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# NAVAL
# SHORE ELECTRONICS
# CRITERIA

## NAVAL TRAINING FACILITIES

DEPARTMENT OF THE NAVY
NAVAL ELECTRONIC SYSTEMS COMMAND
WASHINGTON, D.C. 20360

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FSN 0280—900—7000

APRIL 1972

# LIST OF EFFECTIVE PAGES

Total number of pages in this manual is 178 consisting of the following:

| Page Number | Effective Date |
| --- | --- |
| Title | April 1972 |
| A, B | April 1972 |
| Foreword | April 1972 |
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| 1-1 through 1-3 | April 1972 |
| 2-1 through 2-5 | April 1972 |
| 3-1 through 3-7 | April 1972 |
| 4-1 through 4-9 | April 1972 |
| 5-1 through 5-44 | April 1972 |
| A-1 through A-2 | April 1972 |
| B-1 through B-18 | April 1972 |
| C-1 through C-34 | April 1972 |
| D-1 through D-18 | April 1972 |
| E-1 through E-14 | April 1972 |
| F-1 through F-14 | April 1972 |
| G-1 through G-2 | April 1972 |
| FO C-1 | April 1972 |

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1.75 (paper cover)
Stock Number 0859-0011

# RECORD OF CHANGES

| CHANGE NO. | DATE | TITLE OR BRIEF DESCRIPTION | ENTERED BY |
|---|---|---|---|
| | | | |

# FOREWORD

This handbook presents planning criteria and judgment factors for engineers and planners involved in Naval electronics-training shore-facility design. The purpose is to provide general indoctrinal information for those unfamiliar with the shore training environment peculiarities and to provide general technical installation-planning criteria for Electronics Field Activity (EFA) representatives. Planning, engineering, and installation supervisory personnel will find criteria concerning system configuration details, interface between the various facility elements, and integration of equipments into the shore training complex. Topics pertinent to a shore electronics training facility are treated comprehensively by including or referencing established standards or current field-proven practices. References to source documents are included within the text, and the most current, concise, and accurate sources used in the preparation of the handbook are listed in Appendix G.

The material in this handbook is intended to provide documented acceptable practices for system design and implementation, and to establish a basis for standardization of shore electronics training systems; however, no handbook can substitute for innovative detailed planning and sound engineering judgment. The information contained herein is not a detailed engineering specification for any particular facility or installation project. Rather, the intent is to present criteria and technical information sufficiently broad in scope to cover the major considerations for selecting, designing, and installing electronic systems in training environments ashore. No attempt has been made to establish complete installation criteria for any particular facility. A separate Base Electronic System Engineering Plan (BESEP) should be prepared and submitted for approval for each installation. Prepare the BESEP using the general criteria contained herein, augmented with data given in specific equipment technical manuals. Also, consider the anticipated environmental conditions at the specific training site.

For effective use of the material presented in this handbook, bear in mind that few doctrinal requirements have been formulated. Rather, alternative solutions have been portrayed for each topic or problem. Sufficient concise technical data is furnished to facilitate development of an effective, substantiative justification for the final decisions or recommendations made to NAVFACENGCOM or other cognizant authority. In recognition of the unique nature of each shore training facility, innovation is encouraged to the extent that such innovation leads to a facility which effectively and efficiently responds to a given mission requirement.

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# CHAPTER 1

# THE SHORE ELECTRONICS TRAINING FACILITY AS A SYSTEM

Background information is herewith provided to establish the reasoning for, logic in, and advantages obtainable from, establishment and implementation of a procedural method for the design of new and the augmentation of existing shore electronics training facilities. It is the intent of this chapter to afford an adequate insight to view such facilities as systems, and then to expeditiously draw the necessary line between standardization and innovation (a decision which must be made anew, based on sound engineering judgment, for each program).

## 1.1 THE SYSTEMS ENGINEERING CONCEPT

Systems engineering is the application of engineering effort to achieve an integrated whole composed of usually diverse, specialized structures, and subfunctions. The method must optimize the overall system functions according to judiciously weighted objectives and must also effect maximum compatibility of the component parts to realize an effective response to mission requirements. The selection of a system from a series of choices, in which the characteristics of the parts are evaluated in terms of their ability to contribute to the whole, is a primary segment of systems engineering. The requirements to accomplish this objective are:

o Transform a mission requirement into a description of performance parameters.

o Translate the performance parameters into a system configuration through the use of an iterative process of definitions, synthesis, analysis, design, test, and evaluation.

o Correlate related and interdependent parameters to ensure compatibility of all physical, functional, and program interfaces (optimize the system definition and design).

Any change to or expansion of an existing shore electronics training facility, as well as the development of a new facility, presents complex systems-engineering problems. The level of planning which is adequate and economically justifiable for each such endeavor is outlined for implementation by the Base Electronic Systems Engineering Plan (BESEP). Because each training facility is unique and dynamic, guidance BESEP's are usually inappropriate. However, the preliminary BESEP provides the means for chain-of-command review and cross-command coordination of each project; and approved final BESEP is a user/producer contract. Thus, every BESEP should be as complete, adequate, accurate, and unambiguous as possible. Despite the unique nature of each shore electronic training facility, a methodical, systematic approach to BESEP generation is practicable. The following paragraphs are intended as a guide for the innovative development of BESEP's which address the problem from the perspective of training as an overall, dynamic and complex operational system.

## 1.2 THE ROLE OF ELECTRONIC TRAINING SYSTEMS ASHORE

The familiar phrase, "Practice makes perfect," is as true in the Navy as in any other environment, hence the use of special trainers on shipboard and at operational sites by the tactical forces. But the word "practice" is the key to the justification, the need, for formal shore-based electronics training systems. One can perfect (by practice) only that which he has already learned. The mission of a training system is to provide personnel with initial education, in preparation for subsequent tactical-environment practice and use of acquired skills.

Training can be subdivided into three broad, distinct categories:

o Operator training

o Maintenance training

o Team training

Because of the relatively controlled environment ashore, and the greater availability of technological expertise and specialized equipment and instrumentation, shore training facilities are sometimes requested (or selected) for initial trial and field evaluation of experimental items. Each of these training-system facets is discussed below from the system-design viewpoint.

1.2.1 Operator Training

The keynote here is man-machine interface. The operator, functioning as an individual, must perform specific duties rapidly and accurately in response to situations, conditions, etc. which may or may not be anticipated. All electronic systems, regardless of the degree of automation, require human operations somewhere along the line. In developing systems for operator-trainees, always keep in mind what the operator is not expected to know or do, as well as what his task actually is.

A precisely realistic environment is highly desirable for operator-training in areas such as:

o Placement, size, shape, and color of controls and indicators which the operator will use.

o Ambient lighting approximating the illumination levels normally present in the tactical environment.

o Tactical environment normal distractions such as intermittent or continuous background noise, illumination fluctuations, etc.

On the other hand, ancillary and peripheral equipment need not be placed in a physically realistic configuration. So long as the operator controls and indicators seem (to the operator-trainee) to be functioning realistically, much of the tactical equipment can be simulated. An extreme example is the use of pre-recorded audio tapes synchronized with pre-programmed electronic sweeping of a cathode ray tube (CRT) for sonar-operator training. Such a simulator would negate the need for transducers, hydrophones, power amplifiers, etc., yet as far as the operator-trainee is concerned, sonar indications are observed and heard.

1.2.2 Maintenance Training

The best-designed equipment requires both preventive and corrective maintenance. Specialists who are tasked with electronic maintenance are not concerned with physical configurations or equipment environs, but must be thoroughly rehearsed in the tactical electronic configurations. The maintenance-trainee must be provided with equipment identical to tactical operational equipment, and which exhibits identical electronic actions and reactions.

On a ship, a radar modulator may be below deck, with a long waveguide run to a mast-mounted antenna. In a training lab, the two components may be mounted side by side, with a dummy load simulating the transmission loss of the disconnected antenna, and artificial (but realistic) signal injection to simulate received echoes. The presence of all components is necessary for training, but physical relationships and actual signal-inputs are not required. On the other hand, in order to become proficient and knowledgeable, the trainees will make adjustments of, and measurements on, energized circuits with safety interlocks overridden and protective covers removed. Thus, take special care to ensure the adequacy of protective grounding systems in lab areas for personnel safety in the event of high-voltage, high-current faults. Initial facility planning must complement such using-command efforts as the use of grounding probes to discharge high voltage (HV) capacitors, rubber mats in work areas, compliance with NAVMAT P-5100, and conformance to the guidelines in MIL-STD-882.

### 1.2.3 Team Training

Many different electronic equipments and systems must be interfaced to effect a tactical mission. Personnel who have become familiar with the operation of individual equipments must be further trained to function within a group of operators. In some cases operation of singular electronic systems requires coordinated activity in numerous, often physically remote, areas aboard ship. In other cases, inter-system interface is achieved by human interface. Team training is the means by which specialists in specific operational tasks become proficient in the information-exchange functions necessary for tactical coordination.

As in the case of operator-training, realism is necessary only in an operational rather than an environmental sense. Stations need not approximate the tactical physical configuration. However, to prevent even subconscious unrealistic inter-station contact on the part of trainees, the team training areas should be designed to allow only realistic interface. For example, if two members of a shipboard team are physically isolated, there should be no visual contact in the training environment, lest the trainees unwittingly use hand-signal or head-nod signalling methods. On the other hand, if adjacent stations are standard shipboard practice (as in the case of many sonar sets), the trainee team members should be afforded the same physical closeness in the classroom.

### 1.2.4 Advanced-Technology Field-Evaluation

It is occasionally cost-effective to evaluate new items of equipment or material in a training environment. Especially in the cases of operator and of team training, experimental or provisionally-accepted items may sometimes be used without degrading the training mission. Carefully consider each request for such an evaluation effort from the standpoint of possible mission impact as well as with regard to necessary coordinated approvals. (Such requests may originate from Navy designers, contractors under Navy tasks, or other sources.)

In determining the usability of an equipment or material item in a training environment, a primary factor which must be considered is the probability of actually damaging the basic training equipment or of presenting a physically hazardous situation to the staff or trainees. Another factor to be evaluated is the possibility of increasing system down-time. Beyond that, the big question usually is "Can the system tolerate possible performance degradation," and in many cases the answer (subject to appropriate approvals) is yes. For example, except in maintenance training, reduced radar range (as the result of waveguide attenuation losses) will not be detrimental to training. In some cases, successful completion of an evaluation may even lead to development and acceptance of more cost-effective solutions to configuring tactical shipboard equipment in a shore environment. Keep in mind, however, that whatever is done should not detract from the realism necessary for the type of training being conducted. Once the decision is made to proceed with such an evaluative effort, the cognizant local authorities (EFA, school, etc.) should maintain adequate surveillance of the task to ensure proper monitoring and recording of significant trial parameters so as to make the task meaningful for the original requestor.

# CHAPTER 2

# STANDARDIZATION

Individual elements of any system are constantly changing in response to redefinition of requirements and also in keeping with the state of the art. But effective, economical use of existing resources is necessary if budgets are to be met. To the extent that a particular mission dictates unique system elements, innovation is necessary, but maximum use of existing equipment, interface techniques, etc. means both time and material economies. Consider the total impact on a program of each innovative element in terms of initial design/review/test/evaluation; customized production/installation/checkout; specialized operations/maintenance training; specialized support functions (including documentation, spare-parts inventory, etc.); assurance of continued inter- and intra-system compatibility with other standard and non-standard elements. Each selection of a standard element means readily available documentation, compatibility-assurance, and the ability to draw on all previously completed engineering efforts pursuant to development of that standard element. Most factors such as procurability, documentation, etc. will have been resolved prior to introduction of that element into the new system. Or, to put it in simple terms, "Why re-invent the wheel?" Standardization, as a basic concept, should begin with adherence to the prescribed Base Electronic Systems Engineering Plan (BESEP) format, and continue throughout the systems engineering effort. The most significant standardization factors to be considered are discussed in the following paragraphs.

## 2.1 STANDARD PLANS

Standard plans should be used extensively in the generation of a guidance BESEP. With the understanding and appreciation of the fact that even the most unique facility can use standard structures, air conditioning, power distribution systems, etc., use existing standard plans wherever practicable as a point of departure for development of detailed specifications. Such standard documentation should be referenced in the BESEP as a requirement or as a recommendation, depending on the particular areas of cognizance delineated in Appendix A. Carefully review the specific data available to ensure the appropriateness of any "standard" (with or without modification).

The reviewing and the implementative commands/agencies will be no more responsive to BESEP requirements than the adequacy, accuracy, and documented justification for the requirement permit. For example, 440-volt three-phase primary power is one "standard"; but 480-volt three-phase power is also a (more customary) standard. If a new system requires 440-volt power, NAVFAC will be unaware of this unless the absolute limits of tolerable voltage excursion are specified. As an aid to the NAVFAC engineer, reference appropriate records, including drawings, of existing 440-volt power installations in the BESEP.

## 2.2 CONFIGURATION MANAGEMENT (CM)

The discipline of CM integrates the technical and administrative actions of identifying and documenting the functional and physical characteristics of a system during its life cycle by controlling proposed changes and continuously monitoring and providing information on change-implementation status. By encompassing the areas of configuration identification, configuration control, and configuration status accounting, design integrity and continuity is maintained. Additionally, engineering and cost-tradeoff decisions between technical performance, material availability, operability, and supportability are recorded, communicated, and coordinated by the cognizant agencies/commands. Because shore electronics training facilities are so dynamic, it is of great importance that effective CM be implemented immediately on completion of preliminary design. (Even when station manuals are not required, as-built drawings must be submitted to the program manager in accordance with the current issue of NAVELEXINST 5230.2, and these drawings, prior to submission, must correlate with the Test and Checkout Report certification of as-built system condition.)

## 2.3 MODIFICATION

Changes to final as well as preliminary BESEP's are common. Such changes may occur during the review cycle, but more often modified mission requirements or pre-delivery changes to training equipment dictate BESEP revisions. At this juncture the coupling of standardization and configuration management yields dividends. Requirements which have been carefully selected as basically standard, with only detail-specifications tailored to peculiar needs, can readily be modified to meet altered requirements. For example, the doubling of input primary power from that originally envisioned would mean little more than doubling selected columnar entries, if the original specifications called for adequate chase-nipples and/or duct/raceway clearance to accommodate such expansion. Each change, no matter how minor, must be subjected to thorough configuration management so that a complete history of system evolution is maintained and to prevent the attempted entry of incompatible changes into the system (such as the addition of an auxiliary heat exchanger and a 400-hertz MG set in the same floor space).

## 2.4 THE BASE ELECTRONIC SYSTEMS ENGINEERING PLAN (BESEP)

The preliminary BESEP, when developed as a shore-training-system engineering document, is the logical instrument by which to institute early planning for standardization. Early definition of primary criteria and standards as the nucleus of an evolving complex, dynamic system forms a base from which refinements can effectively be made. Adhere to the requirements referenced in Appendix A, from program inception, to ensure adequate documentary backup, including justification, for each aspect of the system. Judicious, innovative application of criterial constraints will also increase the confidence-factor in the preliminary cost estimates, continued maintenance of configuration-management records will afford substantiative data for any cost differentials which may occur as the program progresses. The adequacy and accuracy of preliminary-BESEP generation and maintenance will be a key factor in the ease or difficulty with which Section 5 of the final BESEP can be prepared. If for no other reasons than these, the entire engineering effort pursuant to the program task must be documented fully in the BESEP by appropriate reference, inclusion, and/or addenda.

## 2.5 ORGANIZATION

A thorough understanding of Navy organizational structure is necessary at the onset of any program. Much valuable time and effort can be wasted if an approval or coordination cycle is inadvertently omitted; a much more efficient and effective effort can be accomplished if all available consultive offices are contacted at appropriate times. Although organizational structure does change from time to time, the basic chains of command are relatively static and major changes, when they do occur, are always well documented before the fact. Appendix A lists the promulgative authorities for the organization as it exists at the time of publication of this handbook.

## 2.6 IMPLEMENTATION

This paragraph provides facility-oriented treatment of the systematic methods to expeditiously engineer new shore electronics training facilities. The guidelines are intended primarily as hints and aids toward development of any specific facility. Refer to the referenced detailed technical material as necessary during the design effort. Since the material is compiled in the order in which the considerations and evaluative effort should flow, no subject should be passed over completely on a first-reading. If the particular subject is already familiar, a rapid scan of that portion of text may be in order—but, as a minimum, each paragraph-heading should be read in order, somewhat as a checklist. Since this chapter covers maximum-flexibility shore training facilities, take special care to review the portions of Chapter 5 which discuss the peculiarities (if any) of the generic equipment types and classes to be initially installed. As a minimum, such specific requirements must be met; time and funds permitting, flexibility and future-expansion capability should be incorporated into the basic facility design. The major functions of system engineering, in the normal order of accomplishment, are summarized below.

### 2.6.1 Preliminary Planning

Preliminary planning determines the basic parameters related to customer training requirements, and is complete when the engineer has developed a preliminary BESEP and a complete schedule for project accomplishment. In completing the preliminary BESEP, the following, as a minimum, must be accomplished:

- o Summarize training requirements.
- o Survey site as required.
- o Extract project description or scope.
- o Tabulate all major equipment.
- o Identify new equipment required.
- o Calculate environmental-control requirements.
- o Determine power requirements.
- o Prepare functional block or system diagram.
- o Develop equipment layout, plot, or plan sketches.
- o List the supporting Public Works items required.
- o Estimate cost.

### 2.6.2 System Design

System design does not begin until preliminary planning is complete, and encompasses:

- o Review for changes to operational/training requirements determined under preliminary planning.
- o Follow-up site survey (if required).
- o Technical liaison with customer.
- o Verify major equipment list.
- o Prepare system specifications.
- o Prepare design sketches/plans for detailing.
- o Prepare special material specifications.
- o Approve material substitutions (within cost limitations) when advance procurement of materials is required (prior to approval of completed engineering package).
- o Approve completed working drawings and specifications.
- o Develop and provide equipment test and checkout procedures.
- o Develop and provide system test and checkout procedures.

o List the technical documentation, with stock numbers, required for the system.

o Perform installation design.

System design is completed upon final approval of the engineering package (all applicable drawings, specifications, and related data lists).

2.6.3 Installation Design

Installation design, part of system design, encompasses:

o Study of plans, sketches, specifications, and data prepared for each task assignment; organize and develop installation details for delineation by draftsmen.

o Visits to sites as necessary to determine/resolve installation details.

o Development and use of standard plans.

o Review of approved Engineering Change Notices (ECN) prior to incorporation into master documents for as-builts.

o Preparation of engineering/installation specifications.

o Overseeing of Drafting Support.

2.6.4 Drafting Support

Translation of basic design into permanent, accurate records which are understandable by suppliers, installers, and maintenance technicians is an on-going support effort which includes:

o Preparation of Bills of Material (BOM's).

o Preparation of cable-tag and lead-designation lists.

o Preparation of detail drawings in accordance with engineering sketches.

(Remember that all formal documents identified by a NAVELEX number must meet the requirements of the current issue of NAVELEXINST 5230.2.)

2.6.5 Installation Engineering

Installation engineering must include:

o Review and approve ECN's (changes or deviations to approved installation plans and specifications, including BOM).

o Interpret working plans and specifications.

o Provide technical liaison with using activity.

o Provide technical and engineering guidance to installation forces.

2.6.6 Test and Checkout

Customer-acceptance and ultimate project-closure depend on satisfactory test and checkout. Therefore, it must provide guidance, liaison, and monitorship for:

o Checkout of installed equipment for operational performance and compatibility. (Normally, an installation-force responsibility.)

o Checkout and evaluation of installed systems for operational performance, using existing procedures.

o Checkout of operating-personnel in system use.

o Preparation of completion (including test) report.

o Sign Job Order acceptance for NAVELEX.

o Turnover and obtain using-activity sign-off on Job Order.

