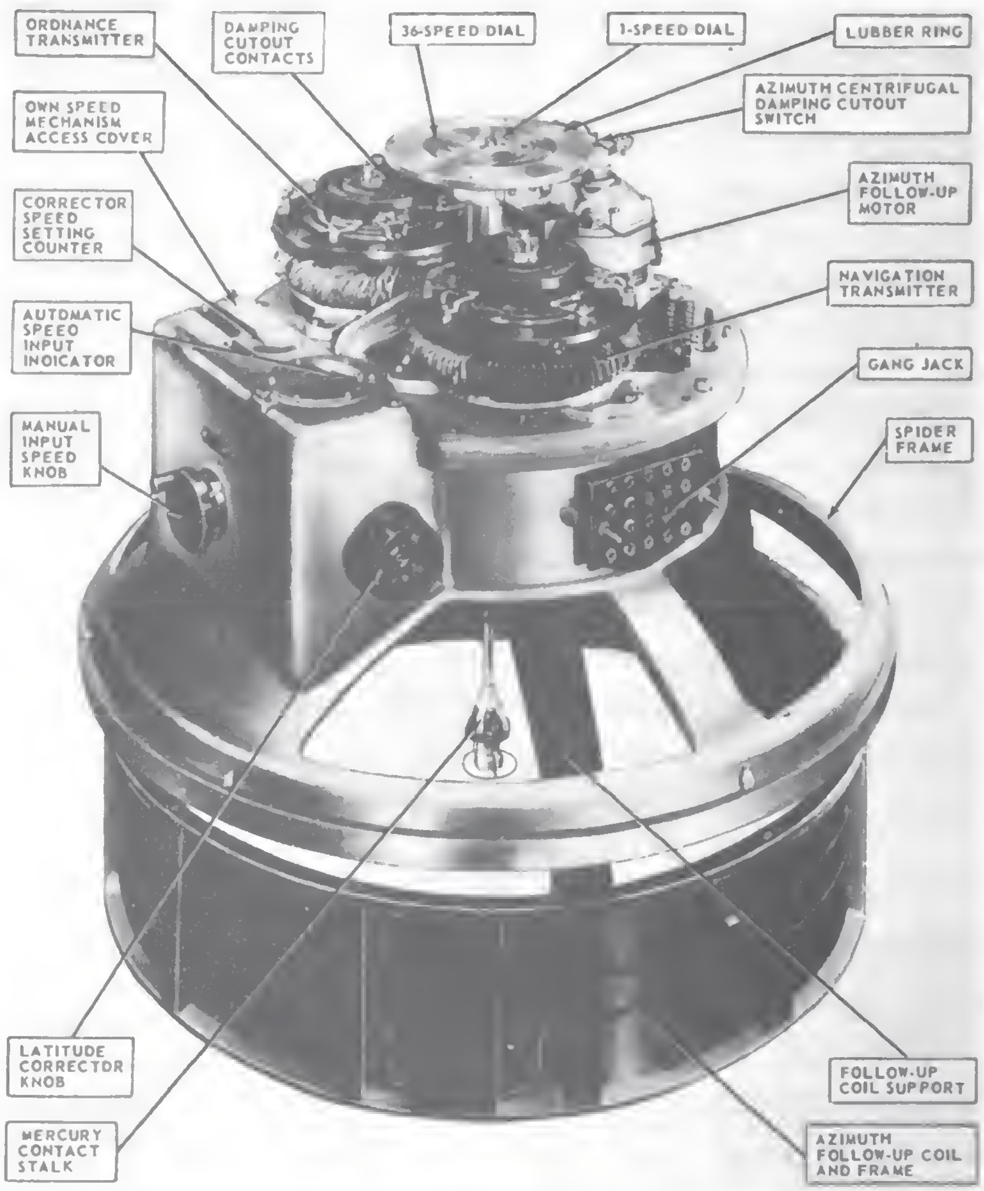


Figure 14–15.—Arma Mk VIII Mod 3A spider.

The spider is provided with four removable transparent covers that fasten between the arms. When the covers are in place the spider and bowl completely enclose the sensitive element.

Azimuth Follow-Up Mechanism

The azimuth follow-up mechanism (fig. 14–12) drives the card dials, and controls the repeater compass readings without placing a drag on the sensitive element. The follow-up mechanism is a part of the master compass. It is distinguished from the follow-up system which includes both the follow-up mechanism and the follow-up panel. The follow-up mechanism consists of (1) follow-up coil, (2) follow-up motor, (3) compass card, (4) commutator transmitters, (5) damping cutout contacts, and (6) speed correction mechanism.

Follow-up coil.—The follow-up coil (fig. 14–12) consists of a winding mounted on a circular bakelite frame that surrounds the sensitive element. The bakelite frame is suspended from the spider by the follow-up coil support which is the movable part of the spider. The winding is connected through slip rings, which are mounted on the spider, to the follow-up panel. Because the coil is fixed in relation to the sensitive element, it turns relative to the ship and spider.

Follow-up motor.—The follow-up motor (fig. 14–12) is a 2-pole d-c motor mounted on the fixed element of the spider. The armature current for this motor is supplied by the follow-up panel. When the follow-up coil is displaced from its neutral position with respect to the sensitive element, current flows through the motor in a direction that causes the motor to drive the follow-up coil into alignment with the sensitive element.

Compass card.—The compass card (fig. 14–12) is mounted on top of the spider assembly and is clearly visible through the glass cover of the binnacle. It consists of two concentric dials having a displacement ratio of 36 to 1. The entire circumference of the outer, or 36-speed, dial is divided into 10 major divisions to indicate 10° of arc, so that each major division corresponds to 1°. The entire circumference of the inner, or 1-speed, dial is divided into 36 divisions, each of which represents 10° of arc. When the ship makes a complete turn of 360°, the inner dial makes 1 revolution and the outer dial makes 36 revolutions, or 1 revolution for every 10° of arc. Actual bearings are read against the lubber's line fixed on the head.

COMMUTATOR TRANSMITTERS.—The two transmitters (fig. 14–15), one for ordnance and one for navigation, are mounted on top of the spider assembly below the compass card. The transmitters and compass-card dials are driven, through gearing, by the follow-up motor to a position that accurately indicates the ship's heading.

The transmitter (fig. 14–16) consists of a transformer,

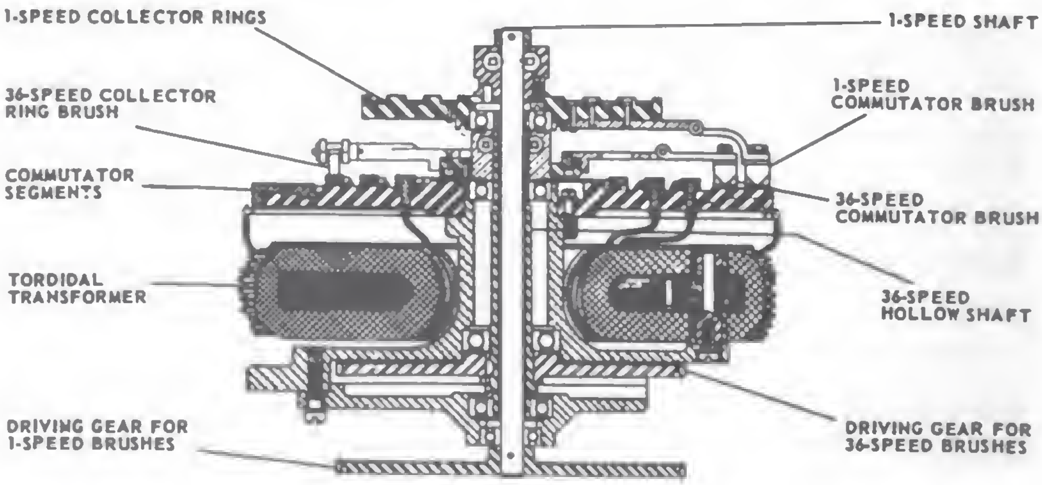


Figure 14–16.—Commutator transmitter.

a commutator having 360 radial segments, two sets of transmitter brushes, and two sets of collector rings. Three brushes spaced 120° apart, bear on the inner ends of the commutator segments. These brushes are driven by a gear and turn with the 36-speed dial. They pick up potentials from the segments energized by the transformer and transmit these potentials through the lower collector rings to the 36-speed dial of the repeater compasses.

Three brushes, spaced 120° apart, bear on the outer ends of the commutator segments. These brushes are driven by a gear and turn with the 1-speed dial. They pick up potentials from the segments energized by the transformer and transmit these potentials through the upper collector rings to the 1-speed dials of the repeater compasses. Hence, the positions of the 1-speed and the 36-speed dials are transmitted independently to the repeater compasses.

DAMPING CUTOUT CONTACTS.—As previously explained, the damping cutout valve is operated when the ship makes a turn of more than 15° at a rate greater than 40° per minute. This action is accomplished by two switches in series. One switch operates on RATE of turn and the other switch operates on AMOUNT of turn.

The RATE OF TURN SWITCH is mounted on the azimuth follow-up motor shaft and is centrifugally operated. The centrifugal switch (fig. 14–15) prevents operation of the cutout on long, slow turns.

The AMOUNT OF TURN SWITCH is operated by means of a lost-motion device mounted on top of the ordnance transmitter, and is driven by the 1-speed brush shaft. This switch prevents the damping cutout from operating due to yawing of the ship, which might momentarily cause a rate of turn in excess of 40° per minute. The damping cutout valve is also closed during rapid changes in ship's speed. The mechanism for closing the circuit under these conditions is located on the follow-up panel.

SPEED CORRECTION MECHANISM.—The speed correction mechanism (fig. 14–12) is mounted on the side of the spider frame below the transmitters. This mechanism introduces a correction into the system because the sensitive element does not settle on the true meridian when the ship is traveling on other than a true easterly or westerly course.

The automatic speed correction mechanism is provided with a synchro receiver that receives an indication of the ship's speed from the underwater log. A follow-up motor applies this quantity to a lever-type multiplier. By means of a manual control, which is graduated in degrees of latitude, the secant of the latitude is introduced into the multiplier, and the resulting product is applied to an eccentric bearing in the correction mechanism. The speed corrector requires manual resetting only for changes in latitude, whereas the speed variations are automatically cared for.

Binnacle and Gimbal Rings

The binnacle and gimbal rings (fig. 14–17), respectively, enclose and support the entire master compass. The compass is suspended in the binnacle by means of a system of gimbal rings. The frame, consisting of the spider and bowl, is suspended from the inner gimbal ring by a number of coil springs and the inner gimbal ring is supported on athwartship ball bearings by the outer gimbal ring. This arrangement allows the compass to swing fore and aft in the binnacle.

The outer gimbal ring is supported on fore-and-aft ball bearings by the binnacle. This arrangement allows the compass to swing from side to side. The outer gimbal ring is also stabilized with respect to the sensitive element by means of a follow-up mechanism that maintains the outer gimbal ring in the athwartship plane of the sensitive element.

The combination of the inner and outer gimbal rings allows the compass to make any fore-and-aft and athwartship movements with respect to the binnacle and permits the compass to hang in a vertical position during rolling and pitching of the ship.

To prevent excessive swinging of the compass when the ship rolls, four steel damping tanks are mounted on the upper surface of the inner gimbal ring. Each tank contains 2½ pounds of mercury.

The binnacle (fig. 14–17) consists of a circular sheet steel body, the upper and lower sections of which are truncated cones. The lower section is secured to a flanged ring that is bolted to the binnacle base. Slots in the flanged ring are provided with elongated holes to permit the compass to be rotated through a small angle relative to the binnacle base, which is rigidly fastened to the deck. This arrangement ensures exact fore-and-aft alignment of the compass.

The midsection carries the gimbal rings and stabilization units. Six terminal blocks, for making corrections to the control panel, are fastened inside the lower section near the bottom. Access to the terminal blocks, and ventilation of the compass is provided by openings covered by perforated removable metal plates.

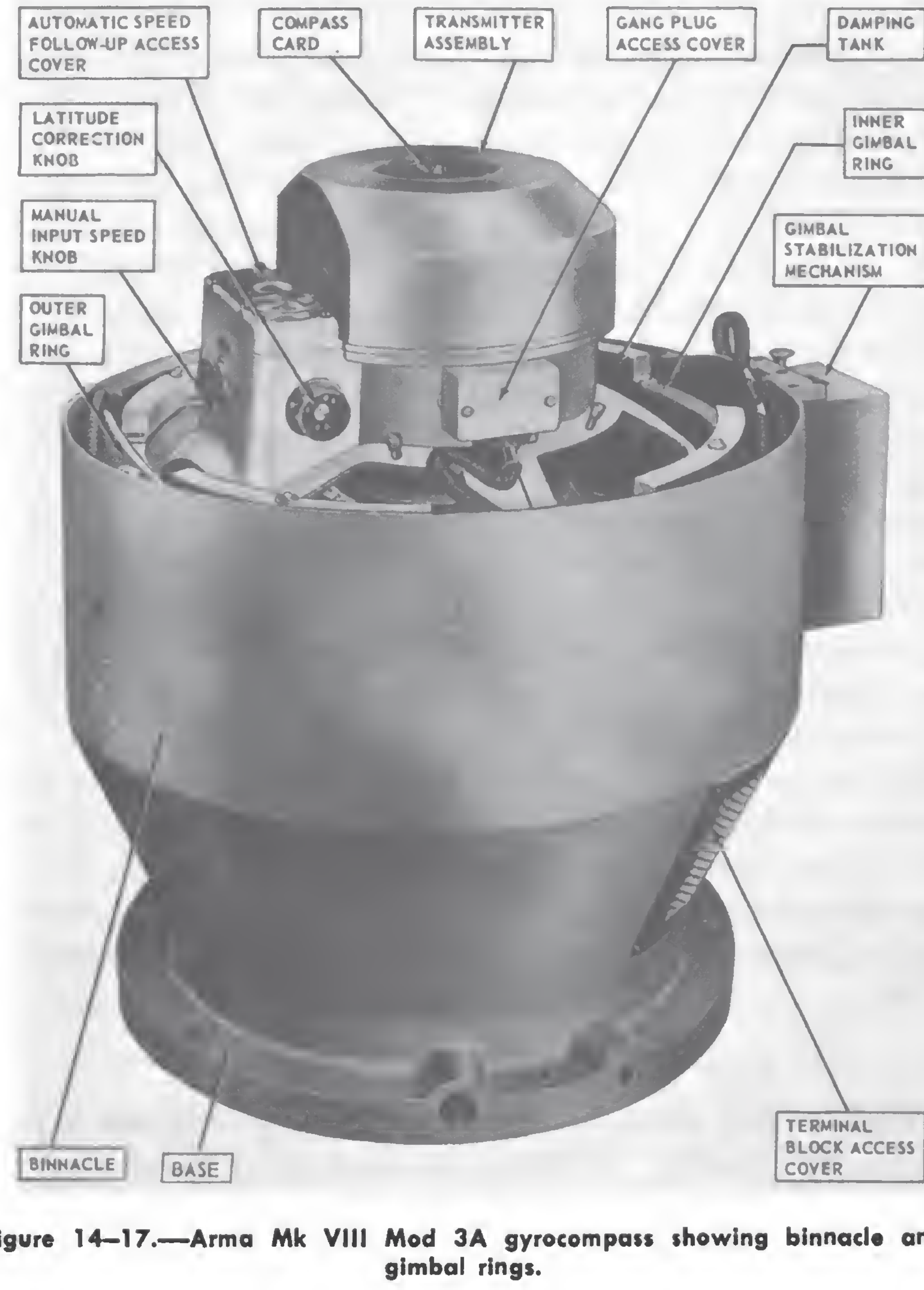


Figure 14–17.—Arma Mk VIII Mod 3A gyrocompass showing binnacle and gimbal rings.

The upper section is a cover attached to the midsection by latches. The top of this cover has a glass window protected by a heavy wire screen, through which the compass card can be read. Two hinged doors are located near the forward and after sides of the cover for access to the speed corrector and for reading the emergency azimuth scale.

ROUTINE INSPECTIONS

As long as a gyrocompass operates satisfactorily it should be left alone except for routine cleaning and oiling. However, certain checks and inspections are made periodically to ensure the best continuous performance. The items to be checked and the intervals at which they should be checked are listed in the manufacturers' instruction books. The ship's standing orders or instructions of the navigator or officer of the deck may require other checks. Years of experience with compasses have contributed to these procedures. Follow these instructions meticulously even though the need for a specific maintenance operation is not immediately evident. Such instructions are designed to prevent, rather than to correct, troubles.

If assigned as a gyrocompass operator, you must become thoroughly familiar with all the maintenance schedules for your compass. A consistent record of good performance is evidence that the operator has performed his duty well. In addition to the compass service record, a rough log is kept for each compass. This rough log should contain the various operating meter readings, vacuum gage readings, cutting in or out of repeaters, transfer of motor-generator sets, checks and adjustments made, periods of cleaning and oiling, and so forth.

Cleaning and Oiling

The greatest source of trouble with gyrocompasses is improper lubrication. Most of this trouble can be avoided by intelligent application of the oiling instructions for each compass. Too much oil around a compass can do almost as much harm as too little oil. Intelligent lubrication requires more than applying the right amount of oil to the right place at the right time. It is also necessary to be certain that the oil goes where it belongs and lubricates the part for which it is intended. This precaution applies particularly to those parts that are lubricated by wicks or tubes that conduct the oil from the place where it is applied to the part to be oiled. Make certain the oil gets to the bearings at the end of the wick or tube.

The compass can be cleaned only when it is secured. The sensitive element is dusted and any excess oil is wiped off. Transmitter contact rings and brushes are cleaned at regular intervals.

Starting and securing the gyrocompass is not difficult, but poor performance and serious damage to the equipment can result from failure to follow instructions and to exercise proper care. Complete instructions for starting and securing each type of compass are contained in the manufacturer's instruction book furnished with the equipment. Refer to these instructions and carefully follow the various steps in the sequence in which they are listed. Certain basic steps are used for all compasses of one manufacturer, but additional steps are required depending upon the complexity of the particular compass.

QUIZ

1. Name the five principal components of the Sperry compass.
2. What is the sensitive element of the Sperry compass?
3. What is the normal gyro rotor speed of the Sperry Mk XI compass?
4. How is the gyro case of the Sperry Mk XI compass supported?
5. What is the purpose of the vacuum in the rotor case?
6. How is the vertical ring of the Sperry Mk XI compass suspended?
7. What is the purpose of the gyro case lock in the Sperry compass?
8. What is the purpose of the vertical ring lock of the Sperry compass?
9. How are the compensator weights supported in the Sperry compass?

