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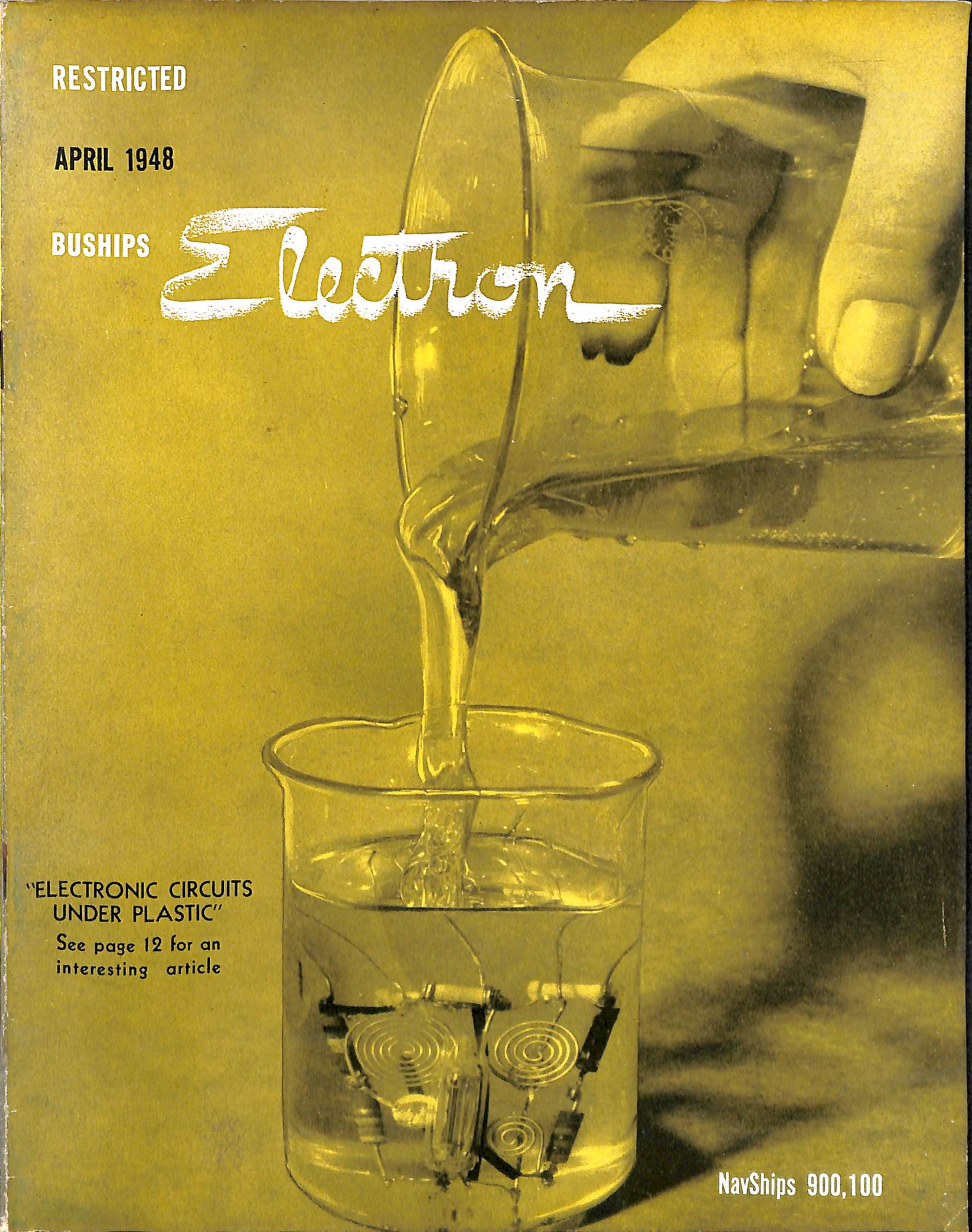


"ELECTRONIC CIRCUITS UNDER PLASTIC"

See page 12 for an interesting article

NavShips 900,100

Vice Admiral Earle Watkins Mills, U.S.N.

The Chief of the Bureau of Ships

Vice Admiral Mills was born in Little Rock, Ark., on June 24, 1896. His family moved to Nashville, Ark., in 1905, and after graduating from high school there in 1913, he entered the University of Arkansas to study for a degree in electrical engineering. He left the University of Arkansas in 1914 to accept appointment to the United States Naval Academy from the Fourth District of his native State. At both the University of Arkansas and the Naval Academy he took a prominent part in athletics and played varsity football. In 1917 he was awarded the Thompson Trophy Cup as the Midshipman who had made the outstanding contribution to athletics at the Academy during that year. He was graduated from the Academy and was commissioned ensign with the class of 1918.

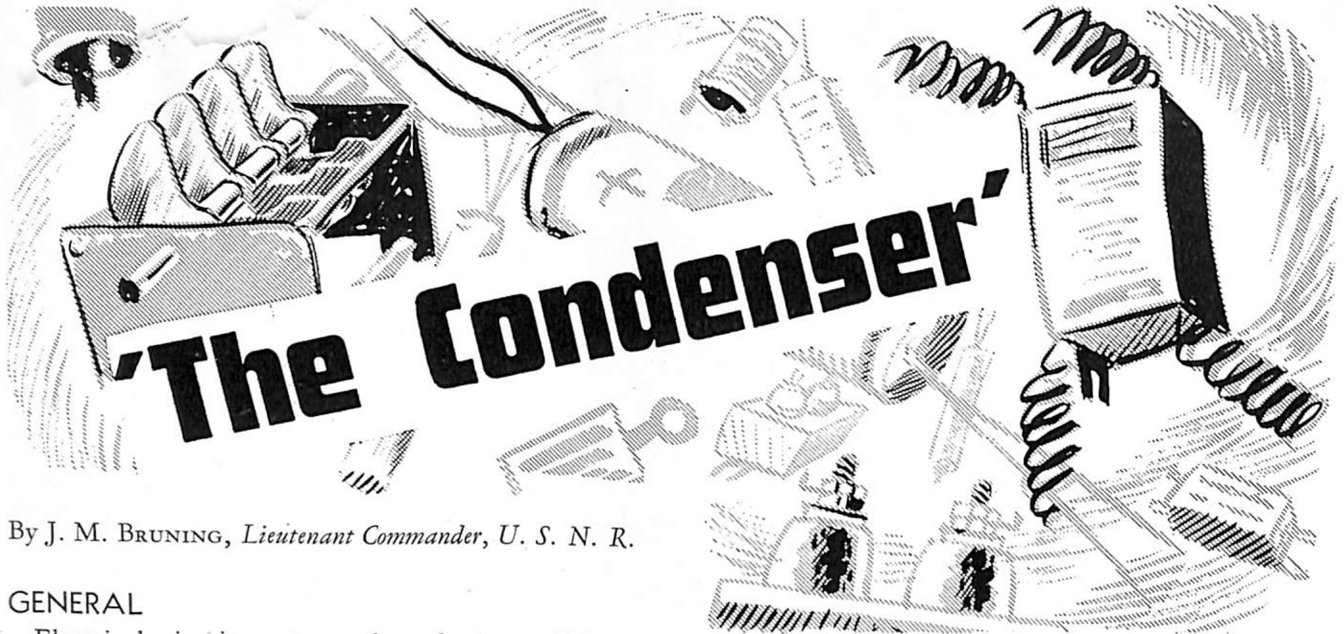
Vice Admiral Mills has had three tours of duty at the Navy Department prior to the current tour, the first commencing in 1933. At that time, with the rank of lieutenant, he served in the Design and Construction Division of the Bureau of Engineering for 4 years. In 1939 he was back again, this time with the rank of commander and serving as engineering assistant to the Head of the Design and Construction Division. When the Bureau of Engineering was consolidated with the Bureau of Construction and Repair to create the Bureau of Ships in June of 1940, he continued the same duty in the new Bureau.

On November 1, 1942, he assumed duty as the Assistant Chief of the Bureau of Ships with the rank of rear admiral. In the administration of the Navy's shipbuilding program, Rear Admiral Mills worked closely with the Maritime Commission, particularly in connection with the construction of the large numbers of troop transports, cargo vessels, escort carriers, frigates, and landing craft for the Navy.

For his long service in connection with ship design and as the Assistant Chief of the Bureau of Ships, prior to and during the World War II period, when the United States Navy became the greatest sea power in the history of the world, Rear Admiral Mills was awarded the Distinguished Service Medal, with the following citation:

"For exceptionally meritorious service to the Government of the United States in a duty of great responsibility as Engineering Assistant to the Head of the Design Division in the consolidated Bureau of Engineering and Construction and Repair from September 1939 to November 1942 and as Assistant Chief of the Bureau of Ships from November 1942 to November 1945. Responsible for vital decisions concerning the engineering and electrical plans of all major fleet units designed since 1939, Rear Admiral Mills supervised the development of the adapted designs and provided for the fleet electrical and engineering installations which were reliable and highly resistant to damage by excessive operation or enemy action. His judgment and foresight were essential factors in the development of high pressure, high temperature, steam main machinery for the ships of our fleet. Throughout this prolonged period of duty Rear Admiral Mills has rendered invaluable service to the Navy, both in establishing the Bureau of Ships and in expanding and maintaining the United States Fleet. By his professional ability, leadership, and devotion to the fulfillment of important assignments, he contributed materially to the successful prosecution of the war and upheld the highest traditions of the United States Naval Service."

He was advanced to the rank of vice admiral dating from December 31, 1945, and as a vice admiral became Chief of the Bureau of Ships on November 1, 1946. Vice Admiral Mills received the honorary degree of Doctor of Engineering from the University of Louisville in 1944. He is a member of the American Society of Naval Engineers, the American Society of Naval Architects and Marine Engineers, and the Army and Navy Country Club.



'The Condenser'

By J. M. Bruning, *Lieutenant Commander, U. S. N. R.*

GENERAL

Electrical circuits possess three basic qualities—resistance, inductance, and capacitance. In the design of a workable circuit these qualities are combined in various amounts to achieve a specific result.

A condenser is a device which concentrates the basic quality of capacitance within one container. This article will discuss certain aspects of condensers which are of importance to the technician.

CAPACITANCE

Capacitance is the ability to store electrical energy in electrostatic form. A single straight wire has this ability to a small extent. A more effective arrangement consists of two metallic plates arranged parallel to each other and separated by an insulator called the dielectric. All practical condensers consist of some variation of this basic design.

The capacity of any condenser is determined by three characteristics of the dielectric:

1—The *nature of the dielectric used* (air, oil, mica, etc.);
2—The *thickness of the dielectric.* The thinner the dielectric, the greater the capacity.
3—The *area of the dielectric common to both plates.*

Note that the third characteristic is not the "area of the plates", as many text books state. This is illustrated by figure 1, in which both condensers have plates of equal area although capacitor A has twice the capacity of B.

It is this feature of the capacitance depending upon the nature and amount of dielectric in use which enables a variable condenser to function. By rotating one set of plates we do not change the area of the plates but we do change the volume of the dielectric being acted upon. When the plates are completely separated we have a minimum of dielectric in use and the condenser exhibits minimum capacity.

UNITS OF CAPACITY

The basic unit of capacity is the farad. Capacitance units normally used in electronics are:

A—The microfarad, abbreviated μfd, or sometimes mfd. This unit is one millionth (10^{-6}) of a farad.
B—The micro-micro-farad. This is 10^{-12} of a farad. The abbreviation is $\mu\mu$fd or mmfd. A micro-micro-farad is sometimes written "pfd" meaning pico-farad. A technician refers to an $\mu\mu$fd as a "micro-mike."
C—The centimeter. This is the unit of capacitance in the electrostatic system of electrical units; it is almost never used in practical work. One centimeter of capacity equals 1.1124 micro-mikes.

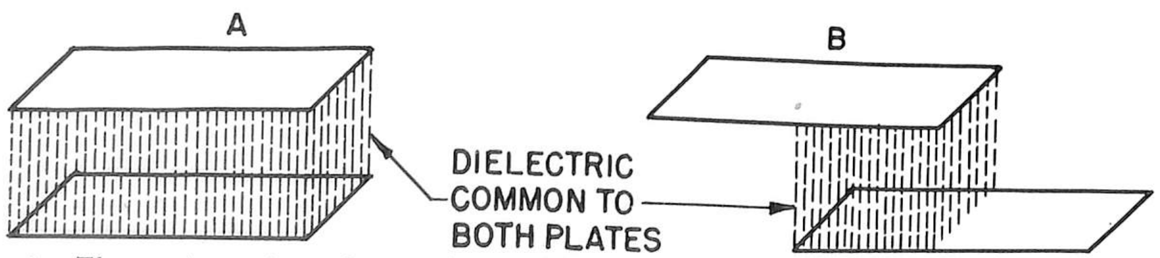


Figure 1.—*The capacitance of a condenser is determined by the area of the dielectric* common *to both plates, and not the area of the plates.*

CAPACITY CONVERSION

An inspection of the relative values of capacity units indicates the following relationships:

$$\mu fds = \frac{farads}{10^6}$$

$$\mu fds = \mu\mu fds \times 10^6$$

$$\mu\mu fds = \frac{\mu fds}{10^6}$$

The following table will enable rapid conversions to be made:

Table I.—*Conversion Table*

μ*fds*	$\mu\mu$*fds*
10.0	10,000,000
5.0	5,000,000
1.0	1,000,000
0.75	750,000
0.5	500,000
0.25	250,000
0.1	100,000
0.05	50,000
0.01	10,000
0.005	5,000
0.001	1,000
0.0005	500
0.0001	100
0.00005	50

ENERGY STORAGE

The amount of electricity a condenser will hold depends upon the difference of potential applied across its terminals. By formula,

$$Q = C \times E,$$

where Q is given in ampere-seconds, C in farads, and E in volts.

Work is actually done in charging a condenser because the molecules of the dielectric resist being forced out of their normal arrangement by the applied potential. Energy from the charging source is converted to electrostatic energy and is stored in the dielectric.

The energy in watt-seconds or *joules* actually stored in a condenser at any instant is equal to:

$$\frac{Ce^2}{2},$$

where C is in farads and e is the instantaneous voltage across the condenser.

In terms of joules, a 2-microfarad condenser charged to 1,000 volts potential represents an energy level of only 1 joule. In terms of "shocking power," the author's left arm was temporarily paralyzed from fingers to shoulder many years ago by 1 joule from such a condenser. It does not follow that one-half joule will merely paralyze an individual from his fingers to his elbow. Energy storage in condensers is *DEADLY.*

DIELECTRIC CONSTANT

Since the capacity of a condenser depends upon the nature of the dielectric, many different materials are used for this purpose depending upon the result desired. The important thing to remember is that a vacuum is the "standard" and has a dielectric constant of unity or (1). Air has a dielectric constant of 1.00059, which is substantially equal to 1. All other substances have constants greater than 1. If mica had been used for the dielectric in figure 1, the capacity of the condensers would have been nearly seven times as great.

The ratio of the capacitance of a condenser having a material other than a vacuum for its dielectric to the capacitance the same condenser would have with a vacuum dielectric is termed the specific inductive capacity or *dielectric constant* of that particular insulating material.

Unfortunately, the dielectric constant of a given substance is rarely constant in value. It changes considerably with temperature, moisture content, applied voltage, and the operating frequency.

These changes usually take place while the condenser is in operation. They have a serious and adverse effect upon the functioning of the unit. Certain types of condensers shift capacity to a considerable degree with temperature increases, and will not return to their original value after the unit has cooled to normal. Therefore, abnormally high temperatures must not be allowed to develop within or adjacent to a condenser.

During design and manufacture, considerable effort is expended to insure that the nature of the dielectric and its constant will not change during operation. Condensers which change their characteristics during operation are prevalent causes of instability and malfunctioning of electronic equipment.

DIELECTRIC HYSTERESIS

After any type dielectric other than air or gas has been placed under stress by the application of a voltage across the condenser terminals, the dielectric will not return to its normal state immediately after discharge.

Shortly after the first discharge, a second and sometimes a third discharge can be obtained. In the case of high-potential high-capacity condensers where the dielectric has been under great stress, this residual charge may be appreciable. A high-voltage condenser which has been discharged by a shorting bar may recover sufficiently to give the unwary technician a severe shock several minutes later. For this reason,

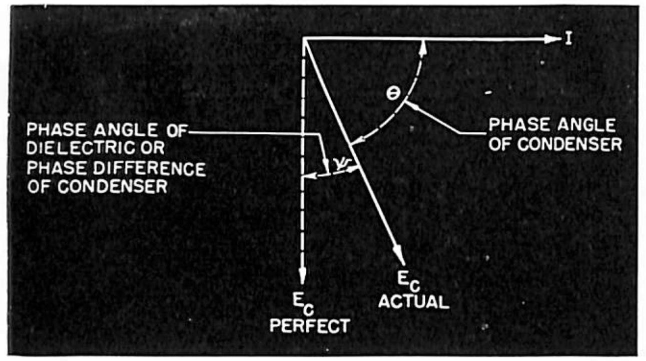


FIGURE 2.—*Phase angles in a condenser.*

if associated bleeder circuits are opened up for any reason, the condenser should have its terminals short-circuited by a looping cord while the technician is working in its vicinity.

DIELECTRIC LEAKAGE

If a charged condenser is allowed to remain with its terminals disconnected, the charge will slowly disappear. This dissipation is due to leakage within the condenser and across the exterior surface between the terminals. Depending upon the insulating quality of the dielectric used, a condenser may lose all of its charge within a few minutes, or it may retain an appreciable charge for days. Leakage is negligible in mica and air condensers but is appreciable in electrolytic types. Leakage in any form is highly undesirable.

Current which leaks through the dielectric is usually confined to several small paths or faults where the insulation is nonuniform or otherwise imperfect. This energy leakage may be small in amount but it is relatively large compared to the area of the leakage path involved. Consequently, the dielectric in the immediate vicinity of the faults will rapidly overheat. This lowers the path resistance and still further increases the leakage current. If moisture is present there will be accelerated deterioration of the dielectric and ultimate failure of the unit.