2.6.7 As-Built Documentation

When the training activity for which installation is made requires as-built plans, they shall be prepared and distributed in accordance with the current issue of NAVELEXINST 5230.2. In such cases, in the final phase of a project the following is required:

o Review working drawings/documents against approved ECN's on completion of Test and Checkout; verify that all approved ECN's are incorporated to the As-Built condition certified by the Test and Checkout Report.

o Approve final As-Builts and other appropriate action to maintain configuration control.

o Convert As-Builts to microfilm.

o Effect distribution of data.

# CHAPTER 3

# INSTALLATION DESIGN CONSIDERATIONS

This chapter is essentially a checklist of key elements to consider irrespective of mission-specifics. The intent is to effect an early awareness of the interrelationship and interdependence of all factors involved in the systematic approach to shore electronics training facility planning. The following paragraphs are arranged in the approximate order of required evaluative flow, but of necessity there will be a continual overlap of factors as a design effort progresses. The guidelines in this chapter are broad in nature, and should be taken on an as-appropriate basis as a point of departure for standards-selection and innovation based on the specific instructions, criteria, and specifications which are apropo to the system being developed. That is, select and temper the technological specifics derived from Chapter 4 as much as is practicable, by the overview generalities presented in this chapter to preclude formulation of a facility so unique that it cannot keep pace with dynamic training requirements.

## 3.1 TECHNICAL FEASIBILITY

It is true that nothing is impossible . . . but at what price? Early in the preliminary planning stage of systems engineering, determine the practicality of responding to mission requirements within the budgetary and time limits of the sponsoring and using commands. The intent of this cursory evaluation should not be to thoroughly analyze any specific technical problem, but rather to determine the availability of plausible courses of action for later consideration and selection. Early recognition of potentially expensive and/or time-consuming solutions is necessary to prevent effort being wasted on simple, more straightforward task segments which may have to be cancelled or altered due to the impracticality of interface with the problem-segments. The factors which should be given such an overview analysis include:

- o Existing electromagnetic (EM) environment
- o Expandability of existing power, air conditioning, and other ancillary/support subsystems
- o Structural integrity or reinforcibility of existing structures to be used (can the upper floor of that WWII frame barracks support those high-power sonars?)
- o State of the art versus interface, dummy-load, and/or simulation requirements
- o Availability/procurability of adequate cooling devices in lieu of ram-air units for high-power avionics
- o Availability of cable access ways through existing floors, bulkheads, and roofs. (Are there sufficient funds available to route antenna leads through that continuous-poured reinforced-concrete roof?)
- o Compatibility of all criterial requirements delineated in the training plan, equipment handbooks, etc. with current applicable standards such as National Electric Code (NEC), NAVFAC, Department of Defense (DOD)?
- o Adequacy of existing real estate for physical-plant expansion

## 3.2 PERMANENCY VERSUS FLEXIBILITY

For equipment-installation only, the permanency of a shore training facility is of relatively little importance. Even for short-term tenancy, adequate security, power, safety, floorspace, etc. must be provided to meet the mission requirements.

However, the greater the anticipated longevity of a physical plant, the greater should be the advance-planning effort. Facilities intended for one-time use may be tailored to specific mission needs; physical plants which may undergo changes in training-system/equipment type, class, and/or configuration from time to time should be designed for easy expansion of and/or drastic modification to the elemental subsystems. Among the factors to consider are:

- o Walls–permanent versus movable
- o Floors–solid, Q-cell, computer, or trenched
- o Cable runs–via ducts, conduit, J-hangers, racks, etc.
- o Cooling-water subsystem–series, parallel or manifold; with or without automatic pressure regulation

## 3.3 TIME AND SCHEDULES

As soon as the technical feasibility of a project is verified, develop firm schedules for the entire effort. Many aspects of a given task may proceed smoothly without advance planning, but key elements overlooked at the onset can delay the overall timetable. The interdependency of tasks should be set out clearly, with a delineation of all prerequisites for each subtask. Long-lead-time production items, developmental requirements for special interface devices, real-estate acquisition, establishment of site-survey teams, and other time-consuming factors should be given special consideration to ensure timely completion of these critical factors. Accurate, detailed milestone charts, if prepared early enough, can be the justification to alter the priority-level of selected portions of a time-constrained program. These charts may be used as one of the decision-making tools during subsequent cost/time trade-off analysis. (For example, should in-stock, expensive RG-111A/U armored cable be used, or is there time for electrically-equivalent RG-22B/U unarmored cable to be approved and procured for a given shore installation?)

## 3.4 REALISM

The degree of realism necessary in a shore electronics training environment is discussed in Chapter 1 from the viewpoint of trainee-acceptance of the system as well as training efficacy (trainee retention of data). If the role of the shore training system is clearly understood, there should be little need to go to extreme cost/efficacy tradeoffs as far as realism is concerned. In such cases as Electronic Warfare (EW) and Command Information Control (CIC) where relatively sophisticated signal-simulation is needed for training, special devices are available or can be furnished by Naval Training Device Center (NTDC).

## 3.5 INTEGRATED LOGISTICS SUPPORT (ILS)

The net worth of any system or facility is directly related to its maintainability/supportability. With the ever-increasing complexity of modern-day systems, the truism of that old adage about "For want of a nail . . ." is becoming more poignant. Select each system segment with consideration for the using agency's need to maintain as well as to operate the system. Excessive use of non-standard equipment and/or configurations, poorly documented system-evolution, inadequate and/or inaccurate as-built drawings and systems-acceptance specifications, etc. may not be a problem at turnover, but such short-comings will eventually cause excessive system downtime. Therefore the identification and the acquisition of facilities logistic support resources in consonance with the current issue of NAVMATINST 4000.20 and program time schedules is essential.

## 3.6 EQUIPMENT AVAILABILITY

Normally a Headquarter's responsibility, the policy and assignment of responsibilities regarding availability of equipment for shore training are delineated in the current issue of OPNAVINST 4490.2. But the instruction addresses itself primarily to the first production units of new equipments being procured. In general, for MILCON programs two significant areas will have been given careful, early consideration:

o Necessary support, ancillary, and interface equipment which is required but is not part of the prime-equipment procurement package

o Exceptions to the basic doctrine, resultant from requirements subsequent to initial planning which require close coordination with OPNAV, in accordance with paragraph 5d of the instruction. (Refer also to OPNAV-INST 1500.8.)

To maintain cost-effectiveness for local design, installation, and modification tasks, keep in mind that what is needed is equipment and material which is best suited for a non-tactical shore environment, and which need not necessarily be identical to equipment/material which meets necessarily stringent shipboard specifications. Always maintain close coordination with each interested office (refer to Appendix A), and base the selection of each equipment/material item on tradeoff-analysis between life-cycle cost, training efficacy, and availability within the milestone schedules previously prepared. The EFA should make recommendations, from the systems engineering standpoint, as to how the training might be accomplished. To be most effective, it is recommended that such recommendations be presented at the Training Plans Conference (TCP). Thus, if at all possible, the principal engineer for the facility (who is thoroughly knowledgeable regarding simulation and the goals of the training program) should attend the TCP as the EFA representative.

## 3.7 SPACE

Space considerations must be a mix of mission-specific operational, human factors, maintainability, and safety factors plus foresighted treatment for facility flexibility. As a minimum, space allocations should meet the barest mission-specific requirements, but within budgetary limits, recommend inclusion of movable walls, multi-branched power and illumination subsystems, etc. to facilitate future expansion and/or reallocation of the physical plant to radically different training programs. To some degree the type of electronics-training will dictate broad space-requirements; the specific mission will dictate some of the specific space arrangements. In any case remember that a school is not an operational facility in the tactical sense. Trainees require subsystems over and above what is expected to be furnished at operational facilities. Some of the school-peculiar factors which should be considered for either inclusion or recommendation to NAVFAC (as appropriate) are:

o Areas for individual study

o Heads capable of handling peak demands which occur during break-times

o Mail stations and/or mailrooms

o Corridors, stairwells, etc. wide enough to accommodate mass-movement of classes

o Water fountains, coffee stations, and/or vending machine/snack bar areas with adequate primary power and space

o Duty-office/bunk room for personnel on off-hours duty

o Data center for textbooks, handbooks, audio-visual aids, etc.

o Administrative space for instructors

o Administrative/personnel records space adequate to handle the anticipated volume and turnover of personnel

o Total floor-to-ceiling clearance adequate for ducts, trenches, Q-cells, raceways, etc. including drop-ceilings and raised floors adequate to accommodate current (and envisioned future) cabling, piping, air ducts, etc.

o Dummy loads, interface devices, and simulators, none of which exist in an operational environment

o Recreation for both staff and trainees

o Housing for both staff and trainees

o Vehicle-parking for staff and visitors.

.8 SAFETY

lost criteria specify maxima, minima, or averages, and leave much to the reader regarding absolute decisions. /ith regard to shore training-environment safety (especially in the labs) the safety factors built into the facility nould be of the highest level permissible. Depending on the nature of the school and the prerequisite level of rainee proficiency, you can anticipate extremely hazardous situations in shore training-system operation. lthough military installations are not legally bound to meet commercial and/or local-government regulations, it s strongly recommended that, in addition to compliance with NAVMAT P-5100 and MIL-STD-882, as a ninimum such standards as National Electric Code (NEC), Underwriters Laboratories (UL), etc. be adhered to vith respect to personnel-hazard reduction. Achieve an overall safety balance and provide, where necessary, upplementary (even unique) devices and/or subsystems to compensate for the hazards peculiar to or worsened y the training environment. For example:

o $CO_2$—flooding (an effective fire-combatant in some situations) can be a personnel hazard (if used under a ecture hall set up on a raised computer floor).

o Overhead obstructions, including periscopes, may go unnoticed (even if properly marked) by trainees ngrossed in their studies.

o Emergency cutouts, usually located at the main power panel in each room, may not be reached quickly nough in a panic situation, especially if there is a circuitous pathway around installed equipment.

o Uneven deck plates, raised cable tunnels, etc. should be avoided in Command Information Control CIC)-mockup, radar-operation, and other areas where ambient illumination is usually low-level.

o Antennas should be provided with (usually specialized) circuitry to facilitate both RF-input disconnection nd drive-motor disablement.

o Remote and/or relatively inaccessible areas such as roof or tower-mounted antennas, screen rooms, and hielded enclosures should be provided with intercoms, sound-powered phones, or other means for contact and oordination with personnel at other system locations.

o Access ways through perimeter fences and into facility structures should be of sufficient size to permit ntry by emergency equipment/personnel.

.9 COST EFFECTIVENESS

Jp to this point in preliminary design evaluations and considerations, economy has played only a superficial role. 3ut once the elemental factors of overall feasibility, practicality, minimum space, safety, schedules, and the like ave been cross-correlated, refined and broadly defined, specific (often innovative) response must be made to the articulars of the mission requirements. At this time cost-effective measures must be brought to the fore in the lesign, development, implementation, and administration of a shore electronics training system to minimize xpenditures of time, material, and funds without adversely affecting schedules or requirements. From the onset, he who, when, and why chain-of-command involved in project development (refer to paragraph 2.5 and

Appendix A) should be adhered to in order to prevent unnecessary parallel or divergent inter- or intra-office/agency effort. As the project progresses, base each administrative and/or engineering action or decision on sound judgment which has been directed by the guidelines presented in this handbook.

Because shore electronic training facilities are dynamic, use long-range planning whenever possible; build the potentiality for expansion and flexibility into the basic physical plant. Such foresightedness can mean significant cost savings even at the first training-mission change or expansion within a given facility. The inclusion of any recommendation in the Base Electronic Systems Engineering Plan (BESEP) for items or space allocations in consideration of envisioned future needs, should be accomplished with definitive, comparative time/cost factors such as: "Install (qty) chase nipples during roof construction at $X each versus boring through reinforced concrete at $Y for each antenna lead required in the future."

## 3.10 CABLE, WIRE, AND CONNECTOR SELECTION

Data such as equipment specifications and installation instructions contained in using-command handbooks are all concerned with equipment which will be installed, operated, and maintained in a tactical environment afloat. Each specified cable, wire, and connector is selected from a relatively short list of standard items (to minimize on-board spares-requirements); each item is selected on the basis of its ability to withstand the rigors of a tactical environment.

Items which meet stringent tactical requirements are more costly, and are often in shorter supply than commercial "equivalents." To achieve a cost-effective shore electronic training facility, carefully consider the pros and cons of using commercial versus military and shore versus ship type cable, wire, and connectors. Except in the case of active-sonar transducers (which must be operated submerged) there is seldom a valid technological reason to use watertight cable or connectors ashore even if the shipboard equipment is so connected. Base the selection of each item primarily on the intended use of the equipment as delineated in the training plan. In other words, to the maximum extent possible use NAVELEX documents as the primary guide in the selection of material. For example, except for maintenance considerations, equipment installed for operator and/or team training could be hardwired with no adverse impact on the mission, whereas lab-installed equipment at an Electronics Technician (ET) school may use connectors which are easier to engage and disengage than are shipboard connectors, and which are capable of withstanding a greater number of fault-free insertions. Another example of possible beneficial deviation is in reduced use of low-loss cable such as heliax. A ship must be able to use electronic systems regardless of distance from other ships or ports, and regardless of climatic conditions. But in a school ashore most equipment is not operated "on the air," and even if it is, maximum ranges and the meeting of tactical reliability-standards is not necessary. Unless equipment is designated dual-mission, reduced-capability caused by a downgrading of tactical cable-requirements will usually not weaken the training program.

Predicate the selection of each specific wire, cable, and connector on a tradeoff analysis based on:

- o Durability with respect to intended shore use
- o Compatibility with equipment, including interface and special training devices
- o Maintainability, including need for special installation tools and/or instructions
- o Availability and reprocurability
- o Cost (to procure, install, and maintain)

The question arises, "How does one locate alternative items?" There are three basic groups of data available:

- o Standards and specifications
- o Government-agency informational publications
- o Commercial informational publications

Current issues of the government data should be used to determine the pertinent parameters of items called for in the tactical-equipment specifications. The available information usually indicates significant parametric limits only by reference to specifications and standards (listed in table C-1).

A comprehensive compilation of data exists in the following government-agency publications:

o MIL-HDBK-216 Military Standardization Handbook, RF Transmission Lines and Fittings

o TO 31-10-15 Air Force Technical Manual, GEEIA Standard, Technical Characteristics of RF Coaxial Cables and Connectors

o 5 ND NNSY P9620/1 Norfolk Naval Shipyard Electrical Information Handbook

o NAVSHIPS 250-660-23 (0283-233-9002) Cable Comparison Guide, Data Pertaining to Electric Shipboard Cable

o NAVELEX 0101,110 Installation Practices and Standards

Because the wire/cable/connector field is so dynamic, government source-data does not always include recent technological developments, newly-introduced items, or recent supersedures. Since manufacturers and suppliers are constantly improving and expanding their product lines, current literature should be obtained directly from each of the well known firms which at least annually publish information fliers, mil-vs-commercial cross-reference indexes, Federal Stock Number (FSN) versus part-number tables, etc. The designer should periodically update his file of commercial data in order to supplement the government data.

The cable/wire/connector industry has a technical terminology all its own, one which is rather consistent within the industry, but which is not always compatible with government-standard acronyms, abbreviations, and type designations. As an aid to the Navy-oriented designer, the most common industrial terms are explained in Appendix D.

With the understanding that changes will continue to occur, selected data (current as of the date of publication of this handbook) has been compiled in ready-reference form to facilitate selection of the best wire, cable, and connectors for a particular shore-training environment. When using this data, double-check the currency of all the pertinent data using tables C-2 through C-6.

## 3.11 WIRING AND CABLE-ROUTING METHODOLOGY/ENCLOSURE SELECTION ALTERNATIVES

The techniques of wiring and cable-routing detailed in NAVELEX 0101,110, Installation Standards and Practices and in the EIMB must be carefully reevaluated during shore electronic training-facility planning. In most operational environments all equipments are electrically compatible, and the physical configurations are relatively static. However, it can generally be expected that training equipment installed one day will be replaced (in whole or in part) with radically different equipment tomorrow. Thus, wiring and cable-routing should be devised with three important factors in mind: minimized electromagnetic (EM) interaction; ease of subsequent cable additions and/or removals; and in maintenance-training areas, wherever practicable the cable, connector, and terminal marking identifications should be in accordance with the ship (not shore) standards and practices with which the trainees should become familiar.

Some of the items which should be analyzed at the onset, within program budgetary limits, are:

o Segregation of power feeders, with adequate legs to accommodate varying inter- and intra-area loads within the facility.

o Minimization of low-level runs, especially for such items as sonar return-signals.

o Avoidance of large J-hangars, deep trenches or ducts, and other devices which will invite the stacking of so many cables that removal of first-installed items will be impractical.

o Avoidance of bends so sharp that cable pulling is difficult. (The minimum-radius bend allowable for a cable is based primarily on the mechanical resiliency of the cable; on long runs with too many maximum-bends, the tensile limit of a cable may be exceeded during installation.)

o Where armored cable must be used, segregate such runs to prevent damage to unarmored cables during pulling.

o Where much inter-deck cabling is anticipated, consider using hollow bulkheads for the vertical runs, possibly including walk-space for future maintenance.

o Where vertically-run coax terminates in horizontally-mounted connectors, consider the use of angled-connector adapters and/or cable-supporting devices to minimize the strain imposed by the cable-weight on the connectors.

o Where temperature-rise is anticipated within or near cables, consider using stacks of wide cable-racks, with only one layer of parallel-run cables per stack, to allow greater air circulation.

o Where much DC signalling will exist, such as in computer, CIC-mockup, and simulation areas, consider making provision to use coax cable to prevent signal interaction.

## 3.12 FLOORING ALTERNATIVES

In general, so-called standard, general-purpose floor configurations should not be designed to accommodate specific equipment, or even classes of equipment in shore electronic training facilities. Rather, load factors should be based on the heaviest equipment likely to be installed in the future (including computers, high-power sonar, periscopes, etc.), and insulation-specifications should be based on the most-hazardous situations probable, such as ET-C training on open modulators and high-power transmitters, etc. Regardless of the equipment to be installed initially, and the type of training to be performed, the selected flooring should (within budgetary limits) give maximum flexibility. False (raised) flooring (commonly called computer deck) is recommended, and is covered in detail in NAVELEX 0101,111.

Where trenching is used, consider providing cable-routing provisions from room-to-room, especially across hallways and corridors. Additional provision should also be made to route cable to equipment which may well be remote from the trenches. Comparative time and material cost analyses should be made to determine whether or not the extra initial cost of installing a raised floor is offset by the alternative cost of installing raceways, supplemental trenches, etc. Also, take into consideration future trench-expansion/modification.

# CHAPTER 4

# TRANSLATION OF OPERATION INTO RESOURCES REQUIREMENTS

This chapter summarizes the most significant aspects to consider when planning a shore electronics training facility. The material presented here is concerned only with the basics of a physical plant, and therefore each broad area covered should be refined by appropriate information contained in the other portions of this handbook.

The proof of success of systems engineering is operational effectiveness. A good system design effects an overall functional system which meets all mission goals better and more economically than any alternative system. For example, in designing a new ship an engineer does not select the best available engine, hull, rudder, bridge, etc., and mate them. The combination of such components will not necessarily result in a seaworthy vessel. Thus, the engineer must, after he has visualized the ship as a whole, adapt or modify the best available components and operationally interrelate them. In this process very often new components must be devised, existing "best" components may lose their original identity in the course of modification, and design/time/cost tradeoff analyses must constantly be made. The end-item ship is not simply a sum of components; it is a functioning entity, an operational system.

Shore electronic training systems, to be efficient functional entities, must be designed in a manner not unlike that used in ship design. The component parts may be radically different, but the principle is the same. To translate the operational requirements of a training plan into resource requirements (the facility building blocks), many diverse factors and components must be considered. Each basic facility building block is discussed in the following paragraphs.