10. What is the function of the compensator weights?

11. What is the purpose of the follow-up indicator in the Sperry Mk XI compass?

12. How is the sensitive element suspended in the Sperry compass?

13. What is the function of the mercury ballistic in the Sperry compass?

14. About which axis of the sensitive element is the mercury ballistic of the Sperry compass free to tilt?

15. How is the gravity controlling force of the mercury ballistic applied to the bottom of the Sperry gyro case?

16. How is the lever arm of each tank varied in the mercury ballistic of the Sperry compass?

17. How is damping eliminated in the Sperry compass?

18. What is the function of the phantom element?

19. What are the three functions of the azimuth motor?

20. What does the small azimuth gear drive?

21. What mechanism operates the speed and latitude corrector in the Sperry compass?

22. What is the purpose of the spider in the Sperry compass?

23. Name the five mechanisms mounted on the spider table in the Sperry compass.

24. Name the six units that comprise the follow-up mechanism.

25. What two elements of the Sperry compass are driven through the same angle as the transmitters with respect to the lubber's line?

26. What is the purpose of the automatic damping eliminator switch in the Sperry compass?

27. Name the five principal components of the Arma compass.

28. What angle relative to the north-south axis is formed by the gyro units of the Arma Mk VIII compass?

29. Why are the gyro units in the Arma compass inclined and coupled by a linkage?

30. On which side of the sensitive-element frame is the oil-damping system mounted in the Arma Mk VIII compass?

31. What is the purpose of the damping cutout valve in the oil line connecting the two oil tanks in the Arma compass?

32. What is the purpose of the mercury flotation in the Arma compass?

33. How are the various parts of the sensitive element arranged on the frame of the Arma compass in order to make it pendulous?

34. How are the electrical connections made between the sensitive element and spider frame?

35. What is the purpose of the oscillating mechanism of the Arma compass?

36. What is the function of the bowl of the Arma compass?

37. How are the spider and bowl of the Arma compass suspended?

38. What two mechanisms are supported by the spider of the Arma compass?

39. The bowl is attached to what element of the Arma compass?

40. Name the six components that comprise the azimuth follow-up mechanism of the Arma compass.

41. How is the follow-up coil supported in the Arma compass?

42. What is the function of the follow-up motor of the Arma compass?

43. The commutator transmitters are mounted on what element in the Arma Mk VIII compass?

44. What two switches operate the damping cutout valve in the Arma Mk VIII compass when the ship executes a rapid change in course?

45. Why is the speed correction mechanism necessary in the Arma Mk VIII compass?

CHAPTER 15

SHIP CONTROL ORDER AND INDICATING SYSTEMS

Ship control order and indicating systems include the engine order system, propeller order system, rudder order system, and rudder angle indicator system. The majority of ship control order and indicating systems are electrical, although mechanical systems may be installed in some small noncombatant ships. Mechanical systems will not be discussed because of their limited use.

Instruments comprising the engine order, propeller order, rudder order, and rudder angle indicator systems are of watertight construction and are designed for mounting on pedestals, bulkheads, or panels depending upon the stations in which they are located. Windows are provided in the instrument covers where required for viewing the dials. The internal units can be withdrawn individually from the housings. Dowel pins locate the units within the housings and serve as supports after the units are removed.

The incoming cables are brought through watertight terminal tubes into the instrument housings and the leads are connected to terminal strips or female connectors. The leads for the synchros, bell circuits, and other components are connected to corresponding terminal strips or male connectors within the housings.

ENGINE ORDER SYSTEM

The engine order system, circuit MB, is used to transmit the desired engine orders from the pilot house, open bridge, or secondary conning station to the enginerooms, firerooms (boiler operating stations), and superheat operator stations located in firerooms 1 and 2. Separate circuits are installed for the starboard engines (circuit 1MB) and the port engines (circuit 2MB).

A typical engine order system installed in a large ship is shown by the block diagram in figure 15–1. This system consists of various transmitters and indicators installed in the conning stations, enginerooms, and firerooms. A combined port and starboard engine order transmitter-indicator is installed in the pilot house, secondary conning station, and sometimes in the open bridge. This instrument is electrically connected to a single transmitter-indicator with wrong-direction signal contacts in each throttle station. The wrong-direction signal contacts sound an alarm at the throttle station if an order is incorrectly acknowledged.

A double engine order indicator is installed in throttle station 1 and in each fireroom operating station. The indicator in throttle 1 receives and answers orders for the port engines only. The indicators in the fireroom operating stations receive the repeat-back orders for both port and starboard engines. A single engine order indicator is also installed in throttle stations 1 and 4.

The entire main engine control is invested in throttle station 1. However, throttles 1 and 4 located on the starboard and port sides respectively in the forward engineroom are called LEADING throttle stations; whereas throttles 2 and 3 located on the starboard and port sides respectively in the after engineroom are called FOLLOWING throttle stations.

An engine order is originated at one of the conning stations by turning the handle of the double transmitter-indicator until the transmitter pointer is over the selected order on the instrument dial. The transmitted order is received on all indicators in the circuit. The order is answered by turn-

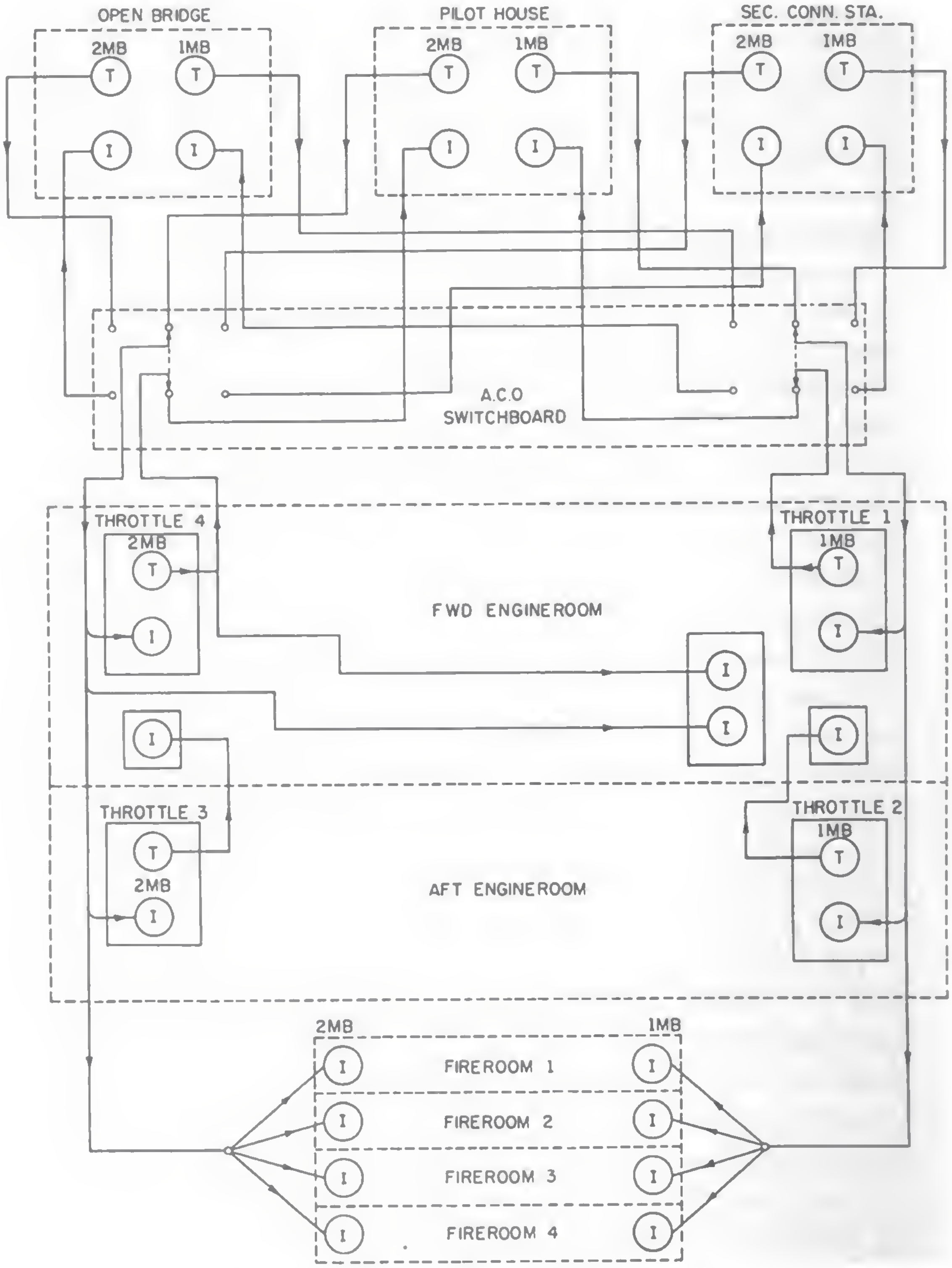


Figure 15–1.—Engine order system block diagram.

ing the handle of the transmitter-indicator at the FOLLOWING throttle station until the reply pointer of the transmitter is over the received order on the instrument dial. The reply is received on the single engine order indicator at the LEADING throttle station. The LEADING throttle station then replies in a similar manner and this reply is received on the double transmitter-indicator in the conning station that originated the order, and also at each fireroom operating station. Thus, the conning station is assured that the transmitted order has been correctly received and interpreted at both leading and following throttle stations.

The instruments in the enginerooms and boiler operating stations are provided with bells that ring each time the transmitted order is originated at the conning station. An audible signal is not provided on the circuits between the forward and after enginerooms.

A selector switch is installed on the A. C. O. switchboard for selecting the double engine order transmitter-indicator to control the circuit. The after engineroom can answer directly to the conning station in an emergency. Cutout switches are installed on the A. C. O. switchboard for indicators in all instruments except those between the after engineroom and the forward engineroom. Cutout switches and transfer switches are combined for circuits 1MB and 2MB.

Double Engine Order Transmitter-Indicator

The double engine order transmitter-indicator installed in each conning station is frequently combined on one pedestal mount with the propeller order transmitter-indicator. These instruments are used to transmit and indicate engine orders and propeller orders respectively.

The double engine order transmitter-indicator is of the drum type (fig. 15–2) and forms the top section of the complete assembly. The instrument housing is made of cast brass and is bolted to the cast aluminum section of the mount by means of flanges. A rubber gasket between the flanges provides watertightness and galvanic insulation between the two sections.

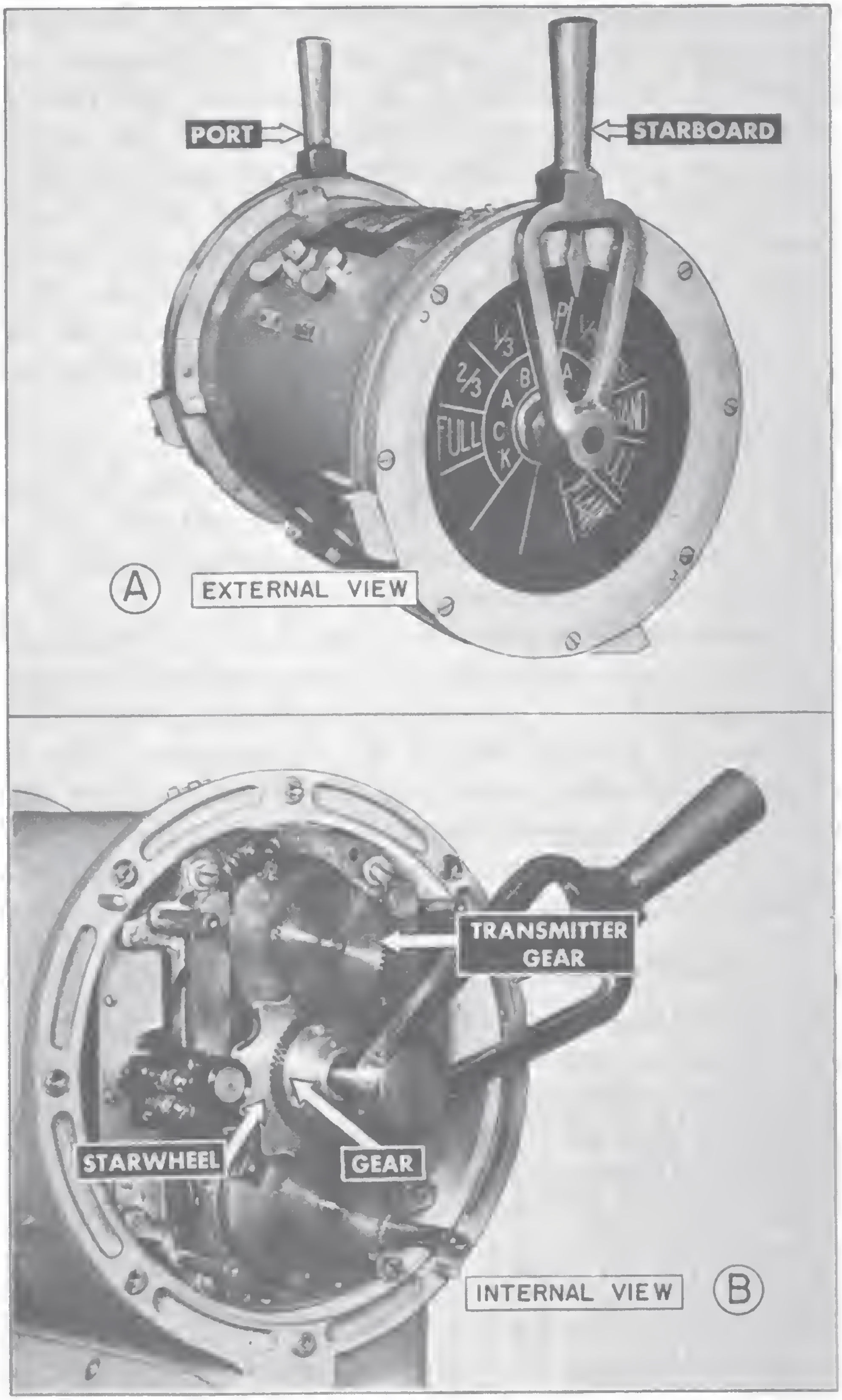


Figure 15-2.—Double engine order transmitter-indicator.

This instrument consists of two type–5G synchro transmitters and two type–1F synchro repeaters indicating on two fixed dials (port and starboard) by means of concentric revolving pointers. The transmitters and repeaters are mounted on individual base plates to form two complete and identical transmitter-indicator units that are mounted in each side of the housing for circuits 1MB (starboard) and 2MB (port).

Each transmitter is driven by a side operating handle, an extension of which is the transmitter pointer (fig. 15–2, A). The operating handle with its pointer is connected to the transmitter shaft by means of a dovetail coupling and gears. A starwheel secured concentrically to one of these gears actuates a microswitch through a ball-bearing roller and lever arm to close the alarm-bell circuit when the operating handle is moved (fig. 15–2, B). This action causes a bell on the engineroom instrument to ring. A lever-operated stop is provided in the operating handle to lock the transmitter pointer in the selected position.

The indicator pointer in this instrument is secured directly to the repeater shaft. This pointer indicates the reply from the engineroom instrument by matching the transmitted order on the dial.

The dials are attached to the sides of the drum housing and are made of a translucent material having a dull black background. The markings are engraved through this background and painted a flat white. The dial markings are arranged so that a forward movement of the transmitter operating handle selects ahead orders and an aft movement of this handle selects backing orders on either the port or starboard dial.

Dial illumination is provided by five lamps located around the perimeter of a light-conducting panel mounted behind each dial. Two 115/6-volt transformers inside the mount supply the port and starboard dial-lamp circuits. A variable resistor in series with this circuit controls the intensity of illumination. A neon pilot light is provided in each internal unit to indicate (through two windows placed in covers at the top of the housing) when the 1MB and 2MB circuits are energized.

Two push switches are provided on the aft side of the drum housing for manual signaling to the port and starboard indicators. These push switches close microswitches that are in parallel with the microswitches operated by the star-wheels and cause bells on the engineroom instruments to ring. Two vibrating bells are mounted externally on the aft port and aft starboard sides of the housing. These bells ring when the reply is received from the engineroom instruments.

The combined circuits for the engine order transmitter-indicator and the propeller order transmitter-indicator are shown in figure 15–3.

Engine Order Transmitter-Indicator With Wrong-Direction Contacts

The engine order transmitter-indicator with wrong-direction signal contacts, circuit DW, installed in each throttle station is used to transmit and indicate engine orders and to close an alarm-bell circuit when the reply from any

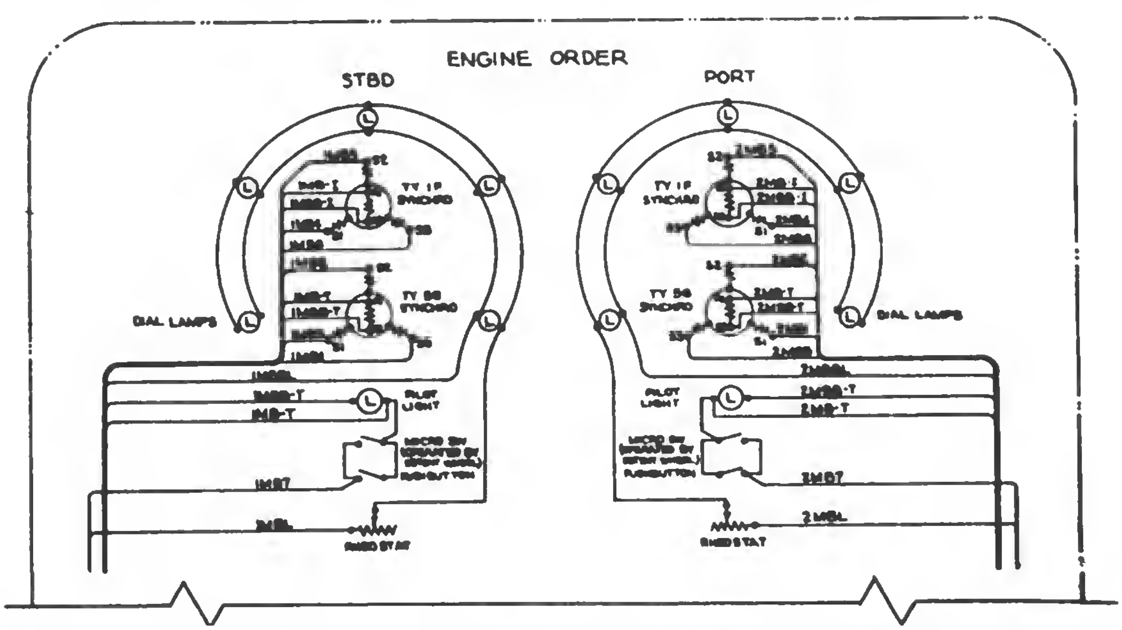


Figure 15–3.—Combined engine order transmitter-indicator and propeller order transmitter-indicator.