Leakage is the most readily measured characteristic of an electrolytic capacitor. Despite the seriousness of the leakage problem, a leakage measurement by itself is not too significant. Low leakage does not necessarily mean a good condenser. A high-resistance electrolyte will restrict the passage of electricity and thus limit the leakage. High-resistance electrolytes may result from a manufacturer's intended design, by chemical deterioration of the solution, by evaporation of the solution, or by drying out of the moist paste used in "dry" electrolytics. A high-resistance electrolyte causes a high power factor.

PHASE ANGLE AND PHASE DIFFERENCE

Dielectric losses cause the current flowing into a condenser to be somewhat less than 90° out of phase with the impressed voltage. The amount by which the current leads the voltage is known as the *phase angle of the condenser*. It is usually represented by the Greek letter "theta" (θ). The difference between this angle and the 90° angle of a perfect condenser is known as the *phase angle of the dielectric* or phase *difference* of the condenser. It is represented by the Greek letter "psi" (ψ).

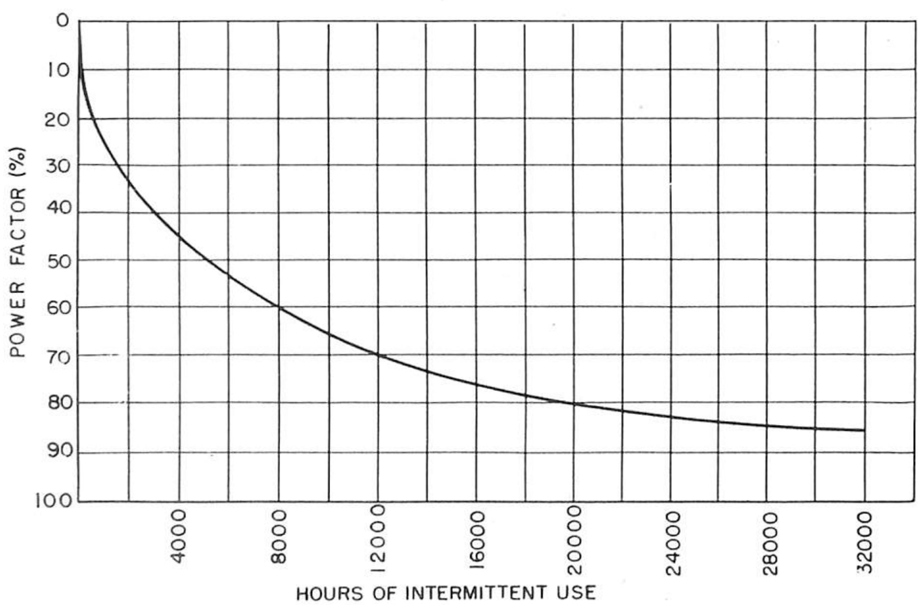


FIGURE 3.—*Increase in power factor of electrolytic condensers with time.*

The relationship of these angles is illustrated by the typical vector diagram shown in figure 2. Note that the sum of these two angles is equal to 90°.

POWER FACTOR

A condenser does not give up quite as much energy on discharge as it absorbs while being charged. Energy not given back represents a loss. The magnitude of this loss is described by the term *power factor*. With no loss, the power factor would equal zero. Since practical condensers have some loss, the amount of p. f. will vary from zero to 100 percent. Power factor can be readily measured with standard testing instruments such as the Navy type 60007 capacitor analyzer.

The value of the dielectric phase angle expressed in radians equals the power factor of the condenser. Since one radian equals 57.3°, a power factor of 20 percent represents a phase difference of 0.20×57.3 or 11.46°.

The power factor of a condenser is expressed by the formula

$$p.f.=\frac{R}{Z}$$

in which R is the equivalent series resistance and Z for all practical purposes is the capacitive reactance at the frequency used for the test.

Only an ideal condenser would have a power factor of zero. Air, paper, and mica capacitors approach this ideal. Electrolytic condensers of high quality will average between 5 percent and 10 percent p. f. when new, but this reading increases rapidly with use. Dry types have a slightly lower p. f. than the wet type.

POWER FACTOR VERSUS AGE

The power factor of air, mica, paper, ceramic, and oil type condensers will remain essentially constant during the service life of the unit.

The p. f. of electrolytics is subject to wide variations depending upon the quality of the original unit and the operating conditions to which it has been subjected. The increase in power factor with length of service is shown in figure 3.

Electrolytic condensers which have had over 5 years of service cannot be depended upon. In general, electrolytic condensers should be replaced as a trouble-prevention measure after 20,000 hours of service or after 5 years of time, whichever is less.

LEAKAGE AND POWER FACTOR LOSSES

Leakage should be measured by a milliammeter in series with the condenser at the rated d-c working voltage after a 5-minute "forming" charge. Leakage should be less than one-quarter milliampere per microfarad at the rated d-c working voltage. Leakage loss in watts is equal to the product of leakage current times the operating voltage.

Power factor loss is equal to total heat loss divided by a-c volts times a-c amperes.

$$(p.f.)=\frac{Watts}{E_{ac}I_{ac}} \quad \text{but} \quad I_{ac}=\frac{E_{ac}}{X_c}$$

$$\text{so } (p.f.)=\frac{Watts}{\frac{E_{ac}^2}{X_c}}=\frac{Watts\times X_c}{E_{ac}^2}$$

When the power factor is known, the heat loss can be calculated approximately, as follows:

$$Watts\ loss=\frac{(p.f.)\times E_{ac}^2}{X_c}$$

Leakage and power factor losses are usually negligible in capacitors other than electrolytics. Losses in electrolytics are principally due to the power factor rather than because of leakage. Compare the following two condensers which were measured while operating in a typical rectifier power supply.

	No. 1	*No. 2*
Working voltage	400	400
Capacity	8 μfd	8 μfd
Leakage	0.2 ma.	0.4 ma
Power factor	20 percent	10 percent
Frequency	120 cps	120 cps
Ripple voltage	20	20
Leakage loss:	*Watts*	*Watts*
(0.0002×400)	0.08	
(0.004×400)		0.16
Power factor:		
(20 percent×2.4* watts)	.48	
(10 percent×2.4* watts)		.24
Total heat loss	.56	.40

$$*W=\frac{E^2}{R}=\frac{E^2}{Z}=\frac{E^2}{X_c} \quad \frac{E^2}{X_c}=\frac{20^2}{\frac{10^6}{2\pi\times120\times8}}=\frac{400}{166}=2.4$$

watts loss for 100 percent $p.f.$

Note that capacitor No. 1 has but *half* the leakage of No. 2 but its total heat loss is 40 percent *greater* than No. 2. From the example it can be seen that relatively greater heat losses are caused by power factor losses than by leakage.

Since power factor does cause heat, and a rise in temperature increases the power factor, the effect is cumulative. Electrolytics should therefore be well-ventilated and physically removed from hot rectifier tubes or transformers in the chassis layouts. They must never be stored near a heating system nor where the ambient temperature will exceed 70° F.

EQUIVALENT SERIES OR SHUNT RESISTANCE

An imperfect condenser absorbs power. A pure reactance does not. Thus an imperfect condenser can be considered as equivalent to a resistance in series with a perfect condenser. This equivalent series resistance expresses total capacity losses.

$$R_{equiv}=\frac{\text{Watts expended}}{I^2}$$

It would be difficult to measure the precise value of each loss associated with a condenser. In practice, we take the combined effect of all these losses and describe this effect as the equivalent resistance value needed to produce an I^2R loss of the same magnitude.

By formula: Equivalent *series* resistance, $R=(p.f.)\times Z$.

but $Z=X_c$ for all practical purposes.

$$\text{so } R=(p.f.)\times X_c$$

$$=(p.f.)\times\frac{1}{2\pi fC}$$

$$=\frac{(p.f.)}{2\pi fC}$$

Similarly, an imperfect condenser may be considered as an equivalent *shunt* resistance in parallel with a perfect condenser.

Equivalent *shunt* resistance, $R=\frac{1}{2\pi fC\times(p.f.)}$

POWER FACTOR VERSUS FILTERING EFFECTIVENESS

The effectiveness of a capacitor as an a-c filter is dependent largely upon the impedance which the capacitor presents to the alternating component in the circuit.

The lower the impedance of the filter capacitor, the less a-c voltage will be developed across the filter output, and the greater will be that portion which is dropped across the internal impedance of the source of the ripple voltage.

To compare the effectiveness of two capacitors as filtering agents, in terms of bypassing a. c., let us consider two condensers, "A" and "B." "A" is a perfect capacitor having a power factor of zero, a leakage resistance of infinity and consequently an equivalent series resistance of zero, and a reactance of X_c to the a-c component present in the circuit. "B" is a practical condenser with power factor equal to *p. f.*, a given leakage resistance R_b, and the same reactance X_c as condenser A.

Since "A" is perfect, its total impedance $Z=X_c$. Condenser "B," however, has a resistive component given by

$$R_b=Z\cos\theta=Z_b\,(p.f.)$$

where Z_b is the total impedance of capacitor B. Substituting in the equation:

$$Z^2=X^2+R^2$$

$$Z_b^2=X_c^2+R_b^2$$

$$=X_c^2+Z_b^2\,(p.f.)^2$$

Rearrangimg:

$$Z_b^2-Z_b^2\,(p.f.)^2=X_c^2$$

So

$$Z_b^2(1-(p.f.)^2=X_c^2$$

and

$$Z_b^2=\frac{X_c^2}{1-(p.f.)^2}$$

Therefore:

$$Z_b=\frac{X_c^2}{\sqrt{1-(p.f.)^2}}$$

To compare the *effectiveness* of the two condensers, we take the ratio of Z_a to Z_b.

$$\frac{Z_a}{Z_b}=\frac{X_c}{Z_b}=\frac{X_c}{\frac{X_c}{\sqrt{1-(p.f.)^2}}}=$$

$$\frac{X_c\sqrt{1-(p.f.)^2}}{X_c}=\sqrt{1-(p.f.)^2}$$

The effectiveness of an imperfect capacitor, then, as compared with a perfect capacitor is equal to

$$\sqrt{1-(p.f.)^2}$$

and *percent* effectiveness $=100\sqrt{1-(p.f.)^2}$

Example: Find the effectiveness of a condenser having a power factor of 60 percent:

$$100\sqrt{1-0.6^2}=100\sqrt{0.64}=100\times0.8$$

$$=80 \text{ percent effective.}$$

Calculating for different power factors, the following table is derived:

TABLE II.—*Effectiveness of a Condenser in a Filter as a Function of Power Factor*

Power factor (percent)	*Filtering effectiveness (percent)*
5	99.9
10	99.6
15	98.6
20	98.0
25	96.6
30	95.3
35	93.6
40	92.0
45	89.3
50	86.5
60	80.0
70	70.0
80	60.0
90	43.5
95	31.2
99	14.0
100	.0

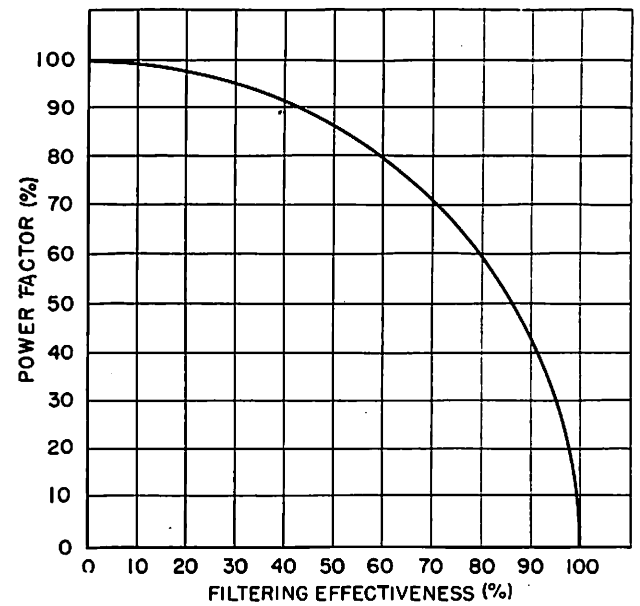


FIGURE 4.—*Effect of power factor on filtering effectiveness.*

Figure 4 illustrates the drop in filtering effectiveness as the power factor increases.

LIFE EXPECTANCY OF CONDENSERS

The dielectric used in a condenser experiences "fatigue" during use and will ultimately rupture even though the normal working voltage of the condenser has not been exceeded.

Thus, the service life of a condenser is directly affected by the usage it has experienced. The dielectric strength of any given material is definitely lower for radio-frequency voltages than for audio-frequency or d-c voltages. Other conditions being equal, a condenser will fail more quickly in r-f applications than in a-f or d-c service.

Assuming normal operation within rated limits, life expectancies for various types of capacitors are as tabulated in table III.

TABLE III.—*Life Expectancies of Various Types of Condensers*

Dielectric	Life expectancy	Limitation
Air	25 years	Deterioration of insulation supports.
Vacuum	20 years	Quality of seal.
Mica	15 years	If hermetically sealed.
Chlorinated diphenyl-paper	12 years	If hermetically sealed.
Ceramic	10 years	Decomposition.
Glass	10 years	Fragile.
Mineral oil-paper	6–10 years	Oil deteriorates by moisture absorption and carbonization from arc-overs.
Castor oil-paper	3–8 years	
Wax paper-tinfoil	2–7 years	Moisture absorption.
Dry Electrolytics	20,000 hours	or 5 years—whichever is less.
Wet Electrolytics	18,000 hours	or 4 years—whichever is less.

DETERIORATION OF ELECTROLYTIC CONDENSERS DURING USE

All electrolytics depend for their action upon the presence of moisture in the electrolyte. The difference between a "dry" and a "wet" electrolytic is simply one of degree. Actual liquid is used for the electrolyte in a wet condenser, while the electrolyte of a dry type consists of a damp paste.

Capacitors operating within normal ratings on pure d. c. should continue to function until the moisture content of the electrolyte has been dissipated. This loss of moisture causes a gradual drop in effective capacity and an increase in series resistance until the unit develops an open circuit characteristic.

The life termination of an electrolytic capacitor is therefore due principally to the rate of evaporation of its electrolyte. This in turn depends largely upon the effectiveness of the container seal and the operating temperatures to which the unit has been subjected.

The normal operating range of electrolytics is between 32° and 140° F. Temperatures above this value will rapidly drive out the moisture from the electrolyte, causing accelerated deterioration. Low temperatures reduce the effective capacity and cause the unit to act as if open-circuited, but do not have a particularly harmful effect upon the capacitor.

SHELF LIFE OF CONDENSERS

The shelf life of a condenser represents the period of time it can be out of service without experiencing an adverse change in its characteristics. Generally speaking, only electrolytic capacitors are seriously affected by lack of operation.

Since electro-chemical reactions are accelerated by an increase in temperature, and because moisture has an adverse effect upon condensers, all units not in operation should be stored in a cool, dry place. Ambient temperature range should be from 40° to 70° F. Relative humidity should not be less than 25 percent nor more than 50 percent.

Air, mica, diphenyl, ceramic, and glass dielectric condensers have a shelf life of better than 20 years, provided they are not roughly handled nor improperly stored. The principal cause of deterioration is moisture working its way into the unit. Since different metals are used in the construction of capacitors, the presence of moisture causes galvanic action to take place and results in the eating away of surfaces where these dissimilar metals are joined.

Oil-filled or oil-treated condensers are subject to chemical action resulting from deterioration or contamination of the oil. Absorption of moisture by the unit causes dilution of the oil and its complete disappearance in small areas where the infiltrated moisture actually displaces the oil. Dielectric strength is thereby weakened and the insulation resistance reduced to unsafe limits. "Boiling" of the infiltrated water takes place when the condenser is again subjected to operating potentials, and the unit may actually explode. The shelf life of oil-type condensers is therefore less than for air or mica types, but should average 15 years or more.

The largest single factor which determines the shelf life of an electrolytic condenser is its leakage characteristic. This in turn is governed by the quality of the anode film. The anode film was initially "formed" by the application of a d-c potential to the condenser terminals, and the presence of a polarizing voltage during operation maintains the film in its proper state. The film has a thickness of the order of several ten-thousandths of an inch. In the absence of a polarizing voltage this film will gradually disappear. The electrolyte also has a tendency to dissolve the anode film when the condenser is not in use. Consequently, the shelf life of an electrolytic is principally determined by the length of time during which no polarizing or operating voltage has been applied to its terminals.

Well-designed capacitors may be expected to return to normal after a period of idleness ranging from several months to a maximum of 2 years. No electrolytic condenser should be allowed to exceed 2 years of idleness without having its anode film restored by the application of a polarizing voltage equal to the rated working voltage of the unit.

TESTING OF CONDENSERS

General.—Dielectric fatigue is governed by the length of time a voltage has been applied to it and the nature of the applied potential. An a-c voltage has a more adverse effect than d. c. A higher frequency is more severe in its effects than a lower frequency. Sharp pulses are more destructive than sine-wave a. c.

Most condensers can withstand momentarily applied voltages greatly in excess of the normal working voltage. In testing condensers, it is desirable to apply an extremely short flash test of high voltage, and an extended test at the working voltage. The rating for a given unit is usually marked upon the container. Where it is not shown, the flash test should be approximately 50 percent higher than the operating voltage. *A flash test must not be used on an electrolytic.*

Where facilities are available, a condenser should be tested in a circuit which provides for superimposing a small 60- or 120-cps ripple voltage in series with the applied d-c working voltage. The amount of ripple voltage employed will be governed by the type of service in which the condenser is to be used. For example, the first condenser following the rectifier tube in a power supply must be able to withstand a much higher ripple voltage than is required for the second or output condenser.

The d-c working voltage shown on the name plate is the d-c potential at which the condenser is expected to operate continuously. The peak voltage rating specified is that voltage resulting from the application of the working d-c potential in series with a sine-wave a-c voltage of such amplitude that the peak potential of the combination is just equal to the peak rating indicated. Remember that the peak value for a. c. is 1.4 times greater than the value indicated on a conventional a-c voltmeter.

Condensers should be tested for insulation resistance, power factor, and capacity. Electrolytic capacitors should have a minimum insulation resistance of one-half megohm, a power factor of not over 50 percent, and a capacity tolerance between plus 200 percent and minus 10 percent of the rated capacity. All other type condensers should have an insulation resistance approaching infinity, a power factor of 5 percent or less, and in general a capacity within ±10 percent of rated value.