## 4.1 SITE FACTORS

Select a new shore electronics training site based on an amalgam of weighted factors in order to:

o Minimize installation problems such as establishment of an adequate ground grid

o Minimize installation/support equipment costs such as for unduly large air conditioning and/or dehumidification units

o Minimize maintenance requirements such as ice-loading and salt-spray erosion of antennas.

Final site selection should be the result of careful cost/efficiency tradeoff analysis made after adequate data has been compiled. The most important areas which should be evaluated prior to development of specific recommendations may be subdivided into two basic environmental categories, physical and electromagnetic.

### 4.1.1 Physical Environment

As a minimum, consider the following:

a. Orientation. Buildings should be oriented to effect optimum economics in heating and cooling, and to reduce road and other paving to a practicable minimum, consistent with security requirements.

b. Expansion. Within budgetary limitations, expansion by construction of separate structures or self-contained elements should be favored over simple extensions.

c. Isolation. Because of inherent electromagnetic (EM) hazards, or for security reasons, it may be desirable to isolate buildings as far as possible from community facilities, population centers, and public transportation lines. On the other hand, in the absence of hazardous conditions proximity to transportation and to community recreational facilities can increase program efficiency by improving trainee morale.

d. Utilities. Utilities, such as those supplying special power not normally provided, may be required. Adequacy of available utilities for special needs and the dependability of basic services must be studied.

e. Meteorology and Climatology. Existing climatological publications and summaries provide sufficient data to satisfy most requirements. They should be consulted as a primary source to avoid unnecessary or duplicative data-processing efforts. Most publications and summaries are not normally held or required by many commands and activities, but they are readily available for consultation at NAVWEASERV activities. (The latter will provide interpretative assistance as requested.) Included among these are:

o NAVAIR 50-1C-series (Listed in NAVAIR Allowance List Section "L" NAVAIR 00-35QL-22-Navy, and in NAVAIR 00-35QL-23-Marine Corps)

o National Intelligence Surveys, issued by CIA and DIA (listed in OPNAVINST 3822.7-series and H.O. Pub. 1, Intelligence)

o Navy and Air Force Station and area climatological summaries which are periodically updated (listed in NAVAIR 50-1C-534, Guide to Standard Weather Summaries)

o Weather Bureau (ESSA) summaries for stations and areas in the U.S. (listed in ESSA Key to Meteorological Records Documentation No. 4.11)

o Monthly local-area climatological summaries which are routinely prepared and distributed to local commands and activities by FLEWEACEN/FLEWEAFAC and NWSED's.

f. Soil and Subsoil Conditions. Investigate:

o Bearing capacity and water conditions

o Soil conductivity (including possible seasonal changes due to changes in the water table).

### 4.1.2 Electromagnetic (EM) Environment

The fact that we are concerned with training equipment ashore (either dedicated or dual-mission) does not significantly alter the basic Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) criteria and doctrine which is applied as a matter of course in operational situations. Refer to paragraph 4.2.6 for a more detailed discussion of EM considerations.

A carefully conducted site survey should delineate each of the following aspects of the EM environment:

a. Existing EM fields which may pose an EMI problem in the foreseeable future. The source, frequency, and power level of each such suspect field should be clearly and concisely denoted. In addition to such obvious radiators as power lines, power substations, radio and radar transmitters, etc., a careful check should be made to determine the preponderance of such items as amateur radio transmitters and licensed mobile radio networks for taxicabs and the like.

b. The potential effect new equipment to be installed may have on the existing EM environment. Bear in mind that although some or all of the radiation sources noted in (a) above may not pose an inward-interference problem to the training facility, high-power transmissions from the facility might disrupt non-training (even non-government) proximate equipment operation.

## 4.2 STRUCTURAL CRITERIA/IMPLEMENTIVE DOCTRINE

Consideration should be given in recommendations for the design of facility structures, to the minimization of installation/reconfiguration problems and maintenance requirements. The ultimate goal should be the turnover of a facility and its systems which is capable of being effectively and efficiently used by the customer. The most important factors involved in the regard are discussed in this paragraph.

### 4.2.1 Building Features

In order for NAVFAC personnel to make proper engineering decisions within their realm of cognizance, address the following factors:

a. Required permanency of new structures, as defined in NAVDOCKS DM-1 Design Manual, Architecture. (Indicate the low-maintenance-cost life-span as 25 years, 15 years, 5 years, or less than 5 years.)

b. The floor live load as defined in NAVFAC DM-2 Design Manual, Structural Engineering should be calculated on a realistic basis of occupancy such as mechanical telephone and radio equipment rooms, receiving rooms (radio) including roof areas supporting antennas and electronic equipment and terminal equipment rooms, all of which carry a guideline of 150 psf (school classrooms without any equipment except for tables and desks carry a guideline of only 40 psf).

c. In the interest of flexibility, recommend movable partitions with top fillers (in accordance with NAVDOCKS DM-1) for some or all non-bearing interior walls. Also consider judicious placement of fabric-covered accordian-type panels to add versatility to the physical plant especially in combined lab/lecture areas, and for team-training to simulate operationally remote locations.

d. If a raised flooring is recommended, cite NAVFAC Type Specification TS-F-126 as the authority.

### 4.2.2 Lightning Protection

The primary responsibility to provide adequate lightning protection for new structures under MILCON projects is vested in NAVFACENGCOM. Equipment protection, even on MILCON projects, is the responsibility of the EFA. Thus, the EFA must be cognizant of all basic lightning protection criteria so that he may effectively provide appropriate guidance to NAVFAC and/or design internal protection systems as required.

When the frequency and/or severity of thunderstorms in an area indicates the desirability of including lightning protection measures on site, use Lightning Protection Code NFPA No. 78 ANCI C5.1 as the basic guide. For the sake of design simplicity and minimal cost, wherever practicable a vertical grounded conductor be used in accordance with Section 31 of the code instead of air terminals (points) mounted on the primary structures. Where the overall size and/or shape of a structure or complex so dictates, multiple masts and aerial ground wires, (as covered in Section 31 of the code) are usually more economical than the building protection systems delineated in Section 21.

In some situations lightning-protection masts may also serve as antenna towers, flag poles, or chimneys, with the guy wires serving as down conductors, to further enhance cost effectiveness.

Recommend the use of building-mounted air terminals (points) for only those multistory and large-area structures where vertical-mast protection would be impractical.

A summary of the key technical factors which are contained (and thoroughly explained) in the referenced criteria sources is included as Appendix F of this handbook as guide for the development of equipment-protection systems and augmentation of systems for existing structures.

### 4.2.3 Power Requirements

In most situations the determination of power requirements is straightforward. Most requirements peculiar to shore training facilities are covered in NAVFAC DM-27 Design Manual, Training Facilities and on that basis power service may be recommended for justifiable items such as:

o Audio-visual remote-control devices at lecterns

o Banked lighting with door and lectern control-centers

o Central service-cores to serve two or more classrooms

o Electric services located so as not to interfere with movable dividing walls.

o Service to accommodate training aids (in order to conform with NAVFAC terminology, training aids should be referred to by one of the following three subcategories: "audio-visual" which is self-evident; "mockup structures" such as full-size replicas of tactical areas; or "synthetic aids" which simulate field conditions and are otherwise termed special training devices).

o Open and/or closed circuit TV, including studio and viewing areas, special voltage regulation, etc.

One special-case situation does occasionally arise, the introduction of 440-volt (shipboard) equipment into the shore environment. Because 440-volt power is not a shore standard, the use of such equipment should be limited to only those cases where training on that specific equipment is required. The arbitrary use of surplus or salvage 440-volt equipment ashore, when such equipment performs functions only ancillary to direct training, is usually not cost-effective, when 440-volt power is required, provide NAVFAC with as much pertinent data and justification as possible. As a minimum, reference governing shipboard specifications and summarize the equipment specifications in the Base Electronic Systems Engineering Plan (BESEP). Additionally, refer to Public Works document NAVDOCKS MO-201, Operation of Electric Power Distribution Systems, Chapter 12, which establishes "favorable" and "tolerable" voltage excursions for shore standard nominal voltage-levels. The data in MO-201 is compatible with guidelines and recommendations of the Edison Electric Institute (EEI) and the National Electrical Manufacturers Association (NEMA). Once the need for nominal 440-volt power is established, the unappropriateness of using short-standard 480-volt power becomes apparent with a simple interpolation of the MO-201 data, as shown in Table 4-1. (Also note that MIL-STD-255A "Electric Voltages Alternating and Direct Current" specifically allows exceptions to standard voltages in cases where it is impractical to use standard ratings for new or replacement equipment.) Additional data regarding special shipboard power is contained in MIL-STD-761B "Electric Power, Alternating Current For Shipboard Use, Characteristics and Utilization Of."

Table 4 - 1. Allowable Voltage Excursions

| NOMINAL | FAVORABLE ZONE | | TOLERABLE ZONE | | REMARKS |
|---|---|---|---|---|---|
| | MIN | MAX | MIN | MAX | |
| 120 | 110 | 125 | 107 | 127 | Note 1 |
| 240 | 210 | 240 | 200 | 250 | Note 1 |
| 440 | 385 | 440 | 368 | 457 | Note 2 |
| 480 | 420 | 480 | 400 | 500 | Note 1 |
| 600 | 525 | 600 | 500 | 625 | Note 1 |

Notes: (1) Data obtained directly from Chapter 12 of NAVDOCKSMO-201.
(2) Interpolation based on (1) and on equipment specifications.

4.2.4 Grounding Systems/Distribution

The green-wire grounding system specified in the National Electric Code (NEC) must be adhered to in every shore training facility. Consider supplemental grounding accommodations in accordance with Chapter 10 of NAVELEX 0101,110, Electronic Installation Practices, on an as-required individual-case basis because green-wire ground systems are designed and intended for use only in DC and relatively low-power 60-hertz circuits. Where specialized situations exist, appropriate supplemental grounding should be used. For example, keep in mind that initially the trainees will be unfamiliar with the equipment, and that at times (of necessity) they will be making adjustments to, and measurements on, energized circuits with safety interlocks overridden, and protective covers removed. Thus special care must be exercised to ensure the inclusion of high-safety-factor protective grounding systems in lab areas. Additionally, consider carefully the advisability of such innovations as enclosing the solid-copper perimeter bus (if used). The most common and important specific considerations which may also arise are:

a. Lightning protection, which requires conductors of very high capacity and must be bonded to the green-wire system. The lightning protection grounding system does not necessarily require as low a resistance to earth-ground as other grounding systems. Refer to Appendix F for additional details.

b. Power at 400 hertz requires conductors larger than specified in the National Electric Code based on AC resistance multiplying factors considerably higher than those given in the code for 60-hertz calculations. To determine the proper wire size, calculate the required size conductor (either solid or stranded) based on either a DC or a 60-hertz system using readily available charts, graphs, and equations. Then simply increase the derived wire size by one AWG unit. In most cases, especially in the range of AWG 8 through 3 conductors, the increased conductor size will afford a safety margin beyond that which is theoretically required, but is the most cost effective resolution in the light of available standard conductor gages.

c. Effective grounding systems to achieve EMC must be developed on an individual-case basis. Refer to NAVELEX 0101,106, Electromagnetic Compatibility and Electromagnetic Radiation Hazards, for a detailed treatment of the subject.

d. Red-Black criteria and methodology are delineated in Chapter 12 of NAVELEX 0101,102 and in MIL-HDBK 232. Additional information is contained in NAVELEXINST 011120.1, Shore Electronic Engineering Installation Guidance for Equipments and Systems Processing Classified Information. The general grounding method consists of:

(1) An isolated shield-ground bus, to which all (nonferrous) shields are single-point grounded, provided in those cabinets requiring it.

(2) All cabinet signal-returns and shield ground bus bonded to an isolated signal ground plate in each cabinet.

(3) Each signal ground plate bonded to an insulated main signal ground bus. (This bus is shielded in conduit throughout its run and is isolated from secondary red circuits.)

(4) Station ground, which is returned to earth ground, is the common tie point for the main signal ground bus and for system structures.

(5) Low-impedance mating surfaces of cabinet structures serve to ground mounted chassis.

(6) Cabinet frames are interconnected via conduit housing the inter-cabinet cables. (Ground studs accommodating AWG 4/0 cable should be located on each cabinet to facilitate low-impedance connections to station ground.)

(7) Power neutral returned to station ground via shielded cable.

(8) The AC protective ground connected to the system structure through the AC distribution system conduit.

(9) All conduit integrally shielded and shall be peripherally grounded via metal-gasketed anodic and paint free surfaces at each termination.

(10) Shields within conduit or cabinets are single-point grounded to the cabinet shield ground bus.

(11) Shields peripherally (crow's foot) grounded to ensure that all shields of a particular wire line form a continuous run.

(12) All ground terminations bonded.

(13) Red AC power routed from the generator to the filtered and shielded AC distribution cabinet in ferrous conduit.

(14) Primary and secondary red lines grouped separately, and each group separately shielded within the conduit.

(15) Each shield individually sleeved to prevent shield-to-shield contact.

e. Grounding design for RF applications entails careful consideration being given to skin effect and reactance as well as the propensity of ground conductors to act as radiating elements (antennas). Because much complex, divergent material exists in the literature, a compendium of the least cumbersome calculation methods, equations, charts, and graphs is presented (in simplified format) in Appendix F.

4.2.5 Physical Security

The shore electronic training environment does not pose peculiar physical security problems. In general, provide for security in accordance with OPNAVINST 5510.45, U.S. Navy Physical Security Manual, and make appropriate recommendations including such factors as:

a. Utility systems designed to permit normal attendance by maintenance personnel without breaching security.

b. Control of access to exclusion areas by means of fences, gates, guardhouses, alarm devices, lighting, etc. (Grouping of buildings that have similar security requirements may be cost-effective, even though such buildings may be unrelated in function.)

c. Exclusion areas should be established only for activities whose revealing characteristics and sensitivity or importance require such exclusion. Supporting facilities within exclusion areas should be limited to those essential for efficient operation of the main structures.

d. Sensitive areas should be grouped together to facilitate control. Control points should permit surveillance of entrances and exits. Offices and/or quarters may be required for security personnel.

e. COMSEC equipment storage, use, and/or training require specialized plant facilities and physical security, as discussed in NAVELEX 0101,108. Requirements and recommendations should be addressed to NAVSEF on an individual-case basis.

f. Equipments/systems requiring compliance with MIL-HDBK 232, DCA Circular 300-175-1, and/or NAG 2/TSEC in an operational environment do not require such adherence in the shore training environment since COMSEC equipment will not be installed or used. Exclusion areas must be provided only for teaching operational installations and problems.

### 4.2.6 Electromagnetic Compatibility (EMC)

In general, shore training facilities have a greater electromagnetic interference (EMI) problem than operational facilities for the following reasons:

o Transmitters are dummy loaded. Since the power radiated is reduced by 90 or more dB, no frequency assignment is required, but signals can still be detected by nearby receivers.

o Transmitters and receivers are usually operated with EMI-tight cases removed. This may increase local-oscillator, multiplier, mixer, and harmonic radiation by as much as 90 dB. Case-removal may also increase receiver susceptibility to interference by as much as 90 dB.

Since the mission of the facility is the training of operators and maintenance personnel, the training equipment must be identical to the equipment in operational facilities, but must also be capable of operation in various stages of disassembly. Consequently, the shore training facility must compensate for the electromagnetic-field retention deficiencies in the training equipments and/or instructional configurations. To achieve a cost effective shore training facility, the following EMC practices are recommended:

a. Use the prediction techniques and installation practices specified in NAVELEX 0101,106 Electromagnetic Compatibility and Electromagnetic Radiation Hazards Handbook.

b. Locate the training facility at as great a distance from operational Communications-Electronics (C-E) sites as is possible.

c. Derive primary AC power from a transformer different from the one supplying operational electronics equipments, especially at dual-mission complexes. Where this is not feasible, a separate secondary winding of the transformer should be used for the training equipment.

d. Use a training-equipment station ground isolated from all other ground nets in the facility.

e. Each classroom should have a separate AWG 4/0 or larger insulated ground feeder.

f. Connect each equipment, subassembly, test fixture, and test equipment in the classroom to the station ground feeder. (The AC green-wire protective ground required by the National Electric Code should not be used as a substitute.)

g. Terminate transmitters, exciters, and power amplifiers in well-shielded impedance-matched dummy loads. (The transmission line to each dummy load should be well shielded and as short as possible.)

h. Unless they are designed to operate in close proximity, space transmitters and receivers as far apart as possible.

i. Use shielded or quasi-shielded enclosures (room lined with metal foil or mesh) where low noise and/or low level devices must be aligned or demonstrated. Refer to Chapter 7 of NAVELEX 0101,106, Electromagnetic Compatibility and Electromagnetic Radiation Hazards Handbook, for detailed treatment of screening and shielding design and implementation.

j. Carefully control frequency-spectrum use. Assign each equipment one or more specific frequencies to prevent jamming. In some cases, time-sharing may be necessary by establishing coordinated, staggered operation of specific equipments.

### 4.2.7 Human Factors Engineering (HFE)

The basic HFE criteria are covered in a multitude of sometimes conflicting, sometimes unclear documents. To properly apply HFE to a system design, consider all aspects. Remember there will be many areas of overlap because the human element of a system is concerned with and affected by safety, operations, emergency, space, environmental, and many other factors.

### 4.2.8 Environmental Control

Current Department of Defense (DOD) directives, particularly DODINST 4270.1, clearly define the degree of environmental control allowable for personnel comfort based on weather zones and types of facilities. Separately, individual equipment specifications cite the extremes of heat and humidity which operational equipments can withstand. However, during the development of recommendations in the areas of environmental control, consider the following areas:

a. Since normally heterogeneous equipments may be colocated in a shore training environment, references to specifications regarding environmental limits must be converted into actual temperature/humidity parameters for evaluation. As can be seen in Tables 4-2 and 4-3, even the most common specifications in use today call for extremely divergent testing parameters. Obviously, if high-power sonar equipment, for example, is to be operated near an avionics radar set, basic environmental control in the area may not be sufficient for proper operation of one or the other (or both) of the equipments.

b. If the heat-load computation of personnel or of equipment alone is used to determine the air conditioning or mechanical ventilation requirements of a building or a zone within a building, the combined heat load (especially in borderline geographical areas) may cause ambients far in excess of permissible limits. Thus, if air conditioning is authorized, be sure to consider all heat sources when the total heat load is calculated, so that appropriate size heat exchangers can be selected. (Remember also that too large a heat exchanger may adversely affect humidity in the controlled area.)

c. Equipment in lab areas is often operated with covers removed. Thus, heat dissipation is partially into the room air rather than into the forced air or chilled water closed system provided for the equipment. Careful analysis of this situation may reveal the need for less equipment-cooling at the expense of increased heat exchanger capability in the room-conditioning system.

### 4.2.9 Inspection, Tests, and Checkout

Very often, because inspection, test, and checkout occurs at the end of a project, planning and preparation for these vital elements is given too little attention too late. (The entire subject is well covered in Sections 15 and 16 of NAVELEXINST 10550.4, Shore Electronic Facilities Projects Handbook.) A careful review of those requirements will make it clear that data-gathering and plan-preparation efforts must be commenced at the earliest phases of each program. To facilitate this final segment of a program, the following factors are among the most critical to consider:

- An adequate, accurate BESEP, Section 5
- Availability of all data referenced in BESEP, Section 5
- Complete, up-to-date configuration management (CM) records
- Schematic and wiring diagrams and test-specifications for each unique or modified equipment (including interface devices)
- Inter-equipment cabling diagrams and system specifications for each unique system and subsystem
- Detailed test of both standard and special test equipment required to perform test and checkout.