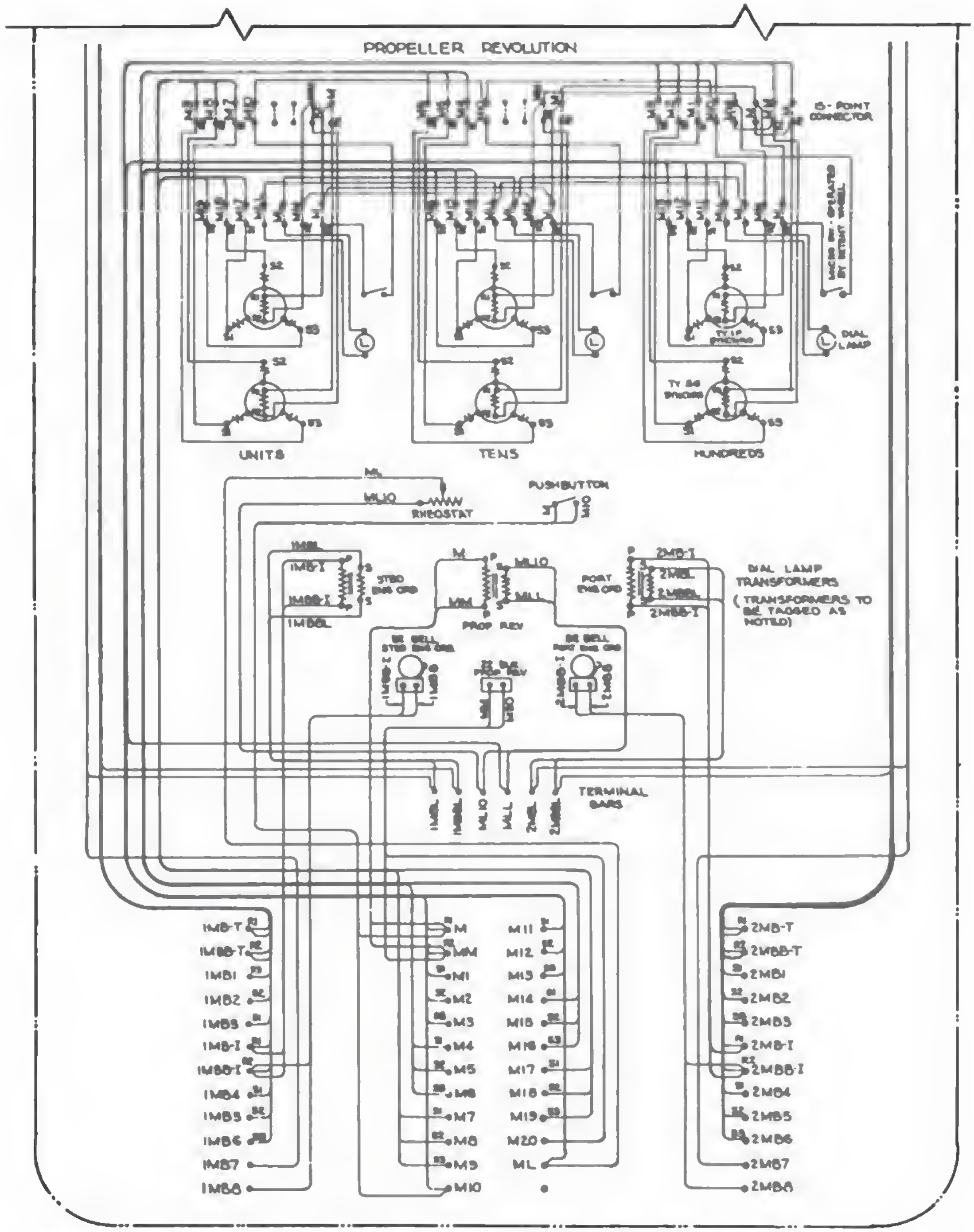


Figure 15–3.—Combined engine order transmitter-indicator and propeller order transmitter-indicator—Continued.

throttle station is in the wrong direction (fig. 15–4). This instrument consists of a type–5G synchro transmitter and a type–1F synchro repeater mounted on a common base plate to form a complete transmitter-indicator unit that is enclosed within the housing.

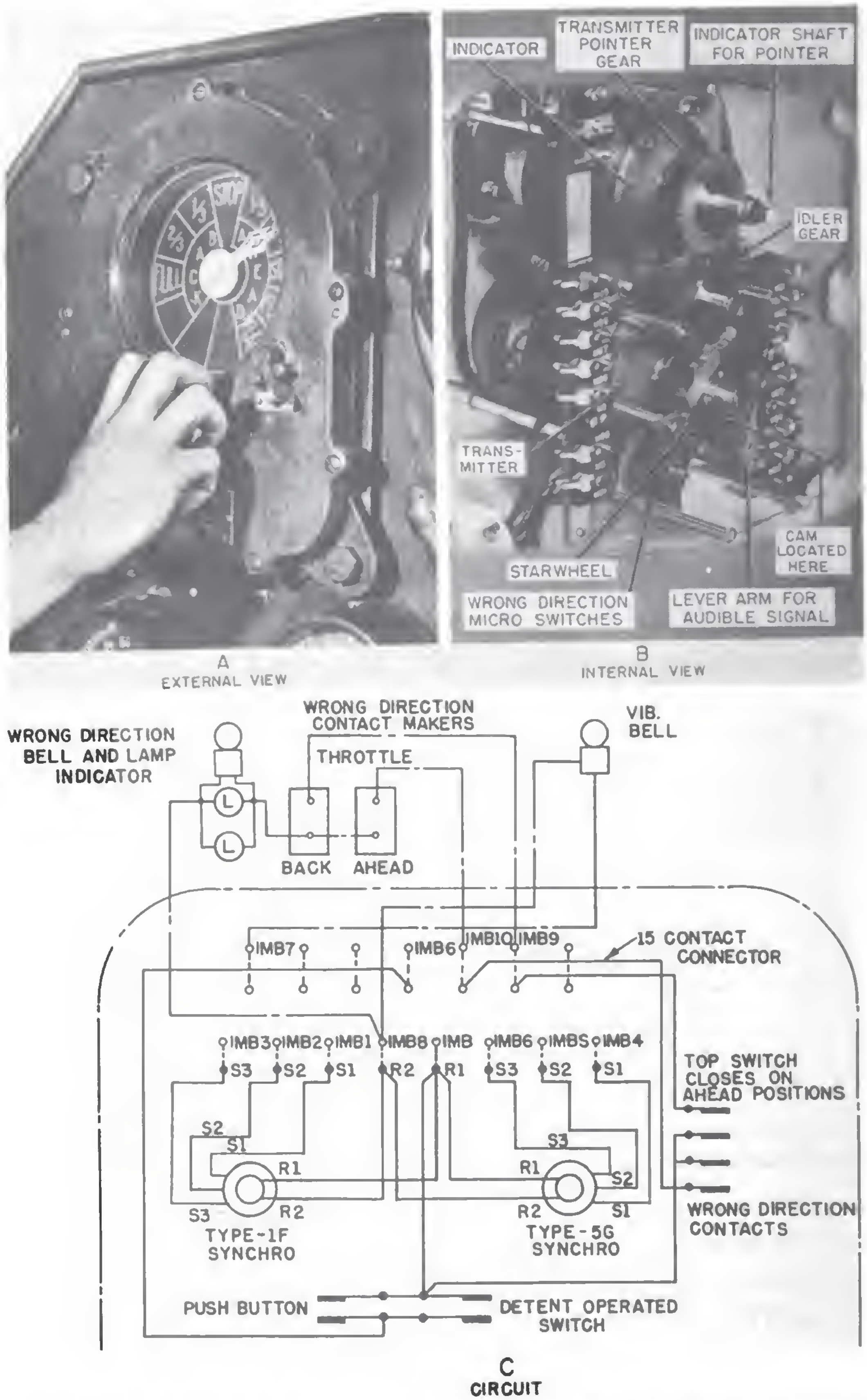


Figure 15-4.—Engine order transmitter-indicator with wrong-direction contacts.

The transmitter is driven through gearing by a handle attached to a shaft that extends through a watertight stuffing gland in the cover below the dial (fig. 15–4, A). The transmitter pointer is connected to the transmitter shaft through two gears and is secured to a bearing housing supported on ball bearings at the center of the dial. This pointer indicates the transmitted order from the conning station. A starwheel secured concentrically to one of the gears on the transmitter shaft actuates a microswitch through a ball-bearing roller and lever arm to close the alarm-bell circuit when the transmitter operating handle is moved (fig. 15–4, B). This action causes a bell on the conning station instrument to ring.

The indicator pointer is connected directly to an extension of the repeater shaft and is concentric with the transmitter pointer at the center of the dial. This pointer indicates the reply to the conning station.

The dial is mounted on four posts that are secured to the base plate. It is made of sheet brass having a black background with white markings. Dial illumination is not provided.

A push switch located on the cover is used for manual signaling to the conning station. This push switch closes a microswitch that is in parallel with the microswitch operated by the starwheel and causes a bell on the conning station instrument to ring. A vibrating bell, which is provided with this instrument, rings each time the engine order setting is originated at the conning station.

The wiring diagram for this instrument is shown in figure 15–4, C.

The transmitter is provided with controls in the AHEAD and BACK positions of the operating handle (wrong-direction signal contacts). These contacts are connected in series with contacts on the main throttle valves. A cam attached to the starwheel on the transmitter shaft operates a lever arm that controls the wrong-direction microswitches. If the engine direction order is misinterpreted at the throttle station these contacts are actuated to provide a warning. This warning consists of a vibrating bell and a single dial (2-lamp) indicator containing a red glass dial located at each throttle station.

Double Engine Order Indicator.

The double engine order indicator (fig. 15–5) installed in throttle station 1 is used to indicate the transmitted 2MB order from the conning station to the port throttles and the answer from throttle station 4, after throttle station 3 has acknowledged the transmitted order.

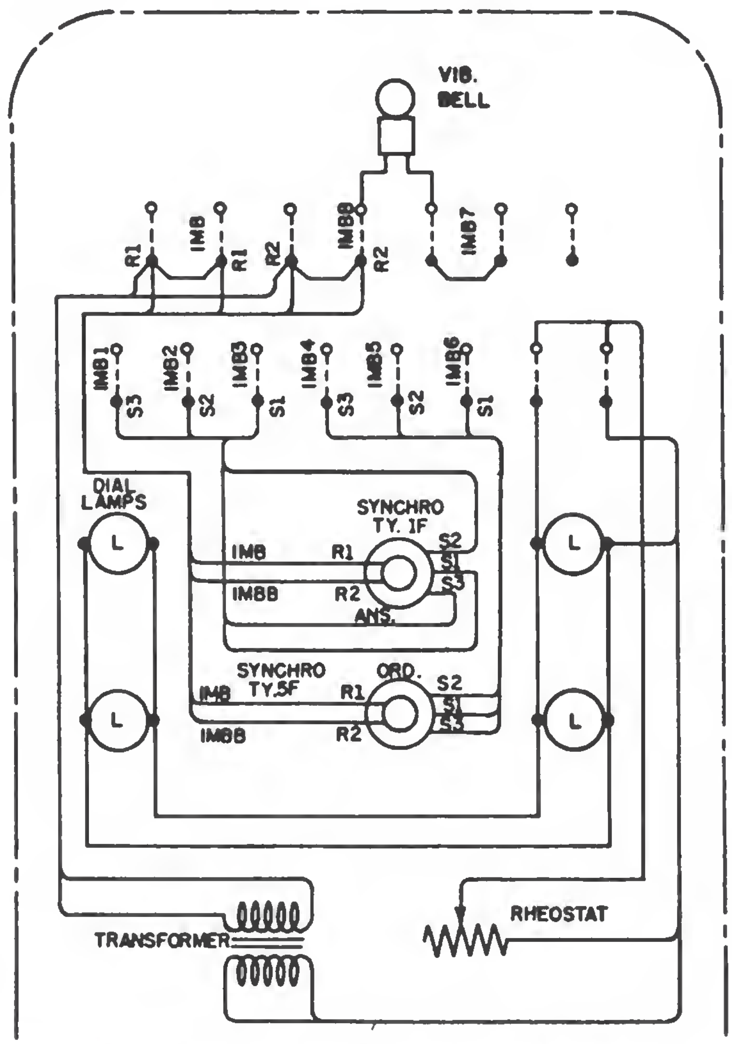


Figure 15–5.—Double engine order indicator.

This instrument consists of a type–5F and a type–1F synchro repeater mounted on a common base plate to form a complete double indicator unit that is enclosed within the housing. The two synchros indicate on a common fixed dial by means of two concentric revolving pointers. The pointer marked ANSWER is connected to the type–1F synchro shaft through two gears and is secured to a bearing housing supported on ball bearings at the center of the dial. This pointer indicates the reply from throttle station 3. The pointer marked ORDER is connected directly to an extension of the type–5F synchro shaft and is concentric with the answer pointer. The order pointer indicates the transmitted order from the conning station.

The dial is mounted on the base plate by four supporting studs. It is made of a translucent material having a black background with white markings.

Dial illumination is provided by four lamps located around the perimeter of a light-conducting panel mounted behind the dial. A transformer inside the mount supplies the dial-lamp circuit. A knob located on the housing controls a variable resistor in the lamp circuit for varying the intensity of illumination.

A vibrating bell on this instrument rings each time the engine order setting is changed at the conning station.

Single Engine Order Indicator

The single engine order indicator installed in throttle stations 1 and 4 is used to indicate the reply from throttle stations 2 and 3 respectively after the transmitted order has been acknowledged by these stations. This instrument consists of a type–5F synchro repeater indicating on a fixed dial by means of a revolving pointer. The repeater is mounted on a base plate to form a complete internal unit that is enclosed within the housing. The indicator pointer is connected directly to the repeater shaft and indicates the reply from throttle stations 2 and 3.

The dial is mounted on four posts that are secured to the base plate. It has a black background with white markings and is not provided with illumination. A vibrating bell on this instrument rings each time the transmitted order is acknowledged.

The leads for the synchro and bell are connected to a 6-point connector attached to the back of the base plate.

Action Cutout and Transfer Switches

The operation of the engine order system (fig. 15–6) depends on the setting of the action cutout switches and transfer switches. For simplicity, switches 2, 3, and 4 are not shown, as they are only for cable selection.

TRANSFER SWITCH 1 is labeled "engine order transmitters and indicators." It has 3 positions marked (1) open bridge, (2) pilot house, and (3) secondary conning station. Position 1 energizes the transmitter and indicator in the open bridge and the indicator in the pilot house. Position 2 energizes the transmitter and indicator in the pilot house and the indicator in the open bridge. Position 3 energizes the transmitter and indicator in the pilot house and disconnects the indicator in the open bridge.

TRANSFER SWITCH 5 is labeled "engine order transmitters and indicators, port (2MB)." It has 3 positions marked (1) engineroom 1, (2) normal, and (3) engineroom 2. Position 1 connects the engine orders to the double indicator without reply in throttle 1. Position 1 also connects the repeat-back from throttle 4 to the forward conning stations and to firerooms 1, 2, 3, and 4. Position 2 connects the engine orders to throttles 3 and 4 and to the double indicator without reply in throttle 1. It connects the repeat-back from throttle 3 to the single indicator in throttle 4 and to the indicators in firerooms 3 and 4. Position 2 also connects the repeat-back from throttle 4 to the forward conning stations and to the indicators in firerooms 1 and 2. Position 3 connects the engine orders to throttle 3 and the repeat-back from throttle 3 to the forward conning stations and to firerooms 1, 2, 3, and 4.

TRANSFER SWITCH 6 is labeled "engine order transmitters and indicators, starboard (1MB)." It has 3 positions marked (1) engineroom 1, (2) normal, and (3) engineroom 2. Position 1 connects the engine orders to throttle 1 and

PAGE NOT AVAILABLE

g sta-
ts the
-back
o the
peat-
nd to
s the
rottle
2, 3,

n the

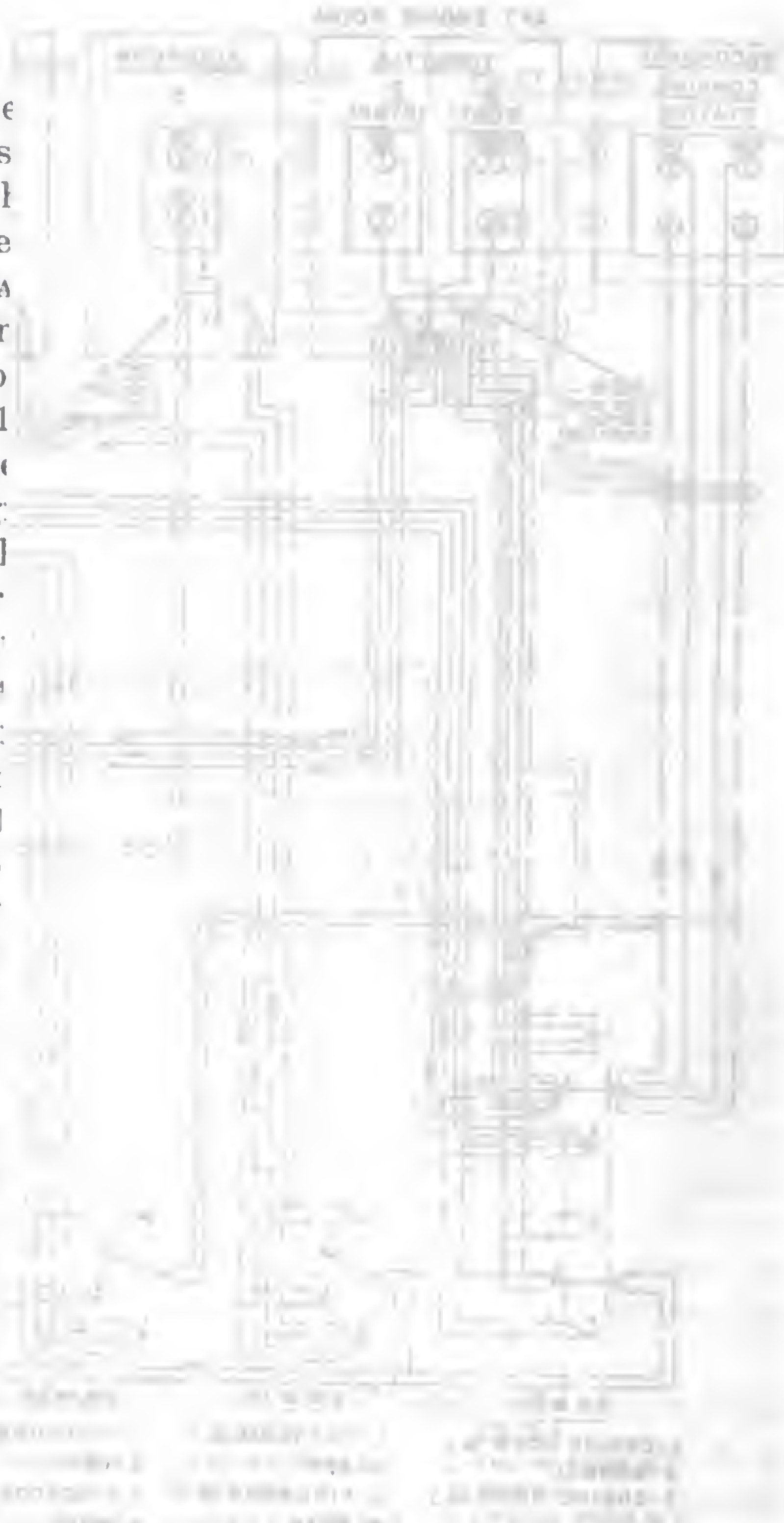
" It
room
o the
indi-
cator

" It
om 4,
o the
indi-
cator

ors—
ttle 1
Posi-
ingle
dica-
e 3 to
both

ed in
beled
d (1)
Po-
-back
sition

The
conne



The
pends
switch
as the
Tra
and ir
(2) p
tion 1
bridge
energ
and th
the tr
nects
Tra
and i
(1) er
tion 1
witho
repea
and t
engin
witho
from
indica
repea
and t
nects
throt
2, 3, a
Tra
and
mark
2. P

the repeat-back from throttle 1 to the forward conning stations and to firerooms 1, 2, 3, and 4. Position 2 connects the engine orders to throttles 1 and 2. It connects the repeat-back from throttle 2 to the single indicator in throttle 1 and to the indicators in firerooms 3 and 4. It also connects the repeat-back from throttle 1 to the forward conning stations and to the indicators in firerooms 1 and 2. Position 3 connects the engine orders to throttle 2 and the repeat-back from throttle 2 to the forward conning stations and to firerooms 1, 2, 3, and 4.