Condensers exceeding the specified power factor limits are not necessarily defective, but it is poor economy to retain for future use electrolytics having appreciable power factor. Any capacitor which has markedly changed its values from the data shown on the name plate, or from the standard set by a number of duplicate condensers under test, should be discarded as unsafe.

Details of the joint Army-Navy method of designating condenser characteristics and capacity tolerances will be found in the publication NavShips 900,113. These tolerances must be met when replacing defective units of working equipment.

Capacitors other than electrolytic.—Small to medium condensers of the air, mica, paper, oil, or ceramic type may be tested with a simple high-resistance type ohmmeter. There should be a strong kick of the indicating needle as the condenser charges, the amount of the kick depending upon the capacity under test and the test voltage. The meter needle should drop back slowly and come to rest at a reading approaching infinity. A rapid falling-off of the needle indicates a leaky condenser.

High potential condensers used in radio and radar transmitting circuits should be tested with a megger. The reading should approach infinity. Tests with high d-c potentials from busbars are dangerous and should not be made by personnel in the field.

After leakage tests have been completed, condensers should be tested for power factor and capacity, using standard equipment.

Electrolytic units.—The d-c leakage of an electrolytic condenser should be measured at the rated working voltage after the unit has been subjected to that potential for a period of at least 10 minutes to allow reforming of the anode film.

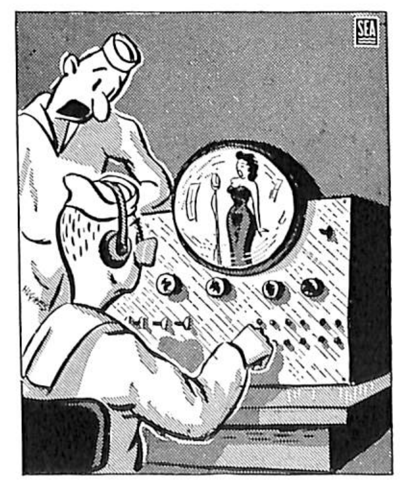
Condensers which have been out of service for many months should receive a moderate d-c polarizing voltage of about one-third the rated working voltage for 30 minutes, after which the voltage should be gradually increased to full rated potential and maintained at that value for another 30-minute period.

The condenser should next be subjected to the combined application of working d-c volts plus superimposed a. c., such that the combined peak value equals the rated peak value specified for the unit. This d. c. plus a. c. check should be extended for approximately 1 hour to insure that the unit under test is in good working condition.

If the condenser does not become short-circuited during the above test, it may next be checked for leakage. Units in which the leakage current exceeds one-quarter of a milliampere per microfarad, when operating at the rated d-c working voltage, should be discarded.

Finally, measurements for power factor and capacity should be made, using standard Navy testing equipment such as the OE capacity meter and the type 60005 capacity analyzer.

In conclusion, it cannot be too strongly emphasized that testing of condenserss must be properly and carefully done. There is a happy medium to be attained between the unnecessary saving of doubtful capacitors, and the wasteful rejection of units having much useful life remaining in them.



"Some improvement over the old radar, eh??"

780276—48——2

Model OMA Noise Level Monitor and Cavitation Indicator. . . . .

The model OMA noise level monitor and cavitation indicator equipment is a complete independent system for installation on submarines. It permits the measurement of changes in the noise projected into the water by the various auxiliary equipment of the submarine. This function is called "noise level monitor" (NLM). It also indicates changes in the noise produced in the water by the submarine's own screws at different underwater speeds. This second function is called "cavitation indicator" (CI).

The correct use of the model OMA equipment makes it possible to obtain frequent noise checks at times when the information is particularly important, such as when a vessel is on patrol. It is also useful for showing in advance which auxiliary equipment will require attention during refitting periods. The measurement of auxiliary noise changes is accomplished through the use of four hydrophones mounted at advantageous carefully-selected positions on the outside of the pressure hull of the ship, and connected to indicating equipment within.

The cavitation indication is obtained by receiving noise energy from a fifth hydrophone located near the ship's screws and connected to suitable warning indicators inside the hull. In these indicators, the beginning of own ship's cavitation is indicated by the flashing of neon lamps. Cavitation is the formation of a series of vacuums when propellers are turning so rapidly that water does not flow in immediately as the blades pass through. Since the volume of propeller noise increases greatly as soon as cavitation starts, quick and accurate information of the onset of cavitation may be of vital importance during evasive action.

The major components of the model OMA equipment (shown in fig. 1) are the Navy type No. RQ-50310 a-f amplifier, the RQ-20576 power supply, two RQ-55209 cavitation indicators and five CQA-51080 hydrophone assemblies and associated cables. A block diagram of the equipment is given in figure 2. The equipment is normally connected and set to perform as a cavitation indicator. To change over to NLM, it is necessary to depress a spring-loaded

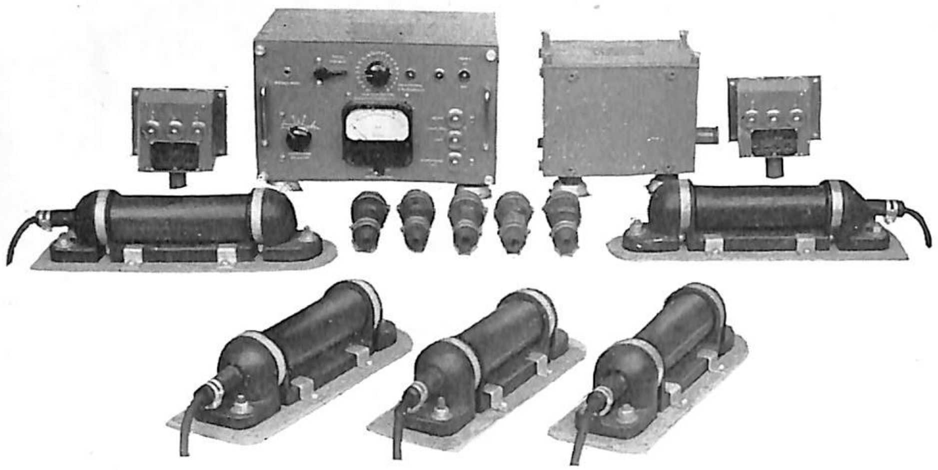


FIGURE 1.—*Major components of the model OMA noise level monitor and cavitation indicator equipment.*

function-selector switch on the RQ–50310 amplifier. When the switch is released, the equipment immediately returns to the CI function.

When it is performing as a cavitation indicator, the equipment is connected to receive propeller noise energy from the No. 5 hydrophone, in the frequency range of 6 to 12 kc, and to indicate the volume of the received energy by flashing neon lamps connected to the amplifier output. When it is performing as an NLM, the amplifier input is connected to a rotary hydrophone selector switch which can be connected to any one of the four NLM hydrophones. The received noise, confined to a band of frequencies from 150 to 3,500 cycles, is connected to the output level meter. The level of the received energy can then be measured by the meter and its associated volume control (step attenuator).

The five CQA–51080 hydrophone assemblies each contain a permanent-magnet magnetostriction CQA–51079 hydrophone consisting of a toroidally wound coil on a nickel tube split to contain a narrow permanent magnet. The hydrophones are rubber-covered for mechanical protection, and rubber-mounted to reduce the effects of hull vibrations on the units. The four NLM hydrophones are mounted on the vessel at approximately equal spacing, and the CI hydrophone is mounted aft of these.

Two separate RQ–55209 cavitation indicators are connected across the CI amplifier output to warn two remote stations of the onset of cavitation. The recommended locations for these two indicators are the maneuvering room and the conning tower. The circuit of the indicators is shown in figure 3. Each indicator contains a set of three neon lamps marked "1", "2", and "3." The igniting potentials of the lamps of each set increase in steps, No. 3 being five db above No. 2, which is in turn five db above No 1. The No. 1 lamp flickers intermittently when the

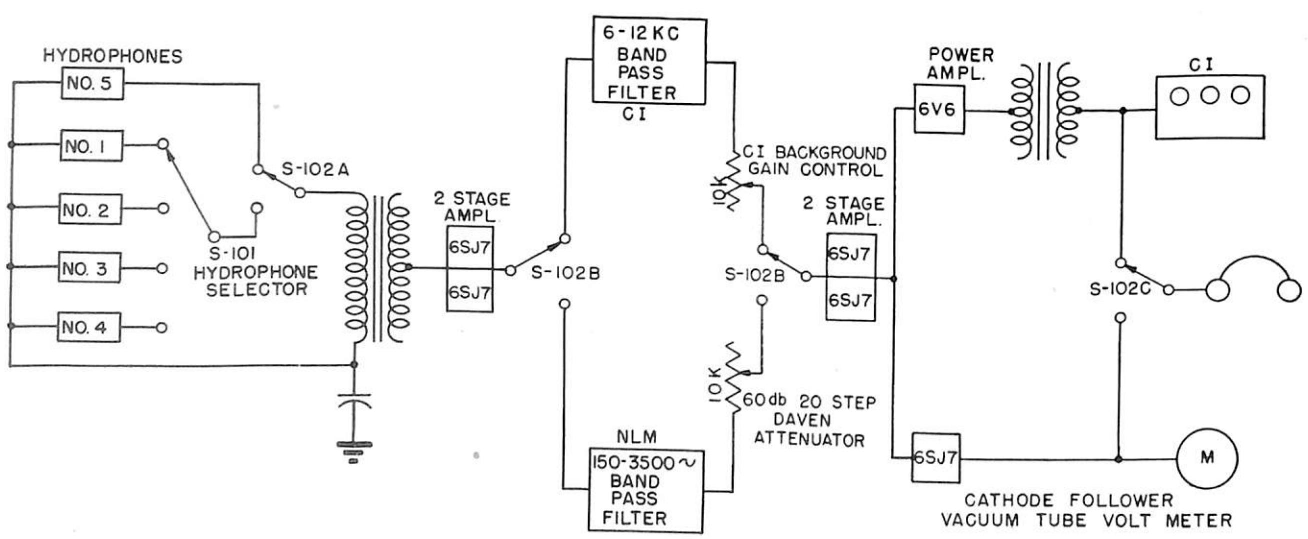


FIGURE 2.—*Block diagram of the model OMA equipment.*

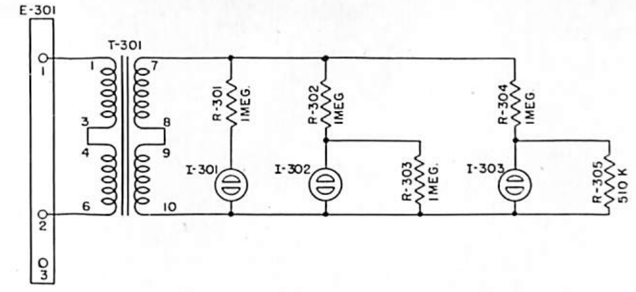


FIGURE 3.—*Schematic diagram of the Navy type No. RQ–55209 cavitation indicator.*

voltage across the secondary of T–301 is approximately 9 volts, the No. 2 lamp lights when this becomes approximately 18 volts, and the No. 3 lamp at 25 volts.

The RQ–20576 power supply contains the power transformer, rectifier, and filter from which the necessary voltages to actuate the amplifier are derived. It uses a standard full-wave rectifier circuit, capable of supplying 60 ma. of direct current at 250 volts. A 6X5GT/G tube is used as the rectifier. A specially-designed power transformer is used to insure low flux density, and a choke input filter circuit to minimize the alternating current ripple in the amplifier output. No operating controls are provided on this unit.

The RQ–50310 a-f amplifier (shown in fig. 4) is the major unit of the model OMA equipment, and contains on its front panel all the various controls for operating the equipment. It operates from a single-phase, 115-volt, 60-cycle alternating-current source, which is fed into the amplifier through a 2-ampere line fuse and safety switch.

Basically, the unit is connected as a four-stage audio amplifier using 6SJ7 tubes, R–C coupled to give a flat frequency response from 20 to 20,000 cycles. The amplifier is divided into two sections, with filters and gain controls connected between them. Each section is provided with sufficient negative feedback to stabilize the gain and to reduce the effects of microphonics in the first stage.

A ganged, three-section, spring return system selector switch (switch S–102A, S–102B, and S–102C of fig. 2), normally set in the CI position, is provided. Section S–102A of this switch connects the input of the amplifier to either the CI hydrophone or a hydrophone selector switch (switch S–101 of fig. 2) which chooses any one of the four NLM hydrophones for noise level measurement. One side of the hydrophone chosen is connected to the input transformer of the amplifier, and the other side is grounded through an 8-mf. capacitor.

Section S–102B of the system selector switch connects the proper filter for either CI or NLM operation. In its normal position, the switch connects a 6- to 12-kc bandpass filter and the CI background gain control into the circuit. This gain control is located on the amplifier panel and adjusts the background level for the amplifier and the two independently located RQ–55209 cavitation indicators. When the switch is depressed for NLM measurements, a 150- to 3,500-cycle bandpass filter and a 20-step 60-db attenuator are connected into the circuit in place of the CI filter and control.

The output from the fourth voltage-amplifier stage is connected to a power-amplifier output stage which drives the CI neon lamps in the CI position, or a cathode follower vacuum-tube-voltmeter circuit in the NLM position. Section S–102C of the system selector switch is used to complete the cathode circuit of the power-amplifier tube for cavitation indication, or the cathode follower vacuum-tube-voltmeter for NLM measurements. This section of the switch is also used to connect headphones to the function selected.

Because of the many types of submarines now in use, and the variations within each class, it is impractical to anticipate detailed procedure for each installation. The RQ–50310 a-f amplifier should be installed in the forward torpedo room, close to the hydrophone cable entrance. Shock mounts are provided on the bottom of the amplifier chassis. A suitable foundation plate should be fashioned and installed at the chosen site to hold the amplifier. The provision of adequate and suitable space, suitable mounting brackets and foundations for the brackets, etc., must be devised at the point of installation.

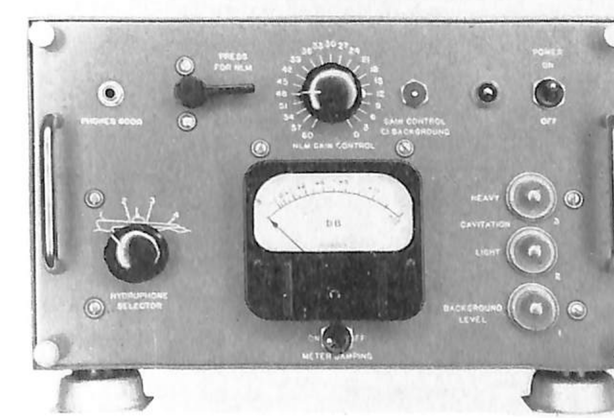


FIGURE 4.—*Front view of the Navy type No. RQ–50310 a-f amplifier showing all the operating controls for the model OMA equipment.*

ELECTRONIC CIRCUITS UNDER PLASTIC

A NEW TECHNIQUE AND A NEW PLASTIC

The word "potted" (which in its usual application is frowned upon by naval circles) will apparently receive a new lease on life, for developmental research at the National Bureau of Standards has produced a radically new and improved method of mounting electronic circuits—embedding components or even entire units in a solid block of inert plastic. The components, electrically connected in the desired hook-up, are immersed in a liquid which later solidifies around the components in a suitable mold. (See figs. 1 and 2.) The process is similar to the now-familiar method which made its appearance during the war, of protecting identification cards by embedding them in transparent plastic. Chassis-less mounting of electronic circuits in this manner is rendered feasible by development for the purpose of a special plastic, the National Bureau of Standards casting resin, possessing unusual electrical, mechanical, and chemical properties.

Following the recent announcement of the Bureau of Standards research, there has been an avid show of interest on the part of industrial corporations, and the development would seem to be as vital to the Navy. Such interest is well-merited, for N. B. S. casting-resin-embedded units exhibit a gratifying list of advantages:

1.—The units are protected against mechanical shock and rough handling.
2.—The components are firmly embedded in place, so that mechanical displacements do not occur, with corresponding stability of electrical characteristics.
3.—Electrical insulation properties are excellent, so that exceptionally-high-impedance circuits may be utilized without significant changes in electrical behavior.
4.—Electrical dielectric losses are exceptionally low, permitting the potting of electronic circuits operating at unusually high frequencies.
5.—Embedded components are not chemically affected by the plastic: Electrical performance is not altered by any corrosive effects.
6.—The chemical nature of the resin of plastic is such that it is admirably unreactive—indeed, it is completely impervious to most chemical reagents. This is important, for units may be operated for prolonged periods of time entirely submersed in fresh or salt water. There is no deterioration from salt spray or humidity, factors which have long been in the forefront of naval equipment design considerations. Delicate electronic circuits can now operate reliably under conditions of corrosion (acid fumes, etc.) depressing to contemplate.
7.—Plastic-embedded circuits are convenient, because circuits may be installed, removed, and otherwise handled as a single assembly or unit. What hard-pressed ETM maintenance man will not immediately recognize the advantage of this?
8.—Such units have an exceptional compactness (and reasonably light weight) which cannot be even approached by conventional chassis mounting.
9.—The technique is well-adapted for utilization in conjunction with other techniques of miniaturization, such as plug-in mounting. It is especially suited for use with the Bureau of Standards technique of "printing" electronic circuits, covering up and protecting the various printed layers of resistive or conductive material. (See figs. 1 and 2.)
10.—Although this is of only indirect importance to Navy personnel in the field, the chemical and physical processing involved in the embedding of electronic circuits, and in the chemical formation of the final solid plastic material, is simple, comparatively rapid, and does not call for highly skilled operators. The plastic will set under mild heating only—no special expensive pressure apparatus is required. Moreover, the liquid which is later catalyzed into plastic is sufficiently fluid so that it may be poured through small holes in the casting molds. Outside manufacturing contractors and naval designers and supply personnel will be glad that the resin possesses these advantages.

Fortunately, it will be noted, the prime advantages of compactness and adaptability to miniaturization go hand-in-hand with the prime advantages of suitability for high-impedance, high-frequency circuitry—high-frequency equipment is just the place where compactness is best appreciated. Of equal importance are the collateral advantages of mechanical protection and resistance to corrosion which the resin affords.