Table 4 - 2. Environmental Testing Comparisons - Temperature

<table>
<tr><th rowspan="3">SPECIFICATION</th><th colspan="4">OPERATE (HOURS)</th><th colspan="4">NON-OPERATE (HOURS)</th><th rowspan="3">NO. OF CYCLES</th></tr>
<tr><th colspan="2">MAX. TEMP</th><th rowspan="2">TOTAL</th><th rowspan="2">PER CYCLE</th><th colspan="2">MAX. TEMP</th><th rowspan="2">TOTAL AT HI TEMP</th><th rowspan="2">PER CYCLE</th></tr>
<tr><th>°F</th><th>°C</th><th>°F</th><th>°C</th></tr>
<tr><td>MIL-E-16400</td><td rowspan="3">122</td><td rowspan="3">50</td><td rowspan="2">4</td><td rowspan="2">36</td><td rowspan="2">167</td><td rowspan="2">75</td><td rowspan="2">4</td><td rowspan="2">89</td><td rowspan="2">1</td></tr>
<tr><td>MIL-F-18870</td></tr>
<tr><td>MIL-T-17296D</td><td>1</td><td>10</td><td>149</td><td>65</td><td rowspan="2">1/2</td><td rowspan="2">1-1/2</td><td>3</td></tr>
<tr><td>MIL-M-22436</td><td>158</td><td>70</td><td>24</td><td>24</td><td>158</td><td>70</td><td>4</td></tr>
<tr><td>MIL-I-983</td><td>149</td><td>65</td><td>8</td><td>26</td><td>149</td><td>65</td><td>24</td><td>72</td><td>1</td></tr>
</table>

Note: Shaded areas are included for academic interest only
Unshaded areas denote the most divergent inter-specification extremes.

Table 4 - 3. Environmental Testing Comparisons - Temperature/Humidity

<table>
<tr><th rowspan="2">SPECIFICATION</th><th colspan="2">HOURS AT MAX. TEMP</th><th colspan="2">HUMIDITY (%)</th><th rowspan="2">HOURS PER CYCLE</th><th rowspan="2">NO. OF CYCLES</th><th rowspan="2">TOTAL HOURS</th></tr>
<tr><th>°F</th><th>°C</th><th>MAX.</th><th>MIN</th></tr>
<tr><td>MIL-T-17296D</td><td>104</td><td>40</td><td rowspan="2">95</td><td>30</td><td>140</td><td>1</td><td>140</td></tr>
<tr><td>MIL-I-983</td><td>160</td><td>71</td><td>90</td><td>24</td><td>5</td><td>122</td></tr>
<tr><td>MIL-M-22436</td><td>149</td><td>65</td><td>90</td><td>50</td><td>18</td><td>10</td><td>237</td></tr>
</table>

Note: Shaded areas are included for academic interest only.
Unshaded areas denote the most divergent inter-specification extremes.

# CHAPTER 5

# FUNCTIONAL ELECTRONIC TRAINING SYSTEMS

The particular electronic systems which might be installed in a shore training facility may vary from a simple one-equipment lab installation to a Command Information Control (CIC) network for the war college. The equipments involved may be standard shore, shipboard, or avionics gear (or a mix of all), plus special Naval Training Device Center (NTDC) or locally-developed items. This chapter does not provide the specific parameters or criteria regarding any nomenclatured equipment in the inventory (only the appropriate equipment specifications can do that). Nor does this chapter provide an in-depth understanding of the theory of operation of any class of equipment, only BUPERS training manuals can do that. What this chapter does is present, for each generic class of equipment, a brief explanation of the tactical function followed by a discussion of only those aspects which do (or may) present problems because of the peculiarities of the shore training environment. Surprisingly, the collocation of diverse equipments ashore presents relatively few problems. To simplify the evaluation and preliminary research task, those areas which do not require special attention are also noted in the text.

## 5.1 ANTISUBMARINE WARFARE (ASW)

### 5.1.1 ASW Functions and Characteristics

Antisubmarine warfare (ASW) comprises all measures required to combat submarines. Strategy, operational employment of forces, tactics, and the equipment and weapons used to find and sink the submarines are included. The most significant ASW electronic systems/equipments are:

a. Aircraft equipped with search radar, to keep submarines submerged for long periods.

b. Surface-search radar, to prevent submarines from operating at night on the surface.

c. Echo-ranging sonar, the acoustic-wave behavior of which depends on, among other things, the temperature, salinity, and pressure of sea water. Acoustic energy from deep submarines may not reach near-surface sonar devices because of the refracting effect of variable temperature gradients. The bathythermograph measures temperatures at various depths. This permits determination of the best listening depth so that Variable Depth Sonar (VDS) may be used effectively.

d. The magnetic airborne detector (MAD), a magnetometer extended on a boom from an aircraft to detect magnetic irregularity caused by submarines.

e. The sonobuoy (a hydrophone suspended from a floating buoy), a radio set which transmits to an aircraft any underwater sound that it picks up. Sonobuoy types depend on the nature and the frequency of the acoustic energy to be detected.

f. High-frequency (HF) radio direction-finders (RDF's) permit rapid alerting so that the positions of submarines transmitting even short radio messages are obtained by cross bearings.

g. Weaponry, including acoustic homing torpedoes delivered by surface ships, submarines, and aircraft. The homing devices can usually distinguish between decoys and submarines.

1.2 Sonar Overview

onar (Sound Navigation and Ranging) refers both to the application of underwater sound to the detection and cation of objects in the sea, and to the equipment used in such applications. Sonar methods are used widely in e detection of submerged submarines. Since electromagnetic radiations do not penetrate the sea significantly, nar is the primary method of underwater detection.

a. Sonar Types. The two general types of sonar are active and passive. In an active system a sound pulse is nerated by the searcher and projected into the water. This sound is reflected back from the target and detected the searcher. Since the speed of sound in sea water is known, both range and bearing of the target are found. is method is called echo-ranging. In a passive system the searcher detects target-emitted noises. Unless more an one listening station is used, passive sonar provides information only as to the existence of a noise source d its bearing from the searcher. The type of sonar used in a given situation depends on operational or tactical quirements. Active systems emit sound which discloses the searcher, and are used sparingly by submarines, hich rely on concealment for safety. Active systems are used mainly by surface vessels which generally operate an environment too noisy for passive detection. (Interfering noise may be generated by the vessel itself or by her nearby ships.)

onar is also used by aircraft for submarine detection by dropping sonobuoys in the water, by mine sweepers, nd by acoustic torpedoes.

n echo sounder (depth indicator) is an active sonar which sends sound pulses to the sea bottom.

b. Limitations of Sonar. Sonar range is limited by conditions that weaken or distort the sound beam as it avels outward (the same conditions similarly affect the returning echo). Echo ranging is not possible if the ound beam and the echo are weakened excessively, or if the sound beam is distorted so that it does not strike e underwater object, or if the echo does not strike the transducer on the way back. The factors that limit nge include:

- o Pulse power
- o Target composition and aspect
- o Transmission loss
- o Ambient noise
- o Refraction of the sound beam
- o Water temperature, pressure, and salinity
- o Other interference

awater temperature is the prime factor governing sound conditions. A normal condition might show a layer of ater from the surface to varying depths of uniform temperature or of only slight temperature change sotherm). Next would be a region of water that has a relatively large temperature difference – the higher fference at the top, decreasing markedly with depth (thermocline). For the remainder of the depth, the mperature would decrease slightly with depth. The thermocline can prevent passage of the pulse and reflect it ck to the surface, or it may pass the pulse but alter its direction considerably by refraction.

1.3 Functional System Descriptions

a. Passive Sonar. Passive systems are undetectable themselves, but have the disadvantage of having to take in l sea and ship noise. A passive system consists of a highly directional and trainable transducer or array of ansducers, electronic amplifiers, and a display system which is usually aural. The effectiveness of passive sonar epends on the magnitude of the radiated noise, the propagation loss between the radiating ship and the sonar nd the background noise (self-noise or ambient sea noise). The former is noise generated either by mechanical quipment on the listening ship or by its motion through the water. If the ship carrying the sonar is in a quiet ndition and is moving slowly, self-noise may be reduced sufficiently so that ambient sea noise (the general ntinuous noise found naturally in the sea) becomes the limiting factor.

An electroacoustic transducer (hydrophone) is used to detect underwater sounds. The hydrophone contains a material that reacts to mechanical stress. When subjected to stress (such as that caused by sound waves striking the hydrophone) the material vibrates or undergoes a change in size, causing a low-voltage output from the hydrophone. The output frequency is essentially the same as that of the received sound waves.

Passive sonars use a hydrophone array (a number of hydrophones connected together in a circle). The array is not trained physically; directivity is obtained by employing a compensator (scanning) switch which is rotated and positioned by the sonar operator at the control console. A simplified block diagram of an array-type passive sonar is shown in figure 5-1.

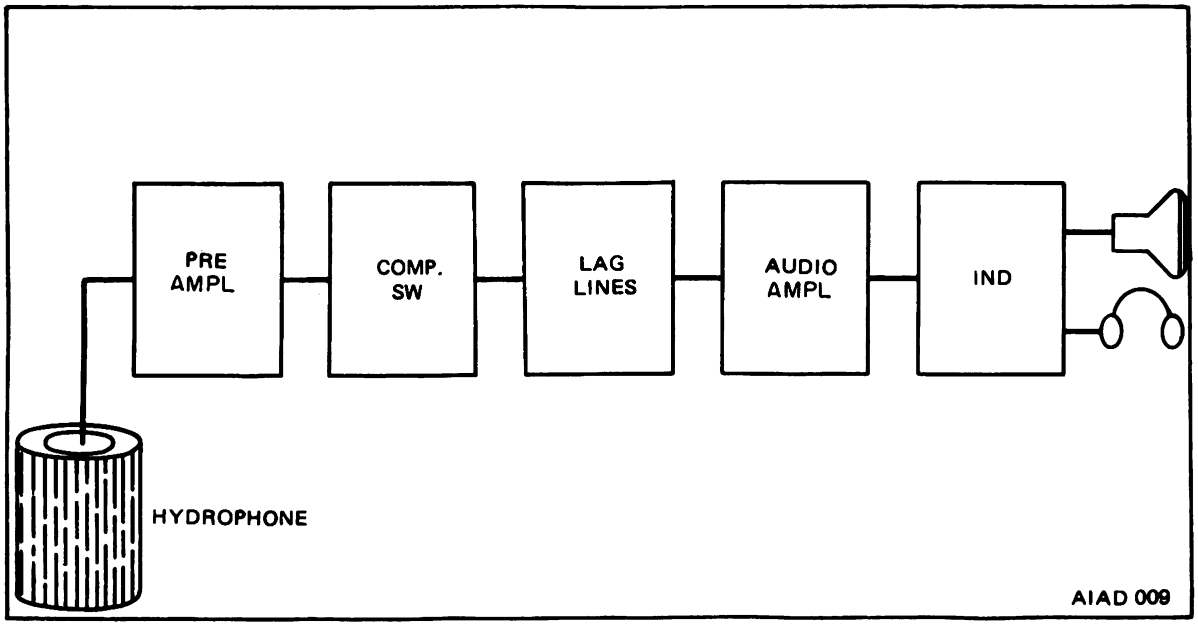



Figure 5 - 1. Array-Type Passive Sonar, Block Diagram

Sound waves received by individual hydrophones are converted to electrical energy which is applied to separate preamplifiers and collected by the compensator switch as it samples the output of each preamplifier. From the switch, the signals enter lag lines. The circular hydrophone arrangement causes the signals to be out of phase with one another at the output of the preamplifiers. The signals are placed in phase with one another by the lag lines, which delay the first received signal a proportional amount until the last received signal catches up. Once the signals are in phase, they are additive. Thus, a strong signal is applied to the audio amplifier. The amplified signal is applied to the indicator, where it is presented visually and audibly.

b. Active Sonar. Active sonar systems consist of one or more transducers to send and receive sound, electrical and electronic equipment for the generation and detection of the electrical impulses to and from the transducer, and a display or recorder system for observation of the received signals. In a typical active system the transmitter consists of a high-frequency audio oscillator and an amplifier which applies a short, powerful pulse to the transducer for transmission into the water in 360 degrees of azimuth. The transducer is located within a water-flooded, streamlined dome to reduce noise generated by transducer-motion through the water. On a surface ship the dome is keel-mounted as deep in the water as possible; to increase this depth, towed sonar is sometimes used. The receiving transducer of an active sonar is directional in order to resolve target bearing. The sonar receiver functions much the same as a conventional superheterodyne radio receiver. The electrical signals resulting from the echo are amplified and turned into audio signals that can be heard through a loudspeaker. The receiver also applies the amplified echo signal to video indicating devices, such as the cathode ray tube (CRT) on the control indicator. A narrow-bandwidth electric pulse is applied to the transducer, which in turn generates a similar pulse of acoustic energy in the water. Targets in the beam reflect part of this energy back either to the same or to another (receiving) transducer, which converts this to electrical energy. This signal is amplified and displayed as a function of time after the original emission, thus indicating reflecting targets in the beam of the transducer. The frequencies used are generally in the range of 5 to 50 kHz. The pulse is repeated periodically at a rate which depends on the maximum range obtainable.

Various display or recording systems are used. Often both a visual and an aural presentation is made. In aural presentations the outgoing pulse (ping) is heard followed by the returning echoes (frequencies which are presented are scaled down from the original ones). In one type of visual indicator, a range recorder, a stylus moves across a chemically treated paper, which is darkened electrically by a received signal. The distance along the trace at which an echo appears indicates target range.

A typical sonar used for detecting, tracking, and displaying targets operates on a frequency of 20 kHz, with a choice of 6-, 30-, and 80-millisecond pulse lengths. (The pulse length controls the amount of energy leaving the transducer.) Power output for the short pulse is about 50 kW; for medium pulse, 10 kW; and for long pulse, 2 kW. Available modes of operation are passive listening, echo ranging at any one of several range scales, and echo ranging with range-gated sweep. With the exception of a capacitor assembly and a signal data converter unit, the function of each major component of a typical sonar was discussed above. The capacitor assembly is a bank of high-voltage (HV) capacitors which supply high voltage to the transmitter power amplifiers during pulse transmission. A high-powered pulse is thus transmitted and the power output is maintained at a relatively constant level for the duration of the pulse.

The signal data converter converts the video presentation on the scope to true bearings, stabilized in the horizontal plane. With stabilization, the position of the echo pip on the scope is unaffected by the ship's own roll and pitch. The signal data converter orients the scope presentation to true north, and also generates a signal that places a stern-line indicator into the display locating the ship's bow relative to the scope presentation. The signal data converter also is used in aided tracking. By applying tracking orders from the attack director to the control indicator so that the cursor tracks the target automatically, the converter aids the sonar operator in keeping the cursor on target. (The operator adjusts the cursor in bearing when it tends to drift off the pip.)

Some sonars incorporate a Rotating Directional Transmission (RDT) mode. In the RDT mode, the total power output is concentrated into a directional beam that covers a narrow sector as it is rotated 360 degrees in azimuth around the ship. Beam rotation is similar to radar antenna rotation, but is accomplished electronically and at a much faster rate. The benefit attained from RDT is improved range.

Some sonars include a means of lowering or raising the normal operating frequency slightly to minimize interference during multiship operations; a beam-depression control that permits downward tilt of the beam to maintain contact with close targets; built-in test equipment (BITE) for evaluating overall system performance; and a unit for inserting synthetic, maneuverable target-signals into the receiving circuits for operator training.

c. Transducer. A projector is a sound generator, a hydrophone is a receiver. Since the same device may serve both purposes, the word transducer is used as a general designation. Any object that vibrates disturbs the material surrounding it, whether that material is a liquid, a solid, or a gas. A projector converts electrical energy to mechanical energy; a hydrophone converts mechanical energy to electrical energy. This energy conversion is usually based on one of the piezoelectric, magnetostriction, or electrostriction properties of certain materials. In each case the transducer contains a diaphragm that is made to vibrate at the frequency of an applied voltage or magnetic field. When the diaphragm moves out, the medium next to it is compressed. As the diaphragm moves back, the particles in the medium move apart, causing a rarefaction (low-pressure area) next to the diaphragm. When the diaphragm moves out again, a new compression is produced. The out-and-in movement of the diaphragm continues, and the alternate compressions and rarefactions spread in a series of waves (compression waves). Compression waves, propagated through a medium, are sound waves. The transducer, being in contact with the water, communicates a similar motion to it, giving rise to a sound wave. The number of sound waves created each second is the same as the frequency of the vibrating body. The speed at which these compressions travel outward depends on the nature of the medium surrounding the body (in water, sound travels at approximately 4800 feet per second). Transducers normally used with scanning sonars operate on the principal of magnetostriction. The transducer elements have nickel laminations pressed in a thermoplastic material. Permanent magnets are so mounted that they provide energy for polarizing the nickel. A scanning transducer contains 48 of these elements, arranged in a circle to give 360 degrees-search in azimuth.

With a hydrophone, the vibratory pressure causes mechanical motion of the material, which in turn generates an electrical voltage. This voltage is amplified and read on a meter, recorded, or played through a loudspeaker.

An important transducer characteristic is its frequency response. In a resonant transducer, response is significant only for frequencies around a characteristic (resonant) frequency. A transducer may be made to have nearly uniform response over a wide frequency range. The desirable frequency response of a transducer depends on its application. Another important property of a transducer is its directivity, which is determined by the geometrical shape of the transducer, and if composed of an array of individual elements, may also be controlled by adjusting the electrical phasing of these elements. A common configuration for echo-ranging transducers is a plane circular radiator which produces a searchlight-type beam pattern. Such a transducer is trained in the desired direction. A common type of receiving hydrophone, a line hydrophone, has the shape of a long circular cylinder. This has greatest response for sound striking parallel to the axis and is independent of the angle about the axis.

d. Echo Ranging. Each ranging sonars for detecting and tracking targets may be divided into two basic types: searchlight and scanning. The main difference between the two is in transducer design. Searchlight sonars use a directional transducer to concentrate an outgoing pulse into a narrow beam. (See part A of figure 5-2.) Target-bearing is determined by training the transducer for maximum echo strength. The only response is audio, and a thorough underwater search is a slow, step-by-step process.

Scanning sonars use a transducer consisting of many fixed elements which are switched rapidly into use by a switching system. As illustrated in part B of figure 5-2, the signal transmitted from the transducer consists of a thin cylinder of sound that travels equally in all directions. The cylinder becomes larger and larger as it travels outward, but its thickness (pulse length) remains constant. Scanning sonar requires less time to search a given area than does searchlight sonar. An additional advantage of scanning sonar is that it presents a continual picture of all underwater objects and all noise sources within range by means of a CRT. Sound pulses spread out in all directions simultaneously instead of being limited to a narrow sector as in searchlight sonars. The received echoes and sounds coming from all directions are displayed on the CRT and remote indicators. Scanning sonars have an additional capability known as Rotational Direction Transmission (RDT). This feature permits transmission of a directional beam throughout 360 degrees, to provide maximum possible ranges while the equipment continues to receive echoes and sounds coming from all directions.

e. Scanning Sonar. The functions of the principal components in a scanning sonar system (figure 5-3) are understood by considering three basic operations of transmission, reception, and presentation.

(1) Transmission. Initiating keying pulses in an automatic function of the keying circuits in the control indicator. The time between pulses and the duration of each pulse is determined by the settings of the indicator console controls. A pulse originating in the keying circuits is applied simultaneously to the transmit-receive switch and to the transmitter. When this pulse is received by the transmit-receive switch, the transducer is switched from receiver to transmitter circuits, and it remains connected there until the outgoing signal is transmitted. Then, the transmit-receive switch automatically reconnects the transducer to the receiver circuits. In the transmitter, the keying pulse triggers the audio oscillator. The oscillator-generated signal is amplified and delivered to the transducer via the transmit-receive switch. The signal is applied simultaneously to all transducer elements (staves) and a sound pulse is emitted in all directions. The pulse released into the water by the transducer continues outward, ever expanding as it goes. When this pulse strikes an object capable of reflecting the sound, a small portion is reflected back to the transducer.