Action cutout switches 7 through 9 are installed on the A. C. O. switchboard.

A. C. O. SWITCH 7 is labeled "engine order indicators." It has 4 positions marked (1) fireroom 1, (2) off, (3) fireroom 2, and (4) both. Position 1 connects the repeat-back to the indicator in fireroom 1. Position 2 disconnects both indicators. Position 3 connects the repeat-back to the indicator in fireroom 2. Position 4 connects both indicators.

A. C. O. SWITCH 8 is labeled "engine order indicators." It has 4 positions marked (1) fireroom 3, (2) off, (3) fireroom 4, and (4) both. Position 1 connects the repeat-back to the indicator in fireroom 3. Position 2 disconnects both indicators. Position 3 connects the repeat-back to the indicator in fireroom 4. Position 4 connects both indicators.

A. C. O. SWITCH 9 is labeled "engine order indicators—throttles 1 and 4." It has 4 positions marked (1) throttle 1 (1MB), (2) off, (3) throttle 4 (2MB), and (4) both. Position 1 connects the repeat-back from throttle 2 to the single indicator in throttle 1. Position 2 disconnects both indicators. Position 3 connects the repeat-back from throttle 3 to the single indicator in throttle 4. Position 4 connects both indicators.

Transfer switches 10 through 13 inclusive are installed in firerooms 1, 2, 3, and 4 respectively and are each labeled "engine order indicator." Each has 3 positions marked (1) secondary conning station, (2) off, and (3) pilot house. Position 1 connects the fireroom indicator to the repeat-back when the secondary conning station is in control. Position

2 disconnects the indicator. Position 3 connects the fireroom indicator to the repeat-back when the pilot house is in control.

TRANSFER SWITCH 14 installed in throttle 1 is labeled "engine order transmitter and indicator." It has 3 positions marked (1) secondary conning station, (2) normal, and (3) pilot house. Position 1 connects the engine orders from the secondary conning station to throttles 1 and 4 and repeats back to the secondary conning station via switching on the auxiliary I. C. switchboard. Position 2 is the same as position 1 but also repeats back to the secondary conning station via switching on the auxiliary I. C. switchboard. Position 3 connects the engine orders from the pilot house to throttles 1 and 4 and the repeat-back to the pilot house via switching on the A. C. O. switchboard.

A. C. O. SWITCH 15 installed in throttle 1 is labeled "engine order double indicator." It has 2 positions marked (1) on, and (2) off. Position 1 connects the 2MB order and answer to the double indicator at throttle 1. Position 2 disconnects the indicator at throttle 1, giving the order and answer of the 2MB system for the port shafts.

TRANSFER SWITCH 16 installed in throttle 2 is labeled "engine order transmitter and indicator." It has 3 positions marked (1) secondary conning station, (2) normal, and (3) pilot house. Position 1 connects the engine orders from the secondary conning station to throttles 2 and 3 and the repeat-back to engineroom 1 or to the secondary conning station via switching on the auxiliary I. C. switchboard. Position 2 is the same as position 1 but also repeats back to the secondary conning station via switching on the auxiliary I. C. switchboard. Position 3 connects the engine orders from the pilot house to throttles 2 and 3 and the repeat-back to engineroom 1 or to the pilot house via switching on the A. C. O. switchboard.

A. C. O. SWITCH 17 installed on the auxiliary I. C. switchboard is labeled "engine order indicators—throttles 1 and 4." It has 4 positions marked (1) throttle 4 (2MB), (2) off, (3) throttle 1 (1MB), and (4) both. Position 1 connects the repeat-back from throttle 3 to the single indicator in throttle 4. Position 2 disconnects both indicators. Position 3 connects the repeat-back from throttle 2 to the single indicator in throttle 1. Position 4 connects both indicators.

A. C. O. SWITCH 18 installed on the auxiliary I. C. switchboard is labeled "engine order indicators." It has 4 positions marked (1) fireroom 2, (2) off, (3) fireroom 1, and (4) both. Position 1 connects the repeat-back to the indicator in fireroom 2. Position 2 disconnects both indicators. Position 3 connects the repeat-back to the indicator in fireroom 1. Position 4 connects both indicators.

A. C. O. SWITCH 19 installed on the auxiliary I. C. switchboard is labeled "engine order indicators." It has 4 positions marked (1) fireroom 4, (2) off, (3) fireroom 3, and (4) both. Position 1 connects the repeat-back to the indicator in fireroom 4. Position 2 disconnects both indicators. Position 3 connects the repeat-back to the indicator in fireroom 3. Position 4 connects both indicators.

TRANSFER SWITCH 20 installed on the auxiliary I. C. switchboard is labeled "engine order transmitters and indicators." It has 3 positions marked (1) engineroom 2, (2) normal, and (3) engineroom 1. Position 1 connects the engine orders to throttles 2 and 3 and the repeat-back to the secondary conning station and to firerooms 1, 2, 3, and 4. Position 2 connects the engine orders to throttles 1, 2, 3, and 4. It connects the repeat-back from throttle 2 to the single indicator in throttle 1 and to firerooms 3 and 4. Position 2 also connects the repeat-back from throttle 3 to the single indicator in throttle 4 and to firerooms 3 and 4. It connects the repeat-back from throttles 1 and 4 to the secondary conning station and to firerooms 1 and 2. Position 3 connects the engine orders to throttles 1 and 4 and the repeat-back to the secondary conning station and to firerooms 1, 2, 3, and 4.

Normal operating conditions are obtained by setting the action cutout and transfer switches to the required positions. For example, if the pilot house is in control of the circuit the following switches would be in the positions indicated:

Switch	*Position*
1	(2) pilot house
5, 6, 14, and 16	(2) normal
7, 8, and 9	(4) both
10, 11, 12, and 13	(3) fwd conning station
20	(2) normal

A 1MB order from the pilot house is transmitted to the engine order transmitter-indicators in throttle stations 1 and 2. Throttle station 2 replies to the single engine order indicator in throttle station 1, and also to the double engine order indicators in firerooms 3 and 4. Throttle station 1 then replies to the pilot house and firerooms 1 and 2.

A 2MB order from the pilot house is transmitted to the engine order transmitter-indicators in throttle stations 3 and 4. Throttle station 3 replies to the single indicator in throttle station 4, and also to the double indicators in firerooms 3 and 4. Throttle station 4 then replies to the pilot house and firerooms 1 and 2.

Emergency operating conditions are obtained by setting the action cutout and transfer switches to the required positions. For example, if engineroom 1 is inoperative the following switches would be in the positions indicated:

Switch	*Position*
5 and 6	(3) engineroom 2
7 and 8	(4) both
9	(2) off
10, 11, 12, and 13	(3) pilot house
15 and 17	(2) off
16	(3) fwd conning station
18 and 19	(4) both
20	(1) engineroom 2

A 1MB order from the pilot house is transmitted to the indicators in throttle station 2 with repeat-back to the pilot house, secondary conning station, and firerooms 1, 2, 3, and 4.

A 2MB order from the pilot house is transmitted to the indicators in throttle station 3 with repeat-back to the pilot house, secondary conning station, and firerooms 1, 2, 3, and 4.

PROPELLER ORDER SYSTEM

The propeller order system, circuit M, is used to transmit the desired changes in the number of propeller revolutions from the pilot house, central station, or secondary conning station to the enginerooms. As previously mentioned, instruments of this system are combined with instruments of the engine order system in the conning stations and enginerooms. This system provides a means of transmitting SMALL CHANGES in speed to the throttle stations.

A typical propeller order system is shown by the block diagram in figure 15–7. This system, consists of a transmitter-indicator in each conning station and in throttle stations 1 and 2. A single indicator is installed in throttle stations 1, 3, and 4. The control engineroom receives the order and answer from the aft engineroom and repeats the orders back to the conning station.

A propeller order is originated at the conning station by turning the handle of the transmitter-indicator until the selected digits are indicated in the transmitter sections of the three windows provided in the instrument cover. The transmitted order is received on all indicators in the circuit. The order is answered by turning the handles of the transmitter-indicator at the following throttle station until the digits in the transmitter sections of the three windows correspond with those in the indicator sections of these windows. The reply is received at the single propeller order indicator at the leading throttle station. The leading throttle station then replies in a similar manner and the reply is received on the transmitter-indicator at the conning station that originated the order. Thus, the conning station is assured that the transmitted order has been correctly received and interpreted at all throttle stations.

A selector switch is installed on the A. C. O. switchboard for selecting the transmitter-indicator to control the circuit and a cutout switch is provided at each engineroom instrument.

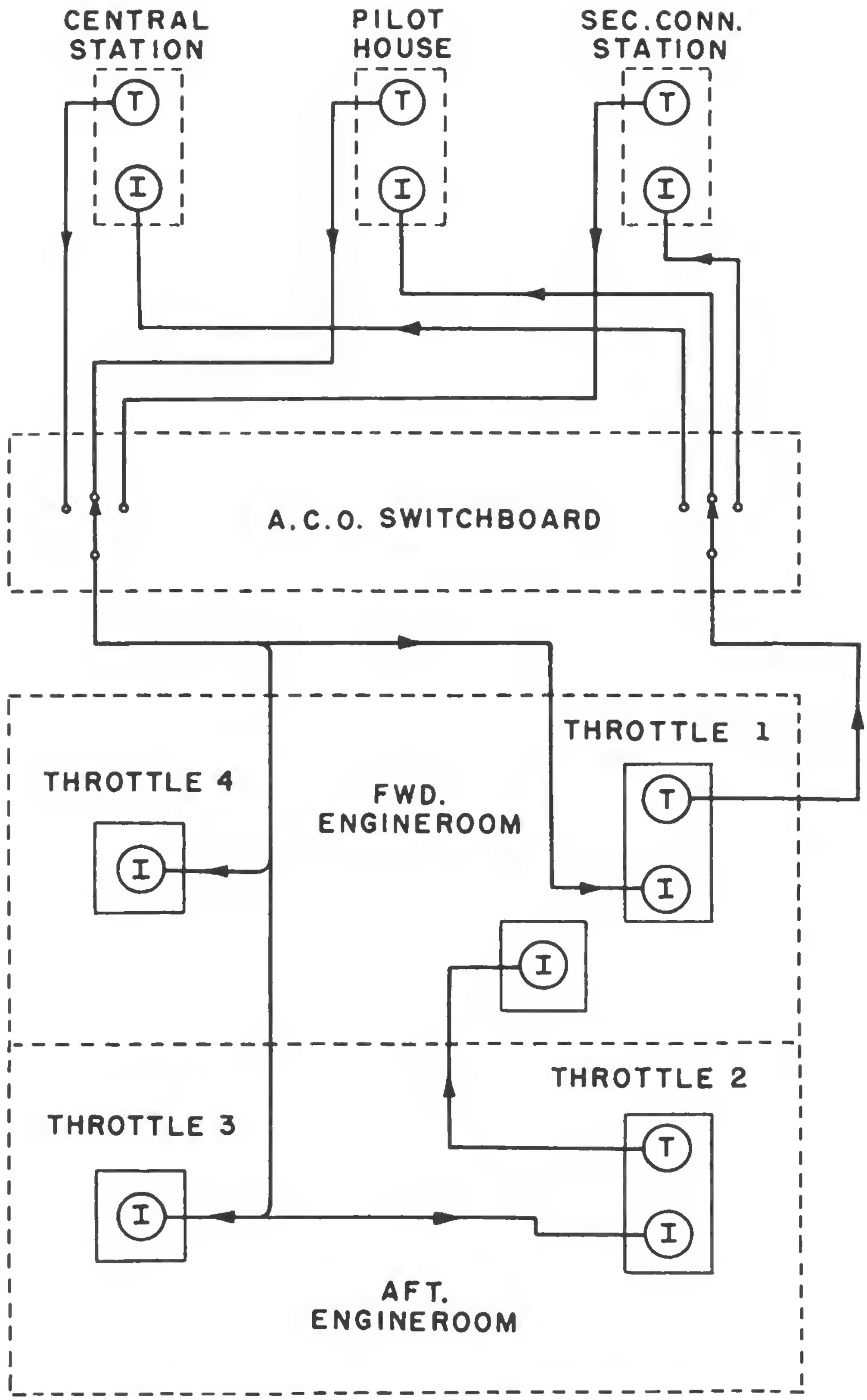


Figure 15-7.—Propeller order system block diagram.

Propeller Order Transmitter-Indicator

The propeller order transmitter-indicator installed in each conning station and in throttle stations 1 and 2 is used to transmit and indicate propeller orders. This instrument is designed for panel mounting and is set into a recess in the pedestal mount directly below the engine order transmitter-indicator (fig. 15–8). This instrument consists of three type–5G synchro transmitters and three type–1F synchro repeaters. The transmitters and repeaters are mounted on individual base plates to form three complete and identical transmitter-indicator units. The circular dials, marked "0" through "9" are attached to each synchro shaft. The units are arranged in the housing so that the three indicator dials are directly above the three transmitter dials, each showing one numeral through its associated window in the front cover. These numerals form a 3-digit number (units, tens, hundreds) for the indicators and transmitters respectively.

Each transmitter is driven by an operating handle attached to a shaft that extends through a watertight stuffing gland in the cover below each dial window (fig. 15–8, A). The transmitter dial, the center of which is fastened to the transmitter shaft, indicates the transmitted order on its associated section of the dial. A starwheel secured to each transmitter shaft actuates a microswitch through a ball-bearing roller and lever to close the alarm bell circuit when the operating handle is moved. This action causes a vibrating bell on the engine-room instrument to ring.

Each indicator dial is secured to an adapter that is connected directly to the repeater shaft and indicates the reply from the engineroom instrument by matching the transmitted order on the associated dials.

The dials, which are of the rotating disk type (fig. 15–8, B), are provided with segregated digit control so that any desired number from 0 to 999 can be set up on the transmitter manually and on the indicator by a remote transmitter. They are made of a translucent material having a black background with white markings.

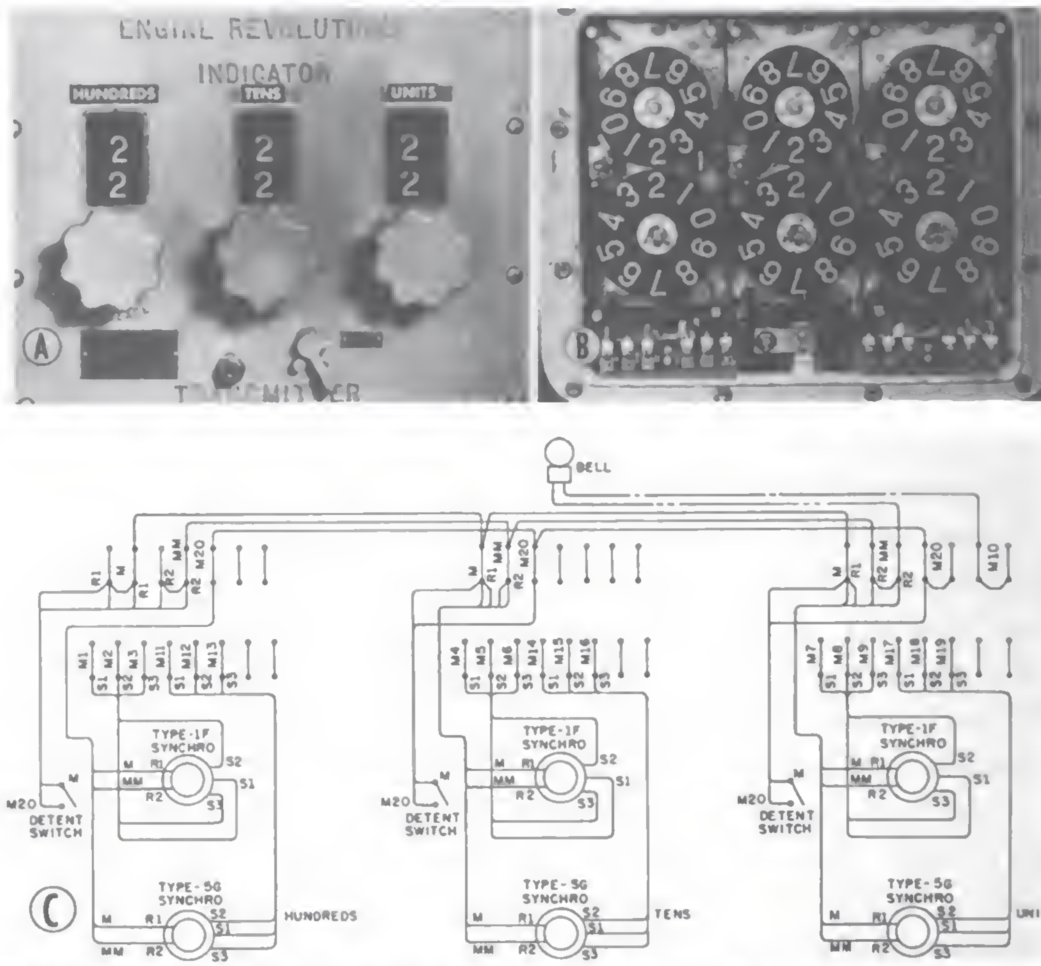


Figure 15–8.—Propeller order transmitter-indicator. A, external view; B, internal view; C, circuit.

Dial illumination is provided by three lamps mounted midway between each transmitter-indicator unit. A transformer mounted behind the base plate supplys the dial-lamp circuit. A variable resistor controls the intensity of illumination.

A push switch located on the cover below the center window is used for manual signaling to the instruments in the enginerooms. This switch closes a microswitch that is in parallel with the microswitch operated by the starwheel and causes bells on the engineroom instruments to ring. A buzzer for the ringing circuit is located externally on the aft side of the mount between the port and starboard bells for the engine order circuit. This buzzer sounds an audible signal when the reply is received from the engineroom instruments.