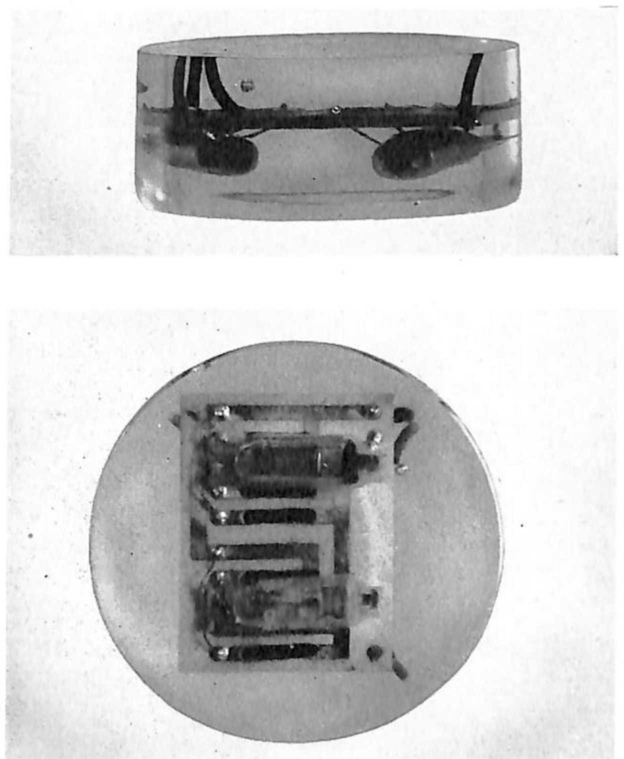


FIGURE 1.—*Two views of an entire electronic circuit potted in the N. B. S. casting resin. The circuit is a commercial two-stage amplifier using subminiature tubes and the new electronic circuit "printing" technique, in which "inks" of resistive or conductive material are printed on a ceramic plate in a pattern appropriate for the circuit. The plastic protects the circuit from rough handling, corrosive fumes, salt spray, and humidity.*

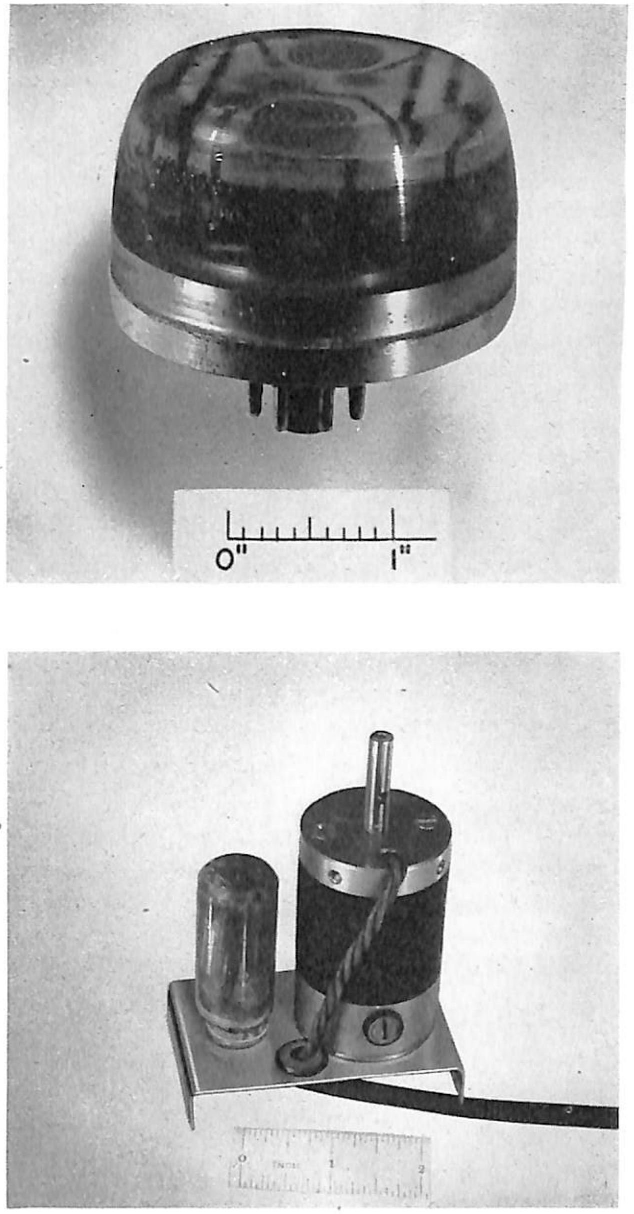


FIGURE 2.—*More potted circuits: (A) A plug-in multistage electronic control unit. (B) A register position-control motor with its potted two-stage control amplifier.*

Industrially, the process is adaptable to many applications, especially those where resistance to corrosion is important, such as high-impedance electronic control devices in the heavy industries—in steel mills and electroplating factories, for example. Hearing aids should be improved by the development, and radio receivers and transmitters can be made more portable.

It would seem that the N. B. S. casting resin and the technique of embedding entire circuits in plastic would have many direct applications to the naval service. Thus, the ability of units to be operated under water will catch the eye of submarine and sonic-listening-device men, and the improvement in compactness and portability of radio gear will appeal, not only to aircraft men, but most certainly to the designer and to the electronic technician. Freedom from salt spray corrosion is another feature needing no elaboration to emphasize its value. Application to portable radio and radar assemblies seems to be of most immediate and important benefit. Indeed, it does not seem like a great flight of fancy, for example, to visualize damage-control personnel at a battle or accident scene carrying small transceivers embedded as a unit, protected from the direct flames, oil and other fumes, moisture, sea-water, and salt spray which are to be met in such situations.

Of course, the N. B. S. casting resin essentially is not, nor meant to be, in competition with other plastic materials for many or even most applications—might indeed be inferior (it is somewhat expensive, for example); it was merely developed to have certain specific properties for one particular application (high-impedance, high-frequency circuits). That application, however, would appear to be of great importance to the Navy and to the electronics industry as a whole.

DEVELOPMENT OF THE RESIN

The N. B. S. casting resin is one result of an over-all program to miniaturize electronic equipment, instigated during the war at the National Bureau of Standards. This program has led to other noteworthy developments, such as the "printed" circuits mentioned above and the "Dick Tracy" cigarette-package-sized portable radio recently featured in LIFE magazine. Specifically, the resin is an outgrowth of research on the famous proximity fuze. Requirements of service in applications of this type called for a degree of compactness which conventional methods of chassis-mounting could not supply. It was realized that cast plastic blocks with the circuits embedded in them would satisfy the requirements, and the characteristics which the plastic must possess were formulated. Mechanically, it must first have high impact strength so that it would not shatter; second, high tensile strength so the casting would not tear loose; third, dimensional stability so that the spacing of circuit components would not change with time, leading to varying electrical characteristics; fourth, a temperature coefficient of expansion approximately equal to that of the materials to be imbedded, and sufficient resiliency, to handle reasonable temperature changes without undue damage to the circuit; finally, the mixture of raw materials, in the pre-plastic state, must be sufficiently pourable so that it would flow easily through the filling holes in the mold. Electrically, the resin must possess the proper power factor and dielectric constant so that losses at the high frequencies and circuit impedances used would be negligible. (See fig. 3.) Had the circuits not been of such high impedance, much greater r-f losses could have been tolerated, of course.

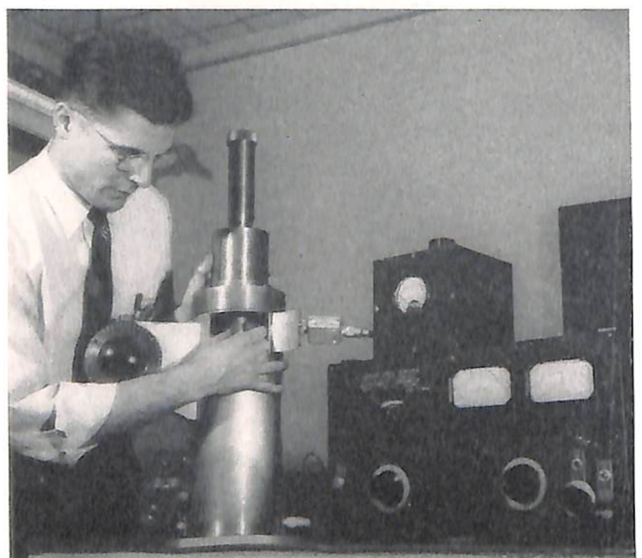


FIGURE 3.—*A Bureau of Standards technician prepares to measure the electrical properties (power factor and dielectric constant) of the N. B. S. casting resin. To permit high-frequency and high-impedance operation, these quantities should be low. The apparatus shown is a quarter-wave reentrant cavity, in which tests are conducted at 100 Mc. (in the v-h-f range), 25° C., and 50 percent relative humidity.*

Available potting materials—from simple tars, pitches, and waxes used in some batteries and transformers to commercially-available resins possessing promising electrical and mechanical properties—were investigated and discarded. To facilitate the development of a suitable plastic, the cooperation of resin manufacturers, with their "know-how" and years of experience, was solicited, and it was largely with their help that the resin was developed.

The first try in a long series of tests involving systematic variation of resin constituents was made with a tung-oil plastic formed by the use of iron salts. It worked well for audio circuits, but failed in high-frequency tests. Corrosion of soldered contacts was observed in tests with this plastic; although this was subsequently eliminated, the r-f losses still remained prohibitive. After the tung-oil plastic was discarded, an oil-soluble, hard, soap-like material was tried ("Soap" from a chemical standpoint, that is). In the processing of this material, the raw materials turn into soap in the molds. Although it exhibited improved corrosion and electrical properties, it was not strong enough mechanically and gave rise to an oil film. Subsequent tries included studies of the usual phenolic casting resins, many varieties of polyesters (which display excellent mechanical properties) and allyl resins, but in all cases both of the electrical and mechanical standards could not be met simultaneously. Finally, after exhaustive investigation, a satisfactory material was evolved, a plastic somewhat similar to polystyrene—N. B. S. casting resin.

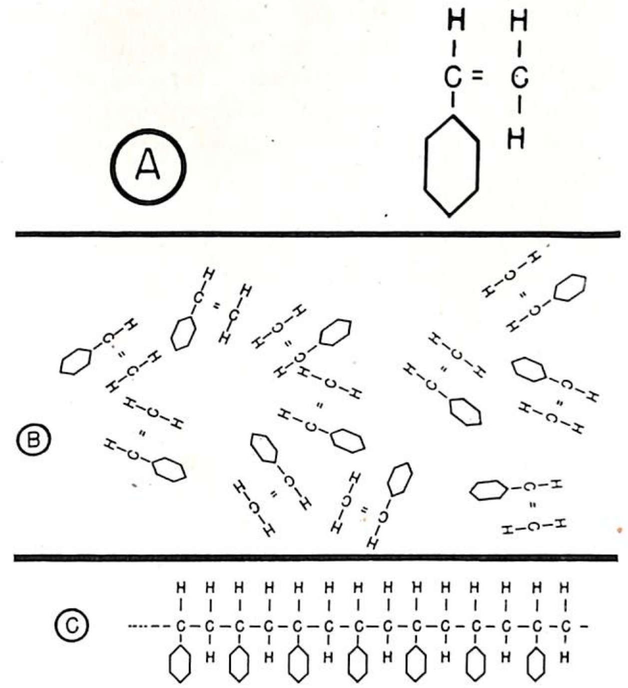
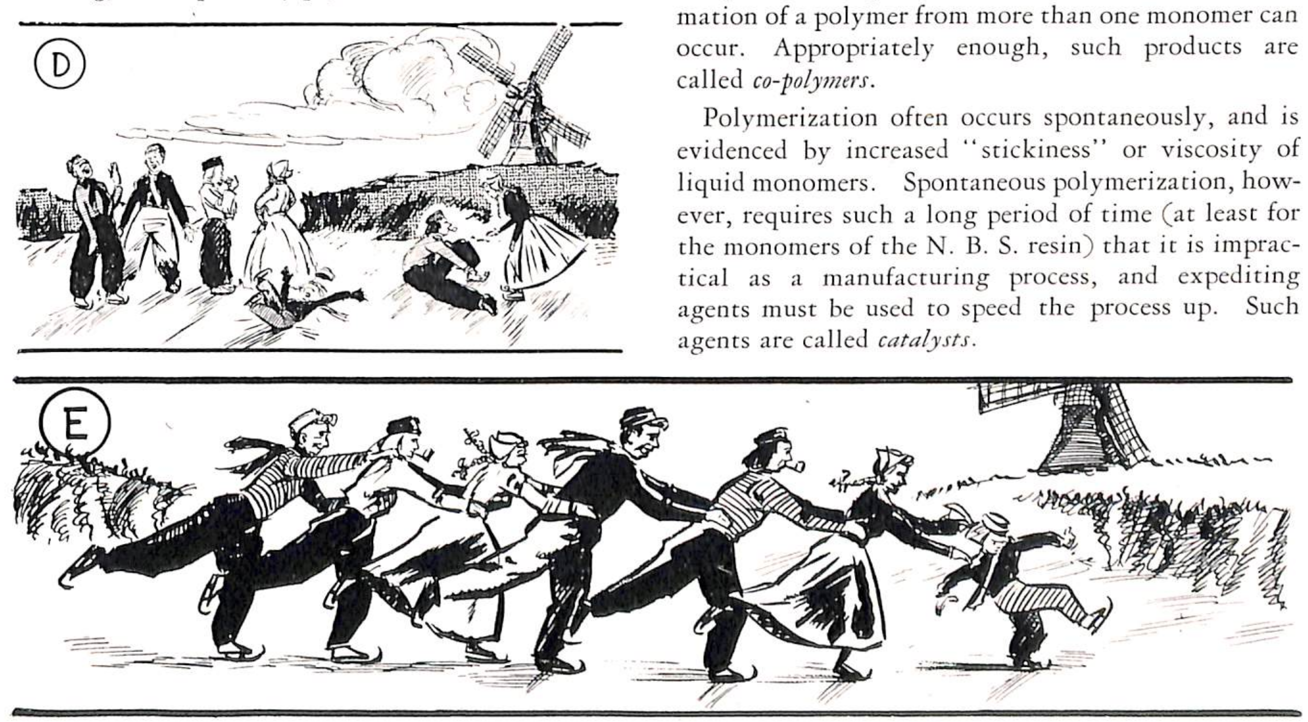


FIGURE 4.—*The formation of a plastic. Polymerization of a monomer into a polymer is displayed—liquid styrene into the familiar solid polystyrene. (A), the chemical formula of styrene, represents a single molecule. (B) shows a group of styrene molecules in a beaker of liquid styrene on the laboratory bench. The molecules are oriented in random directions. In (C) the molecules have merged together or polymerized into solid polystyrene. The actual polystyrene molecule, a portion of which appears, would consist of thousands of merged molecules. In (D) and (E) is an illustration in analogy to the process of polymerization.*



COMPOSITION AND PROCESSING

The composition of the N. B. S. resin is rather interesting. Plastics of the family to which the resin belongs are formed by the process of *polymerization*. In this process, many similar molecules of a simple chemical substance, called the *monomer*, combine or "gang up" to form a new molecule of a new substance called the polymer ("Poly" for "many," and "mer" from the word "merge," perhaps?). This polymer is the plastic. The polymerization of styrene (the monomer) into the plastic polystyrene (the polymer) is illustrated in figure 4. Such polymers are often of enormous molecular weight (those of great weight are called *high polymers*). A polymer molecule often is formed from as many as 5,000 molecules of a monomer. Indeed, sometimes it is possible to consider a whole block of plastic, hefted in one's hand, as a single gigantic molecule! (The N. B. S resin is of this type.) At times more complex polymerizations than the simple chain formation illustrated take place. The chain may develop side-branches or "arms" which may become linked with other chains to form a "patchwork quilt" or network. Moreover, formation of a polymer from more than one monomer can occur. Appropriately enough, such products are called *co-polymers*.

Polymerization often occurs spontaneously, and is evidenced by increased "stickiness" or viscosity of liquid monomers. Spontaneous polymerization, however, requires such a long period of time (at least for the monomers of the N. B. S. resin) that it is impractical as a manufacturing process, and expediting agents must be used to speed the process up. Such agents are called *catalysts*.

Applying the above concepts, we find the published chemical composition of the N. B. S. casting resin somewhat more understandable.

The raw materials are as follows:

Ingredient	Approximate amount by weight
Pre-polymerized plastic filler (co-polymer of styrene and dichlorostyrene).	One-third.
Various dichlorostyrene monomers	One-third.
Styrene monomer	One-fifth.
Hydrogenated terphenyl	One-tenth.
Solution of divinylbenzene	One-two-hundredth.

Each of these ingredients has a direct bearing on the physical and electrical properties, and there is a logical and interesting reason for the inclusion of each: The co-polymer of dichlorostyrene and styrene is nothing more than a plastic added as a filler, much as one adds crushed stone to cement when mixing concrete. It supplies body and prevents excessive shrinkage of the plastic during polymerization. The dichlorostyrene and styrene monomers merge and build up during polymerization to form the final co-polymer. It is similar to the styrene-dichlorostyrene co-polymer just mentioned as being used as a filler, but not identical with it in the solidified plastic. The hydrogenated terphenyl furnishes the plastic with enough "give" or resiliency to keep the circuit elements from being crushed during hardening. The minute amount of divinylbenzene performs the vital function of supplying the plastic its ability to withstand corrosion and chemical action.

During polymerization, roughly equal numbers of styrene and dichlorostyrene molecules gang up to form enormously-long chains of molecules. Each chain is built up from perhaps 1,000 to 2,000 individual molecules. Adjacent chains then link to one another at one or two points—credit the divinylbenzene for this—until a mesh or network of molecules is formed extending throughout the entire block of the plastic. This link-molecule co-polymer of dichlorostyrene and styrene should be distinguished from the filler, which is also a co-polymeric aggregation of dichlorostyrene and styrene molecules, but with a different structure.

Two catalysts are called upon to expedite polymerization: heat and a chemical reagent. Benzoyl peroxide proves to be the chemical supplying the the best solid end product, but others may be used if an alternate is necessary.