(2) Reception. When an echo is returned to the transducer, it is converted to an electrical signal and applied to a preamplifier (via the transmit-receive switch) for amplification. Each transducer stave has its own preamplifier. The preamplifier outputs are sent to the transducer scanning assembly for distribution to the receiver. The video scanner rotates continuously, thereby sampling the echoes from each transducer element,

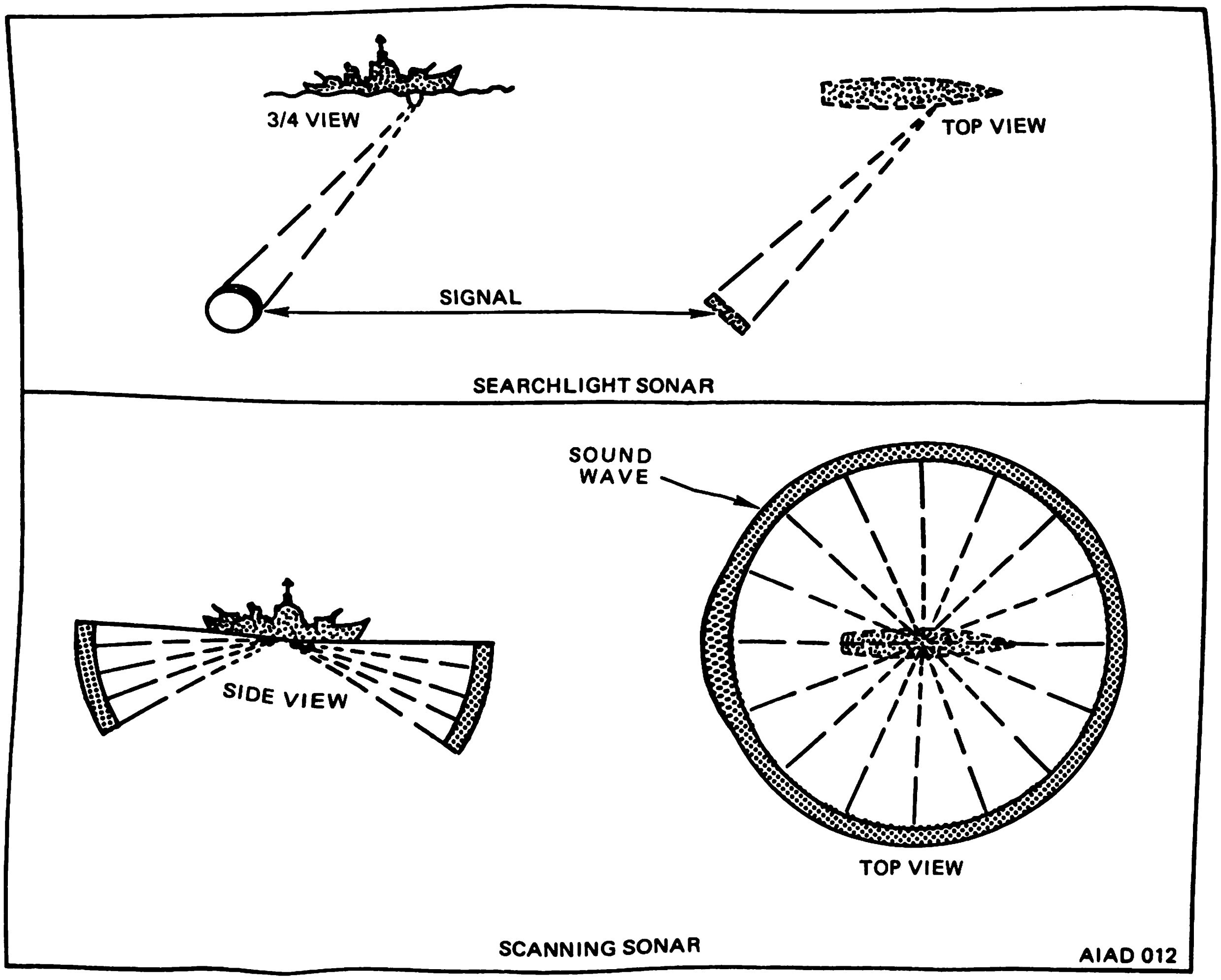



Figure 5 - 2. Echo-Ranging Sonar Signals

giving an effect similar to what would be produced by a rapidly rotating, highly directional transducer. The audio scanner does not rotate continuously; it is positioned by the sonar operator to receive audio signals from any particular direction. The audio scanning switch output is applied to the receiver audio channel. In the receiver, the video and audio signals are detected and amplified for presentation at the control indicator console.

(3) Presentation. Before entering the receiver, the echo is converted from acoustical to electrical energy in the transducer, then is sent to the video scanning switch. Rotation of this switch is synchronized with the sweep presentation, and the echo appears as a brightening of the CRT sweep at the bearing from which it originated. The sweep, seen on the CRT as an expanding circle, is adjusted to expand at a rate proportional to half the speed of sound in water. Thus the sweep reaches a point equivalent to true range from the center of the scope at the same time the target-echo returns to the transducer. The location of the ships is at the center of the pattern, and the spot moves outward in a direction corresponding to the axis of the receiving transducer. This display, which gives both range and direction of targets, is also used in radar and is called a plan-position indicator (PPI).

A line (cursor) is printed on the scope after each sweep. Because of the long persistency of the CRT, the echo remains visible long enough to determine range and bearing. (The operator can control the direction (bearing) and length (range) of the cursor with handwheels.)

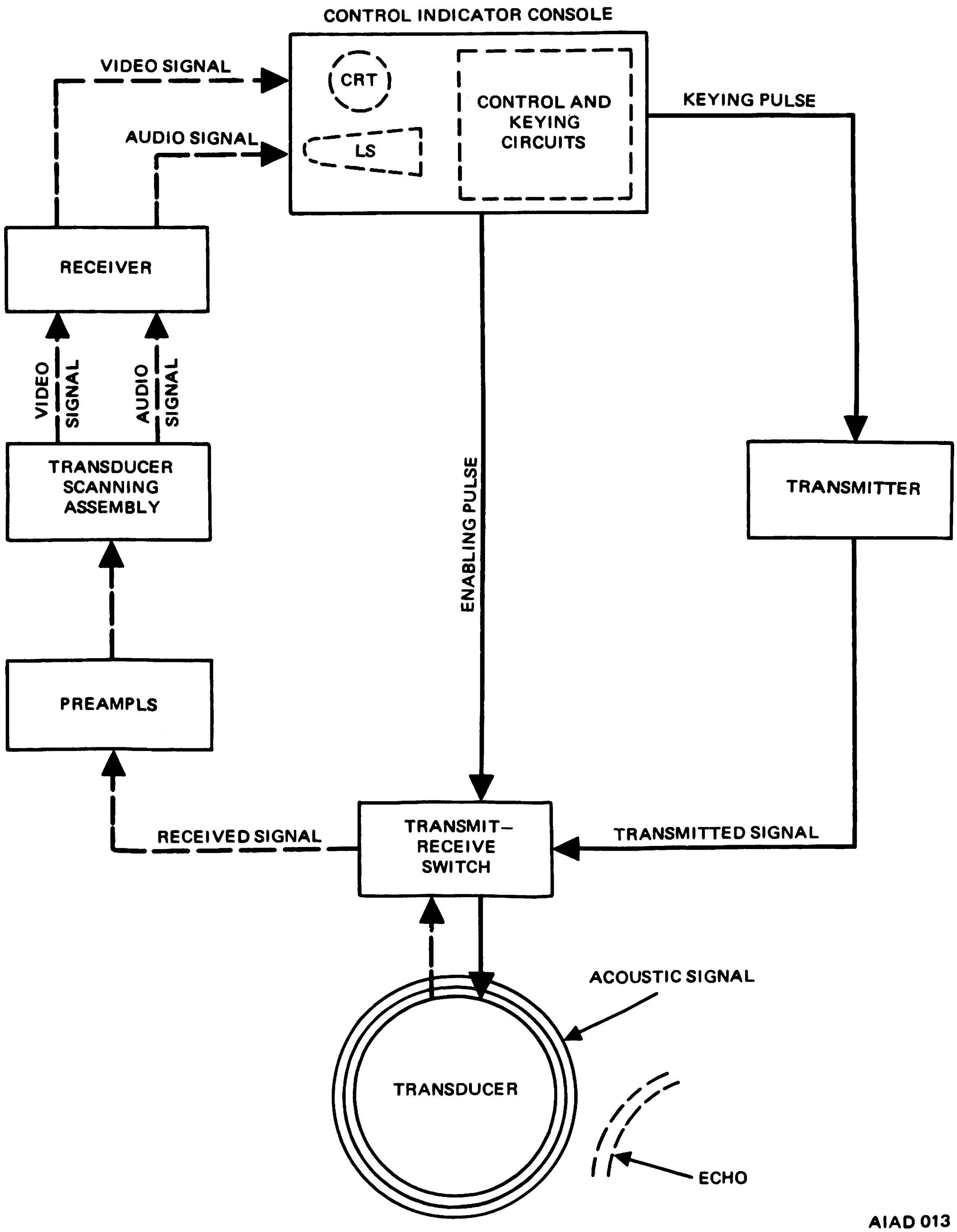



Figure 5-3. Scanning Sonar System, Block Diagram

A CRT also may be operated so that the spot initiated with the outgoing pulse moves from left to right: the echo then deflects the spot vertically. This Variable Displacement Indicator (VDI) shows targets as a function of range for a fixed bearing. (In radar this display is called A-Scan.)

The audio signal is sent from the receiver to the loudspeaker or headset. Together with the CRT display, the audio signal is used to ascertain the nature of the target.

Many factors influence active-sonar performance. Chief among these is the propagation loss between transducer and target. This loss is determined by the sound frequency and by thermal gradients in the ocean which refract sound waves. Another determining factor is the reflecting power of the target (target strength). For an echo to be detected it must be of greater strength than other signals which may be received at the same time. (Interfering sounds are generally due to sonar self-noise or to reverberation). Sonar self-noise, generated by the motion of the ship carrying the sonar, is mostly generated by cavitation and turbulence close to the transducer. Self-noise increases rapidly with ship speed, especially above the speed where cavitation sets in. Reverberation, the combination of all echoes returned to an active sonar system from the ocean itself, is heard as a quavering ring which sets in as soon as the outgoing sound pulse is emitted. Since reverberation is the result of a large number of very weak scattered echoes, individual echoes are not resolved. There are three kinds of reverberation: volume, surface, and bottom. Volume reverberation (caused by suspended marine organisms and inhomogeneities of the sea) is evident as soon as the outgoing pulse leaves, and decays rapidly. Surface reverberation appears as soon as the outgoing pulse reaches the surface of the sea and increases markedly with increased sea state. Bottom reverberation, due to irregularities in the ocean floor and bubbles, is most significant in shallow water.

f. Mine-Detecting Sonar. Equipments used to search for mines and other small underwater objects use two transducers (projector and hydrophone) in a single housing. The projector transmits a beam covering an arc 60 degrees wide in azimuth and 10 degrees in the vertical. Echoes received by the hydrophone are converted into an electrical signal, and applied to a Plan Position Indicator (PPI) scope, showing object range and bearing. Either manual or automatic searching is available. In manual mode the transducers are caused to rotate as a bearing handwheel is rotated, searching through 360 degrees in azimuth. In the automatic mode, the transducers may be caused to rotate through 360 degrees in azimuth or to scan back and forth through a selectable arc of 90 degrees or 180 degrees in azimuth ahead of the ship. For both search modes, the equipment can be set to one of several ranges, and the transducers are controlled manually by a handwheel to cover from plus 5 degrees to minus 50 degrees in depression. The scan pattern appears on the face of the scope as a 20 degree triangular sector with the vertex (point) at the center. Targets are indicated as a bright spot at the correct range and bearing.

g. Depth-Sounding Sonar (Fathometer). Depth-sounding sonars operate on the same principle as detecting sonars but, because of reduced power requirement, are smaller in size and have fewer components. A block diagram of a typical depth-sounding system is shown in figure 5-4. When the system is keyed (automatically or manually), a pulse is generated in the transmitter, amplified, and applied simultaneously to the transducer and the receiver. The transducer converts the signal to acoustical energy and transmits it downward into the water. The returned bottom echo is converted by the transducer to electrical energy and applied to the receiver, amplified, and presented on the recorder or the CRT. When recording, stylus-markings provide two points spaced in proportion to the depth of water beneath the transducer. Visual indication of water depth is provided by a circular sweep on the face of a small CRT. Most fathometers are compact units capable of giving accurate readings from about 1 to 6000 fathoms. They record depths on three chart-indications; two visual-indicator shallow-depth ranges are available.

## 5.1.4 Sonar Accessories

Supplementing basic sonars are a number of equipments that extend or complement the capability of the system. Some supplementary or accessory equipments form an integral part of the system, others are completely isolated from the system.

a. Variable Depth Sonar (VDS). The VDS is a conventional-type sonar modified to transmit and receive signals through a transducer in a vehicle which is lowered below the interfering thermal layers and then towed behind the ship. Thus, the affect of the thermal layers (thermocline) on the signals is minimized. The transducer inside the vehicle is connected electrically to the shipboard sonar equipment by an electrical cable that extends through the center of the armor of the tow cable. Thus the transducer is removed from the hull of a ship and

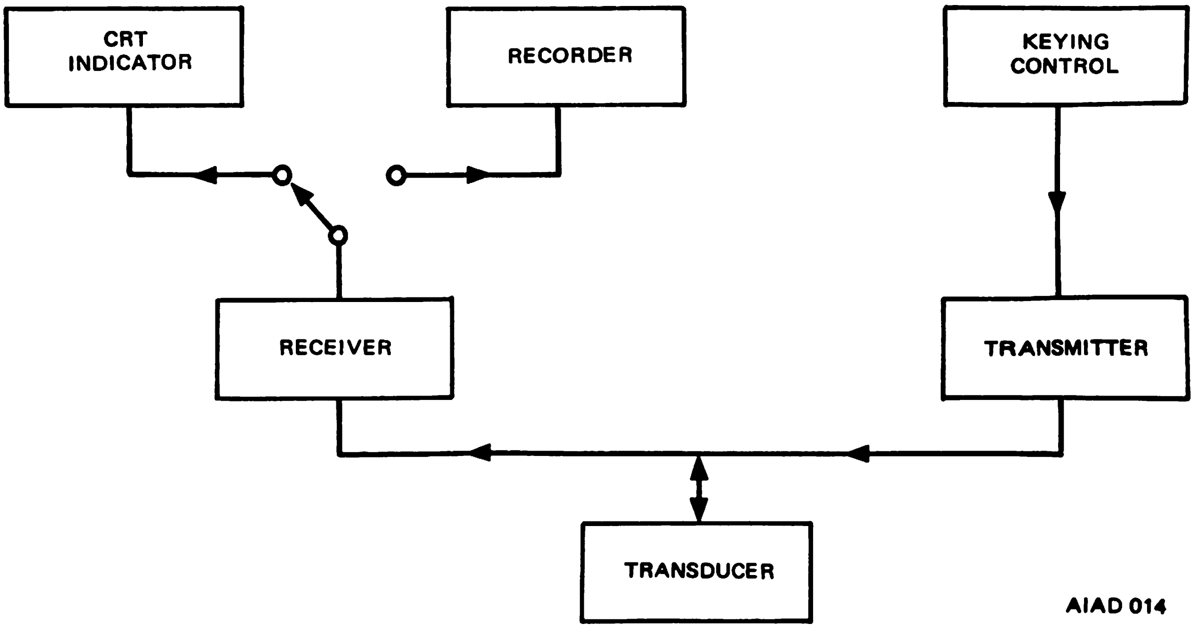



Figure 5 - 4. Depth-Sounding Sonar System, Block Diagram

owed through the water, separated from its sonar set by a long tow cable. The shipboard sonar equipment performs all functions unchanged by the addition of the towed transducer.

b. Azimuth-Range Indicators. An azimuth search sonar includes two remote azimuth-range indicators. These units, video repeaters of the scope presentation at the sonar control indicator, indicate target bearing and range, and have provisions for audio-monitoring of echoes. Typically, front panel controls on the azimuth range indicator affect the audio and video response of the remote unit, but do not affect sonar-console operation. Target bearing is read from an azimuth ring surrounding the video presentation. Target range is indicated on dials. Audio response is heard from either an external speaker or headphones, as desired.

c. Recorder-Reproducer. A tape recorder-reproducer is used with most sonars to record information of actual ASW operations. Information thus obtained is used for post-analysis of ASW actions and for training sonar operators. Typically, a recorder-reproducer set is a two-track magnetic-tape recorder and reproducer. Channel B normally monitors underwater sound information directly from the sonar. Voice information from the vicinity of the sonar operator's station is applied to Channel A. Both tracks usually are recorded simultaneously, but either one may be recorded separately. The tape recorder allows simultaneous recording and reproducing of sounds to permit direct audio monitoring of what is being recorded.

d. Bathythermograph (BT). The BT is an instrument for obtaining a permanent, geographical record of water temperature against depth as it is lowered in the sea.

The temperature element consists of about 45 to 50 feet of fine copper tubing filled with xylene. The tubing is wound around inside the tall fins of the BT, and it comes into direct contact with the sea water. As the xylene expands or contracts with changing water temperature, the pressure inside the tubing increases or decreases. This change is transmitted to a hollow brass coil spring (Bourdon tube) which carries a stylus at its free end. The movements of the Bourdon, as it expands or contracts with changes of temperature, are recorded by the stylus on a metallic-coated glass slide. The sensitivity range is from 28° to 90°F. The slide is held rigidly on the end of a coil spring enclosed in a bellows. Water pressure, which increases in proportion to water depth, compresses the bellows as the BT sinks. Bathythermographs measure three different depth ranges. In general, No. 1 designates a shallow-type, No. 2 a medium-type, and No. 3 a deep-type BT.

### 5.1.5 Basic ASW Considerations

The most significant factors which require special attention during the planning of shore-training ASW installations are:

a. The weight of sonar transmitters, especially high-power equipments which use capacitor banks, may require floor reinforcement.

b. Active-sonar transducers, especially long-range scanning types, generate considerable heat and require a substantial volume of relatively unobstructed, calm water for operation.

c. Hydrophone signals, especially those for passive and VDS systems, are of such a low level that specified-cable electrical-characteristics must be strictly adhered to. Also, the coupling of extraneous noise into a return line can seriously degrade sonar performance. When VDS or long-range passive sonar is to be installed for shore training, extreme care must be used in the selection of cables and connectors. In some cases there may be no electrically suitable substitute for the specified armored, waterproof cable normally used on shipboard. Here then is one of the few exceptions to the general recommendation that shore-type interfacing and interconnecting be accomplished in the shore training environment.

### 5.1.6 Operational Criteria

Except for the MAD, no special problems arise in the shore-training ASW installation. Simulation is usually used for MAD operator-training, whereas simulation is optional (but desirable) for all other sonar training ashore. Since a sonar operator must be able to discriminate between echoes and reverberation, recognize doppler shifts, and also (in passive monitoring) distinguish between types of targets, consider inclusion of a simulation system which contains pre-programmed, pre-recorded audio indications of every type. Such a sound system would entail a relatively elaborate internal communications system, as discussed in paragraph 5.5.

### 5.1.7 Maintenance Criteria

Most special sonar features are not electronic-related, so EFA planning for maintenance-training should present no particular problems.

### 5.1.8 ASW Training Devices

Many excellent ASW training devices are already in Navy inventory and are in current use. Selection of items depends on the particular mission to be accomplished. As a cost-effective measure, keep in mind that many tactical ASW equipments include, in the basic item, provision for training. Also, special trainers (intended for shipboard installation) may, in some cases, prove effective in the shore school also, especially for team-training in conjunction with weapons direction procedures.