The wiring diagram for this instrument is shown in figure 15–8, C.

The propeller order transmitter-indicator installed in throttle stations 1 and 2 is the same as the instruments installed in the conning stations except that a vibrating bell is provided instead of a buzzer. This instrument has no illumination and is mounted on the gage board.

Propeller Order Indicator

The propeller order indicator (fig. 15–9) installed at throttle stations 3 and 4 is used to indicate propeller orders. This instrument consists of three type–1F synchro repeaters mounted on individual base plates to form three complete and identical indicator units. The units are arranged in the housing so that each dial shows one numeral through its associated window in the cover to form a 3-digit number.

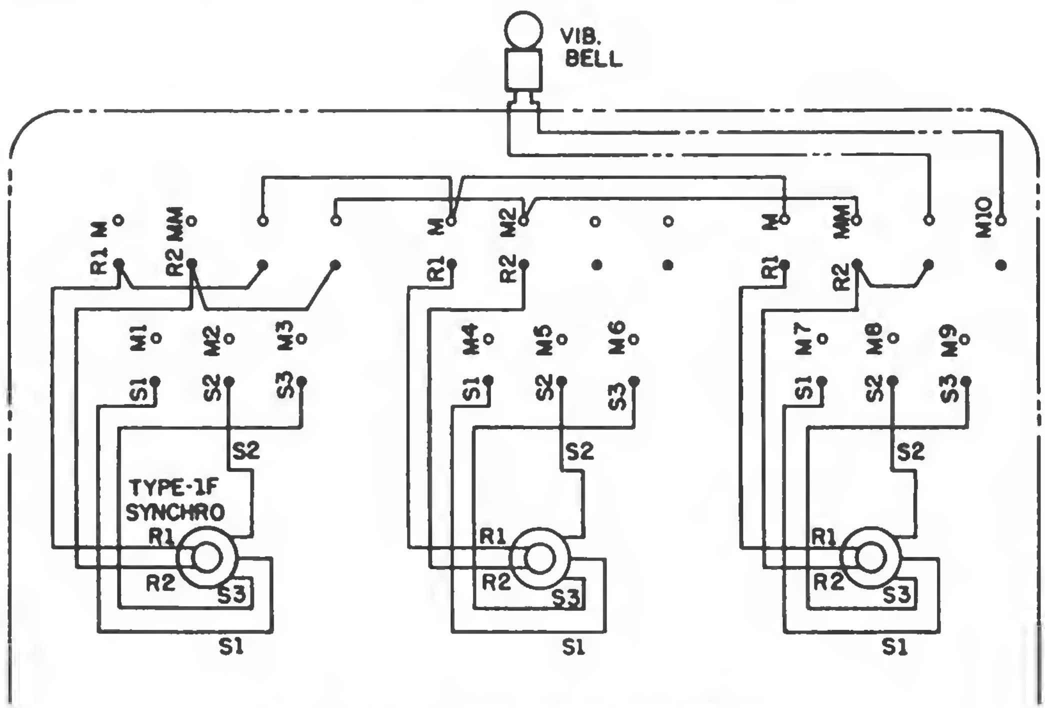


Figure 15–9.—Propeller order indicator.

Each indicator dial is secured to an adapter that is directly connected to its repeater shaft and indicates the transmitted ord-r from the conning station. The dials are similar to those of the propeller order transmitter-indicator (fig. 15–8, B). However, dial illumination is not provided. A vibrating bell on this instrument rings each time the propeller order is changed at the conning station.

RUDDER ORDER SYSTEM

The rudder order system, circuit L, is used to transmit rudder orders from the pilot house, central station, and secondary conning station to the after steering station. Instru-

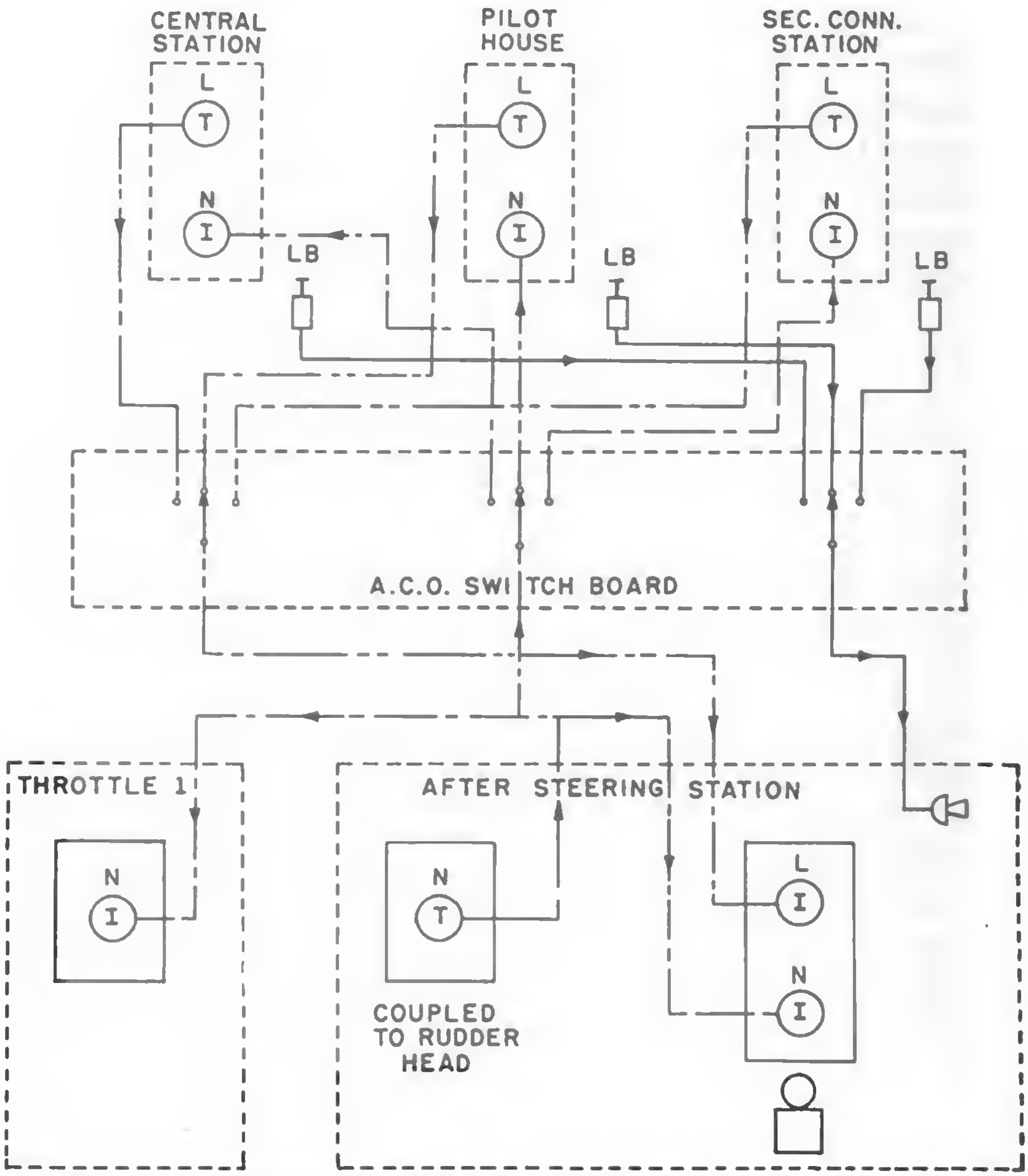


Figure 15–10.—Combined rudder order, rudder angle indicator, and steering emergency signal systems.

ments of this system are combined with instruments of the rudder angle indicator system in the conning stations and after steering station to indicate the positions of the rudder and thus serve as a repeat-back indicator for the rudder order system. A single rudder angle indicator is installed in throttle station 1. The rudder order system is also interconnected with the steering emergency signal system to provide an audible signal in the after steering station for this station to take over the steering control locally.

A block diagram of combined rudder order, rudder angle indicator, and steering emergency signal systems is shown in figure 15-10.

The rudder order system consists of a double rudder order transmitter-rudder angle indicator installed in the pilot house, central station, and secondary conning station. This instrument is electrically connected to a combined rudder order indicator-rudder angle indicator in the steering gear room.

A rudder order is originated at the conning station by turning the handle of the double rudder order transmitter-rudder angle indicator until the transmitter pointer marked RUDDER indicates the desired order on the instrument dial. The transmitted order is received on the rudder order indicator in the after steering station and in throttle station 1.

A selector switch is installed on the A. C. O. switchboard for selecting the combined rudder order transmitter-rudder angle indicator to control the circuit.

Double Rudder Order Transmitter-Rudder Angle Indicator

The double rudder order transmitter-rudder angle indicator installed in each conning station is used to transmit steering orders and to indicate rudder angle positions (fig. 15-11). This instrument consists of a type-5G synchro transmitter and a type-1F synchro repeater indicating on a fixed dial by means of two concentric revolving pointers. The transmitter and repeater are mounted on a common base plate to form a complete internal unit.

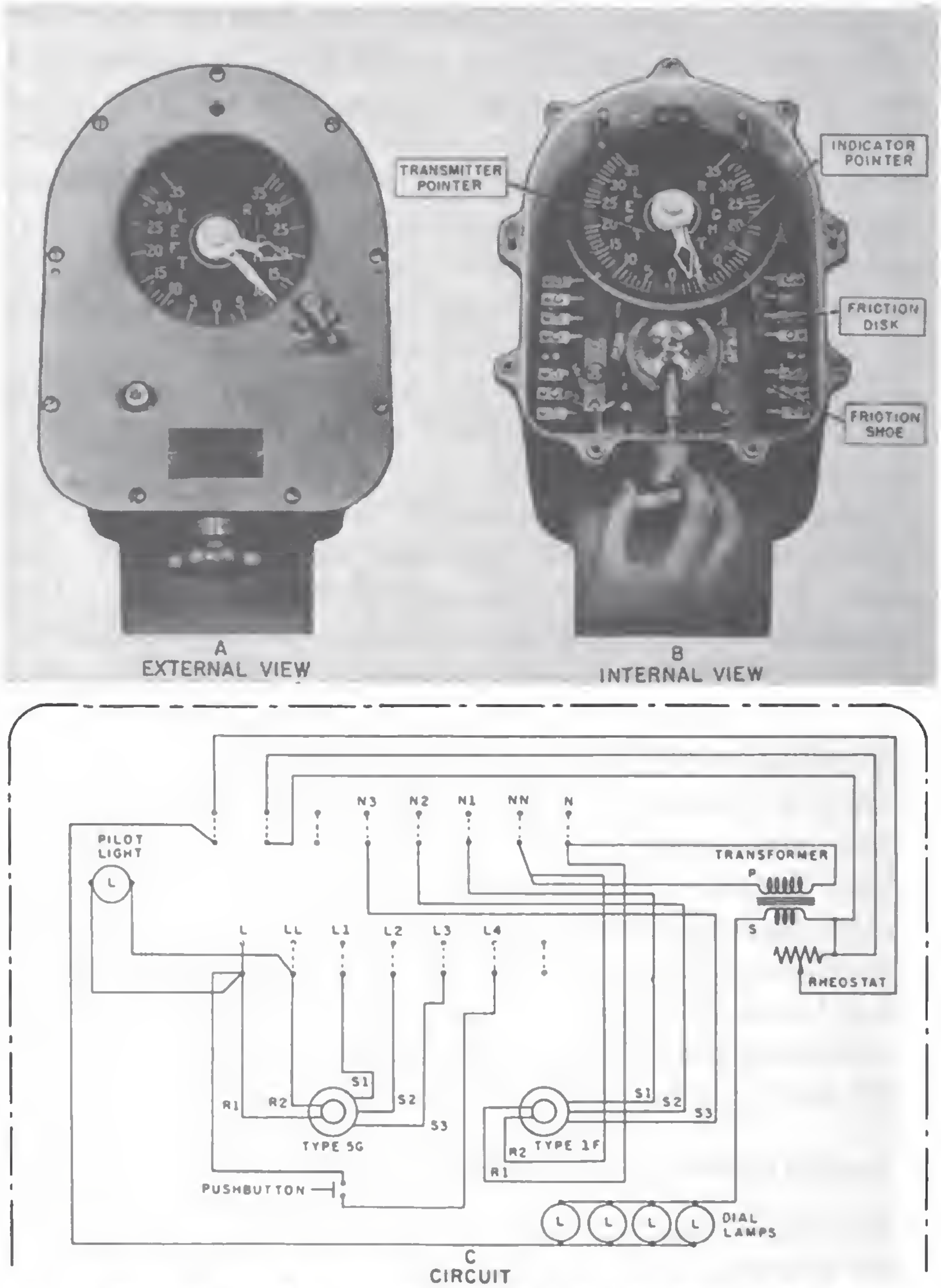


Figure 15–11.—Rudder order transmitter-rudder angle indicator.

The transmitter is driven through gearing by a handle attached to a shaft that extends through a watertight stuffing gland in the bottom of the housing (fig. 15–11, A). The gear ratio between the input shaft (handle) and the transmitter shaft is 1:4—that is, 1° of movement of the input shaft equals 4° on the transmitter shaft. The transmitter pointer marked RUDDER is connected to the transmitter shaft through two gears and is secured to a bearing housing supported on ball bearings at the center of the dial. This pointer indicates the transmitted rudder order to the after steering station and throttle station 1. A friction brake holds the transmitter shaft in the selected position (fig. 15–11, B). This instrument is not provided with automatic ringing.

The indicator pointer marked STEERING is connected directly to an extension of the repeater shaft and is concentric with the transmitter pointer. The two pointer supports turn concentrically about the same axis. This pointer indicates the reply from the rudder angle transmitter (coupled to the rudder head) to the transmitted rudder order from the conning station. This reply is also indicated on instruments in throttle station 1 and the after steering station.

The dial is mounted on four posts that are secured to the base plate. It is made of a translucent material having a black background with white markings. The dial is graduated in degrees to read from 0° to 35° left rudder and from 0° to 35° right rudder.

Dial illumination is provided by four lamps located in the corners of a light-conducting panel mounted behind the dial. The dial-lamp circuit is supplied by a transformer. The intensity of illumination is controlled by means of a variable resistor. A neon pilot light is provided to indicate (through a window in the cover) when the circuit is energized.

A push switch is provided on the cover for manual signaling to the after steering station. This push switch closes a microswitch that causes a bell on the after steering station instrument to ring.

The wiring diagram for this instrument is shown in figure 15–11, C.

Double Rudder Order Indicator–Rudder Angle Indicator

The double rudder order indicator–rudder angle indicator (fig. 15–12) installed in the after steering station is used to indicate the transmitted order from the conning station and the answer from the after steering station when the position of the rudder is changed to correspond with the transmitted order. The instrument consists of a type–5F and type–1F synchro repeater mounted on a common base plate to form a complete double indicator unit that is enclosed within the housing.

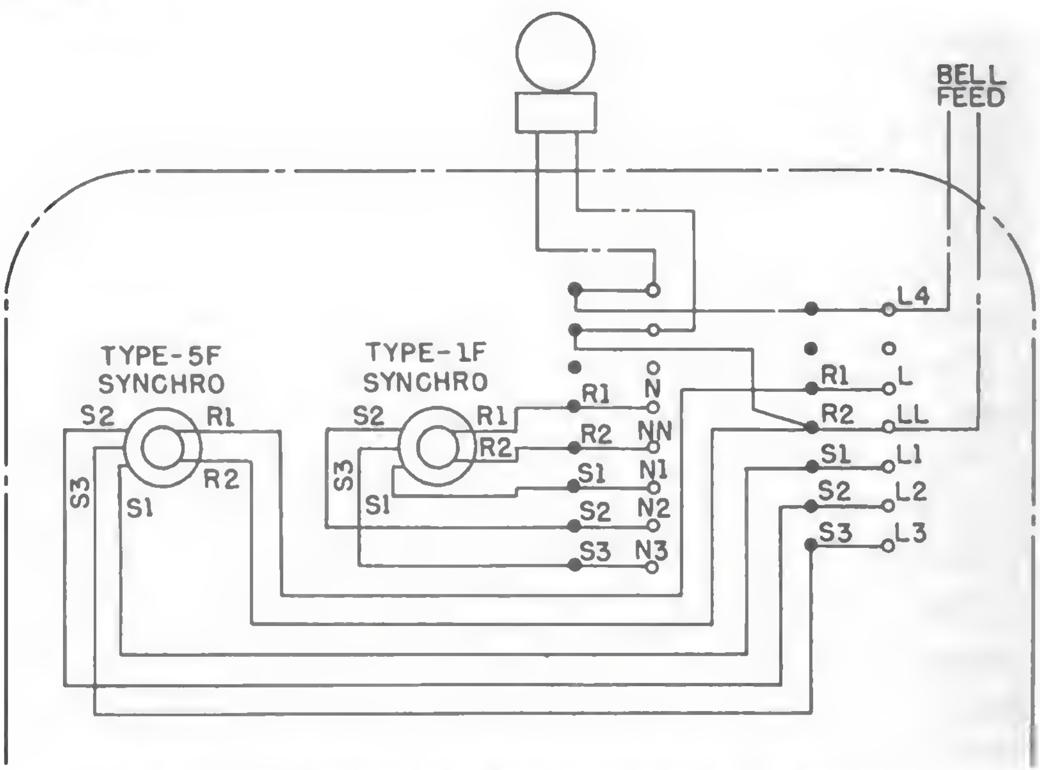


Figure 15–12.—Rudder order indicator–rudder angle indicator.

The two synchros indicate on a fixed dial by means of two concentric revolving pointers. The pointer marked PORT is connected to the type–1F repeater shaft through two gears and is secured to a bearing housing supported on ball bearings at the center of the dial. This pointer indicates the transmitted port rudder order on the after steering station instrument.

The pointer marked STARBOARD is connected directly to an extension of the type–5F repeater shaft and is concentric with the port pointer. The starboard pointer indicates the transmitted starboard rudder order on the after steering station instrument. The two pointer supports turn concentrically about the same axis.

The dial is similar to that of the rudder order transmitter–rudder angle indicator (fig. 15–11, A). No dial illumination is provided. A vibrating bell on the instrument rings each time the rudder order is changed.

RUDDER ANGLE INDICATOR SYSTEM

The rudder angle indicator system, circuit N, is used to transmit rudder angle positions to the after steering station; throttle station 1; and the pilot house, central station, or secondary conning station.

The rudder angle indicator system (fig. 15–10) consists of a transmitter coupled mechanically to the rudder head in the after steering station. This instrument is electrically connected to a double rudder order transmitter–rudder angle indicator in each conning station, a double rudder order indicator–rudder angle indicator in the after steering station, and a single rudder angle indicator in throttle station 1.

When a rudder order is received on the instrument in the after steering station, the position of the rudder is changed to correspond with the transmitted order from the conning station. As the position of the rudder is changed, the rudder angle transmitter transmits the angular position of the rudder to the rudder angle indicators.