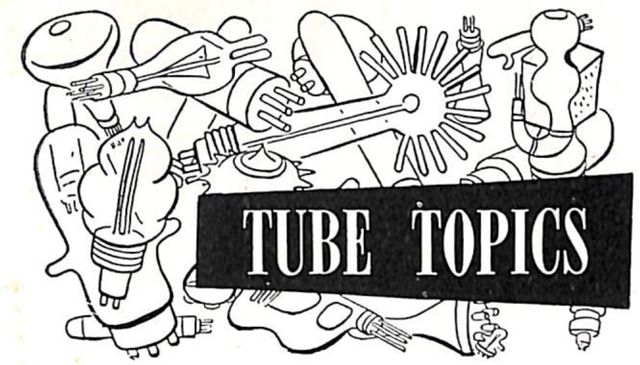
Fortunately, the mechanical processing of the plastic is a relatively simple process. First the raw ingredients are chemically purified with little difficulty, being freed from "chemical handcuffs" or inhibitors present in the raw materials to keep them from self-polymerizing, or exploding upon shock. Then they are mixed, and the chemical catalyst, benzoyl peroxide, is added. The electronic units to be embedded are inserted in the molds, and the pre-plastic liquid is poured in and allowed to gel slightly (see front cover). The filled molds are then placed in ovens at mild temperatures (50° to 60° C.), and baked for a period of one or more days, depending on several factors, such as the size of the potted unit. The cooking process is known as the "curing" of the plastic.

The Bureau of Standards suggests several practical measures which manufacturers should observe for best results. Rubber jackets should be placed around glass vacuum tubes to supply greater cushioning against cracking than the intrinisic resiliency of the resin can supply. It is well to eliminate sharp corners from all objects to be cast; otherwise strains may be set up. Components to be suspended in the center of the casting should be first embedded in a small amount of the pre-plastic liquid, which is allowed to gel into a coating around the component. The coated unit can then be embedded in plastic in the usual manner, with the coating merging smoothly into the remainder of the plastic. A slight coating of silicone grease is recommended to allow the finished plastic to be separated easily from the mold. If a hard-surface finish is desired, it may be obtained by previously floating a small layer of glycerine above the plastic on areas exposed to air.

CONCLUSION

As we have indicated, the new technique and the new resin making possible the application of this technique to electronic circuits are developments which should before long make potted circuits widely used both in the Navy and in civilian life. Perhaps the greatest effect embedding in plastic has is that it reduces the "delicacy" of delicate electronic circuits, permitting them to function underwater and under strongly-corrosive conditions, such as exposure to acid fumes, high humidity, or salt spray.

Fortunately, the electrical performance of potted circuits is but slightly altered by potting. (For example, an oscillator lost only 7 percent of its grid-drive and had its frequency lowered only 6 percent by potting in one Bureau of Standards test; in another test of an audio amplifier involving very-sensitive feedback operation, a loss in gain of only 3 percent was experienced, and there was no change whatsoever in frequency response upon mounting the amplifier in plastic.) Although it is adapted to circuits of small size only, it may be employed in individual components of large units, and is particularly suited to operation at high frequencies. Watch for the appearance of potted electronic circuits as processing on an industrial scale is perfected. —L. M. F.



SUBMINIATURES VS. STANDARD TYPES

Electron tubes, receiving types in particular, are exhibiting the same trend toward smaller size or "miniaturization" as are most components of electronic equipments. The size of tubes started to shrink in the middle 1930's when metal and "GT" envelopes superseded the dome-shaped "G" style bulb. This trend was accelerated during the war years with the influx of miniatures. Now a complete line of subminiatures is being planned, and it is anticipated that soon they may supplant most of the larger-bulb receiving tubes in equipments of new design. In the

Table I.—*Cross index, conventionel tubes to subminiatures*

Application	G, GT and metal	Lock-in	Miniatures	Subminiatures
		Battery Types		
Diode			1A3	VX21
H-V Rectifier			122, 1654	SN956A(5642)[1]
Triode, Medium Mu	1G4GT, 1H4G	1LE3		CK568AX(5677),[1] CK556AX(6676)[1]
Diode-Pentode	1N6G	1LD5, 1LD6	1S5, 1U5	1Q6, 2E41
Twin Triode	1J6G		3A5	
Pentode-Remote	1P5GT		1T4	
Pentode-Sharp	1N5GT	1LC5, 1LN5	1S5, 1U4, 1U5, 1L4	2E31, CK569AX(5678),[1] 1W5
Pentode-Power	1Q5GT, 1A5GT, 3Q5GT	1LA4, 1LB4, 3LF4	3A4, 3S4, 3V4, 1S4, 3Q4	1V5, CK503AX, CK506AX
Converter	1A7GT	1LA6, 1LC6	1R5	1C8
		Heater Types		
Double Diode	6H6	7A6	6AL5	1106, SN946(5647),[1] SN978,[2] CK606BX(5704) } equal half of 6AL5
Duo-diode, hi-mu triode	75, 6Q7, 6SQ7GT	7B6, 7C6	6AQ6, 6AT6, 126C6	
Duo-diode, Medium Mu triode	6R7, 6SR7GT	7E6	6BG6	
Twin triode, high-Mu	6SL7GT	7F7	12AX7	SN917(5637),[1] SN980,[2] CK619CX } equal half of 6SL7GT
Twin triode, Medium Mu	6SN7GT, 6J5	7N7, 7F8	12AU7, 2C51, 12AT7	6K4, SN979,[2] CK608CX(5703), SN955 } equal half of 6SN7GT
Medium Mu triode	6J5, 76	7A4	6C4	SN957A(5645),[1] SN1006(5646)[1]
Pentodes-Remote	78, 6D6, 6K7, 6SK7GT	7A7, 7B7	6BD6, 6BJ6	SN944(5633),[1] SN972[2]
High Gm semiremote pentodes	6SG7	7H7	6BA6, 26A6	
Pentodes-Sharp	77, 6C6, 6J7, 6SJ7GT	7C7		
High Gm video Pentodes	6AC7, 6SH7	7G7/1232, 7L7, 7V7, 7W7	6AG5, 6AK5, 6AH6, 6AU6, 6BH6	605CX(5702),[1] SD828E(5634),1039A
Power Output Pentodes	6G6G		6AK6	SN828A(5638)[1]
Video Pentodes Output	6AG7		6AN5	SN953A(5639)[1]
Beam Pentodes	6V6GT	7C5	6AQ5, 6AS5	SN947(5640),[1] SN976
Beam Pentodes (high voltage)	35L6GT, 50L6GT		35B5, 35C5, 50B5, 50C5	
Converters	6SA7	7Q7	6BE6, 26D6,	
Mixer			6AS6	SN1007A(5636)[1]
Rectifiers	6X5GT	7Y4	6X4	SN954(5641)[1], SN977[2]
Rectifiers (high volt)	35Z5GT	35Y4	35W4	
Thyratrons	884		6D4	
Thyratrons	2050		2D21	SN949(5643)[1], SN982[2]
		Voltage Regulators		
75-volt	OA3/VR75		5651	
90-volt	OB3/VR90			SN948(5644)[1], SN981[2]
105-volt	OC3/VR105		OB2	
150-volt	OD3/VR150		OA2	

[1] RMA numbers recently assigned.
[2] Long-life versions of subminiatures now under development at Bureau of Ships.

more distant future it is quite possible that even smaller bulbs will be available, such as the "micro-tube" mentioned in recent literature.

The tabulation below illustrates this trend. The first column lists a number of representative receiving tubes of the old form, which fall into a general application classification. Subsequent columns show corresponding types of miniature and subminiature tubes in the same general classification. To complete the picture, the electrically-similar lock-in types are also listed in another column.

It is pointed out that tubes in the different columns are in no sense mechanically interchangeable, due to differences in dimensions, basing, and pin connections. Also, there are in some cases minor electrical differences, particularly capacitance, filament current, power dissipation, due to different internal construction, improved design, and smaller electrodes of the modern types. Therefore it is unlikely that any old equipments will be modified to use smaller tubes. Equipments currently being designed for both commercial and military use already incorporate a large percentage of miniatures, and future designs will doubtless use more and more subminiatures.

SHIPBOARD TELETYPEWRITER INSTALLATIONS

For several years, the navy has stocked a large supply of "shipboard" teletypewriters. They differ from the standard type teletypewriter mainly in that the printer is provided with a heavy bottom plate and shockmounts, the relay is clamped in place, the printer and cover are bolted down to the table, and the table legs are provided with flanges so that they can be fastened to the deck. Spark suppressors and noise filters, plus automatic carriage return and line feed are also included. These accessories were provided by the manufacturer, and the complete assemblies were procured by the Navy as shipboard teletypewriters.

This large stock of printers, however, is now depleted, and no more of this type are on order. A new series of light-weight Model 15 consoles are under procurement for shipboard use but will not be available for approximately 6 months. The only alternative for the present, therefore, is to install the standard Model 15 or the Army type TG-7-A or TG-7-B printers which are still plentiful. From an operational standpoint, the three equipments are identical but from an installation viewpoint they differ in that the Army equipments do not include an operating table or rectifier, while the Model 15 lacks shockmounts.

In those installations where the TG-7-A or TG-7-B equipments will be used, it will be necessary for the installing activity to fabricate suitable tables. Steps should be taken to insure that the equipments are adequately fastened to the tables, and the tables to the decks. Covers need be fastened down only on small ships. Adequate shockmounts and baseplates are provided with the TG-7-A and TG-7-B.

In new shipboard installations, the question arises of how to supply line current to TG-7-A or TG-7-B equipments, since they are not provided with a rectifier. In most installations, the TG-7-A or TG-7-B will be used primarily in receiving circuits, and therefore will be used in conjunction with Models FRC, FRA, and FRF frequency shift receiver converter equipments, which supply their own line current.

If, however, it becomes necessary to use the TG-7-A or TG-7-B for transmitting, it will be necessary to provide another source of line current. In new installations, the Type TT-23/SG teletype panel should be installed. This panel contains facilities for connecting a local source of line current such as from the rectifier of a Model 19 teletypewriter, to the TG-7-A or TG-7-B. By operating toggle switches incorporated in the panel, it is possible to select or reject local line current for any of the six teletypewriter channels of the panel.

In those installations where the standard Model 15 will be used, it is necessary for the installing activity to attach baseplates and shockmounts, since the Model 15 is supplied without them. There is a large surplus quantity of baseplates for the Models TG-7-A and TG-7-B. Using these plates, the addition of shockmounts to a standard Model 15 teletypewriter becomes a simple matter. Mounted on shockmounts, the Model 15 is suitable for shipboard installation. These baseplates, Navy type No. -103542, need only be fitted with Lord mountings, type 200-P-25, and fastened to the base of the printer, since all necessary holes are already drilled and tapped. Type 200-P-25 Lord mountings bear the Navy stock No. N16-M-5052-7, and may be requisitioned from either SSB, NSC, Oakland or ESB, NSD, Bayonne.

A considerable quantity of shipboard modification kits are available which provide the automatic carriage return and line feed features. These kits should be requisitioned from either ComServPac or NSC, Bayonne, and installed in the teletypewriter equipment.

A new type page printer, the Model 28, is expected to be available in 1950. It will be approximately one-half the size of the present Model 15 and weigh about 40 pounds.

More About Perchloric Acid Type Batteries

The hazards arising from stocking or using perchloric acid type batteries were discussed in an article "Perchloric Acid Type Batteries" on page 19 of the August 1947 ELECTRON. Two such batteries are the Navy Type No. -19048 and the -19052. These batteries are furnished dry, with the electrolyte packed separately, as shown in figure 1. It is recommended by the Bureau of Ships that this perchloric acid electrolyte be disposed of as an explosive material, and replaced with hydrofluoboric or hydrofluosilicic acid. Commercial 43 percent hydrofluoboric acid in 100-ml. shatterproof plastic bottles can be obtained from the General Chemical Co., 40 Rector Street, New York 6, N. Y., or the Harshaw Chemical Co., 1945 East Ninety-seventh Street, Cleveland 6, Ohio. The use of this acid as the electrolyte in these batteries will result in a slightly lower voltage for the same discharge time, and a 2-percent lower watt-hour output than are obtained when perchloric acid is used as the electrolyte.

Figure 1 shows various views of some batteries and accessories that are used with perchloric acid electrolyte.

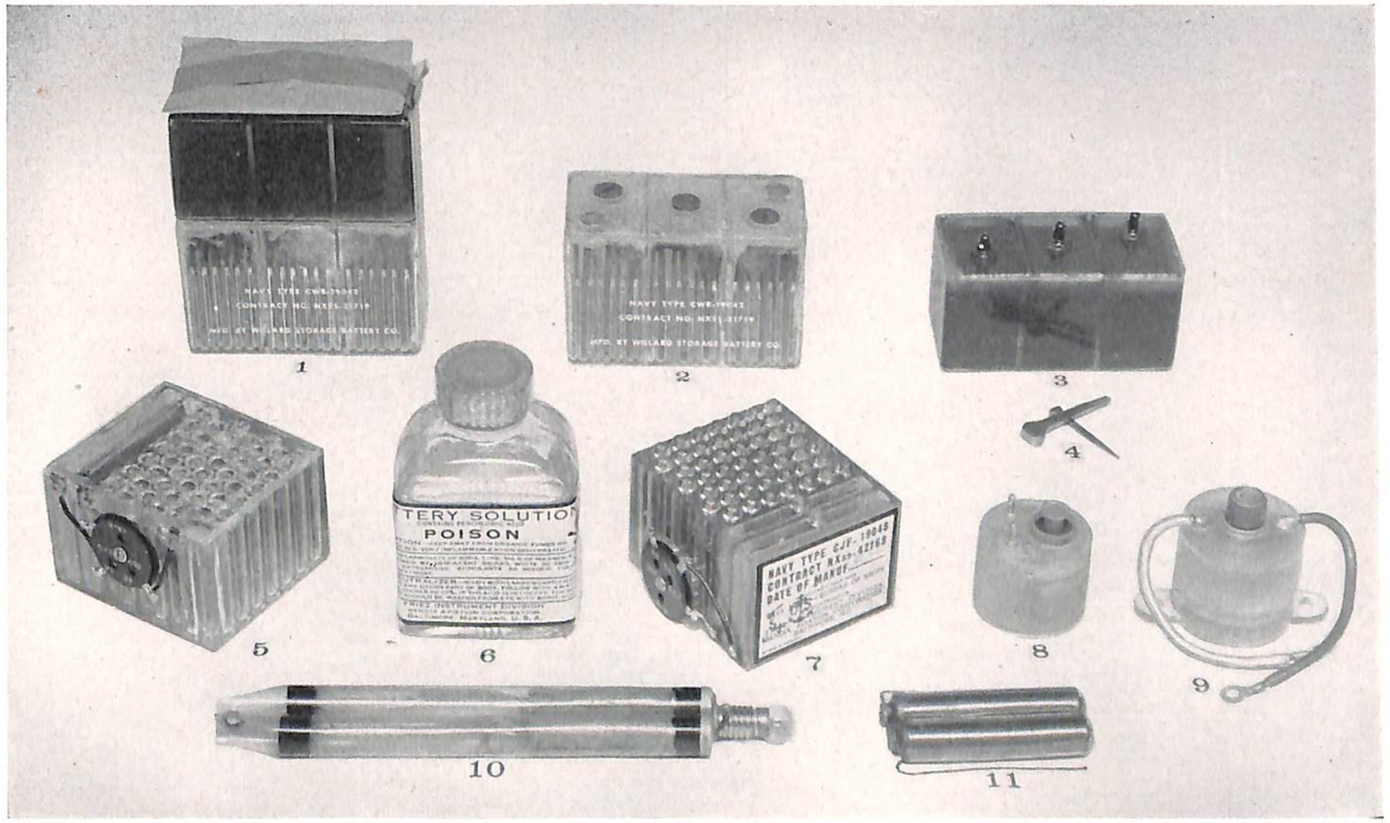
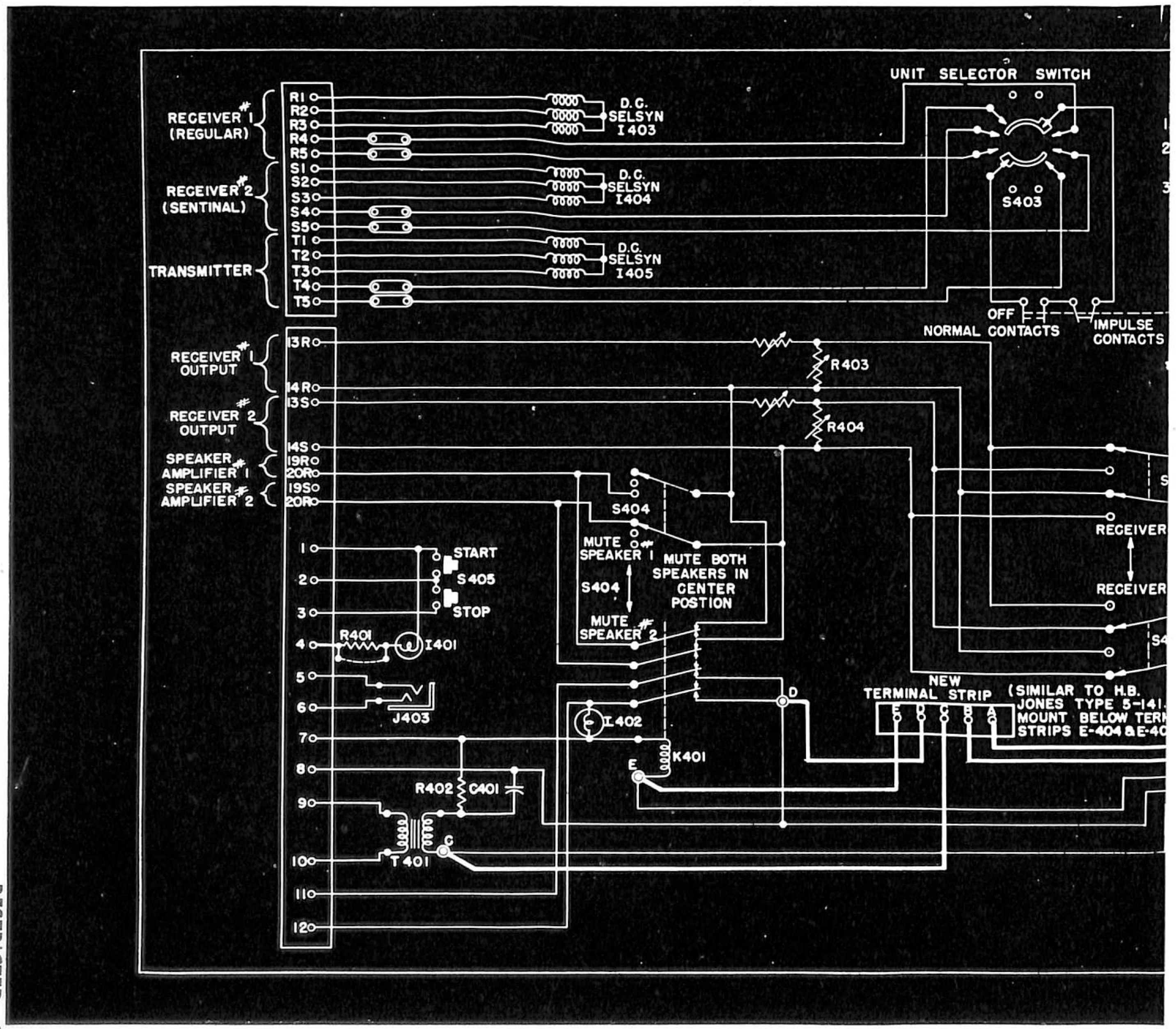


FIGURE 1.—*(1) Type -19042 battery; (2) active part of (1); (3) electrolyte container of (1); (4) activating tool; (5) and (7) type -19048 battery; (6) perchloric acid electrolyte; (8) N2P40 battery-early model; (9) later model of (8); (10) pilot balloon battery BB211/AM and light; (11) active part of (10).*

HANDSET EXTENSION FOR TYPE -23496 REMOTE CONTROL INDICATOR

Recent reports received in the Bureau of Ships indicate that some ships feel the need for an extension handset from a Navy Type -23496 Remote Control Indicator Unit. Accordingly, a method has been devised to connect a new terminal strip in parallel with one of the handset receptacles in this unit. Since it would prove difficult to connect additional conductors to the receptacle lugs, other solder points have been found to facilitate wiring the new terminal strip. In figure 1, each of these points is indicated by a circle and designated by a letter which corresponds to the appropriate pin designation on the handset jack. Also, all wiring to the new terminal strip is drawn in heavy lines in figure 1.