## 5.2 RADAR

### 5.2.1 Radar Functions and Characteristics

No single radar set performs all the combined functions of air-search, surface-search, altitude-determination, and weapons direction (fire control) because of size, weight, power requirements, frequency-band limitations, and so on. Individual sets have been developed to efficiently perform each separate function. Each radar is designed to fulfill a particular need, but it also may be capable of performing other functions. For example, most height-finding radars can be used as secondary air-search radars; in emergencies, fire control radars may serve as surface-search radars.

a. Surface-Search Radars. The principal function of surface-search radar is the detection and determination c accurate range and bearing of surface targets and low-flying aircraft while maintaining 360 degree search withi line-of-sight (LOS) distance of the radar antenna. Because maximum range of surface-search radar is limite mainly by the radar horizon, X-band is used to give maximum reflection from such small target-areas as shi mastheads and submarine periscopes. Narrow pulse widths permit short minimum range, a high degree of rang resolution, and greater range accuracy. High pulse repetition rates (PRR) are used for best illumination of target: Medium peak powers can be used to detect small targets at line-of-sight distances. Wide vertical beamwidth compensate for pitch and roll of own ship and to detect low-flying aircraft. Narrow horizontal beamwidth permit accurate bearing determination and good bearing resolution.

Designed for installation aboard DDs and larger ships, medium range, two-coordinate (bearing and range surface-search and limited air-search radar maximum range (when detecting surface targets) is greater, normally then the optical horizon as viewed from the antenna reflector.

Detection range depends on a number of conditions, including antenna height, target size and composition, an weather. Typical medium-range surface-search radars have a tunable magnetron that permits selection of an operating frequency between 6275 and 6575 MHz; some models have a frequency range of 5450 to 5825 MH: Power output varies between 170 and 285 kW, depending mostly on the operating frequency selected. A puls length of 0.37 μsec may be used as a compromise between long and short ranges, or long pulses (1.30 μsec) ma give a longer range, and short pulses (0.25 μsec) a shorter range. The pulse repetition rate (PRR) may be variabl between 625 and 650 pulses per second (PPS).

The antenna usually is a horn-fed, truncated parabolic reflector, which rotates in a clockwise direction at a average speed of 16 revolutions per minute. Radiated signals have a horizontal beamwidth of 1.5 degree an between 12 degrees and 16 degrees in the vertical plane. Short-range (25 yards or less to about 40 miles) compac surface-search radars are used for close-range navigation. These sets have narrow pulse width (0.1 to 0.4 μsec) an low power output (7 to 10 kW). Operating frequency is fixed or selectable within the frequency range 550 to 5600 or 9335-9405 MHz. A parabolic antenna that radiates a beam about 2 degrees wide in the horizonta plane and 15 degrees to 30 degrees high in the vertical plane is usually used.

b. Air-Search Radars. The primary function of air-search radar is detection and determination of range an bearing of aircraft targets at ranges greater than 50 miles while maintaining complete 360-degree search from th surface to high altitude. Low frequencies (P- or L-band) permit long-range transmissions with minimum signa loss. Wide pulse widths (2 to 4 microseconds) increase the transmitting power to detect small targets at greate distances. Low pulse repetition rates provide greater maximum range. High peak power permits detection of smal targets at long ranges. Wide vertical beamwidth ensures detection of targets from the surface to high altitude an helps to compensate for own-ship pitch and roll. Medium horizontal-beamwidth gives fairly accurate bearin determination and bearing resolution while maintaining 360 degree search. High-power (500 kW), long-rang search radars have parabolic antennas that provide a vertical beamwidth from about 10 degrees to about 3 degrees. Horizontal beamwidths of 3.5 degrees are typical.

The equipment is usually tunable with a center frequency about 1300 MHz and may provide a choice of puls lengths between 1 and 4 μsec. Typical medium-range (30 to 50 miles) air-search radars have a frequency rang of 215 to 225 MHz, a peak power output of 300 kW, a fixed pulse length of 4 μsec, and use a bedspring-typ antenna with a horizontal beamwidth of 18 degrees and a vertical beamwidth of 27 degrees.

c. Altitude-Determining Radars. The function of the altitude-determining radar is to find accurate range bearing, and altitude of aircraft targets detected by air-search radar. Its antenna must be tilt-stabilized to provid a stable reference for altitude determination. High frequencies (S-band) are a compromise between the long-rang capabilities of lower frequencies and the narrow beam-forming characteristics of higher frequencies. Narrow puls widths (1 microsecond) permit good range resolution. High pulse repetition rates (PRR) of 600 to 1000 pulse per second (PPS) permit detection of small targets at medium ranges (30 to 50 miles). High peak power permit detection of small targets at medium ranges while using narrow pulse width. Narrow vertical and horizonta beamwidths (1 degree to 3 degrees) permit accurate bearing and position angle determination and good bearin and elevation resolution.

Most radars present only range and bearing, so their beams are narrow in azimuth and broad in the vertical plane. Altitude information, however, depends on knowing the exact angular position of the radar beam above the horizon when it is enveloping a target. For this reason, the beams of height-finding radars are quite narrow in both the vertical and the horizontal planes.

The height-finding radar beam must be independent of own-ship motion. Stabilization is accomplished by means of antenna stabilizing systems. Typical height-finding systems present target height, slant range, bearing and beacon (IFF) information on remote radar repeaters and in Range/Height Indicators (RHI). These radars are found on large ships (cruisers and carriers mostly) and many destroyer radar picket ships.

Operational characteristics vary with different models. Bearing this in mind, the characteristics of one model are: frequency in the X-band, peak power 650 kW, pulse width 1 or 2 μsec, PRR 500 or 100 PPS, vertical beamwidth 1.1 degree, and horizontal beamwidth 3.5 degrees. Antenna rotation-rates are 1, 2, 3, 5, or 10 revolutions per minute. The antenna may be made to scan any sector from 30 degrees to 200 degrees vertically, or it may be trained manually. Antenna elevation scan rates are 300, 600, and 1200 revolutions per minute. Maximum range using 1-μsec pulses is 83 miles; with 2-μsec pulses it is 165 miles. Minimum range is about 4500 yards.

d. Airborne Early Warning (AEW) Radars. AEW systems are shipboard and avionic radar equipments that work together as a single system. The AEW system extends the normal radar horizon by placing the radar set in an aircraft, and relaying the radar information for presentation on shipboard indicators. Thus, targets can be seen at greater ranges than is possible with standard shipboard radar. For example, an aircraft at a 1000-foot altitude will have a radar detection range of 55 miles on a target 50 feet high. If the aircraft is relaying radar data to a ship 50 miles away, the ship has an AEW search range of 105 miles in the aircraft's direction. If the aircraft is directly over the ship at 5000 feet, the ship has an AEW 360 degree search range of 100 miles. One or two radio receivers, a video decoder, and a data converter make up a typical AEW radio receiving set. The number of receivers is governed by the type of antenna available; if an omnidirectional antenna is used, only one radio receiver is required. Because a satisfactory location for an omnidirectional antenna is unavailable on most surface ships, the usual installation of this equipment includes two radio receivers and two antennas operating as a diversity system. The antennas are mounted on opposite sides of the ship superstructure so that each antenna covers half of the azimuth circle. The antenna-receiver arrangement that intercepts the strongest signal takes control of the system automatically to assure reception of the strongest possible signal at all times. In either type of installation, the receivers provide video outputs that are used for indicator displays and also supply decoded synchronizing pulses for further processing and use in the control of the indicator sweeps and associated IFF beacon equipment.

e. Weapons Direction Radar. Because weapons direction systems encompass much more than radar, the subject is treated separately in paragraph 5.9.

f. Radar Repeaters. As the tactics of electronic warfare became more sophisticated, there was more and more evidence that the information obtained from radar would have to be displayed at any one of several physically separated stations. The size and weight of the relatively bulky and complex radar console made it unsuitable for remote (redundant) installations. The need was for a smaller and lighter general-purpose unit, capable of accepting relatively low-level inputs from more than one type of radar and presenting the data on self-contained indicators. To fulfill this need, remote indicators (repeaters) are used. Several types of repeaters are in current use. The repeaters, depending on type, duplicate all or some of the functions of the indicators furnished with basic radar sets.

### 5.2.2 Basic Radar Considerations

a. Types of Radar. The types of radar to be installed are determined by the using command, and will be specified in the training plan. Except for avionics radar, which may require special power and cooling, no peculiar problems need be anticipated.

b. Radar Antenna Location/Orientation. For radar operator-training with live transmission, take special care to preclude interference by direct beaming from one antenna into another. Careful examination of the full 360 degree sweep should be made in this regard. Depending on the size, weight, and type of antenna, concrete slab, roof, or tower mounting may be appropriate. In some cases it may prove cost-effective to erect a salvaged ship's mast as a free-standing (or guyed) tower. Where inter-antenna interference cannot be otherwise eliminated (especially at dual-mission facilities), consider electronic blanking of transmission and/or reception at selected azimuths.

c. Dummy Loads. Most shore radar-training installations require dummy loads capable of handling duty cycles far in excess of that required of dummy loads used during maintenance in a tactical environment. In some cases live tranmission may never be used, such as in a maintenance lab, where the normally mast-mounted antenna may be adjacent to the equipment which would be below-deck on shipboard. Often, commercial dummy loads function well, but carefully consider impedance-match, RF-leakage, and heat-dissipation requirements.

d. Waveguide and Signal Distribution. For strictly training purposes, the radar tactical-environment specifications need not necessarily be adhered to with regard to RF transmission media. Often the total capability (range, etc.) of shore training equipment need not equal that of the tactical counterparts. On the other hand, especially in radar maintenance training, avoid unrealistic attenuation, impedance mismatch, etc.

e. Radiation Hazards. Radiation Hazards (RADHAZ) considerations are concerned with environmental danger to personnel. Hazards of electromagnetic radiation to ordnance fall under NAVORD cognizance, and must also be carefully considered, especially in shipyard or other vicinities where radiation-sensitive materials may occasionally (or regularly) be present. Because many radar trainees will, at the onset, be unfamiliar with the inherent dangers of RF energy fields, substantial precautions should be taken to ensure safety. Remember that high-power equipment may be energized with safety covers removed, and that several antennas may be in simultaneous operation on the same or nearby structures. Consider inclusion of auxiliary safety interlocks, power-on warning devices, antenna-cutout switches, and in the case of antennas remote to transmitter units, even sound-powered or other intercomm systems, as part of the total training system.

f. Radar Displays. For radar operator and team training, extra remote displays (repeaters) are often required. If the number of repeaters exceeds the signal-driving capability of the basic equipment, additional (non-standard) amplifiers may be required. Care should be taken so as not to confuse maintenance trainees, however. Such ancillary items must be so interfaced that the trainees are unaware of the non-standard configuration.

### 5.2.3 Operational Criteria

Radar operator and team training both require absolute realism in the areas of control locations, functions, and interactions and in the displays presented. The means by which this realism is achieved is immaterial. In an extreme case, all signals may be simulated, and the operator controls may in actuality be mock-ups feeding data into a computer which in turn dictates screen presentations. In the case of live transmission, extreme range is of little or no importance, so long as all tracking functions are maintained. In the area of ECCM, the nature of the training environment is such that ECM-simulation (possibly coordinated with co-located ECM training activities) is indicated.

### 5.2.4 Maintenance Criteria

Since the radar maintenance technician must be capable of working on any and every portion of a tactical system, each component must be readily available within the lab area. In some cases, it may be expedient to use an operator/team training operational antenna for maintenance training as well, in which case additional, reinforced walkups, ladders, guard rails, etc. should be provided. But, in general, interior antenna installations are more effective. Although cabling need not be to shipboard specifications, no point-to-point connectors should be altered, to avoid confusion of the radar trainee in a subsequent tactical environment.

### 5.2.5 Training Devices

Presentational realism is the keynote where special radar training devices are concerned. Theoretical, pure radar responses should be avoided in all aspects of training. The operator and team trainees should become familiar with the moderate background noise and clutter which is normally present in tactical situations. Similarly, radar maintenance personnel need not be taught in an area as confined, noisy, or vibratory as on board ship, but the parameters to be measured and/or adjusted should be identical to those on shipboard.

## 5.3 IDENTIFICATION FRIEND OR FOE (IFF)

An electronic system that is used with radar permits a friendly craft to identify itself automatically before approaching near enough to threaten the security of other naval units. This system, called IFF, consists of a pair of transmitter-receiver units. One set is aboard the friendly ship; the other is aboard the friendly craft (ship or aircraft). Because space and weight aboard aircraft are limited, the airborne system is smaller, lighter, and requires less power than the shipboard transmitter-receiver. Airborne equipments are automatic, and operate only when triggered by a signal from a friendly-craft unit.

### 5.3.1 Functional System Description

The IFF system operates as follows: A search-radar operator sees an unidentified target on his radarscope. He turns on the IFF transmitter-receiver (transponder) which transmits an interrogating signal to the airborne transmitter-receiver (transponder). The signal is received by the transponder, which automatically transmits a characteristic signal (identification). The shipboard equipment receives the signal, amplifies and decodes it, and displays it on the radarscope or on a separate indicator. When the radar operator identifies the signal as proper, he knows that the aircraft is friendly. If the transponder does not reply, or if it sends the wrong identification signal, the operator must assume that the target is not friendly.

Two types of interrogation are used: direct and indirect. Interrogation is direct when the interrogating signal is a pulse from the radar equipment. Interrogation is indirect when the interrogating signal is a pulse from a separate recognition set operating at a frequency different from that of the radar. Early IFF systems used direct interrogation, which proved unsatisfactory because the transponder was required to respond to radars that differed widely in frequency. Later IFF systems use indirect interrogation within a frequency band reserved for IFF operation. A typical radar recognition set consists of four major units: a receiver-transmitter, a coder-decoder, a video amplifier, and a radar set control. The set uses the shipboard radar display for presentation of its IFF data. The antenna is either integral to or slaved with the radar antenna.

### 5.3.2 Basic IFF Considerations

The nature of IFF is such that most equipments (or at least the salient characteristics thereof) are classified. Consequently, early consideration should be given to the necessary security aspects of an IFF training installation. One way to minimize the degree of access-limitation required may be by restriction of equipment use to simulation. Where live transmission is desired, only obsolete codes might be used. But, because the equipment is low power, even the possible requirement for a screen room or a shielded enclosure usually presents no real problem. Of course, because IFF works with radar, the simulation or other equipment ancillary to an IFF training installation can be extensive, especially for team training.

### 5.3.3 Operational Criteria

As sophisticated as IFF equipment may be electronically, the operational considerations are quite simple. Provision must be made to couple relatively low-level signals to radars and/or radar repeaters, and in some cases an additional antenna may be required, but operational IFF should pose no special problems.

### 5.3.4 Maintenance Criteria

Since IFF does operate in conjunction with radar, the maintenance trainee of necessity must have available realistic (or actual) appropriate radar input/output signals and even radar presentations very similar to those he will encounter in tactical systems. The inherent precision of IFF pulse width, shape, timing, etc. means that any interfacing and/or interconnecting in the lab environment must be accomplished in such a manner that IFF performance is not degraded in any way.

### 5.3.5 IFF Training Devices

The nature of IFF is such that hands-on experience with actual equipment is the most appropriate means to achieve maintenance training. However, operator and/or team training may be effected with simulated inputs without detracting from realism. Such simulation may be applied to either actual or simulated radar displays equally well. Consideration may also be given to coordinating otherwise independent radar and IFF training; it may be advantageous to consolidate such equipments in adjacent classrooms and/or labs.

## 5.4 ELECTRONIC WARFARE (EW)

By classical definition, EW is that division of the military use of electronics involving actions taken to prevent or reduce an enemy's effective use of radiated electromagnetic (EM) energy and actions taken to insure our own effective use of radiated EM energy. In turn, there are two major subdivisions of EW:

o Electronic countermeasures (ECM), involving actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing or affected by EM radiations and to exploit the enemy's use of radiations. This category includes electronic jamming (the deliberate radiation, reradiation, or reflection of EM signals with the object of impairing the use of electronic devices by the enemy) and electronic deception (the deliberate radiation, reradiation, alteration, absorption, or reflection of EM radiations in a manner intended to mislead an enemy in the interpretation of data received by his electronic equipment or to present false indications to electronic systems).

o Electronic counter-countermeasures (ECCM), involving actions taken to insure our own effective use of EM radiations despite the enemy's use of countermeasures.

### 5.4.1 Functional System Description

The EW equipment and techniques can be classified into four general categories:

a. Reconnaissance ECM. Reconnaisance ECM is used to detect and analyze EM radiation from transmitters in enemy aircraft, missiles, ships, and fixed installations. Such systems usually carried in ferret aircraft, submarines, or ships, consist of one or more very sensitive receivers which can be rapidly tuned over a wide portion of the EM spectrum in search of enemy transmissions. When EM radiation is intercepted, automatic direction-finding pinpoints the bearing to the transmitter. If the signal comes from an enemy radar, it is recorded on magnetic tape. Subsequently, the tape is played back through suitable equipment, which analyzes the radar signal to determine its pulse repetition rate, pulse width, and other important characteristics. Reconnaissance ECM is also valuable in spotting enemy-radar coverage and in locating blind spots in coverage due to terrain obstructions. Another type of ECM reconnaissance receiver is carried aboard aircraft to warn the pilot when his aircraft is being illuminated by radar energy. Generally, an aircraft equipped with a reconnaissance receiver can detect radar radiation at considerable greater distance than the radar can detect the presence of the aircraft because the strength of the energy striking the aircraft is always considerably greater than that which is reflected back to the radar receiver.

b. Passive ECM. Passive ECM devices and techniques change the nature of the energy reflected back to enemy radars; they generate no EM energy themselves. One type of passive ECM is the corner reflector (Luneberg lens), a simple mechanical device which strengthens the radar energy which is reflected back to the radar. If one or more of these devices are installed, for example, on a small aircraft, the energy reflected back to the radar is so enhanced that the aircraft appears to be a large bomber on the radar scope. Tiny drone aircraft equipped with corner reflectors, launched from a bomber, produce multiple targets on an enemy radar scope so that the radar operator does not know which is the real bomber, or to confuse an attacking missile which uses radar to find its target.

c. Active ECM. Active ECM devices generate EM radiation designed to interfere with enemy signals or to confuse enemy operators. The earliest form of active ECM was employed against radio communications in an effort to blot out enemy transmission, or to so irritate the radio operator that he could not do an efficient job. This approach (jamming) requires comparatively simple equipment, but it constantly alerts the enemy to the fact that he is being jammed. One simple technique employs a spark gap to produce short-duration jagged peaks of noise. The effect resembles the noise produced in home broadcast receivers by some electric razors. Spark jamming is easy to produce with simple equipment at low frequencies.

White noise, a sophisticated version of spark jamming, can be used at any frequency. Random noise (produced by a gas discharge tube) is used to modulate the output of the ECM transmitter. White noise and spark jamming require large, powerful transmitters because energy is radiated over a large portion of the EM spectrum.

Another simple, effective type of jamming can be achieved by sweeping the ECM transmitter's carrier frequency back and forth over a portion of the radio spectrum several hundred times per second. This creates hundreds of noise pulses per second in the enemy receiver, each momentarily blanking out the incoming message. Because of the time required by the receiver detector circuits and the human ear to recover from each pulse, the effect is practically equivalent to continuous jamming. Less transmitter power is required because the ECM energy is concentrated in a narrow part of the radio spectrum at any instant. Another advantage is that one jammer can simultaneously be used against a number of receivers, each operating at a different frequency.

If an ECM transmitter carrier frequency differs only slightly from that of the enemy transmitter, it can produce a continuous beat note in the receiver output. This high-pitched squeal can be quite irritating to an enemy operator. If the ECM transmitter carrier frequency is slowly varied back and forth across the enemy radio carrier frequency, the resulting beat note in the radio operator's ear varies continuously in pitch and volume.