Rudder Angle Transmitter

The rudder angle transmitter coupled to the rudder head in the after steering station is used to transmit rudder angle positions to indicators in the conning stations, after steering station, and throttle station 1 (fig. 15–13). This instrument consists of a type–5G synchro transmitter mounted on a bracket that is secured inside the housing (fig. 15–13, A). The transmitter is driven through gearing by a shaft that

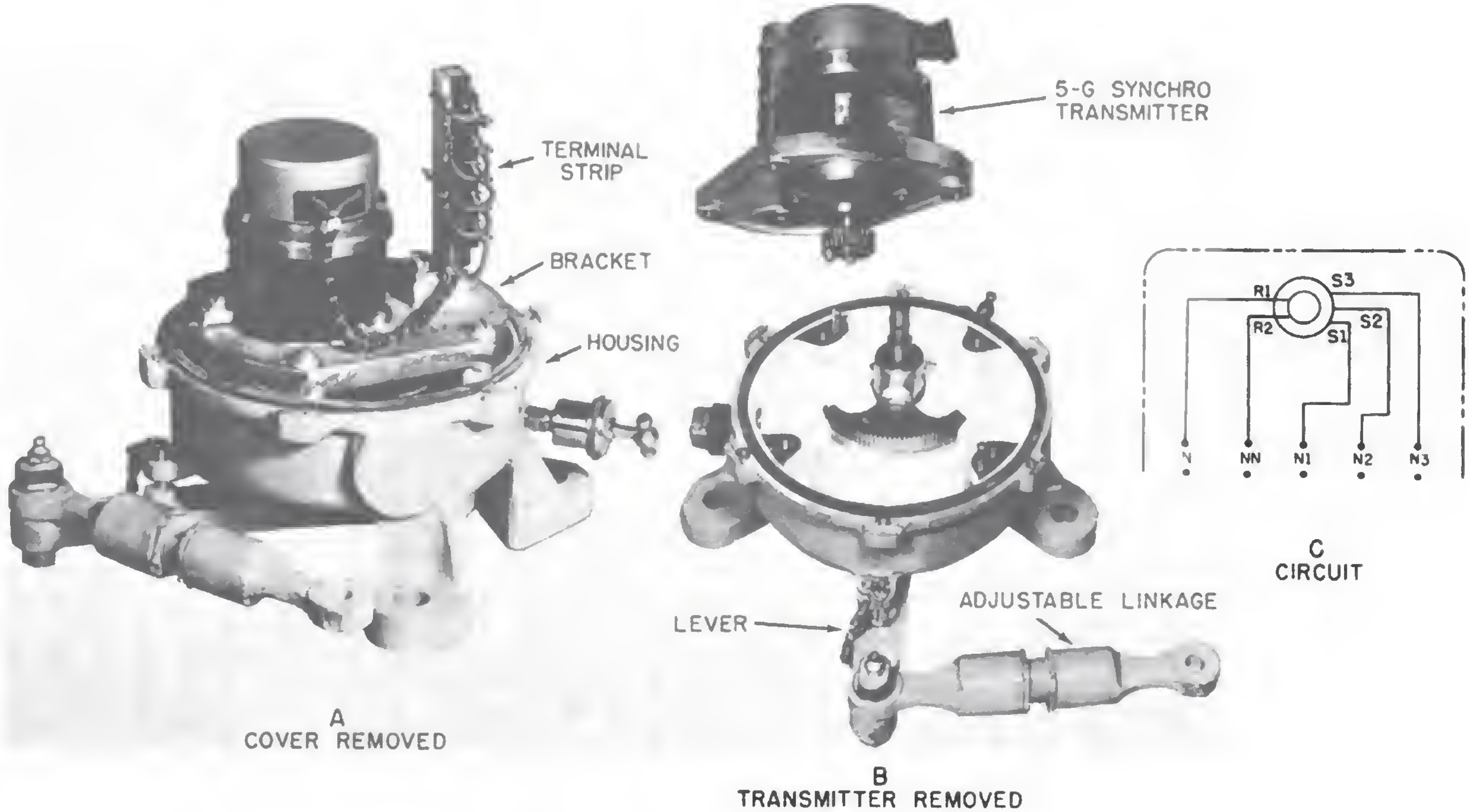


Figure 15-13.—Rudder angle transmitter.

extends through a watertight stuffing gland in the bottom of the housing (fig. 15–13, B). This shaft is coupled mechanically to the rudder head by means of a lever and an adjustable linkage. The gear ratio between the input shaft and the transmitter shaft is 4:1—that is 4° of movement of the transmitter shaft equals 1° on the input shaft. The transmitter is connected electrically to indicators in the conning stations, after steering station, and throttle station 1.

The wiring diagram for this instrument is shown in figure 15–13, C.

Rudder Angle Indicator

The single rudder angle indicator (fig. 15–14) installed in throttle station 1 is used to indicate the positions of the rudder. This instrument consists of a type–1F synchro repeater indicating on a fixed dial by means of a revolving pointer. The repeater is mounted on a base plate to form a complete internal unit. The pointer is connected directly

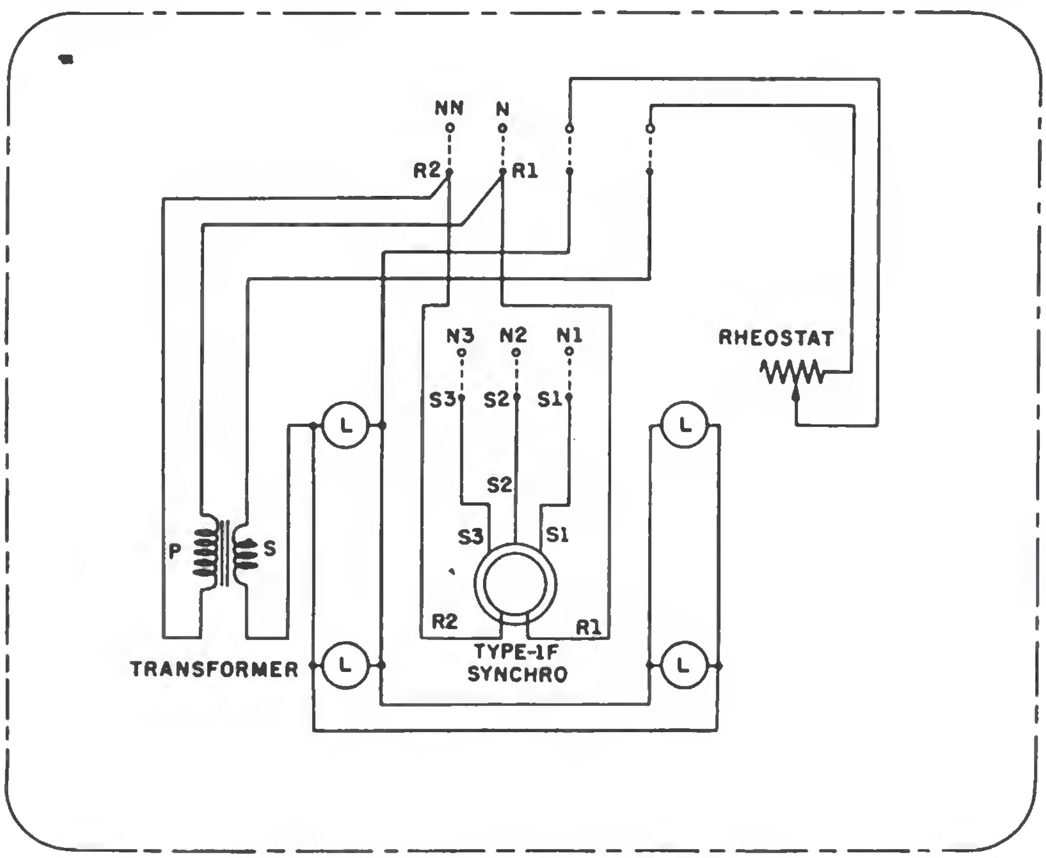


Figure 15–14.—Rudder angle indicator.

to an extension of the repeater shaft at the center of the dial. This pointer indicates the rudder angle positions transmitted by the rudder angle transmitter coupled mechanically to the rudder head.

The dial is similar to that of the rudder order transmitter–rudder angle indicator (fig. 15–11, A). Dial illumination is provided by four lamps located in the corners of a light-conducting panel mounted behind the dial. The dial-lamp circuit is supplied by a transformer. A variable resistor in series with this circuit controls the intensity of illumination. The leads for the synchro and transformer are connected to a 7-point connector attached to the back of the base plate.

STEERING EMERGENCY SIGNAL SYSTEM

The steering emergency signal system, circuit LB, provides an emergency signal in the after steering station for shifting the steering control to the trick wheel in the steering-gear room.

The steering emergency signal system (fig. 15–10) consists of a contact maker installed adjacent to the double rudder order transmitter–rudder angle indicator in the pilot house, central station, and secondary conning station. These contact makers are electrically connected to a siren in the after steering station.

When steering control is lost at the conning station the contact maker is manually operated to complete the circuit to the siren in the after steering station. This signal is an emergency warning to the steering motor room to take over the steering control locally.

QUIZ

1. What two circuits comprise the engine order system?
2. What are the locations of throttle stations 1 and 4 within the forward engineroom?
3. What are throttle stations 1 and 4 called?
4. What are the locations of throttle stations 2 and 3 within the after engineroom?
5. What are throttle stations 2 and 3 called?
6. What feature is provided in the transmitter-indicators located at the throttle stations to warn the operator when an order is answered incorrectly?
7. Where are transmitted engine orders received?
8. How are transmitted orders acknowledged?
9. Where is the reply from the following throttle station received?
10. Where is the reply from the leading throttle station received?
11. What two instruments are frequently combined on one mount in the conning stations?
12. What is the purpose of the propeller order system?
13. Why are instruments of the rudder angle indicator system combined with instruments of the rudder order system?
14. What is the purpose of the double rudder order indicator–rudder angle indicator installed in the after steering station?
15. What is the purpose of the steering emergency signal system?

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

ORGANIZATION

1. Machinery, Boiler, Electrical, Repair, and Auxiliary Divisions.
2. Office of the Engineering Department.
3. Power, lighting, and I. C. groups.
4. Equipage Custody Record cards.
5. Watch, Quarter, and Station Bill.
6. The instruction received from senior petty officers and their quarterly recommendations.
7. Ship's Allowance List.
8. Stub Requisition.
9. A comprehensive listing of all machinery and equipment, other than electronic equipment, installed in each ship.
10. Machinery History, Electrical History, Electronics History, and Hull History Cards.
11. Repair Record Card, Alteration Record Card, and Record of Field Changes Card.
12. Official NavShips forms and individual ship's forms.
13. The true condition of a battery.
14. Shop records for major overhauls, for inspections and tests, and for lubrication and cleaning.
15. Ship's memorandum work requests.
16. To inform the Bureau of Ships of all electrical and mechanical troubles encountered aboard ship.
17. Once each quarter.
18. Manufacturers' instruction books.
19. *Bureau of Ships Manual.*
20. In the log room.

CHAPTER 2

I. C. AND A. C. O. SWITCHBOARDS

1. To energize all I. C. and F. C. circuits including F. C. electronic systems in large ships and to supply power to other electronic equipment in small ships.
2. Behind the armour belt and below the waterline.
3. Normal, alternate, and emergency power supplies.
4. Live-front, semidead-front, dead-front, and dead-front front-service switchboards.
5. Installation, operation, and maintenance can be accomplished from the front of the switchboard.
6. To isolate various I. C. systems and to transfer control of certain systems from one station to another.
7. In the I. C. room.
8. To vital circuits the loss of which might endanger the ship.
9. By grouping two synchro indicators on each multipole rotary switch.
10. "Either or both" selection.
11. To energize local I. C. circuits.
12. In each steering gear room and in each turret.
13. By means of the letters "A" through "H."
14. A type-JR switch having a 4 JR-type rotor and containing 5 type-4JR sections.
15. Through a voltage-sensitive relay.
16. The preferred, alternate, or emergency power supply.
17. To provide a visible indication to the operating personnel showing the condition of the circuits supplied by these switchboards.
18. About 3,000 hours.
19. The gas used and the spacing of the electrodes.
20. A fault in the associated circuit.
21. To supply power to the most important I. C. and F. C. circuits.
22. Once each quarter.

CHAPTER 3

ELECTRONIC POWER SUPPLIES

1. Direct voltage.
2. (1) Battery; (2) rectified a-c power supply; (3) rectified output of a vibrator; and (4) motor-generator set.
3. (1) Transformer; (2) rectifier circuit; (3) filter circuit; (4) voltage regulator; and (5) voltage-divider system.

4. Electron tubes and metallic-oxide rectifiers.
5. About 15 volts; lower than that of the high-vacuum rectifier tube.
6. Gas-filled tube.
7. Maximum peak plate current and maximum peak inverse voltage.
8. The peak plate current may reach values of from three to four times the output current.
9. Because of the lower voltage drop in the gas-filled tube.
10. Copper to copper oxide.
11. Because when a bridge rectifier is used the full transformer secondary voltage is applied to the load circuit, whereas with the conventional rectifier, half of the secondary voltage is applied to the load.
12. To provide a discharge path when the circuit is deenergized and to equalize the voltages of the capacitors when they have different values of d-c leakage resistance.
13. Capacitor-input filter.
14. Choke-input filter.
15. For a given shunting effect, the capacitance varies inversely with the frequency. For a given series impedance, the choke inductance varies inversely with the frequency. For a given transformer, the exciting current varies inversely with the frequency.
16. If the line voltage increases, the ballast tube current and temperature increase. Thus, the series resistance increases and checks the rise in current.
17. By introducing any output voltage changes as a changing bias. The bias varies the opposition to load current through the tube in direct proportion to the voltage change.
18. About 10 percent.
19. To change a d-c source of power to a higher or lower value.

CHAPTER 4

ELECTRON-TUBE AMPLIFIERS

1. According to frequency, use, bias, and resonant quality of load.
2. D-c, a-f, i-f, r-f, and v-f.
3. (1) Voltage amplifiers amplify only voltage; (2) power amplifiers amplify both current and voltage.
4. In order to produce the largest possible amplified signal voltage across the plate load.
5. When the plate load impedance is equal to the plate resistance the power output is maximum.
6. Class-A, class-B, class-AB, and class-C operation.
7. Minimum distortion, low power output for a given tube, high-power amplification ratio, and low efficiency.

8. Medium power output, medium plate efficiency, and moderate power amplification.
9. Because of relatively large power output for a given minimum distortion and relatively high plate circuit efficiency.
10. Essentially a compromise below the low distortion of the class-A amplifier and the high efficiency of the class-B amplifier.
11. High plate efficiency, high power output, and low power amplification ratio.
12. Tuned and untuned amplifiers.
13. Frequency distortion, phase distortion, and amplitude distortion.
14. Resistance-capacitance, impedance, transformer, and direct coupling.
15. By replacing the tube with its equivalent circuit and analyzing the circuit.
16. Resistance-capacitance coupling.
17. (1) Good fidelity over a wide frequency range; (2) freedom from undesirable induced currents; and (3) suitability for pentodes and high-mu triodes.
18. For a given tube a lower B-supply voltage can be used because of the lower *IR* drop in the coil.
19. Because the high frequencies are bypassed to ground through the distributed capacitance acting in shunt with the coil.
20. (1) Use of a step-up transformer ratio will provide greater amplification per stage than the amplification of the tube; (2) d-c isolation is provided without the use of a blocking capacitor; (3) to provide a match between a high impedance source and a low-impedance load, or vice versa; and (4) to provide phase inversion without the use of special phase-inverting tubes.
21. (1) Higher cost; (2) more space requirement; (3) necessity for greater shielding; and (4) possibility of poorer frequency response at the higher and lower frequencies.
22. Better low-frequency response.
23. Require a higher B-supply voltage.
24. To feed back an in-phase signal to the input from the output of the amplifier.
25. To feed back a 180° out-of-phase signal to the input from the output of the amplifier.
26. (1) To reduce nonlinear distortion; (2) to reduce noises in the high-level stages of an amplifier; and (3) to make the gain independent of the effective load resistance.
27. (1) Employing a voltage-divider circuit; (2) current feedback; (3) voltage feedback; and (4) compound feedback.

28. A single-stage degenerative amplifier the output of which appears across the unbypassed cathode resistor.
29. The output voltage is in phase with the input voltage.
30. A cathode follower has a high input impedance and a low input capacitance.
31. The output impedance is low and the amplitude distortion is a minimum.
32. The output waveform is clipped and does not follow the input waveform.
33. (1) To match a high impedance to a low impedance; (2) to obtain good frequency response; (3) to prevent polarity inversion; and (4) to improve circuit stability.
34. (1) Transformer phase inverter; (2) vacuum-tube phase inverter; (3) single-tube paraphase amplifier; and (4) two-tube paraphase amplifier.
35. Distortions and transformer losses.
36. Omitting the cathode bypass capacitor.
37. (1) By degenerative feedback; and (2) by a voltage divider in the input circuit.
38. To drive class-A push-pull audio power amplifiers.

CHAPTER 5

OSCILLATORS

1. By feeding a portion of the output voltage back into the grid circuit in phase with the input signal and amplifying this signal beyond a certain critical point so that the feedback energy is sufficient to supply the grid-current losses.
2. The resonant frequency of the tuned circuit.
3. (1) Self-controlled, or self-excited, oscillators; and (2) crystal-controlled oscillators.
4. By means of transformer action (mutual inductive coupling) between the tickler coil and the grid coil.
5. Class-C operation.
6. When the energy fed back from the plate circuit to the grid circuit is sufficient to supply the circuit losses.
7. Series feed and shunt feed.
8. By mutual coupling between the grid and plate sections of the tank inductor.

9. Because the feedback is obtained from the voltage drop across the tank capacitor in the grid circuit.
10. Through the interelectrode capacitance of the tube.
11. The grid tank circuit.
12. By tuning the plate tank circuit to a frequency slightly higher than the grid tank circuit.
13. Cathode- to-plate electron stream within the tube.
14. By properly adjusting the tap on the screen voltage-divider resistor.
15. To hold the frequency of an oscillator to an exact value.
16. The grid-tank circuit.
17. Through the interelectrode capacitance within the tube from plate to grid.
18. The interelectrode capacitance is reduced by the screen grid and the feedback voltage is thereby limited to a value that will not damage the crystal.
19. The tank resembles a capacitance beyond point *A* instead of an inductance and the feedback becomes negative instead of positive, and therefore oscillations cease.
20. The plate tank circuit must be inductive.
21. Through the plate-to-cathode and grid-to-cathode interelectrode capacitance of the tube.
22. *R-C* networks.
23. (1) Phase-shift oscillator; (2) Wien-bridge oscillator; (3) saw-tooth generator; and (4) multivibrator.
24. By adjusting either the resistance or the capacitance.
25. By increasing the B-supply voltage so that the output voltage varies along the linear portion of the voltage characteristic curve.
26. To the grid of the triode.
27. By increasing the grid bias.
28. By slight changes in electrical quantities in the circuits.
29. By using three *R-C* networks which shift the feedback voltage 60° each, or a total of 180°.
30. Normally fixed.
31. To eliminate feedback voltages of all frequencies except the desired frequently in the output to provide the stable output frequency.