Inasmuch as there are two handset receptacles in the Type -23496 Remote Control Indicator Unit, the Bureau of Ships desires that the flange of the receptacle (J-401), to which the new terminal strip is paralleled, be painted white for identification purposes.



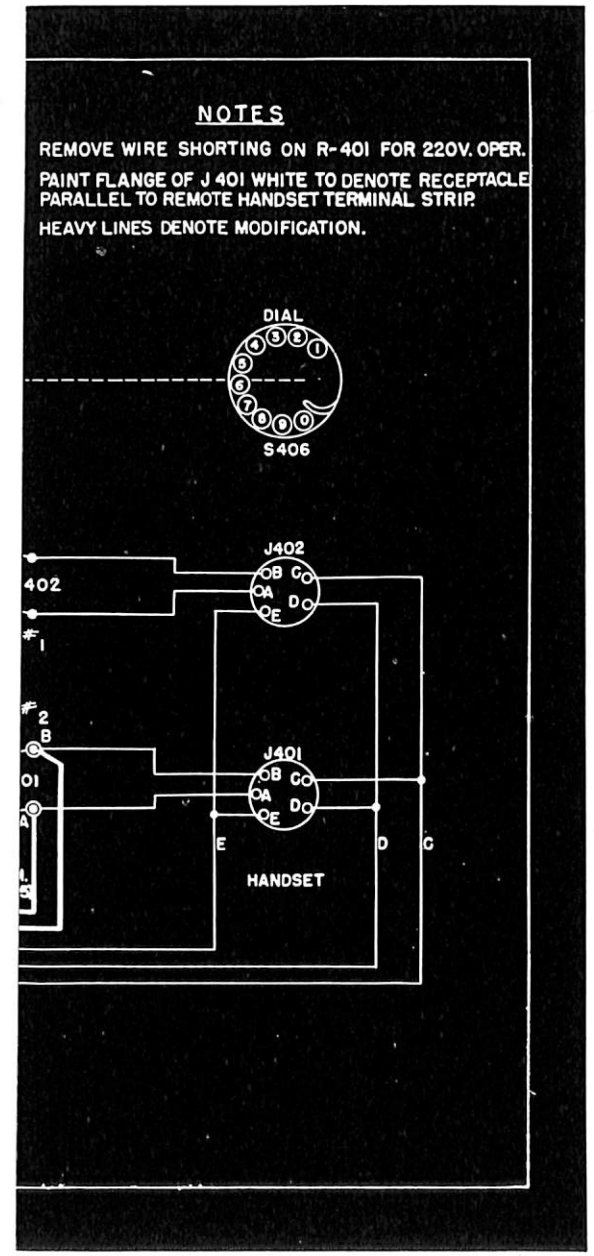


Figure 1.—*Type -23496 remote control indicator unit modified to accommodate an extension telephone handset. New wiring is shown by heavy lines, and soldering points by circles.*

Type of Approach	Last Month	To Date
Practice Landings	7,406	90,930
Landing Under Instrument Conditions	307	4,671

DEFECTIVE DRY BATTERIES

The Bureau of Ships has been advised that type BA-51, 67.5-volt dry batteries (Navy type 19032), manufactured prior to 15 December, 1947, by the National Carbon Co. (trade-mark "Everready"), may have defects which will reduce their service life. Notification was by Signal Corps letter SIGAI-5A4, of 5 February 1948.

In order to reduce to a minimum the operational failure of equipment using these batteries, it is recommended that issue and use of batteries of the type described, failing the following test, be avoided whenever possible:

1. Connect a 2,000-ohm, 5-watt resistor across the battery to be tested.
2. Read the battery voltage within 15 seconds after the resistor is connected. Use a voltmeter having at least 1,000 ohms per volt resistance.
3. The battery voltage should be 63 volts or higher at the end of the 15-second test period for an acceptable battery. If the battery voltage is below 63 volts at the end of the test period, the battery is not suitable for use.

BASIC PHYSICS
PART TEN

The Parallel Circuit

The parallel circuit is the exact antithesis of the series circuit. In electronics literature the parallel circuit is often referred to as an antiseries circuit. The student is urged carefully to compare the axioms of the two types of circuits because their fundamental differences are of major importance in future work.

The voltage axiom.—Figure 1 shows a typical arrangement of three resistances in parallel. Each resistance in this figure forms a *branch* of the circuit. The voltmeter V is connected across all three branches of the circuit as well as directly across the terminals of the source. It may then be said that *the electromotive force E is applied directly across all branches of a parallel circuit.* From Ohm's Law it is known that the difference of potential developed across any resistance must be equal to the e. m. f. applied across that resistance. Therefore *the difference of potential developed across all branches of a parallel circuit is equal to the applied e. m. f.* The logical conclusion is that electrical equilibrium can exist in a parallel circuit only when the same voltage appears across all branches of the circuit.

The current axiom.—Each branch of a parallel circuit represents an individual current path. The total current flowing into or out of a parallel combination is called the *line* current and represents the current supplied by the source. The actual current in any branch must be equal to the e. m. f. across that branch divided by the resistance of the branch. If the branch contains more than one component resistance, the total resistance of the branch will be the sum of the series-connected resistances in the branch.

Consider the line and branch currents in the parallel circuit of figure 2. The line current may be measured by placing an ammeter at any point in the line between points A and B or between C and D. At point B the line current divides to form the branch currents I_1, I_2, and I_3, whereas, at point C, the currents through the branches join to reform the line current I_L. Electrical equilibrium exist in the circuit only when

$$I_L = I_1 + I_2 + I_3 \; . \; . \; . \; . \; . \; . \; . \; .$$

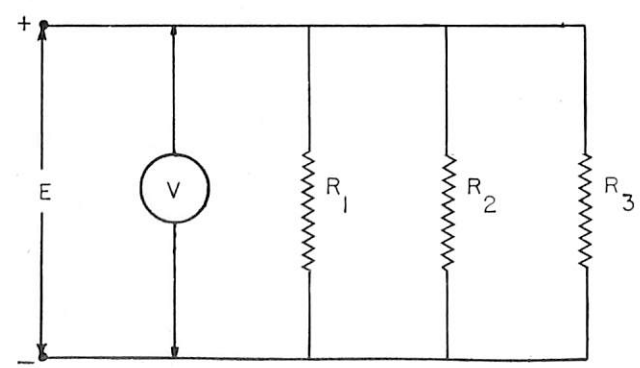


FIGURE 1.—*Typical parallel circuit.*

This equation states: *The total current through a parallel combination is equal to the sum of the branch currents.* Although only three branches are shown in figure 2, it should be evident that any number of branches may be used in this way to form a parallel combination.

A very important corollary of the current axiom is known as *Kirchhoff's Current Law.* If

$$I_L = I_1 + I_2 + I_3 \; . \; . \; . \; . \; . \; .,$$

then

$$I_L - I_1 - I_2 - I_3 \; . \; . \; . \; . \; . = 0.$$

In this form the current axiom becomes: *The algebraic sum of all the currents at a point of junction in a circuit is equal to zero.*

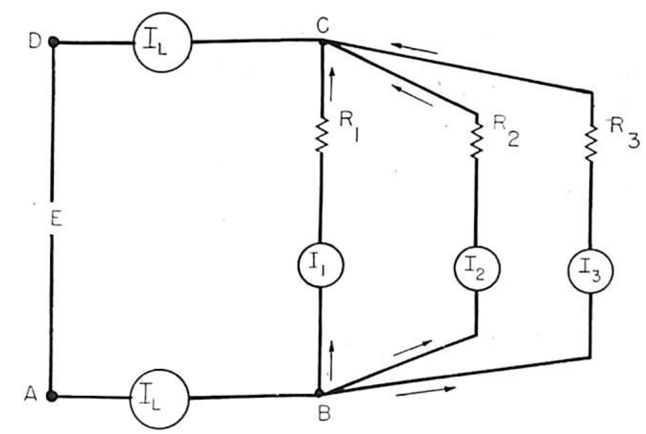


FIGURE 2.

In order to make use of Kirchhoff's Current Law it is necessary arbitrarily to assign polarity to the currents flowing into and out of a point of junction. For example, in figure 2, I_L flows into point B, whereas I_1, I_2 and I_3 flow out of the same point. If I_L is considered positive, then the branch currents are said to be negative. Conversely, if the direction of I_L with respect to B is said to be negative, then the direction of the branch currents is considered positive.

The conductance axiom.—You will recall that in a series circuit composed of two or more resistive elements, the total resistance must be greater than that of any individual resistance. Two ohms and 5 ohms in series has an equivalent resistance of 7 ohms, which is greater than either 2 or 5 ohms.

On the other hand, adding branches to a parallel circuit will cause the line current to increase. Since the applied e. m. f. is assumed to be constant, an increase in the line current can only be accomplished by a decrease in the equivalent or total resistance of the circuit. Adding resistance to a parallel circuit *in the form of additional parallel branches* results in a decrease in the equivalent resistance of the circuit. It should be evident that the equivalent resistance of a parallel circuit cannot be found by the simple expedient of adding branch resistances.

In figure 2, assume that only the ohmic resistances of R_1, R_2, and R_3 are known. To apply Ohm's Law, one must know two of the three factors: E, I, and R. The problem is to find the equivalent resistance of the circuit when only the branch resistances are known. A possible approach is indicated by

$$R_e = \frac{E}{I_L}$$

E is known to be the same across all branches of a parallel circuit and I_L is the sum of all the branch currents. R_e, the equivalent resistance, is that single valued resistance which if connected directly across the source terminals would pass current identical in amperage to that flowing through the given parallel circuit it replaced.

Resistance has been defined as a property of matter. Changing the voltage or e. m. f. across a resistance causes the current through the resistance to change, *but the resistance itself does not vary with E.* If temperature effects are ignored, resistance is a constant which depends primarily upon the nature of the material composing a circuit. It does not vary with either E or I. Therefore it is feasible to *assume a voltage across a parallel circuit in order to find the equivalent resistance.* Using an assumed e. m. f. as one of the factors, the branch currents may be calculated, added, and the sum divided into assumed voltage to find R_e. This is the fundamental idea of all parallel circuit solutions.

It will be remembered that conductance defines the current established in a resistance by unit potential. The conductance in mhos of any branch of a parallel circuit is the current in amperes established in that branch by an e. m. f. of 1 volt. If 1 volt is *assumed* to be applied across the circuit in figure 2, then the branch current in R_1 is

$$I_1 = \frac{E}{R_1} = \frac{1}{R_1} = G_1,$$

in R_2

$$I_2 = \frac{1}{R_2} = G_2,$$

and in R_3

$$I_3 = \frac{1}{R_3} = G_3.$$

The line current I_L is the sum of the branch currents, or

$$I_L = I_1 + I_2 + I_3 = G_1 + G_2 + G_3 = G_e,$$

where G_e is the equivalent conductance of the circuit and represents the line current obtained with an applied e. m. f. of 1 volt. Since

$$R_e = \frac{E}{I_L},$$

and $E=1$ then

$$R_e = \frac{1}{I_L} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} = \frac{1}{G_1+G_2+G_3}$$

Hence

$$R_e = \frac{1}{G_e}$$

The equivalent conductance of a parallel circuit is equal to the sum of the individual branch conductances. The equivalent resistance of a parallel circuit is the reciprocal of the equivalent conductance.

An important corollary of the conductance axiom is: *The equivalent resistance of a parallel circuit will always be less than the least branch resistance.* This follows from the fact that the line current in a parallel circuit will always be greater than the largest branch current.

A special type of parallel circuit is one in which all branches contain the same resistance. An e. m. f. of 12 volts will establish a current of 2 amperes in a 6-ohm resistance. If a second 6-ohm resistance is connected across the first, the line current will be 4 amperes and the equivalent resistance $\frac{12}{4}=3$ ohms. A single 6-ohm resistance has an equivalent resistance of 6 ohms; when paralleled with an equal resistance the equivalent resistance is halved; if three 6-ohm resistances are connected in parallel across 12 volts, the line current will be 6 amperes and the equivalent resistance 2 ohms. It should be evident that the equivalent resistance of several equal resistances in parallel is simply the resistance of one element divided by the number of elements in parallel. For example,

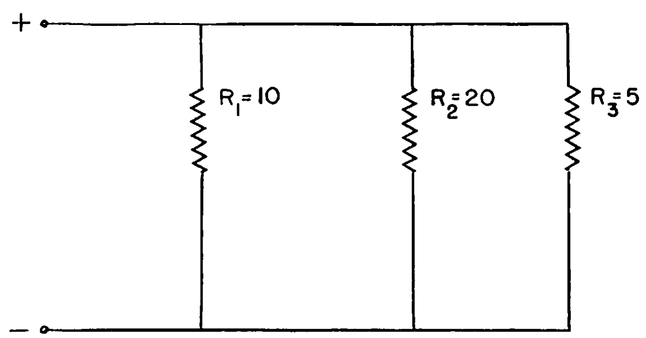


FIGURE 3.

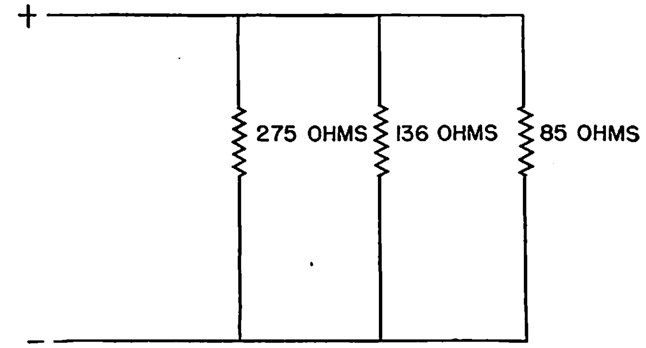


FIGURE 4.

if five 10-ohm resistances are connected in parallel the equivalent resistance is $\frac{10}{5}$ or 2 ohms.

Solution of parallel circuit.—Solution of parallel circuits on the basis of the conductance axiom is the fundamental method of solving all such circuits. However, a number of variations of this method have been developed to minimize mathematical labor and mental effort. If the student becomes thoroughly familiar with these variations, much time and effort will be saved in future work. Example problems will now be presented to explain the various methods of solving parallel circuits.

The conductance method.—In figure 3, find the equivalent resistance of the circuit when $R_1=10$ ohms, $R_2=20$ ohms, $R_3=5$ ohms.

$$G_1 = \frac{1}{R_1} = \frac{1}{10} = 0.1 \text{ mho.}$$

$$G_2 = \frac{1}{R_2} = \frac{1}{20} = 0.05 \text{ mho.}$$

$$G_3 = \frac{1}{R_3} = \frac{1}{5} = 0.2 \text{ mho.}$$

$$G_e = G_1 + G_2 + G_3 = 0.1 + 0.05 + 0.2 = 0.35 \text{ mho.}$$

$$R_e = \frac{1}{G_e} = \frac{1}{0.35} = 2.86 \text{ ohms.}$$

The least branch resistance is 5 ohms and R_e is less than 5 ohms. This simple check will often indicate whether an error has been made in the arithmetical work.

The assumed voltage method.—The conductance method finds greatest use in algebraic analyses of networks. The average engineer does not prefer to use it in the arithmetical solution of circuits because practical circuits usually are composed of resistances of such magnitude that conductances are a small fraction of a mho. Where a slide rule is used to facilitate the arithmetical work great care must be exercised in calculating conductance to avoid misplacing the decimal point. The assumed voltage method is particularly suited to slide rule calculations.

Since resistance is independent of the electromotive force applied across the resistance there is no reason for restricting the assumed voltage to 1 volt. Any e. m. f. may be assumed if desired. In figure 4 is shown a parallel circuit in which the greatest branch resistance is 275 ohms. If it is assumed that 1,000 volts is applied across the combination, then the current in the 275-ohm branch will be between 1 and 10 amperes and the current in all the other branches greater than 1 ampere.