Because radar receivers operate from extremely weak signals reflected from the target, low-power ECM transmitters can swamp the radar echo. If the ECM transmitter is modulated by white noise, it tends to obscure the target echo much as tall grass hides a golf ball.

Another approach creates a number of false targets on the radar scope. Radar has two basic means for establishing target bearing and range. Bearing is determined by means of a device that indicates the direction the radar antenna is pointing when the echo is received from the target. Range is determined by measuring the time it takes for a radar pulse to travel from the antenna to the target and back to the antenna. If the target carries a small ECM transmitter that sends out a series of suitably spaced pulses each time a radar pulse is received, the radar will indicate the presence of a group of targets, each at a slightly different range, and will be unable to determine which is the real target. The ECM pulses naturally must be identical to those transmitted by the radar, in terms of their shape, time duration, repetition rate, and radio frequency. (Radar-directed interceptors and guided missiles require accurate target range information to compute the flight path for interception.) If the target's ECM transmitter sends out a single pulse every time it receives a burst of radar energy from the interceptor or missile, then slowly begins to shift the timing of its own pulse transmissions, the radar tracking circuits will measure a target range different from what it actually is. This can cause the interceptor or missile to compute and fly an erroneous path.

A more effective way to divert an attacking interceptor or missile is to mislead it as to target bearing by means of decoys such as small drone aircraft outfitted with passive reflectors or with ECM transmitters. A drone with an ECM transmitter is a more attractive target to radar than the real target, because the signal transmitted by the ECM equipment is much more powerful than the real target echo. If the bomber releases an ECM decoy missile, and guides it by remote control on a different course from the bomber's, the enemy radar will lock onto and follow the decoy instead of the bomber.

d. ECCM. Many ECM equipments must be accurately tuned to the operating frequency of the EW equipment they are designed to counter. One way to negate their effectiveness is to design EW systems so that the operating frequencies can be changed almost instantly. To prevent radars from being fooled by ECM mimics, new radars change the characteristics of their pulses, as well as their operating frequencies, rapidly. Some radars discriminate between repetitious signals, such as are received from a target, and random ones produced by simple ECM transmitters.

### 5.4.2 Basic EW Considerations

Although it is common practice to speak of EW equipment, ECM antennas, and the like, keep in mind the fact that each component of an EW system or equipment is very similar (if not identical) to its radio, radar, or other non-EW counterpart. Significant differences lie in only two areas:

- o A usually high security classification
- o A need to maintain exceptionally accurate frequency control

Both areas of consideration are the result of the same factors. As explained, active ECM and ECCM equipment functions to confuse enemy electronic equipment. To be effective, such equipment must precisely respond to (or radiate) enemy EM radiation. Once an enemy is aware that his transmission characteristics (precise frequency, pulse width, pulse shape, or any other significant parameter) are known and can be countered effectively, the tactical advantage of using such ECM or ECCM equipment is negated. Thus, while school equipment must radiate very precise signals, provision must be made to prevent unauthorized monitoring of the transmissions. (The fact that EW training is in progress may in itself, not be classified, nor may be the fact that the equipment is a radar jammer, but what would be classified would be the precise characteristics of the equipment, lest the enemy become aware and modify his basic radar characteristics or devise an ECCM device to negate the jammer's effectiveness.)

Security provisions for active EW, especially ECM and ECCM equipments, may mean use of a shielded enclosure or a screened room. Such planning must be started very early in the program because TEMPEST pre-test is not applicable here. Because EW equipment is designed to deliberately radiate energy, the need for enclosures or screening cannot be based on the results of TEMPEST (such testing is concerned only with inadvertent transmission). Instead, approval for installation of an enclosure must be obtained from OPNAV, based on verification of the security classification of the transmission parameters by the cognizant SYSCOM (typically NAVSHIPS/NAVSEC).

This approval must be coordinated by NAVELEX HQ. Once approval is obtained, EFA-managed installation of the enclosure may begin. The degree of attenuation required must be determined if not specified. (This will be a function of such factors as transmitter power, area security, geographical location, use of dummy loads, etc.) Upon completion of the installation, the integrity of the system should be checked by TEMPEST, and appropriate modifications (if required) made at that time.

Once this is realized, there should be no problem in dealing with EW shore training systems. Use discretion in selecting non-standard cable and connectors which may degrade performance, but otherwise EW systems may be treated essentially in the same manner as more commonplace equipments.

### 5.4.3 Operational Criteria

Because EW is a battle of wits between ECM and ECCM operators, the degree of realism for operator and team shore-training must be exceptionally high. Care must be taken to interface the devices so that all actions, interactions, and results (whether live or simulated) are precisely as they would be in a tactical situation. With the advent of increasingly sophisticated techniques, there will be increased reliance on computerized simulations, including computer-scoring of trainee progress, so appropriate expandable digital-data communications should be included in your design.

### 5.4.4 Maintenance Criteria

The nature of EW equipment-function is such that maintenance training must be more demanding than for similar non-EW equipments. There is a need for more precise test equipment and methods, with the attendant precise environmental controls and regulated power.

### 5.4.5 EW Training Devices

In view of the rapidly changing state of the art in EW, very carefully analyze the pertinent specifications of each special EW training device to determine any peculiar requirements including shielding, screening, regulated power, security, etc.

## 5.5 COMMUNICATIONS SYSTEMS

Shore electronics training facility communications-systems fall into two basic categories: direct training configurations, and training-support subsystems. At one time or another, any particular facet of the overall communications realm may be slated for a shore training mission. Usually though, the support functions (communications incidental to, but necessary for, the training mission) are limited to only these few generic forms:

- o Patch and test facilities
- o Intercom networks
- o Audio distribution systems
- o Sound-powered phones
- o Teletype (TELEX)

The many currently available possibilities, configurations, etc. tend to overshadow the real simplicity of any communications system. Bear in mind the basic fact that regardless of mission, any such system (in any environment) is really not radically different from many similar existing tactical and/or non-tactical systems. Base the selection of particular equipments and/or systems to fulfill a particular need on the mission-specific requirements; special consideration need be given in only one area because a shore-training environment is involved; take extra care to avoid channel-interactions, electromagnetic interference (EMI), etc. Harmonic as well as basic frequencies used must be carefully reviewed because of the unusual mix of radiating equipment at most training facilities.

### 5.5.1 Functional System Description

Except for laser and digital (data-link) equipments (covered in paragraphs 5.6 and 5.9, respectively) all contemporary equipments and networks are well documented in numerous technical reference sources. The long list of equipments which may be candidate for inclusion in a shore-training facility precludes detailed coverage here. Among the analog equipments (including voice) likely to be encountered are:

Air-Ground Communications
Air Route Traffic Control
Command Control
Control Center
Facsimile (FAX)
Inside Plant (Telephone,Teletype (TTY), etc.)
Intercommunication
Intersite Radio
Outside Plant (Telephone, Telegraph (TWX), etc.)
Point-to-Point Communication
Public Address (P.A.)
Sound Recording
Teletypewriter (TTY)

### 5.5.2 Basic Communications Considerations

Once the generic equipments and/or subsystems have been selected based on functional need, develop the basic areas of consideration (in general terms) from existing technical documentation. In most cases NAVPERS and similar informational publications should be adequate. Additional recommended data is:

NAVELEX 0101,103 HF Radio Propagation and Facility Site Selection

NAVELEX 0101,106 Electromagnetic Compatibility and Radiation Hazards

NAVELEX 0101,111 Digital Computer Systems, Vol. I of II

NAVELEX 0101,115 Digital Computer Systems, Vol. II of II

NAVELEX 0101,112 Microwave and Tropospheric Communication Systems

NAVELEX 0101,102 Naval Communication Station Design

NAVELEX 0101,104 HF Radio Antennas Systems

NAVELEX INSTR. 011120.1 Shore Electronics Engineering Installation Guidance for Equipments and tem Processing Classified Information

DCA-C 300-175-1 DCS Red Black Applications.

Underwater-telephone functions similarly to a conventional telephone system except that the energy is carrie sound waves in water rather than by electrical signals through a wire. The sound is generated by a transd projector and is received by a hydrophone. Generally, a fixed-frequency carrier wave is amplitude-modulate the voice signal and demodulated in the receiving system. For planning purposes, consider underwater teleph equipment as sonar sets without ranging capability (refer to paragraph 5.1).

### 5.5.3 Operational Criteria

In many cases the performance of the delegated equipment may be (often must be) degraded from tha counterpart tactical configurations. This is especially true of high-power transmitters which, in a shore trai environment, would interface with "receiving" stations co-located with the transmitter. In each such case training requirement must ensure development of an adequate installation. On the other hand, ancillary sup networks for trainee/instructor interface, personal safety, etc., must operate at peak efficiency. Thus, element of hardware and of interface criteria must be specified based on a considered analysis of ac requirements. Here, in the field of communications, more than anywhere else, an opportunity exists to d cost-effective innovations–in many situations non-standard devices or configurations, as well as altern hardware elements such as coaxial cable vs. heliax cable, phantom circuits for intercom systems, etc., may p worthwhile.

### 5.5.4 Maintenance Criteria

The design goals relative to communications-equipment maintenance training should not be any different f the goals of any other electronics training system. However, take special care to ensure the maintainability overall supportability of mission-support subsystems, including those designed or configured for a un application. Thoroughly document each subsystem, and maintain tight configuration control throughout entire project. Eventually (if not immediately upon customer acceptance) the customer will be intern responsible for facility maintenance; an adequate and accurate EFA-furnished data package will be the prin means to effect ongoing support.

### 5.5.5 Communications Training Devices

As with all electronic equipment, simulators for communications-equipment technician-training are usu inappropriate. However, the functional nature of communications is such that in most school applications possible to devise simple devices for operator and/or team-training. So long as the location, feel, and seer response of all controls and indicators is realistic, normal transmission-media can be disregarded in the classro From a human-factors standpoint, team members who would be physically isolated in a tactical situation sh not be within view of one another in the classroom, but two radio stations, for example, can effectively efficiently be simulated within one small area by the use of a back-to-back operator configuration o partitions or screens are used, in a side-by-side configuration. With appropriate coupling networks and boo amplifiers, many trainees may be accommodated simultaneously via remoting techniques. In the case teletypewriter repeaters, if the number of desired stations exceeds the driving capability of the transmi solid-state hubbing or serial feed into separate banks of parallel machines may be considered. The spe methodology selected will depend entirely on the capabilities and limitations of the equipment to be used, the training parameters defined in the program plans.

## 5.6 DIGITAL SYSTEMS

The complexities of digital systems preclude inclusion of a theoretical discussion here. For information regar functional description, basic considerations, and generic-type operational and maintenance criteria refe

NAVELEX 0101,111 and NAVELEX 0101 ,115. In general, the shore-training environment does not alter the normal requirements for an operational digital system. The following paragraphs discuss only the facets peculiar to shore training installations.

5.6.1 Operational Criteria

Because training programs are dynamic, and most digital subsystems are dual-mission, extra switching capability should be included in the network. Often a system will be shared by several users, and provision must be made for extensive cabling (often shielded to prevent signal-interaction), and for massive cutovers from one termination to another, often several times daily. Usually customer complaints occur regarding the down-time required to effect subsystem reconfiguration, a problem which can be compounded by the lack of serial coding and the ensuing large number of physical interconnections required. The keynote for future installations should be rapid, maintenance-free interconnection and transfer capability.

5.6.2 Maintenance Criteria

In the usual operational environment, digital systems present few maintainability problems. But the severe demands of shore training facilities must be countered by appropriate design considerations such as:

o High utilization rates and long duty cycles indicate the possible need for supplemental cooling to prevent heat-buildup within interframe cabling.

o Extensive use of large multi-pin patch connectors indicate the desirability of providing either angled connectors or (even better) adequate support facilities to prevent undue strain of cable dead weight on the connectors themselves.

o Extensive use of high-level signals (to simulators) indicates the need for shielding, which may well take the form of individual, inexpensive coaxial cables. (One effective means of physically isolating a lineup of coaxial connectors is to provide suitably spaced fuse clips on a non-conducting surface, to which the individual leads can be attached.)

o Repetitive patch reconfigurations indicate the need for heavy-duty connectors with simple, effective mechanical dis-engagement devices or electronic switching.

5.6.3 Digital-System Training Devices

From the standpoint of an overall ancillary digital subsystem, training devices are usually interfaced with, rather than part of, the basic subsystem; or, in a broad sense, the digital system functions as part of a training device (simulator). The key factor, in any case, is interface; appropriate data sets, modems, etc. must be selected on the basis of the specific parameters under consideration.

## 5.7 NAVIGATIONAL AIDS (NAVAIDS)

Among the navaids systems which may be encountered in a shore training facility are:

o Air Route Traffic Control
o Area Radar Air Traffic
o GCA (Ground Control Approach)
o Ground Control Intercept
o Height Finder Radar
o HF Direction Finding (High Frequency Direction Finding)
o Homing Beacon
o ILS (Instrument Landing Systems)
o Long Range Search Radar
o Loran (Long Range Navigation)
o Low Frequency Range

- o Marker Beacon
- o Omega
- o Radar Air Traffic Control
- o Radar Beacon
- o Shoran (Short Range Navigation)
- o Tacan (Tactical Air Navigation)
- o Terminal Air Search Radar
- o UHF Direction Finding (Ultra High Frequency Direction Finding)
- o UHF Range (Ultra High Frequency Range)
- o VHF Direction Finding
- o VHF Range (Very High Frequency Range)
- o VOR (VHF Omnirange)

For a functional description and a discussion of basic considerations of specific navaid systems, refer to existing documentation such as NAVELEX 0101,107 and Air Force Systems Command Design Handbook AFSC DH-2, as well as technical publications concerning the specific equipment under consideration. The ensuing discussion treats only the peculiarities pertinent to the shore electronics training environment.

### 5.7.1 Functional System Description

Since the obtaining and use of navigational data from a fixed point is far from realistic, provision should be made (for both operator and team-training) to incorporate adequate simulation so that, from the student's point of view, operational-system function is achieved.

### 5.7.2 Basic Navaids Considerations

Navaids installations ashore may seem straightforward, and for the care of equipment normally operated in air stations and the like, this is so, but much equipment allocated for shore electronics training is either shipboard or avionics gear. Additionally, even the shore-type equipment may include high-power transmitters. Thus, the following factors should receive timely and proper consideration:

a. Navaids Antennas and RF Distribution. Initially, follow the guidelines in NAVELEX 0101,106, Electromagnetic Compatibility and Electromagnetic Radiation Hazards. Additionally, evaluate the relative merits of eliminating live transmission and going to dummy loads. In other cases, live transmission may be at reduced power levels. Reception, on the other hand, most likely would be simulated because of the fixed-location of the navaid receiving equipment.

b. Interface with Communications Systems. A portion of a navaid system will usually be devoted to team training, thus supplemental internal communications will be required.

c. Special Power Requirements. Shipboard or avionics equipment may require special power. Refer to paragraph 4.3.3 for a discussion of the specification, recommendation for, and implementation of, special electrical power.

### 5.7.3 Operational Criteria

Navaids operator and team proficiency can be effected only with an extremely credible, realistic environment. The physical aspect of a shipboard or aircraft navaid installation is of no importance, but indicator and control interaction must be precisely simulated if the trainees are to benefit from the sessions. The overall performance of a navaid system in the school must duplicate the expected performance of a counterpart operational system.

### 5.7.4 Maintenance Criteria

The electronic sophistication of navaid systems means that a greater than average complement of calibrated test equipment be on hand. Unless the trainee can actually see the results of "almost" as opposed to "exact" alignment and calibration, the training course will have reduced value. As an adjunct to the maintenance training program, give thought to the availability of requisite live or simulated signal sources for such equipments as Loran receivers.

## 5.8 OPTICAL SYSTEMS

The complexities and interrelationships of military systems are such that a fine line cannot always be drawn between electronic systems and optical systems. Especially in the course of developing a shore-training facility, it may be necessary (or advisable) to include (or recommend inclusion of) various optical systems either for direct training or as training aids. Each such generic optical system is discussed below.

### 5.8.1 Optical Systems Overview

a. Periscopes. Usually periscopes are thought of as simple prismatic viewing devices, but in actuality the rather complex lens/prism system is only one portion of a periscope. There is a sophisticated complex of electro-mechanical items which also comprise a portion of the periscope. The basic functions and operations are self-evident (raising, sighting, training, and lowering), and need not be reiterated here. Suffice it to say that both operator and maintenance training is required ashore.

b. Television (TV) Systems. The preponderance of TV systems which may be encountered are closed circuit TV (CCTV), in which no RF transmission or reception is involved via the airwaves. In such systems the camera and the viewing set each function in exactly the same manner as their counterparts in commercial TV. However, the transmitter antenna systems, and RF receiving/demodulating equipments and components are eliminated. Instead, the data which commercially would be used to modulate the transmitter is applied (via coax cable) directly to the receiver circuits. Such systems vary in basic design, and may or may not be compatible with commercial TV synchronization standards. Resolution (picture clarity) likewise is dependent on particular design. Some simple, relatively inexpensive systems are suitable for little more than casual remote visual monitoring due to poor image quality; others provide sufficient resolution for satisfactory display of printed matter, diagrams, and the like. Most systems can (with or without booster-amplifiers) accommodate innumerable monitors (viewing sets) for simultaneous viewing the same material in many locations. Multi-channel provisions may be incorporated whereby individual monitors can be tuned to variant programming. The programming itself may be live (via cameras), video tape playback, or a remoting of commercial TV from a central receiver. Because of the similarities to commercial TV, in-depth discussion here will not be provided.

c. Infrared (IR) Systems. With the increasing sophistication of electronic warfare, IR systems are becoming more significant. The IR spectrum spans the gap between visible light and microwave electronics, and the nature and properties of IR also span the same gap. Since the IR portion of the electromagnetic spectrum is broad (see figure 5-5), an understanding of the spectrum itself is a prerequisite to understanding even the broad classes of systems and equipments available. Infrared radiation is electromagnetic radiation with wavelengths ranging from about 0.8 micron to 1000 microns (1 mm). The lower boundary is set by the long-wavelength limit of human-eye sensitivity to red light and the upper by the short-wavelength limit to radiation which can be generated and measured by microwave electronic devices. All solid bodies with a temperature above absolute zero radiate IR energy, and if the effective temperature is up to about 3500$^{\circ}$K, the radiation is primarily IR. The IR region is often subdivided, but there is no general agreement about the names and boundaries of the subdivisions.

Table 5-1 gives a subdivision based on instrumental characteristics but which also corresponds roughly to the subdivision of natural frequencies of molecules as shown in the last column.

Near IR, detectable by photoelectric cells, corresponds in frequency range to the lower energy levels of electrons in molecules and semi-conductors (the higher electronic levels correspond to the frequencies of visible and ultraviolet radiation). Intermediate IR covers the frequency range of most molecular vibrations. This region is sometimes called the prism IR because spectrometers equipped with alkali-halide prisms are commonly used here. The far IR, where diffraction gratings must be used in spectrometers because no suitable prism materials are known, spans the region of very low molecular vibrational frequencies and most rotational frequencies of the lighter molecules. Radiation of about 1 mm wavelength (the upper limit for far IR) can also be produced and detected by radar.