32. (1) Can produce a wide range of frequencies; (2) the wave-form is nearly a true sine wave; (3) the frequency stability is excellent; and (4) the output voltage amplitude is nearly constant over a wide frequency range.
33. (1) Can be adjusted to generate a wide range of frequencies; (2) generates a wave that contains many harmonics; and (3) frequency of oscillation is readily controlled.

CHAPTER 6

ELECTRONIC TEST EQUIPMENT

1. Direct voltages, alternating voltages, resistances, and direct currents.
2. (1) Basic meter circuit; (2) d-c voltmeter; (3) a-c voltmeter; (4) ohmmeter; (5) milliammeter; and (6) power supply.
3. An electronic bridge circuit.
4. The meter is connected across one pair of diagonally opposite corners and the d-c supply voltage is connected across the other pair.
5. Directly through the d-c probe and voltage divider to the grid of a triode in one of the bridge arms.
6. Through a high-voltage adaptor screwed onto the end of the d-c probe.
7. Through the 250-volt a-c probe which employs a voltage-doubling circuit.
8. Through the 1,000-volt probe which employs a crystal rectifier.
9. It is the mutual conductance or transconductance which includes the effect of load impedance in the plate circuit of the tube being tested.
10. Because this test indicates the over-all condition of the tube in actual operation by measuring the grid-plate dynamic transconductance and not merely the condition of the cathode emitting surface.
11. (1) Power supply; (2) line-voltage test; (3) short-circuit test; (4) rectifier test; (5) transconductance test; (6) gas test; (7) noise test; (8) voltmeter; (9) ohmmeter; (10) capacity test; and (11) milliammeter circuits.
12. To adjust the voltage to the rated value for the tube.
13. Emission test.
14. To determine the effectiveness of the grid to control plate current.

15. Reverse grid current lowers the bias and increases plate current.
16. Audible signal similar to static.
17. (1) Signal tracing; (2) comparing waveforms; and (3) comparing and calibrating frequencies.
18. Measurements of (1) direct voltages, (2) alternating voltages, (3) phase relations, and (4) signal amplitude and frequency.
19. (1) Cathode-ray tube; (2) time-base (sweep-frequency) generator; (3) *Y*-axis amplifier; (4) *X*-axis amplifier; and (5) power supply.
20. Cathode, control grid, and two anodes.
21. Positive.
22. Anode 1 trims the edges of the electron beam and anode 2 increases the speed of the beam.
23. As a bright spot at the center.
24. A horizontal line extending across the screen through its center.
25. A vertical line extending across the screen through its center.
26. (1) The amplitude of the deflection voltages and (2) the speed of the electrons in the beam.
27. By varying the bias on the grid.
28. To apply a linear saw-tooth voltage to the horizontal deflecting plates in a controlled relation to the signal voltage applied to the vertical deflection plates so as to present a waveform on the screen.
29. To increase the amplitude of the signal before it is applied to the vertical deflection plates.
30. To increase the amplitude of the signal applied to the horizontal deflection plates.

CHAPTER 7

ALARM AND WARNING SYSTEMS

1. To indicate abnormal or dangerous conditions in time to prevent casualties to machinery and personnel.
2. (1) Manual, (2) pressure, (3) thermostatic, (4) mechanical, and (5) conductivity switches.
3. Type-JR switch.
4. A bellows or diaphragm that works an adjustable spring which causes the contacts to close automatically when the operating pressure fails below a specified value.

5. A sealed-in liquid that expands with rising temperature to operate a bellows that works against an adjustable spring which causes the contacts to close when the operating temperature exceeds a specific value.
6. Push-action type and the cam-action type.
7. A pair of platinum-sheathed electrodes molded into an insulating base and enclosed by a perforated shield.
8. An electromechanical device by means of which a current change in one circuit causes contacts to produce a change in the electrical conditions in its own or other circuits.
9. To open and close circuits that may operate indicating lights, annunciator drops, or audible signals.
10. (1) Nonwatertight, (2) watertight, and (3) pressure-proof types.
11. Mercurial thermostat.
12. The intermediate and upper contacts.
13. To minimize the separation of the mercury column when subjected to shock.
14. (1) Noise level of the location; and (2) the kind of sound desired.
15. (1) Bells; (2) buzzers; (3) horns; and (4) sirens.
16. (1) Lamp-type indicators and (2) annunciators.
17. To provide protection against loss of illumination if one lamp burns out.
18. To illuminate the colored glass and brass target of the indicator and identify the alarm being sounded.
19. Drop type and drum type.
20. Changing current through an electromagnet causes a drum target to turn to the indicating position.
21. The mercury is driven up to the upper contact on the thermostat, shorting out the resistor and allowing full current to operate the alarm.
22. The mercury falls below the intermediate contact on the thermostat and opens the supervisory circuit to sound the trouble alarm on the switchboard.

CHAPTER 8

SOUND AND SOUND EQUIPMENT

1. A state of vibration.
2. Transverse and longitudinal.
3. At right angles to the direction of propagation.

4. Forward and backward in the direction of propagation.
5. Because gases and liquids offer only elastic resistance to compression and no sustained resistance to shear or change in shape.
6. A longitudinal wave disturbance consisting of alternate compressions and rarefactions in the medium.
7. The time in seconds required for the particle to complete one vibration.
8. The number of vibrations completed per second.
9. The maximum displacement of the particle from the undisturbed, or equilibrium, position.
10. When they continue to pass through corresponding points in their respective paths at the same instant.
11. When they reach their maximum displacement in opposite directions at the same instant.
12. The distance, measured along the direction of propagation, between two corresponding points of equal intensity that are in phase on adjacent waves.
13. Elasticity, density, and temperature.
14. Interference between the waves results.
15. Constructive interference is produced.
16. Destructive interference is produced.
17. The beat frequency or difference frequency.
18. It produces alternately loud and soft pulses or throbs.
19. Doppler effect.
20. Acoustics.
21. An echo.
22. Reverberation.
23. Pitch, intensity, and quality.
24. The vibration frequency of the sounding source.
25. The amplitude of vibrations.
26. Fundamental tone.
27. Upon the number and frequency of the overtones and their relative intensity with respect to the fundamental.
28. The decibel.
29. The least sound perceptible to the ear.
30. To convert sound energy into electrical energy.
31. (1) Magnetic; (2) dynamic; (3) crystal; and (4) carbon types.
32. Magnetic microphone.

33. Permanent magnet and a coil of wire inside of which is a small armature attached to a diaphragm.
34. Frequency response, impedance, and sensitivity.
35. By cutting off the system response at some lower limit and by employing an emphasized frequency-response characteristic which rises with increasing frequency.
36. Only as it relates to the load impedance into which the microphone is designed to operate.
37. To obtain a high signal-to-noise ratio and thus reduce the number of amplifier stages.
38. Direct radiator type and horn type.
39. Dynamic or moving coil driving mechanism.
40. The operation is the reverse of that of the dynamic microphone.
41. To prevent the back wave from neutralizing the front wave at low frequencies.
42. A baffle.
43. To produce an impedance match between the loudspeaker driving unit and the air.
44. By coupling individual horn sections that are combined mechanically into a common loudspeaker assembly.
45. The frequency response of the loudspeaker.
46. The frequency and the horn size of the loudspeaker.
47. As the frequency increases the directivity increases.
48. Heating, mechanical strength, and production of nonlinear distortion.
49. Matching transformers.

CHAPTER 9

ANNOUNCING AND INTERCOMMUNICATING SYSTEMS

1. (1) Central amplifier system and (2) intercommunicating system.
2. The central amplifier system broadcasts orders or information simultaneously to a number of stations. The intercom system provides two-way transmission of the orders or information.
3. Circuit designation in the MC series.

4. (1) Microphone components, (2) amplifier components, and (3) loudspeaker components.
5. (1) Portable microphones; (2) transmitter control stations; (3) control boxes; (4) talk-back switches; and (5) microphone jack boxes.
6. Low, standard, medium, and high, depending on the power output.
7. Size of space to be covered and the noise level in that space.
8. Direct radiator design.
9. Folded-horn design.
10. Circuits 1MC, 2MC, and 6MC.
11. (1) General alarm; (2) chemical attack alarm; (3) salvo; and (4) cease firing signals.
12. One voltage amplifier with compressor and one 500-watt power amplifier.
13. To make speech more intelligible when there is high background noise.
14. To receive, amplify, and reproduce speech from a sound-powered telephone line using a sound-powered telephone headset.
15. Where the noise level is high, such as machinery spaces and gun mounts.
16. (1) To direct amphibious operations; (2) for topside communications; and (3) for intership communications.
17. Two-way amplified voice communications between any two stations or from one station to any number of stations in the system.
18. The intercom system.
19. It serves as a loudspeaker and as a microphone.
20. For receiving, the loudspeaker is connected directly to the transmitting amplifier.

CHAPTER 10

SOUND RECORDING AND REPRODUCING SYSTEMS

1. (1) Mechanical; (2) magnetic; and (3) photographic.
2. Disks or films.
3. (1) Microphones; (2) audio amplifier; (3) recording head; (4) cutting stylus; and (5) recording medium.

4. Pick-up head.
5. A magnetic microphone.
6. No.
7. Tape or wire.
8. The orientation of magnetic particles in a tape or wire according to the signal pattern by an electromagnet energized by a signal current.
9. In length, intensity, and direction (polarity).
10. The recording head functions as the playback head.
11. By feeding a high-frequency a-c signal to the erase head that cancels the magnetic fields comprising the recording.
12. By exposing a moving photo-sensitive film to a beam of light that is modulated by the sound pattern being recorded.
13. Variable-density recording and variable-area recording.
14. Magnetically coated paper tape.
15. Two.
16. On a rotating disk 90° apart.
17. Magnetic recording heads are used for playback.
18. To distinguish channel 2 from channel 1.
19. (1) Audio amplifier; (2) oscillator; (3) oscillator amplifier; and (4) power supply.
20. (1) Resistance measurements; (2) voltage measurements; (3) ground tests; and (4) sensitivity tests.
21. Ground tests.
22. Sensitivity tests.

CHAPTER 11

SOUND MOTION PICTURE SYSTEM

1. Because of the high temperature of its filament.
2. The sun and stars.
3. The moon and planets.
4. No; they are transverse.
5. The amplitude of a light wave.
6. The wavelength.
7. The wavefront.

8. A light ray.
9. They are mutually perpendicular.
10. $v = f\lambda$
11. The frequency of vibration or the wavelength of the light wave.
12. Because all colors are contained in sunlight and each object reflects that part of the spectrum associated with its own color.
13. Yes.
14. The incident ray.
15. The point of incidence.
16. The reflected ray.
17. The normal to the surface.
18. The angle of incidence.
19. The angle of reflection.
20. The angle of incidence equals the angle of reflection.
21. The refracted ray.
22. The principal focus.
23. The focal length.
24. A convex lens.
25. By using a lens of different focal length and changing the distance from the lens to the object.
26. The sound track leads by 26 frames.
27. To concentrate the light from the projection lamp on the picture area.
28. To focus the image of the film frame on the screen.
29. To focus a beam of light from the exciter lamp on the sound track.
30. (1) Sound motion picture projector; (2) amplifier; and (3) loudspeaker.

CHAPTER 12

DIAL TELEPHONE SYSTEM

1. By means of the dial.
2. It causes a series of interruptions, or impulses, in the current flowing in the line circuit.
3. (1) Type-A desk telephone; (2) type-B bulkhead telephone; (3) type-C watertight bulkhead telephone; (4) type-D intercom telephone; and (5) type-E compact telephone.
4. (1) Handset; (2) dial; (3) cradle switch; (4) ringer; (5) capacitors; and (6) induction coil.

5. A diaphragm and a carbon button microphone.
6. The transmitter current.
7. The voice current.
8. To convert the voice current back into sound waves.
9. Permanent-magnet type.
10. (1) Finger plate; (2) number plate; (3) speed control governor; (4) impulse cam and springs; (5) shunt cam and springs; and (6) driving mechanism.
11. Equal.
12. To shunt the receiver and transmitter circuits and prevent the impulses from being heard in the receiver during dialing.
13. The signaling circuit is connected across the line and the talking circuit is open.
14. The talking circuit is connected across the line and the signaling circuit is open.
15. Polarized untuned type of ringer.
16. It allows a-c ringing current to pass through the ringer and prevents the flow of direct current.
17. It improves the transmission output characteristics of the telephone.
18. To (1) couple the transmitter and receiver units to the line; (2) increase the output volume by boosting the voice current variations; and (3) prevent or decrease sidetone.
19. (1) Dialing; (2) ringing; (3) transmission; and (4) receiving circuits.
20. Strowger step-by-step type.
21. 100 pairs.
22. In an arc of a circle with vertical rows parallel to the axis of the cylinder.
23. When digit "3" is dialed, the wipers on the shaft of the Strowger switch step up to the third level in the connector bank, and when digit "2" is dialed, the wipers rotate in 2 steps on the third level.
24. Because it operates under the control of dial impulses.
25. Because its operation is automatic and not under the control of the calling telephone dial.
26. One.
27. Line normals.
28. Between the two 100-line groups of connector banks.
29. Trunks.
30. Trunk hunting.

CHAPTER 13

GYROCOMPASS ERRORS

1. The lubber's line.
2. Linear speed over the surface of the ocean.
3. Changes in course and speed.
4. Roll and pitch.
5. Tangent latitude error and speed, course, latitude error.
6. Ballistic deflection error and ballistic damping error.
7. Acceleration and centrifugal forces due to roll or pitch.
8. The angle between the true meridian and the settling position of the north axle of the Sperry compass in any latitude other than the equator.
9. Slightly east of the meridian with an upward tilt.
10. Slightly west of the meridian with a downward tilt.
11. The tangent latitude error.
12. The tangent of the latitude in which the compass is operating.
13. By the speed and latitude corrector, which permits manual movement of the lubber's line.
14. Because the Arma compass does not use an offset connection in the pendulous weight that would cause compound precession.
15. The apparent or virtual meridian.
16. The tangent latitude error or the speed, course, latitude error.
17. Westerly.
18. Easterly.
19. Speed and latitude corrector and cosine ring.
20. Speed and latitude correction mechanism and eccentric bearing and fork.
21. Only during changes of speed or course.
22. Ballistic deflection.
23. Ballistic deflection error.
24. Approximately 85 minutes.
25. During the period when the speed is being changed.
26. By adjusting the mercury tanks to provide the additional torque necessary to cause a faster or slower rate of precession.
27. By varying the speed of the rotors to cause a faster or slower rate of precession.
28. Ballistic damping error.

29. Acceleration forces.
30. Centrifugal forces.
31. By a device that automatically moves the mercury ballistic arm from the eccentric position to the true vertical axis to eliminate damping.
32. By a device that automatically closes a valve in the pipeline between the oil damping tanks to eliminate damping.
33. To the east.
34. To the west.
35. By dynamically balancing the sensitive element about the horizontal axis.
36. By using two gyros mounted on the sensitive element at an angle of about 40° and coupled by a linkage to prevent the sensitive element from swinging in an east-west direction.
37. By compensator weights attached to the vertical ring to make the sensitive element a truly hemispherical mass.
38. By maintaining a uniform distribution of the masses of the sensitive element about the vertical axis.

CHAPTER 14

GYROCOMPASSES

1. (1) Sensitive element; (2) mercury ballistic; (3) phantom element; (4) spider; and (5) binnacle and gimbal rings.
2. The north-seeking gyroscopic element of the master compass.
3. 11,000 rpm.
4. By means of horizontal bearing studs mounted in the vertical ring.
5. To reduce the friction caused by air resistance.
6. By a wire suspension from the head of the phantom element.
7. To prevent the gyro case from tilting about its horizontal axis when the compass is not operating.
8. To keep the vertical ring in line with the phantom ring when the compass is not operating.
9. By two frames that project out beyond each end of the rotor axle.
10. To provide an even distribution of the weight of the gyrocompass.
11. To indicate a misalignment between the phantom element and the sensitive element.

12. By means of flexible wires attached to the phantom élement.
13. To apply the gravity-controlling force to the gyro unit and make it north-seeking.
14. About the east-west axis of the sensitive element.
15. Through an adjustable offset bearing stud mounted on the ballistic connection arm.
16. By simultaneously rotating the mercury tanks closer to or farther from the horizontal center line of the gyrocompass.
17. By moving the pivoted connection arm until the connection bearing is in line with the vertical axis of the gyro.
18. To provide a follow-up support for the sensitive element.
19. To drive the (1) phantom element into alignment with the vertical ring by means of the azimuth gear; (2) automatic damping eliminator switch; and (3) 36-speed synchro transmitter.
20. The 1-speed synchro transmitter through the rotor gear.
21. The cosine cam.
22. To support the entire inner, or moving, member of the gyrocompass.
23. (1) Azimuth motor; (2) automatic eliminator switch; (3) speed and latitude corrector; (4) 36-speed synchro transmitter; and (5) 1-speed synchro transmitter.
24. (1) Follow-up transformer; (2) azimuth follow-up motor; (3) compass cards; (4) synchro transmitters; (5) automatic damping eliminator switch; and (6) speed correction mechanism.
25. The sensitive element and the phantom element.
26. To automatically eliminate damping when the ship executes rapid changes in speed or course.
27. (1) Sensitive element; (2) mercury flotation; (3) spider; (4) azimuth follow-up mechanism; and (5) binnacle and gimbal rings.
28. 40°.
29. To eliminate the intercardinal error by preventing the sensitive element from swinging in an east-west direction.
30. East side.
31. To automatically eliminate damping when the ship executes rapid changes in speed or course.
32. To provide a frictionless suspension for the sensitive element.
33. So that the center of gravity of the sensitive element is slightly below the level of flotation.
34. By means of mercury contacts located at the center of the float ball.

35. To eliminate any possible static friction in the mercury that might tend to reduce the freedom of the sensitive element.
36. The bowl surrounds and supports the sensitive element and mercury flotation.
37. From the inner gimbal ring by 24 helical springs.
38. (1) The azimuth follow-up mechanism and (2) the speed-course correction mechanism.
39. The spider.
40. (1) Follow-up soil; (2) follow-up motor; (3) compass card; (4) commutator transmitters; (5) damping cutout contacts; and (6) speed correction mechanism.
41. The follow-up coil frame is suspended from the spider by the follow-up coil support which is the movable part of the spider.
42. To drive the follow-up coil into alignment with the sensitive element when the follow-up coil is displaced from its neutral position with respect to the sensitive element.
43. On top of the spider assembly.
44. (1) Rate of turn switch and (2) amount of turn switch.
45. To introduce a correction into the gyrocompass because the sensitive element does not settle on the true meridian when the ship is traveling on other than a true east or a true west course.