Assumed E method	*Conductance method*
Assumed $E=1{,}000$ v.	Assumed $E=1$ v.
$I_1=\frac{E}{R_1}=\frac{1{,}000}{275}=3.64$ a.	$G_1=0.00364$
$I_2=\frac{E}{R_2}=\frac{1{,}000}{136}=7.35$ a.	$G_2=0.00735$
$I_3=\frac{E}{R_3}=\frac{1{,}000}{85}=11.8$ a.	$G_3=0.01180$
$I_L=I_1+I_2+I_3$	$G_e=0.0228$
$I_L=3.64+7.35+11.8=22.8$ a.	$\frac{1}{G_e}=\frac{1}{0.0228}=43.9$ ohms.
$R_e=\frac{E}{I_L}=\frac{1{,}000}{22.8}=43.9$ ohms.	

It should be reasonably obvious that the only difference in the two methods used above is in the position of the decimal point. A current of 0.00364 ampere per volt in the conductance becomes 3.64 amperes per 1,000 volts in the assumed E method.

A little thought should be given to the selection of an assumed e. m. f. If the slide rule is to be used, it is recommended that some multiple of 10 such as 10, 100, 1,000, 10,000, etc., volts be assumed. The actual value should be such that the current in the branch of greatest resistance is between 1 and 10 amperes. Currents in the other branches will then be greater than 1 ampere. When the assumed E is a multiple of 10, branch currents may be calculated most readily on the reciprocal scales of the slide rule. A mathematical table of reciprocals may also be used as readily as the slide rule.

If the slide rule is not used, a better plan is to assume an e. m. f. exactly equal to the greatest branch resistance. In figure 4, if an e. m. f. of 275 volts is assumed, the current in branch 1 is established as 1 ampere without further calculation, and the currents in the other branches will be greater then 1 ampere. This automatically reduces the number of branch current calculations by 1.

The assumed voltage method may be used to find the equivalent resistance of a parallel circuit even when the actual applied e. m. f. is known. This is not recommended since there is always the possibity that the assumed E may inadvertently be substituted for the given e. m. f.

The formula method.—The equivalent resistance of a two or three-branch parallel circuit is readily calculated by formula. The formula for the two-branch circuit is derived from the conductance axiom. Let R_1 and R_2 be two resistances in parallel. Then from the conductance axiom

$$R_e = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}}$$

Multiplying both sides by $\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$

$$\frac{R_e}{R_1}+\frac{R_e}{R_2}=1$$

Multiplying by the common denominator R_1R_2

$$R_eR_2+R_eR_1=R_1R_2$$

$$R_e(R_1+R_2)=R_1R_2$$

Dividing by (R_1+R_2)

$$R_e=\frac{R_1R_2}{R_1+R_2}$$

which states *The equivalent resistance of two resistances in parallel is equal to the product of the resistances divided by their sum.* For example, the equivalent resistance of 95 ohms in parallel with 225 ohms is

$$R_e=\frac{95\times225}{95+225}=\frac{21375}{320}=66.8 \text{ ohms.}$$

This formula may also be used to find the equivalent resistance of a three-branch circuit by considering the branches in pairs. To find the equivalent resistance of 10, 20, and 30 ohms in parallel, first find the equivalent resistance of 10 and 20 ohms.

$$R_a=\frac{10\times20}{10+20}=\frac{200}{30}=6.67 \text{ ohms.}$$

The equivalent resistance of 6.67 ohms in parallel with 30 ohms is

$$R_e=\frac{6.67\times30}{6.67+30}=\frac{200}{36.7}=5.45 \text{ ohms.}$$

It is left to the student to demonstrate that the equivalent resistance of a three-branch parallel circuit is given by

$$R_e=\frac{R_1R_2R_3}{R_1R_2+R_1R_3+R_2R_3}$$

In general, the arithmetical labor involved in solving circuits by formula increases so rapidly with the number of parallel branches that this method has little advantage for circuits with more than three branches.

Power and work in parallel circuits.—The power and work formulas previously derived from Ohm's Law may be applied to parallel circuits in much the same way as to series circuits. *The total power in a parallel circuit is equal to the sum of the individual branch powers.* The power in any branch may be calculated by any of the following expressions:

$$P_b = EI_b = I_b^2R_b = \frac{E^2}{R_b}$$

where E is the e. m. f. across the circuit, I_b the branch current, and R_b the branch resistance. If the equivalent resistance and line current are known, the total power in a parallel circuit is given by

$$P = EI_L = I_L^2R_e = \frac{E^2}{R_e}.$$

Any of the power formulas may be converted to a work formula on the basis of $w=Pt$.

$$w = EI_Lt = I_L^2R_et = \frac{E^2t}{R_e}.$$

Analysis of the parallel circuit.—The practical applications of the parallel circuit are many times more numerous than those for the series circuit. The parallel circuit is essentially a constant-voltage variable-current arrangement, since adding or removing parallel branches changes the line current but does not affect the e. m. f. across the circuit. The only limit to the number of parallel branches that may be connected in a parallel circuit is the maximum current-carrying capacity of the line and the maximum rated load-current of the source.

The parallel circuit is particularly suited to the distribution of electrical energy since it has few of the faults previously described for the series circuit. Devices may be connected across the line or removed from the circuit without affecting the operation of other devices. If one device should burn out (open circuit), it will not affect the operation of the other circuit elements. A short circuit in any one device does not endanger the other equipment in the circuit, although it will affect the operation of the circuit because of the overload placed upon the source. The source is usually protected against overload by some type of protective device. A circuit breaker, often used for protection, is a device connected in series with the line and adjusted to open the circuit when the line current exceeds some predetermined amplitude. The circuit breaker is usually located as close as is practicable to the source. A protective device known as a *fuse* is often used to protect the main line from short circuits at the point where the electrical energy is utilized. The fuse contains an element of some soft metal through which the current must flow. The dimensions of the element are such that a current of a predetermined amplitude will generate sufficient heat to melt the element and open the circuit. In general fuses are slow-acting devices compared to circuit breakers. A fuse rated at 20 amperes may pass a current of 30 amperes for several seconds before sufficient heat is generated to open the circuit, whereas a circuit breaker adjusted to 20 amperes will open the circuit within a fraction of a second if the current exceeds the rated value by a few percent. Where fuses are used, it is customary to place one fuse in each side of the line, thereby dividing the responsibility for protection against overload.

Resistance symbols.—The student should be aware by this time that the drawing symbol is used in electrical drawings to represent resistance. The symbol is also occasionally used for resistance.

In electronics work the symbol for "ohms" is the Greek capital omega (Ω). Occasionally the lower case omega (ω) is used. This is not recommended in electronics work, because lower case omega is customarily used as the symbol for angular velocity in alternating current calculations. The symbols "kΩ" and "MΩ" are used to represent kilo-ohms (1,000 ohms) and megohms (1,000,000 ohms), respectively. Where there is little chance for misunderstanding, the omega may be omitted from the symbol. Thus, 20k means 20,000 ohms; 2M represents 2,000,000 ohms; etc.

THE SERIES-PARALLEL CIRCUIT

As previously mentioned, the series-parallel circuit is a hybrid arrangement of series and parallel combinations of resistances. The principles of series and parallel circuits must be combined to obtain the solution of such circuits. The general method of solution is to reduce each parallel combination to its equivalent resistance, substitute the equivalent resistance for the appropriate parallel combination, and then solve the circuit by series principles. Alternatively the student may start by reducing each series combination. Which method is used will be dictated by the layout of the circuit. In any case, start at the bottom and work up. The examples will clarify the procedure.

Solution of a series-parallel circuit.—Since no new principles are necessary to solve a series-parallel circuit, the solution of such circuits is best demonstrated by example. In the solution of the circuit shown in figure 5A, particular attention should be given to the analysis immediately preceding each arithmetical operation. It will be found that the actual analysis of the operation is much more difficult than the arithmetical work required to carry it out.

The first step in solving any electrical circuit is to study the circuit and marshal all the available information. It is noted in the given circuit that the ammeter A_1 is connected in the negative lead from the source and hence reads the line current. At point Y, this current divides, 5 amperes flowing upward through R_d, which means that the total current through each of the parallel combinations A, B, and C must be 12−5 or 7 amperes. It will be seen that this item of information will shorten the work of finding the equivalent resistance of the parallel combinations.

The equivalent resistance of parallel combination A may be found by either the conductance or assumed voltage method, but if the combination is studied for a moment it will be evident the formula method is best suited. Two 32-ohm resistances in parallel have an equivalent resistance of 16 ohms. The equivalent resistance of combination A is then the equivalent resistance of 16 ohms in parallel with 6 ohms.

$$R_{ea} = \frac{6\times16}{6+16} = \frac{96}{22} = 4.36 \text{ ohms.}$$

The current through combination A is 7 amperes, hence

$$E_a = IR_{ea} = 7\times4.36 = 30.5 \text{ volts.}$$

The power in combination A is

$$P_a = E_aI = 30.5\times7 = 213.5 \text{ watts.}$$

This may be checked by calculating the power in each branch. With 30.5 volts across the circuit, the power in the 6-ohm resistance is

$$P = \frac{E_a^2}{R} = \frac{30.5^2}{6} = \frac{930}{6} = 155 \text{ watts.}$$

The power in *each* of the 32-ohm branches is

$$P = \frac{E^2}{R} = \frac{30.5^2}{32} = \frac{930}{32} = 28.8 \text{ watts.}$$

The sum of the branch powers is

$$P_a = 155+28.8+28.8 = 213.6 \text{ watts.}$$

which checks closely with the previous calculated value 213.5 watts.

Now turning to the parallel combination B, ammeter A_2 indicates the current in the 16-ohm branch of this combination is 2 amperes, hence the voltage drop across the combination is

$$E_b = IR = 2\times16 = 32 \text{ volts.}$$

The current in the 10-ohm branch is

$$I = \frac{E_b}{R} = \frac{32}{10} = 3.2 \text{ amperes.}$$

The current through both the 10- and 16-ohm branches s 2+3.2, or 5.2 amperes. The total current through the combination is 7 amperes, hence the current in the middle branch must be 7−5.2, or 1.8 amperes. The resistance of the middle branch is

$$R = \frac{E_b}{I} = \frac{32}{1.8} = 17.8 \text{ ohms.}$$

The middle branch consists of a 14-ohm resistance in series with an unknown resistance R_b. Since the total branch resistance is 17.8 ohms, the resistance R_b will be the difference between this value and 14 ohms, or 3.8 ohms.

The equivalent resistance of the combination B is

$$R_{eb} = \frac{E_b}{I} = \frac{32}{7} = 4.57 \text{ ohms.}$$

The power in combination B is

$$P_b = IE_b = 7\times32 = 224 \text{ watts.}$$

This may be checked by

$$P_b = I^2R_{eb} = 7^2\times4.57 = 49\times4.57 = 224 \text{ watts.}$$

The parallel combination C now remains to be solved. The voltmeter V indicates the voltage drop across this combination is 75 volts. The current in the upper branch is then

$$I = \frac{E_c}{R} = \frac{75}{20} = 3.75 \text{ amperes.}$$

Since the total current through the combination is 7 amperes, the current in the lower branch must be 7−3.75, or 3.25 amperes. The resistance of R_c is

$$R_c = \frac{E_c}{I} = \frac{75}{3.25} = 23.1 \text{ ohms.}$$

The equivalent resistance of the combination is

$$R_{ec} = \frac{E_c}{I} = \frac{75}{7} = 10.7 \text{ ohms.}$$

This may be checked by the formula

$$R_{ec} = \frac{20\times23.1}{20+23.1} = \frac{462}{43.1} = 10.7 \text{ ohms.}$$

The power in the combination C is

$$P_c = E_c I = 75 \times 7 = 525 \text{ watts.}$$

Now, it is possible to figure the total voltage drop across the three parallel combinations in series, which is

$$E_{abc} = E_a + E_b + E_c = 30.5 + 32 + 75 = 137.5 \text{ volts.}$$

Since the total current through all three parallel combinations is 7 amperes, the total power in A, B, and C is

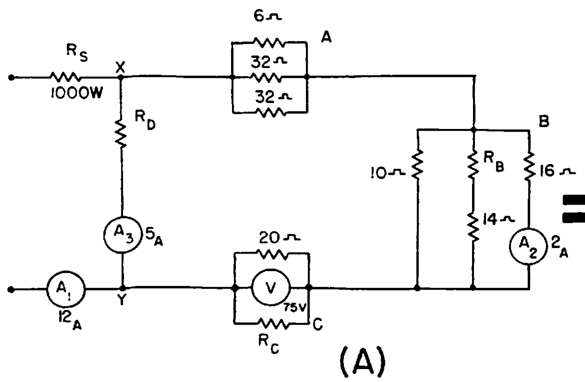
$$P_{abc} + E_{abc} I = 137.5 \times 7 = 962.5 \text{ watts.}$$

This may be checked by

$$P_{abc} = P_a + P_b + P_c = 213.5 + 224 + 525$$
$$= 962.5 \text{ watts.}$$

Having completed the calculations for the equivalent resistance of each parallel combination, it is desirable to redraw the circuit, substituting R_{ea}, R_{eb}, and R_{ec} for their respective parallel combinations. This has been done in figure 5B. It will be noted that R_{ea}, R_{eb}, and R_{ec} are connected in series across R_d. The equivalent resistance of 4.36, 4.57, and 10.7 ohms in series is

$$R_{abc} = 4.36 + 4.57 + 10.7 = 19.6 \text{ ohms.}$$



The voltage drop across R_{abc} is 137.5 volts, which must be the voltage drop across R_d, since the two resistances are in parallel. With 5 amperes through R_d, and 137.5 volts across it,

$$R_d = \frac{E}{I} = \frac{137.5}{5} = 27.5 \text{ ohms.}$$

$$P_d = EI = 137.5 \times 5 = 687.5 \text{ watts.}$$

The evolution of the given circuit to this point is shown in figure 5C. The equivalent resistance between points X and Y is the equivalent resistance of R_d and R_{abc} in parallel.

$$R_{xy} = \frac{R_d R_{abc}}{R_d + R_{abc}} = \frac{27.5 \times 19.6}{27.5 + 19.6} = 11.4 \text{ ohms.}$$

All the parallel combinations in the given circuit have now been reduced to their equivalent resistance of 11.4 ohms. Substituting R_{xy} for the parallel combination R_d and R_{abc} reduces the given circuit to the simple series arrangements hown in figure 5D. The resistance of R_s may be calculated on the basis that a current of 12 amperes expends electrical energy at the rate of 1,000 watts in the resistance. Since

$$P_s = I^2 R_s$$

$$R_s = \frac{P_s}{I^2} = \frac{1{,}000}{12^2} = \frac{1{,}000}{144} = 6.94 \text{ ohms.}$$

The equivalent series circuit of figure 5A is

$$R_e = R_{xy} + R_s = 11.4 + 6.94 = 18.3 \text{ ohms.}$$

$$I_1 = 12 \text{ amperes.}$$

$$E = I_L R_e = 12 \times 18.3 = 220 \text{ volts.}$$

$$P = EI_L = 220 \times 12 = 2{,}640 \text{ watts} = 2.64 \text{ kilowatts.}$$

The *equivalent series circuit* of the original circuit is shown in figure 5E. An 18.3-ohm resistance connected directly across the terminals of the source produces exactly the same effect on the source as the circuit shown in figure 5A. Analysis of the data obtained in solving the given circuit reveals that the current, voltage drop, resistance, and power in all parts of the circuit has been determined in addition to the e. m. f., current, and power delivered by the source.

Further analysis of equivalent resistance.—Resistance has been defined as that property of matter by virtue of which electrical energy is converted to heat energy. All circuits discussed to this point have contained nothing but resistance elements. The student is well aware that electrical energy can be converted to many other forms besides heat energy. The natural question is, "How may circuits be analyzed when the electrical energy in the circuit is converted to some form other than heat?" To obtain a satisfactory answer, it is necessary to elaborate upon the idea of equivalent resistance.

It has been pointed out in an earlier chapter that conversion of energy from one form to another cannot be accomplished with 100 percent efficiency; that is, the energy output of any device must be less than the energy input. It was also explained that the difference between input and output energy represented the so-called energy lost from the system in the form of heat. In every operating electrical device, regardless of its nature, some electrical energy will be converted to heat energy, whether such conversion is desired or not. It follows then that *every electrical device must possess the property of resistance.*

It is quite practical to develop a factor similar to resistance to explain the conversion of electrical energy to forms other than heat. For example, it might be said that mechanical resistance is that property of a circuit by virtue of which electrical energy is converted to mechanical energy. Chemical resistance, light resistance, sound resistance, etc., might be defined in the same way. In the specialized engineering fields, there are special definitions for a variety of oppositions peculiar to each field. However, if a variety of resistance factors were adopted in electrical engineering, the analysis of electrical circuits would become exceedingly complex. For the sake of simplicity it is desirable to interpret all electrical energy conversions in terms of just one type of opposition—electrical resistance. The expression "equivalent resistance" embraces all the different types of opposition that might be encountered in converting electrical energy to other forms. In adopting this concept, we must make an assumption: *Regardless of the form of energy to which electrical energy is converted, it will be assumed to be converted to heat energy.*

A simple example will demonstrate how an electrical motor may be analyzed mathematically in terms of electrical resistance. A motor, of course, is a device for converting electrical energy to mechanical energy. If the internal resistance of an electric motor is measured with the rotating element stationary, a very low value of resistance (a fraction of an ohm) will be obtained. Assume that such a measurement yields a resistance of 0.5 ohm. If the motor is designed to deliver full mechanical power output with 120 volts across its input terminals, it would seem that the current drawn by the motor would be $\frac{120}{0.5}$ or 240 amperes. This current is called the starting current, and is the value that would be measured at the instant the motor is energized. However, a fraction of a second after the motor is energized, the rotor begins to rotate and the line current will begin to decrease. When the motor attains the rated speed of rotation, the line current will become constant and will have an amplitude much less than the starting current. Assume that, at full power output and rated speed, the line current is 10 amperes. Under these conditions, the equivalent resistance of the motor is

$$R_e = \frac{E}{I_L} = \frac{120}{10} = 12 \text{ ohms.}$$

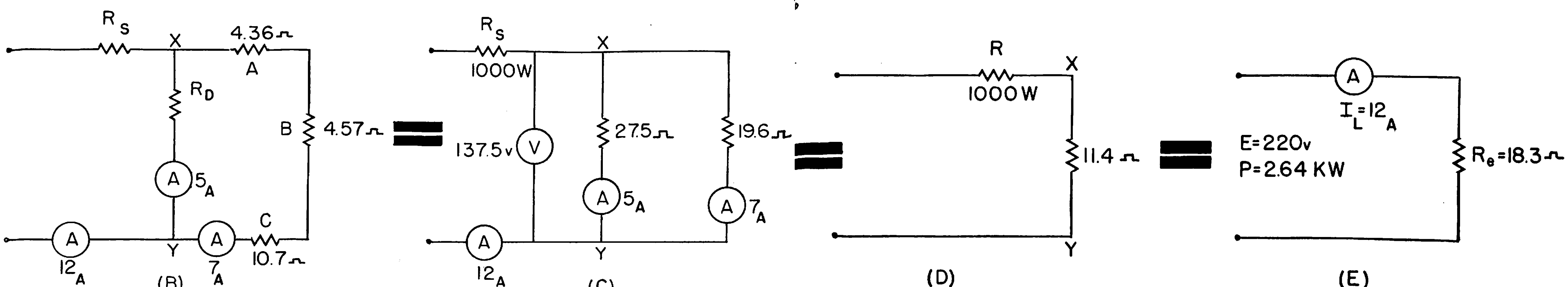


FIGURE 5.—*Steps in reducing a complicated series-parallel circuit to a single equivalent resistance.*

At rest the internal resistance is 0.5 ohms, while at full power output the internal resistance is 12 ohms. In making the change from zero to full rotational speed, the motor resistance has increased 11.5 ohms. The mechanical power output at zero speed is zero, which increases to maximum as the machine comes up to rated speed. It is logical, then, to assume that the increase in internal resistance of the motor is the result of the increase in mechanical power output. The mechanical power developed in the motor is easily calculated. The total electrical power input is

$$P_{in}=EI_L=120\times10=1{,}200 \text{ watts.}$$

The power converted to heat in the internal resistance of the motor windings is

$$P_h=I_L^2R_i=10^2\times0.5=50 \text{ watts.}$$

The difference between the power input and the power heat loss is 1,150 watts, which must represent the mechanical power being developed by the motor. The increase in motor resistance resulting from the mechanical power is 11.5 ohms, and the current through this resistance is 10 amperes. The mechanical power may be calculated in terms of the increase in R_m.

$$P_m=I_LR_m=10^2\times11.5=1{,}150 \text{ watts.}$$

P_m represents the mechanical power developed within the motor, not the mechanical power delivered to the load. In overcoming the resistance offered by the air to the rotating element as well as the mechanical friction in the motor bearings, some mechanical energy is converted to heat energy. The actual mechanical power output P_o will be slightly less than P_m. If P_o is measured by some method at the output pulley of the motor, then the efficiency of the motor is

$$\mathit{Efficiency}=\frac{P_o}{P_{in}}$$

and the total internal losses (conversion to heat) are given by

$$\mathit{Loss}=P_L=P_{in}-P_o$$

Since P_L is produced by I_L,

$$P_L=I_L^2R_L$$

where R_L is the equivalent internal loss resistance of the motor, and includes the electrical resistance of the windings as well as the resistance resulting from the bearing and air friction.

If, in the above example, the bearing and air friction produce an additional 50 watts of heat loss, then the actual mechanical power output of the motor is 1,100 watts, the input 1,200 watts, and the power loss 100 watts.

$$\mathit{Efficiency}=\frac{P_o}{P_{in}}=\frac{1{,}100}{1{,}200}=0.917=91.7 \text{ percent.}$$

The equivalent internal resistance of the motor is

$$R_L=\frac{P_{in}-P_0}{I_L^2}=\frac{1{,}200-1{,}100}{10^2}=1 \text{ ohm.}$$

To this the internal winding contributes 0.5 ohm of real electrical resistance. The remaining 0.5 ohm is a fictitious resistance which is used in conjunction with the line current to determine the actual electrical energy converted to heat by mechanical friction. The source will see the motor circuit as 12 ohms of electrical resistance, for the source is unaware of the form to which the load converts electrical energy. As far as Ohm's Law is concerned, the motor produces exactly the same effect on the source as would a resistance of 12 ohms, and since equals may be substituted for equals, the circuit may be analyzed in terms of 12 ohms of electrical resistance. When necessary, the equivalent resistance may be broken down into its components as was done above.

In figure 6A is shown a circuit containing a 100-watt, 120-volt incandescent lamp, a 1,000-watt, 120-volt electric heater, and a 120-volt, 5-ampere electric motor. In B is shown the equivalent resistance circuit. The equivalent resistance R_L of the lamp, R_h of the heater, and R_m of the motor are calculated as follows:

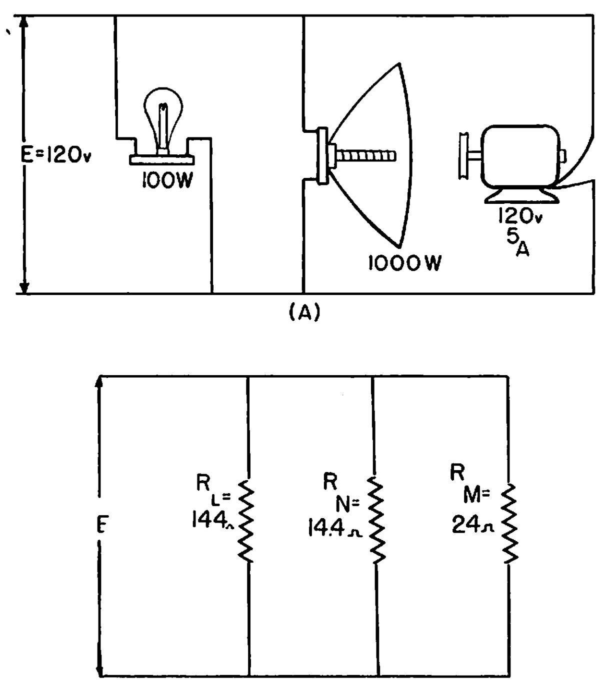


Figure 6.

$$R_L=\frac{E^2}{P_L}=\frac{120^2}{100}=144 \text{ ohms}$$

$$\left(\text{from the formula } P_L=\frac{E^2}{R_L}\right)$$

$$R_h=\frac{E^2}{P_h}=\frac{120^2}{1{,}000}=14.4 \text{ ohms.}$$

$$R_m=\frac{E}{I}=\frac{120}{5}=24 \text{ ohms.}$$

The equivalent circuit is readily analyzed in terms of Ohm's Law and the results obtained apply to the given circuit.

Internal resistance.—In the preceding chapter, the assumption was made that the e. m. f. of the source would always be considered a constant. This was necessary in order to simplify the explanation of circuit solution. It is now time to investigate the basis for this assumption.

It has been stated that a generator develops an e. m. f. by the process of performing work upon free electrons. Within the machine, electrons are compelled to move from positive to negative, thereby gaining potential energy. The generator accomplishes this process by developing an electric field.

Electrons may move freely from the positive to the negative terminal only if a satisfactory conducting circuit exists within the machine. A conducting circuit always possesses the property of resistance, and if very accurate current solutions are required, a method that will take the effect of the internal resistance of the source into account is necessary.

A *perfect* or *ideal* generator is one that has zero internal resistance. A practical generator may be pictured as a perfect generator in series with a resistance R_g as shown in figure 7. R_g represents the internal resistance of a practical generator. The figure may be used to represent the equivalent series circuit of any source of electromotive force. Electrons, when moved from the positive to negative terminal of the source, must overcome the opposition of R_g. Let E_o represent the e. m. f. developed by the perfect generator G. Then E, the electromotive force measured across the output terminals A and B of the machine, will be

$$E=E_o-I_LR_g$$

where I_L is the current delivered by the source to the load. E_o is called the open-circuit e. m. f. of the machine, because, if the load circuit is open, $I_L=0$ and $I_LR_g=0$, in which case $E=E_o$. E represents the closed-circuit e. m. f.

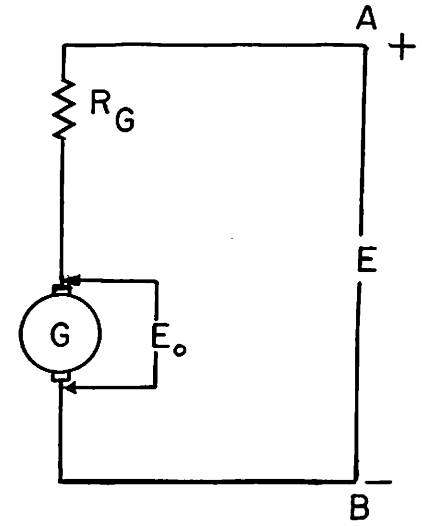


Figure 7.

In any given generator, R_g is fixed by the original design of the machine, hence the only variable in the quantity I_LR_g is the load current I_L. As the load current increases, I_LR_g increases, and the e. m. f. across terminals A and B decreases. If the load circuit becomes a direct short circuit (equivalent to a zero-resistance load), the quantity I_LR_g approaches E_o in magnitude and E approaches zero. The short-circuit current that may be delivered by any source of e. m. f. is limited by the internal resistance R_g.

In most devices designed to supply electrical energy, every attempt is made to minimize R_g. In dry- and wet-cell batteries and in mechanically-driven electrical generators, R_g is usually very small, of the order of a few hundredths of an ohm. In practical work, if I_LR_g is quite small, it is usually neglected and E is assumed to be equivalent to E_o. In electronics work, vacuum tubes are often utilized as sources of electrical energy. High internal-resistance is an inherent characteristic of all vacuum tubes. Internal resistances ranging from several hundred to millions of ohms are to be expected in electronic generators. This complicates the solution of vacuum-tube circuits because R_g cannot be neglected.

Where the internal resistance must be considered, Ohm's law may be written in the form

$$I_L=\frac{E_o}{R_e+R_g}$$

from which

$$R_e=\frac{E_o-I_LR_g}{I_L}=\frac{E}{I_L}$$

The load current in flowing through R_g will develop heat energy, causing the temperature of the source to rise. In general the maximum load current that can be continuously supplied by any source is limited by the maximum permissible temperature rise in the machine. In many machines about a 40° C. rise above ambient room temperature is permitted. The short-circuit current in a machine may be many times greater than the normal load current, and since power varies as the square of the current, a very large quantity of heat may be generated in R_g in a very short interval of time, resulting in a rapid and excessive temperature rise. The high internal temperature produced within the machine may destroy the internal insulation and thereby ruin the machine. Where a machine may be seriously damaged by a short circuit, circuit breakers or fuses are commonly used to guard against overload.

The internal resistance of any source may be measured without difficulty. E_o is measured with a voltmeter with no load ($I_L=0$) on the machine. E may be measured with a known value of I_L. Then

$$R_g=\frac{E_o-E}{I_L}$$

It should be noted that

$$E_o-E=I_LR_g.$$

Dry cells and batteries (devices for converting chemical energy to electrical energy) are not seriously injured by a momentary short circuit. Indeed, the short-circuit test is often used to check the internal resistance of such devices. An ordinary 6-inch carbon-zinc type of dry cell should deliver a short-circuit current of 30 or more amperes. In such cells, R_g increases with age and with the quantity of electrical energy removed from the cell. By measurement of the current the cell will deliver on short circuit, the internal resistance may be calculated from

$$R_g=\frac{E_o}{I_{sc}}$$

The carbon-zinc type of dry cell maintains an open circuit e. m. f. of approximately 1.5 volts throughout its useful life. The minimum acceptable short-circuit current in such a cell is 30 amperes, which would indicate that the internal resistance is

$$R_g=\frac{1.5}{30}=0.05 \text{ ohm}.$$

A more active cell might have an internal resistance of the order of 0.03 ohm. Cells of wet batteries are often tested by measuring the short-circuit current of each cell. In making the test, be certain that the ammeter has an adequate maximum range. Wet cells may deliver as much as 300 amperes on short circuit, the actual value depending upon cell design. The short-circuit test is never to be used with sources other than dry cells or batteries.

ANSWERS TO PART 9, BASIC PHYSICS

1. (a) 103.4 volts.
   (b) 279 volts.
   (c) 12.2 volts.
2. 12.27 amps.
3. Circuit current 2 amperes.
   $R_1=66$ watts.
   $R_2=36$ watts.
4. 39.25 coulombs.
5. 7.56×10^6 joules, or 7.56×10^{13} ergs.
6. 15.75¢.
7. Either 2 or 8 ohms.

QUESTIONS PART 10, BASIC PHYSICS

1. In a parallel circuit consisting of the following loads: 12 ohms, 17 ohms, and 53 ohms, on a 110-volt line, calculate the conductance and line-current of each branch.

2. In a diagram similar to figure 2, R_1 is 82 ohms, R_2 is 16 ohms and R_3 is 25 ohms. Find the total load current and the applied voltage when the current through R_2 is found to be 7 amperes.

3. What is the conductance of each branch in question 2? What is the conductance of each branch when the voltage drops to 98 volts?

4. When the voltage across a parallel circuit is held constant, and the total current increases after a change has been made in the circuit, the conductance has (increased, decreased?), the resistance has been (increased, decreased?), and the power dissipated has (increased, decreased?). Check correct words.

5. Two resistive loads across a 220-volt circuit have an equivalent resistance of 6.67 ohms. 4.48 kilowatts are dissipated in one load. What is the ohmic value of the other load?

6. By use of the formula for three resistors in parallel, calculate the equivalent resistance of a parallel combination consisting of 80 ohms, 120 ohms, and 40 ohms. Check by the conductance method. Which is easier?

7. Find the equivalent series resistance of the circuit of figure 5B, if the total resistance of branch A is changed to 12.8 ohms.

8. What is the total power developed by a heater on a 440-volt line if the efficiency is assumed to be 92 per-cent, and the line-current measures 4.8 amps.?

9. In figure 5B, R_d is halved; how much increase in power is developed across R_s? If the present fuse is 15 amperes, will it require changing?

10. It is desired to measure the internal resistance of a certain motor, utilized across the 110-volt a. c. line. The starting current is 5.8 amperes, and running current found to be 2.1 amps.

U. S. GOVERNMENT PRINTING OFFICE 1943

APRIL VOLUME 3 NUMBER 10

BUSHIPS Electron

A MONTHLY MAGAZINE FOR ELECTRONICS TECHNICIANS

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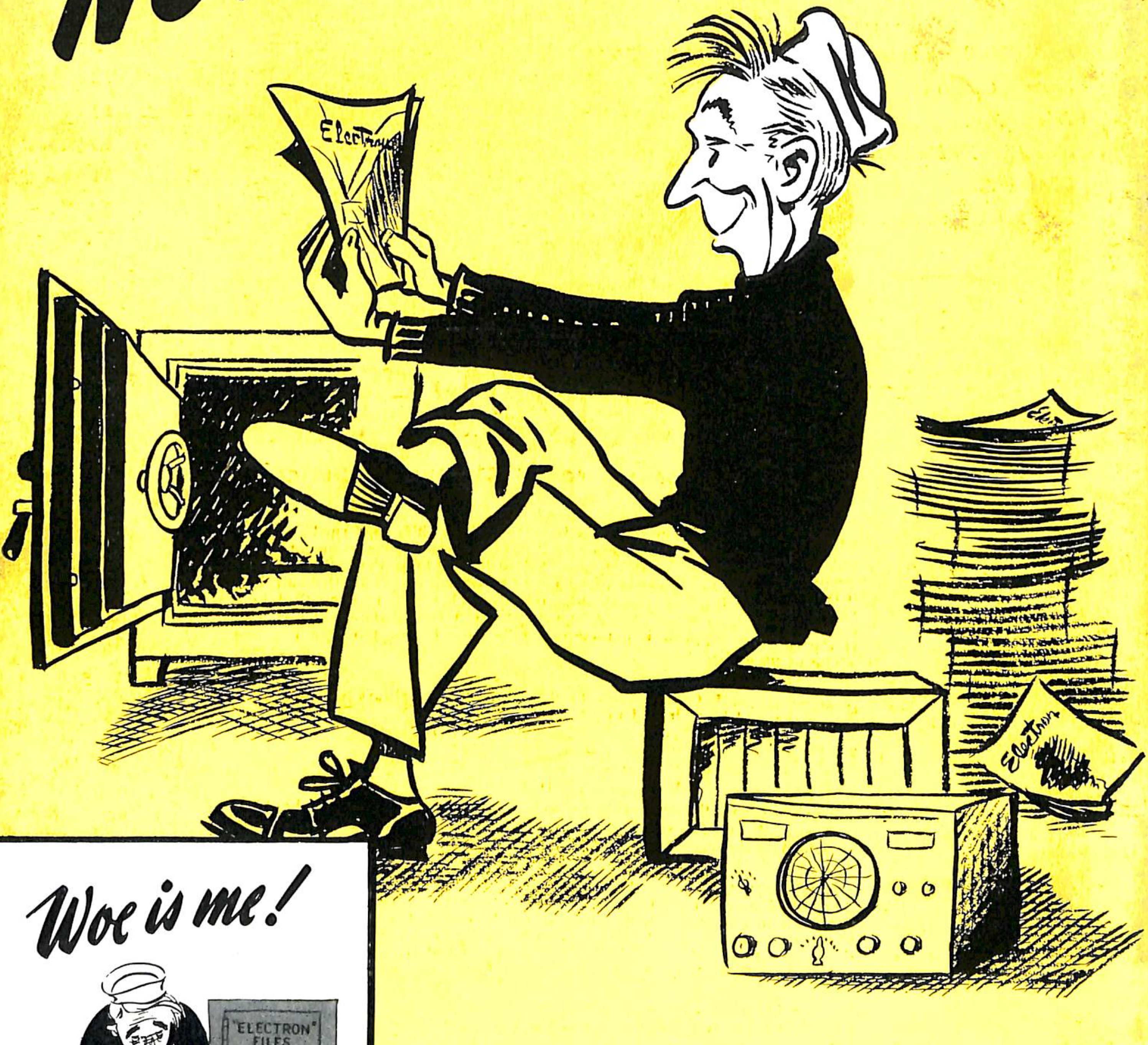

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