CHAPTER 15

SHIP CONTROL ORDER AND INDICATING SYSTEMS

1. Circuits 1MB and 2MB.
2. Throttle 1 starboard and throttle 4 port.
3. Leading throttle stations.
4. Throttle 2 starboard and throttle 3 port.
5. Following throttle stations.
6. Wrong-direction signal contacts, circuit DW.
7. On all indicators in the circuit.
8. By matching the reply pointer with the received order on the transmitter-indicator in the following throttle station.
9. On the single indicator in the leading throttle station.
10. On the double transmitter-indicator in the conning station that originated the order and at each fireroom.
11. Double engine order transmitter-indicator and propeller order transmitter-indicator.

12. To transmit small changes in speed to the throttle stations.
13. To provide a repeat-back indicator system for the rudder order system.
14. To indicate the transmitted order from the conning station and the answer from the after steering station when the position of the rudder is changed to correspond with the transmitted order.
15. To sound an alarm in the after steering station for shifting the steering control to the trick wheel.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

I. C. ELECTRICIAN (IC)

Rating Code No. 4200

General Service Rating

Scope

I. C. Electricians maintain and repair interior communications (IC) systems, gyrocompass systems, amplified and unamplified voice systems, alarm and warning systems, and related equipment; stand I. C. and gyrocompass watches.

Emergency Service Rating

(Same as General Service Rating.)

Navy Job Classifications and Codes

For specific Navy job classifications included within this rating and the applicable job codes, see *Manual of Enlisted Navy Job Classifications*, NavPers 15105 (Revised), codes IC–4700 to IC–4799.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	Applicable rates IC
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Identify insulation materials and varnishes	3
2. Identify electrical cables, wiring, and fittings	3
3. Locate and identify I. C. equipment and circuits	3
4. Read electrical drawings and sketches	3
5. Operate I. C. and action cut-out (A. C. O.) switchboards:	
a. Transfer circuits for normal operation and battle conditions	3
6. Use all electrician's common hand and small bench tools, including soldering irons and electric-powered tools such as drills and grinders	3

Qualifications for Advancement in Rating	Applicable rates IC
100 PRACTICAL FACTORS—Continued	
101 OPERATIONAL—Continued	
7. Use voltmeter, ammeter, ohmmeter, megger, and tachometer	3
8. Inspect condition of, and install, dry cell and wet cell batteries	3
9. Extinguish electrical fires using CO_2 extinguishers. (Simulated conditions)	3
10. Rescue a person in contact with an energized circuit; resuscitate a person unconscious from electrical shock; treat for electrical shock and burns. (Simulated conditions)	3
11. Energize and start, test for proper operation, operate (making any external adjustments), and secure ship's metering and indicating systems, ship's control systems, alarm and warning systems, amplified voice and projection equipment, and signal system	2
12. Work from electrical drawings	2
13. Use electronic voltmeter, tube tester, multitester, circuit analyzer, oscilloscope, and signal generator	2
102 MAINTENANCE AND/OR REPAIR	
1. Maintain all electrician's hand and bench tools, including soldering copper and electric-powered tools	3
2. Find and clear short and open circuits, and grounds in cables, wiring, fittings, call bells, and buzzers	3
3. Make complete casualty analysis and repair sound-powered telephone hand and head sets	3
4. Cross-connect I. C. systems to operate under emergency conditions	3
5. Renew section of flexible cable between a junction box and a synchro instrument such as a gyrocompass repeater	2
6. Replace tubes, and handle troubles of starting panel controllers as applied to I. C. equipment	2
7. Clean, test, and lubricate dead-reckoning equipment	2
8. Tighten connections on switchboards and control panels	2
9. Casualty analysis and corrective maintenance on the following:	
a. Alarm and warning systems—contact makers, audible signal, and indicators	2
b. Voice recorders and record players	2

Qualifications for Advancement in Rating	Applicable rates IC
100 PRACTICAL FACTORS—Continued	
102 MAINTENANCE AND/OR REPAIR—Continued	
9. Casualty analysis and corrective maintenance on the following—Continued	
c. Sound motion picture projectors (16-mm.)	2
d. Intercoms and portable announcing equipment	2
e. Ship control order and indicating system	2
f. Repeater units (synchros)	2
g. Motor-generator sets and rotary converters (no disassembly) and control panels as applied to I. C. equipment	2
h. Sound-powered telephone circuits except sector control and C. I. C. circuits	2
103 ADMINISTRATIVE AND/OR CLERICAL	
1. Maintain all required records at watch station	3
2. Request replacement parts for I. C. devices	3
3. Use electrical publications furnished to the electrical division for selecting materials and identifying equipment parts	3
4. Take charge of I. C. room while under way	2
200 EXAMINATION SUBJECTS	
201 OPERATIONAL	
1. Procedures and safety precautions involved in performing tasks appropriate to the applicable rates listed under 100 Practical Factors	--------
2. Nomenclature and function of I. C. devices and associated equipment	3
3. Function and use of voltmeter, ammeter, ohmmeter, megger, and tachometer	3
4. Classifications, markings, and functions of I. C. circuits	3
5. Theory of direct and alternating current; principles and application of electromagnetic induction; relationship of current, voltage, and resistance in d-c circuits; effects of resistance, capacitance, and inductance in simple a-c circuits	3
6. Types and uses of electron tubes in I. C. systems	3
7. Relation between filament (cathode) plate and grid in electron tube	3
8. Transferring circuits on I. C. and A. C. O. switchboards for normal operation and battle conditions	3

Qualifications for Advancement in Rating	Applicable rates IC
200 EXAMINATION SUBJECTS—Continued	
201 OPERATIONAL—Continued	
9. Operating principles of power units such as motor-generator sets, control panels, transformers, and rectifiers as applied to I. C. equipment	3
10. Procedures for energizing, starting, testing for proper operation, and securing I. C. systems	3
11. Fundamentals of power distribution systems aboard naval vessels	3
12. Function and use of oscilloscope, tube tester, circuit analyzer, electronic voltmeter, multitester, and signal generator	2
13. Principles of I. C. polyphase circuits	2
14. Types and uses of gas-filled tubes and cathode-ray tubes in I. C. systems	2
202 MAINTENANCE AND/OR REPAIR	
1. Care and stowage of I. C. materials	3
2. Casualty analysis and corrective maintenance for the following I. C. equipment:	
a. Cables, wiring, and fittings	3
b. Sound-powered telephone hand and head sets	3
3. Procedures for cross-connecting I. C. systems under emergency conditions	2
4. Procedures for replacing electron tubes	2
5. Corrective maintenance on the following:	
a. Alarm and warning systems—contact makers, audible signals, and indicators	2
b. Voice recorders and record players	2
c. Sound motion picture projectors (16-mm.)	2
d. Intercoms and portable announcing systems	2
e. Sound-powered telephone circuits except sector control and C. I. C. circuits	2
f. Ship control order and indicating system	2
g. Repeater units (synchros)	2
h. Motor-generator sets, rotary converters, and control panels as applied to I. C. equipment	2

INDEX

Acoustics, 272
Action cutout (A. C. O.) and transfer switches, 508
Action cutout (A. C. O.) switchboards, 28–32
Alarm
  and warning systems, 7, 237–263
    circulating-water high-temperature, 263
    lubricating-oil low-pressure, 261
    sprinkling, 261
  circuit test, high-temperature, 17
  switchboard, 254
Allowance list, 7
Alternating-current power supplies, 62–89
Amplifier(s)
  1A-TW intercommunicating unit, 339
  cascade, 108
  circuit, 214
  classes, 96–102
  classification of, 94–103
  components, 304
  control panel, 395
  distortion in, 103–107
  electron-tube, 94–149
  feedback, 130–137
  IC/QAF-1D, 391
  paraphase, 146–149
  portable announcing system, 333
  power, 96, 316
Amplifier(s)—Continued
  push-pull power, 393
  R-C coupled, 111–115
  system
    central, 298, 300–336
    sound-powered telephone, 325–331
  telephone, 326
  troubles, 364
  tuned, untuned, 103
  type-MCA, 306
  type-MCF, 306
  type-MCG, 305
  type-MCT, 306
  vacuum-tube; equivalent circuit of, 108
  voltage, 95
  X-axis, 229
  Y-axis, 228
Announcing and intercommunicating systems, 298–345
  MCG general, 307–325
  portable, 331–336
Annunciator-type indicators, 252
Audible signals, 246–249
Azimuth follow-up mechanism, 471, 487

Ballistic errors
  damping, 447
  deflection, 443, 444
Basic
  100-line system, 421
  finder-connector link, 424
Beachmaster announcing system, 331
Bells, 247

Bureau of Ships
  Bulletin of Information, 21, 22
  Manual, 6, 21, 22, 298, 401
  technical bulletins, 22
Bus-transfer equipment, 37–41
Buzzers, 247

Capacitors, 413
Carbon microphone, 284
Cards
  field changes, record (NavShips 537), 13
  history
    electrical (NavShips 527A), 11
    electronic (NavShips 536), 11
    hull (NavShips 539), 11
    machinery (NavShips 527), 11
  record
    alteration (NavShips 530), 13
    megger test (NavShips 531). 12
    repair (NavShips 529), 13
Catalog of Navy Material, 8
Cathode followers, 137–143
Centrifugal forces due to roll or pitch, 455
Circuits
  amplifier, 214
  attenuator, 215
  basic meter, 18
  capacity test, 207
  compressor, 315
  compressor-limiter, 315
  dialing, 415
  filter, 70–76
  limiter, 316
  milliammeter, 192, 208
  ohmmeter, 190, 207
  operation, 139
  oscillator, 154, 213
  power supply, 193, 198, 215, 230
  receiving, 418
  ringing, 415
Circuits—Continued
  telephone, 413
  transmission, 415
  voltmeter, 205
Circulating-water high-temperature alarm system, 263
Colpitts oscillator, 160
Compass
  Arma, 434, 441, 447, 449, 453, 456
  card, 431, 472, 487
  master, 459
  record book, 18
  Sperry, 434, 438, 446–449, 453, 456
Control(s)
  amplifier gain, 233
  beam, 231
  fine frequency, 232
  focus, 231
  general, 194, 209, 215, 231
  intensity, 231
  order and indicating systems, ship, 496–526
  panel, 395
  station, 322
  systems; ship, 7
  time-base, 232
  unit, constant-frequency, 56–58
  X-axis gain, 233
Coupling methods, 108–129
Cradle switch, 410
Crystal
  microphone, 284
  oscillator, 163–167

Devices and components, switchboard, 35
Dial telephone system, 403–429
Direct coupling, 127–129
Direct-current power supplies, 89–92
Distortion
  amplitude, 106
  caused by limiting, 141

Distortion—Continued
frequency, 104
phase, 105
Double engine order transmitter-indicator, 499
Duties, IC, 2, 5, 13
Dynamotor, 91

Electrical
Division, 3
History Card, 15
shops, 3
Electronic
inventory, 11
power supplies, 61–92
test equipment, 182–234
Electron-tube amplifiers, 94–149
Engine order system, 497
indicators, 506, 507
transmitter-indicators, 499, 502
Engineering Department, 1
Equipage Custody Record (NavSandA Form 306A), 3
Equipment
accessory, 405
automatic switchboard, 404
bus-transfer, 37–41
IC/QEB–1D, 383
line station, 404
power, 405
sound, 281–295
switching, 419–429
Errors
ballistic
damping, 447
deflection, 443, 444
constant motion, 433
gyrocompass, 431–456
oscillating, 442
quadrantal, 449
speed, course, latitude, 435

Feedback
amplifiers, 130–137
capacitive, 161
Feedback—Continued
negative, 132–137, 394
positive, 131
Film, 377
recording, 348
sound, 378
Filter circuit, 70–76
Frequency, 267
effect of, 76
of oscillations, 156
response, 95
Fuses and fuseholders, 41–47

Generators
saw-tooth, 168–173
time-base, 224
Ground sheet, weekly, 15
Grouping and numbering, line, 419
Gyrocompasses, 459–493
errors, 431–456
master
Arma Mk VIII Mod 3A, 478
sensitive element, 479
Sperry Mk XI Mod 6, 460
phantom element, 460, 467
sensitive element, 462

Handset telephone, 405
Hartley oscillator, 159, 393
High-temperature alarm system, 253–261
History card
electrical, 11, 15
electronic, 11
hull, 11
machinery, 11
Horns, 248

Image(s)
formation of, 375
projector; formation, 380
Impedance
coupling, 120
input, 140

Image(s)—Continued
output, 141
Indicating system. *See* Ship control order
Indicators
annunciator-type, 252
blown-fuse, 47
lamp-type, 250
overload, 49
Induction coil, 413
Inspections, 18
routine, 492
Instruction books, 21
Insulation resistance test record (NavShips 531), 20
Intercommunicating systems, 6, 298, 337–345
1A–TW unit, 338–345
Interior communications (I. C.) switchboards, 25–28
local, 32
power supply, 52–58

Lenses, 373–376
Light, 368–373
characteristics, 370
velocity of, 370
Line finding, 423
Loudspeakers, 397–401
characteristics, 292–295
components, 306
groups, 323
IC/QMD–1D, 397
permanent-magnet, 326
talk-back, 338
types of, 287–292
Lubricating-oil low-pressure alarm system, 261

Machinery index, 11
Maintenance
sound recorder-reproducer, 363
switchboard, 58
Maintenance project, current ship's (CSMP), 13
Manual switch, 237–239
Material
analysis data form, 18
history
card, 20
record, 11
Megaphone, electric; type PAE–1, 331
Mercury
ballistic, 465
flotation, 483
Metering and indicating systems, ship's, 6
Microphones, 281
carbon, 284
characteristics, 285
components, 300
crystal, 284
dynamic, 283
magnetic, 282
Motor, 244
relays, 243
Multimeter
ME–25A/U, 182–196
section operation, 205

Negative feedback, 132–137, 394

Oil damping system, 481
Optical system
projection, 382
sound, 382
Organization, 1–24
Oscillators, 151–180
circuit, 154, 213
electron-coupled, 162
Hartley, 159, 393
inductance-capacitance, 151–156
LAJ–2 audio, 210–217
multivibrator, 178–180
OBL–1 cathode-ray, 218–234
phase-shift, 174
Pierce crystal, 167
resistance,capacitance, 168–180

Oscillators—Continued
self-controlled, 157
tuned-plate tuned-grid, 161
Wien-bridge, 176

Paraphase amplifier, 146–149
Phase inverters, 144–149
Pierce crystal oscillator, 167
Plans, ship's, 23
Portable announcing systems, 331–336
Positive feedback, 131
Power supply circuit, 193, 198, 215, 230
Projector, IC/QPB–1D, 385–391
Propeller order system, 513
indicator, 517
transmitter-indicator, 515
Publications, 21–24
references to. *See titles*

R-C coupling, 111–119
Recording, sound, 346–366
disk, 347
film, 378
magnetic, 348
maintenance, 363
mechanical, 346
medium, 356
methods, 346
photographic, 352
tape, 351
variable-area, 353
variable-density, 352
wire, 350
Records, 10
card
alteration (NavShips 530), 13
megger test (NavShips 531), 12
repair (NavShips 529), 13
compass book, 18
Electrical Installations and Electrically Operated Auxiliaries with Performance Data, 22

Records—Continued
Equipage Custody (NavSandA Form 306A), 3
field changes (NavShips 537), 13
insulation resistance test (NavShips 531), 20
maintenance, 13
storage battery tray record, 14
Rectifier tube, gas-filled, 64
Rectifiers, alternating current, 62
circuits, 66
Reflection, sound, 268
Refraction, sound waves, 269
Regulators, voltage. *See* Voltage
Relays, motor, 243
Repair parts, 9
Reports, 10
Reproducing system, sound, 346, 353–366
Request for Repair Parts (NavSandA Form 302), 10
Resonance, 271
Reverberation, 273
Rings, binnacle and gimbal, 476, 490
Rudder systems
angle indicator, 523–526
order, 518–523

Saw-tooth generator, 168–173
Selector system, basic, 427
Selectors, 194
function, 194
range, 194
Ship control order and indicating systems, 496–526
Signal systems, 7
Signals
audible, 246
visual, 249–253
Sirens, 249
Sound, 265
and sound equipment, 265–295
characteristics, 274

Sound—Continued
equipment, 281–295
measurement of, 276
motion picture system, 368–401
projection, principles of, 376
nature, 265
recorder-reproducer, RD–115/UN, 354–363
recording and reproducing systems, 346–366
designations, 353
maintenance, 363
velocity, 267
Sperry compass, 434, 438, 446–449, 453, 456
Spider, 470
and bowl, 485
Sprinkling alarm system, 261
Steering emergency signal system, 526
Storage battery tray record (NavShips 151), 14
Stores, general, 8
Stowage, 10
Stub Requisitions (NavSandA Form 307), 9, 10
Supplies, 7–10
Switchboards
action cutout (A. C. O.), 28–32
local, 32
alarm, 254
automatic, 418
Switches
action cutout, 508–511
alarm and warning systems, 237–263
and selectors, 194
automatic damping eliminator, 474
conductivity, 242
cradle, 410
input, 233
manual, 237–239
mechanical, 241
multiple rotary, 35
Switches—Continued
press for peak-to-peak, 194
press-to-talk, 343
pressure, 239
push, 210, 245
range, 215
relay and control, 52
selector, 209, 343
talk-back, 303
thermostatic, 240
toggle, 209
transfer, 508, 510, 511
X-axis input, 233
Switching, equipment, 419–429

Talk-back
loudspeaker, 338
switch, 303
Telephone
amplifier, 326
dial system, 403–429
circuit, 413
common-battery, 403–405
instrument, 405–413
sound-powered; amplifier systems, 325–331
Tests, 18
gas, 204
ground, 364
line-voltage, 200
noise, 204
rectifier, 202
sensitivity, 364
short-circuit, 201
transconductance, 202
Thermostatic switch, 240
Thermostats, 245, 256
Time-base generator, 224
Transfer switches, 508, 510, 511
Transformers
alternating current, 62
coupling, 121–127
phase inverter, 144–146
Transmission circuit, 415

Transmitter
commutator, 488
synchro, 473
Transmitter-indicator, double engine order, 499
Tube
cathode-ray, 219
tester, TV-3/U, 196
section operation, 198–205

Vibrator, 89
synchronous, 90
Visual
intelligence systems, 6
signals, 249–253
Voice
and projection systems, amplified, 6
communication systems, unamplified, 6

Voltage
amplifier, 95
dividers, 84
gain, 139
regulators, 77–83
Voltmeter circuit, 185, 188, 205

Warning systems. *See* Alarm
Wave motion, properties of, 268, 371
Wavelength, 267, 369
Wien-bridge oscillator, 176
Work
request, ship's memorandum, 18
sheet, circuit, 15, 20

X-axis
gain control, 233
input switch, 233

U. S. GOVERNMENT PRINTING OFFICE : 1955 O - 317993