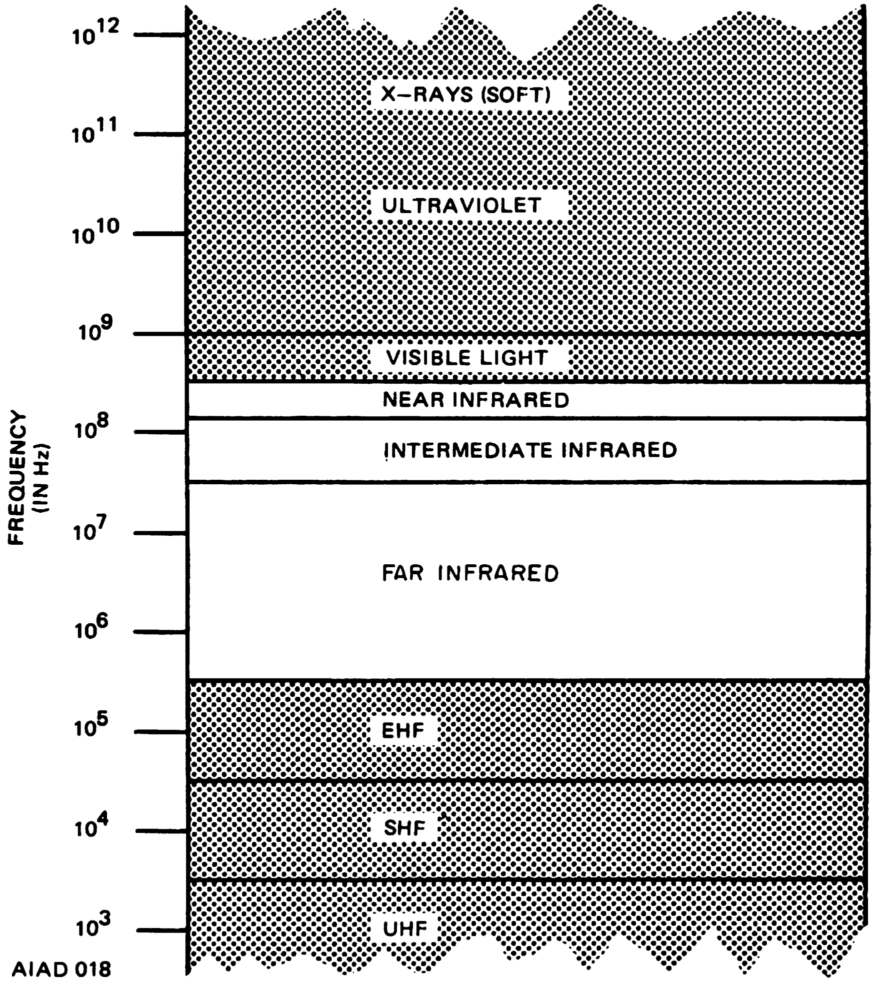



Figure 5 - 5. Electromagnetic Spectrum, Portion of

Table 5 - 1. Infrared Spectrum

| WAVELENGTH RANGE, $\mu$ | WAVE NUMBER, RANGE, $CM^{-1}$ | NAMES USED | APPROPRIATE MOLECULAR MOTIONS |
|---|---|---|---|
| 0.8 - 2.5 | 4000 - 12,500 | Near IR; photoelectric IR | Low electronic levels; vibrational overtones |
| 2.5 - 50 | 200 - 4000 | Intermediate IR; prism IR | Molecular vibrations |
| 50 - 1000 | 10 - 200 | Far IR; grating IR | Molecular rotations |

properties of IR-radiation transmission-media are quite different from those of visible light. For example, low glass is opaque to 5 μ radiation, but pure germanium crystals (opaque to visible radiation) are sparent to this wavelength. Nitrogen, oxygen, and the rare atmosphere gases are transparent to all IR elengths, but water vapor and carbon dioxide are strongly absorbing in certain regions. In the range 0.8 to 4.0 nere is irregular absorption, and from 4 to 8 μ strong absorption with more or less transparency at about 1.0, , 1.6, 2.2, 3.4 to 4.0, and 8.0 to 13.5 μ. Beyond 14 out to 600 μ, there is almost continuous absorption by iospheric water vapor. Liquid water is generally opaque above 2 μ in path lengths longer than 1 mm.

ctromagnetic radiation detectors may be classified broadly into quantum, resonant, and heat engine (thermal) ectors. The first devices convert a quantum of radiation into a proportionate signal by a process which is ensitive to quanta of less than a certain energy (for example, the mean energy of quanta emitted by a body at om temperature). Photographic emulsions, photoelectric cells, and Geiger counters are examples of quantum tectors. Resonant detectors respond only to radiation of the frequency to which they are tuned. Heat engines nvert radiation into heat and use the heat to operate a device that produces a signal proportionate to the nount of radiant energy received.

esonant detectors are not tuneable to IR. For photoelectric IR, quantum detectors of specially sensitized otographic emulsions, photoemissive cells, and photoconductive cells are usable. The response of such detectors ries with frequency and drops to low values at wave numbers of about 2000 to 3000 $cm^{-1}$ (3.5 to 5.0 μ avelength). Photoconductive detectors have good response below 2000 $cm^{-1}$ (above 5 μ), but must be operated or near liquid helium temperatures (less than 10K).

a large part of the IR region, heat-engine detectors, whose response is the same to all kinds of radiation if the diation is converted entirely to heat in the detector, are the only generally usable kind. Examples of heat gine detectors are themocouples and thermopiles, which produce a voltage when heated; bolometers, which ange their electrical resistance when heated; and pneumatic radiometers, in which heat is detected by the crease in pressure of a heated gas. Thermal detect rs operating at room temperature have a lower limit of nsitivity of about $10^{-10}$ watt with response times of about 0.1 second. This limit can be considerably reduce, if e detector is capable of operation at low temperature.

mong the applications of IR radiation are invisible signalling for messages and the like, active and passive tection of targets, and missile guidance.

d. Lasers. The laser (light amplification by stimulated emission radiation) extends the range of controllable ectromagnetic radiation to the infrared and visible light spectrum. Laser communication systems generally use e CW helium-neon laser, amplitude modulation, and noncoherent detection by the use of photomultiplier bes. More sophisticated superheterodyne laser receivers and systems use the injection-diode laser.

tmospheric effects, primarily absorption, refraction, and scattering, are the major factors impeding communicaon applications for point-to-point terrestrial service. (A controlled environment, such as a "light pipe" is quired for most uses of this type.) Aircraft applications deal to some degree with both sets of difficulties. cquisition generally requires auxiliary RF or IR equipment.

n understanding of laser theory involves in-depth study of quantum mechanics and quantum electronics, both f which are beyond the scope of this handbook.

e. Masers. A device for coherent amplification or generation of electromagnetic waves by use of excitation nergy in resonant atomic or molecular systems; an acronym for Microwave Amplification by Stimulated mission of Radiation. The device uses unstable atomic or molecular particles which may be stimulated by an lectromagnetic wave to radiate excess energy at the same frequency and phase as the stimulating wave, thus roviding coherent amplification. Masers are not limited to the microwave region; amplification includes a range om audio through optical frequencies. Maser-type amplifiers and oscillators are also referred to as molecular, or uantum-mechanical, since they involve processes on a molecular scale.

laser amplifiers can have exceptionally low noise, and come close to amplifying a single quantum or radiation in e microwave region; that is, they approach the limits, set by the uncertainty principle, on the precision with hich phase and energy of a wave may be amplified.

Inherently low noise makes maser oscillators that use very narrow atomic or molecular resonances extremely monochromatic, providing a basis for frequency standards. Since atoms or molecules may have resonances and effective amplification over a wide frequency range down to very short wavelengths, masers are useful as coherent amplifiers of millimeter, IR, and optical wavelengths, where older types of circuit elements are not effective. Because of their low noise and high sensitivity, maser amplifiers are particularly useful for reception and detection of very weak signals in long-distance radar and microwave communications.

Because the maser is so complex a device to explain, the theory of operation is left to advanced physics textbooks, but in the following paragraphs pertinent operational, installation, and support information is provided.

5.8.2 Basic Optical-System Considerations

a. Periscopes. The size and weight of a periscope is such that usually a single installation should be considered for both operator and maintenance training. If through-the-roof mounting is used, the roof itself must bear the weight of not only the periscope but the winches and monorail systems which are a near-necessity for maintenance training. Since more than one periscope may be installed, live-loads should be calculated accordingly. Also, early in the planning stages, consider the means by which the periscope will be raised to the topmost floor and placed within the building.

Since even through-the-roof mounting will not require extraordinary weatherproofing, consider using salvage or pressure-reject collars as a cost-effective measure. Also, since the facility is an electronics school, it may be possible to eliminate or simplify the hydraulic subsystems. In any case, close early coordination will be required with the sponsor and the using command to ensure inclusion of appropriate hydraulics and also to effect suitable placement of the Electrical and Electronic (E&E) adapter. (Often the E&E adapter is removed from the periscope base and wall or bench mounted.)

b. TV Systems. If it is intended to include a CCTV system as a shore-training aid, little attention need be given the monitors. Primary power, coaxial cable runs, and the controllable ambient illumination in the viewing areas should present no particular problems. However, the control center and/or studio (for live programming) should be carefully analyzed. Not only may considerable floor space be required (for staging, storage, and operating equipment), but filtered, regulated power and exceptionally stringent ambient illumination and temperature/humidity control may be needed. As an adjunct to such a system, an expanded-capability internal communications system may be advisable (especially for multi-channel TV).

c. Infrared. The nature of particular IR equipment will determine whether shore training will be predominantly team or individual-operator as well as maintenance, and instruction areas should be laid out accordingly. Aside from considerably reduced illumination levels, special treatment of IR areas is not usually necessary. The following description of generic IR equipments is intended to give an insight into the ramifications of entering such equipment into the shore-training environment.

Transmitting (source) equipment produces and directs the radiations; receiving equipment detects and converts the radiations into either visible light, for viewing purposes, or into voice or code signals, for audible presentation.

Infrared devices can be used for weapon guidance, detection of enemy equipment and personnel, navigation, recognition, aircraft proximity warning, and communications. Depending on application, the equipment is either active (both transmitting and receiving) or passive (only receiving).

Equipments operating in the near and middle bands (used for ranging, recognition, and communications) normally have about a 6 to 10 mile range. Equipment operating in the far infrared band (used for ranging, missile guidance, and the detection and location of personnel, tanks, ships, aircraft, etc.) usually is effective at distances between 100 yards and 15 miles.

Some IR devices are blinker, voice/tone, and detection/tracking equipments. One widely used transmitting equipment is a hood with filter lens mounted on a standard Navy 12-inch searchlight. The light is operated in the same manner as an ordinary communication searchlight. Using the same design, variations of the equipment are

onmagnetic minesweepers and the 8-inch signal light. Another IR transmitting equipment is
light, installed in pairs on yardarms of ships. These lights operate in the same manner as yardarm
ey can be used as a steady source for Point of Train (POT) or they can be used for signalling or
.

ewers convert IR rays to visible light. A typical viewer consists of a main housing and a pair of
eable eyepiece lens assemblies. When the viewer is used, where 115-volt AC power is available, a power
it (provided with the set) provides the 20 kV DC power required by the viewer. If primary power is
e, or if the viewer is used as a portable unit, it can be battery powered.

converter tube is an evacuated tube which has on one end a transparent photocathode sensitive to IR.
to be viewed is optically focused on the photocathode, causing electrons to be emitted in proportion
tensity of IR illumination. The emitted electrons are focused by electrostatic lenses on a fluorescent
the other end of the tube, which is excited by electron impact into radiating visible light and thus gives
image of the invisible excitation at the other end of the tube. The limit of the visual spectrum is 0.7 $\mu$,
tubes are sensitive to 1.2 $\mu$. The tube itself is not sensitive enough to see any but very warm objects,
hot engine or a lighted cigarette. Thus, an IR searchlight is used to illuminate the field to be viewed.

sers. Because lasers are comparatively new in the inventory, and little experience has been had as yet
equipment, the following checklist is provided for initial guidance:

) Wherever feasible, locate laser equipment in a room separate from general laboratory areas or in a
f enclosure. Lasers with outputs exceeding protective-device capabilities shall be housed in an area to
rsonnel will be denied access during operation. (Treat the laser as an ordnance piece; confine operation
o gunnery or missile ranges or sites where similar safety measures are in force.)

) Laser spaces shall be free of reflective surfaces or objects, particularly in the target area.

) Provide high general illumination, except where accomplishment of a mission would be impaired.

) Provide a warning sign or signs such as that of figure 7-61 of NAVMED P-5052-35 permanently
each entrance of the laser enclosure.

) For pulsed and continuous wave (CW) laser installations with reflected intensities exceeding maximum
safe levels:

o Provide safety interlocks at each entrance to the laser space so that unauthorized or transient
cannot enter while the laser power supply is charged and capable of firing; when interlocks are
a fail-safe circuit shall de-energize the laser system in 5 seconds or less.

o Provide an alarm system including an audible signal and flashing lights (visible through laser safety
which are actuated when the laser power source is being energized.

o Walls and ceilings should be diffuse nongloss black near the target area and a light color elsewhere
ce ambient illumination.

o Provide adequate ventilation where inert liquified coolant gases are used in the system.

o Provide a master electrical power shut-off outside the laser enclosure.

6) Install electrical and electronic circuits associated with laser apparatus in accordance with NAVMAT
nd Requirement 1 of MIL-STD-454.

7) Design firing systems with fail-safe controls to prevent accidental laser firing.

(8) Components that can produce extraneous direct, deflected, or reflected radiation of harmful visible, ultraviolet (UV), IR, X-ray, or RF energy shall be shielded. Flash lamps, rotating parts, capacitor banks, and other components that can fail and produce hazardous flying pieces shall also be shielded.

(9) Provide fire-resistant low-reflective material as a backstop for carbon dioxide-nitrogen gas ($CO_2$-$N_2$) laser beams.

(10) Safety precautions and safe operating procedures shall be posted in accordance with NAVMAT P-5100.

(11) Systems using liquid nitrogen as a coolant shall comply with NAVWEPS OP-3199.

e. Masers. At present masers are experimental, but in anticipation of forthcoming entry of such devices into shore electronic training facilities, be aware of the fact that extremely rigid environmental controls are required for maser operation. The devices are dependent on cryogenic processes which lower the temperature to nearly absolute zero (-459.72°F, or -273.18°C). Thus, the use of liquid nitrogen or liquid helium cooling apparatus, should be anticipated.

### 5.8.3 Operational Criteria

The fact that optical systems seem afield of electronics should not confuse the issue. The operational criteria for these systems, whether they be training aids or mission-type devices, require no more nor less consideration than for any other type of system. The nature of the equipment is such that mock-ups and simulation techniques are usually inappropriate or impractical, so the engineer must rely heavily on proper placement of the prime equipment in order to provide effective, safe training. In many team-training situations it may be necessary to segregate the class into two or more areas (different structures) separated by considerable distances in order to achieve a suitably realistic environment.

### 5.8.4 Maintenance Criteria

Although electronic-technician trainees will not be directly involved with the purely optical components of the devices, provide at least rudimentary cleanliness and environmental controls to prevent degradation of sensitive parts during handling. In other respects, no special considerations should be necessary for maintenance training.

## 5.9 WEAPONS DIRECTION

Electronic equipment in weapons direction (including missile guidance) systems is closely related to mechanical and optical equipment both physically and electrically. Radar is only one part of a weapons direction system.

### 5.9.1 Functional System Descriptions

a. Fire Control Radars. The principal function of weapons direction radar is the acquisition of targets detected and designated by search radars, and the extremely accurate determination of their ranges, bearings, and position angles. Antennas must be tilt-stabilized to compensate for own-ship pitch and roll. Very high frequencies (X and K-band) permit formation of narrow beamwidths with comparatively small antenna arrays, detection of targets with small reflecting areas, and good definition of targets. Pulse widths of 0.1 to 30 microseconds provide high range accuracy, short minimum range, and excellent range resolution. Repetition rates of 1500 to 2000 pulses per second (PPS) afford maximum target detection while using narrow pulse widths. Because long ranges are not required, peak power under 100 kW permits use of smaller components. Vertical and horizontal beamwidths of 0.9 degrees to 3.0 degrees provide accurate bearing and position angles and high bearing and elevation resolution.

b. Missile Guidance Radars. Missile guidance radars operate on the same principles as weapons direction radars. Although used for missile or target tracking in several systems, the chief application is beam-rider guidance. The beam-rider system is effective for use with short- and medium-range surface-to-air and air-to-air missiles. For long-range missiles, a beam-riding system may be used during the midcourse phase of flight. As it roaches the limit of beam-riding range, the missile switches over to other forms of guidance. In the simplest e of beam-rider system a single radar with a narrow lobe is used for both target tracking and missile guidance. another type one radar is used for tracking, while another generates the very narrow guidance beam. The gle-radar system has the advantage of simplicity, but it is not as effective as the two-radar system. In the o-radar system, a computer between the radars controls the missile guidance radar. The computer takes target eed, range, and course data from the tracking radar, and computes missile course. The computer output ntrols the guidance-radar antenna orientation, and points the guidance beam toward the point of target erception. Because the computer receives data constantly, it is able to alter missile course to offset target asive action.

9.2 Basic Considerations

general, considerations to be given weapons direction systems are similar to, but less extensive than, the ctors pertinent to radar systems as discussed in paragraph 5.2. However, if on-the-air actual missile guidance is be performed as part of operator training, frequency allocations must be specified to prevent inter-system terference.

9.3 Student-Training

he nature of weapons direction systems is such that simulation must be relied upon to a great extent for both perator and team training. In some cases fire-control radar may be interfaced with actual shore gun batteries, ut this would be the exception rather than the rule. In most cases, all portions of the system will be installed ithin the school structure. Thus, take the heavy equipment into consideration when floor-loading factors are lculated.

9.4 Weapons Direction Training Devices

imarily in the area of missile-guidance radar operator and team training, there is usually heavy reliance on mulation. Thus, take into consideration floor space, cabling, and proximity to computer and ancillary uipment. Environmental realism serves little purpose, but credible indicator and display response is a must. For aintenance-training, of course, unmodified equipment is required.

10 COMMAND AND CONTROL SYSTEMS

a broad sense, a Command and Control System may be thought of as a sophisticated digital system/ mmunications network complex. The coverage provided in paragraphs 5.6 and 5.7 addressed, primarily, the use f operational equipments in a shore-training environment. Here, broader and deeper treatment of the subject is rovided to accommodate those situations where more basic design and development is required as, for example, the establishment of an annex to or augmentation of a WARCOL or FAAWTC.

Command and Control System must provide information on an on-line real-time basis, and also provide inputs assist in decision-making in a predictive, graduated response system. Evaluate requirements and convert these equirements into electronic data processing (EDP) and communications parameters; develop a cost-effective ystem comprising all elements required to satisfy individual parameters. Each system is unique in its require- ents and in part of its mode of operation. Command and Control system requirements are somewhat similar to hose of conventional business-oriented systems. Distinctions lie primarily in the urgency of response, the need or extreme reliability, the consequences of decisions and, above all, in a fundamental cohesive bond between ommunications, computer, and human factor considerations. In most systems, communications play a minor ole and computer technologies are significant.

5.10.1 Functional System Description

Remote and Procedural Functions should provide a real-time communications equipment/software interface for remote Input/Output (I/O) and procedural functions such as:

- o Switched voice communications
- o Radio communications
- o Teletypewriter communications
- o Visual displays and updating techniques
- o Status map displays including manual updating
- o Console operation procedures
- o Terminal stations
- o System restart and recovery
- o Back-up system status update

An on-line system is one in which input data enter the computer directly from the point of origin and output data are transmitted directly (or through switches or data concentrators) to the point of use. On-line data sources include terminal stations, other computers, teletypewriters, backup switched-communications, cathode ray tube (CRT)-keyboard (data base inquiry) devices and intermediate storage devices (tape, drum, and disk). Data terminals include other computers, status map displays, printers, visual displays, and intermediate storage devices. A typical, generalized equipment configuration is shown in figure 5-6. The equipment complement should be designed to grow modularly as a function of system I/O data requirements and processing system functional requirements. The entire system should be capable of smoothly evolving as a function of state-of-the-art equipment development. Three alternative processing-system configurations are:

- o Single processor
- o Multiprocessor
- o Dual processor

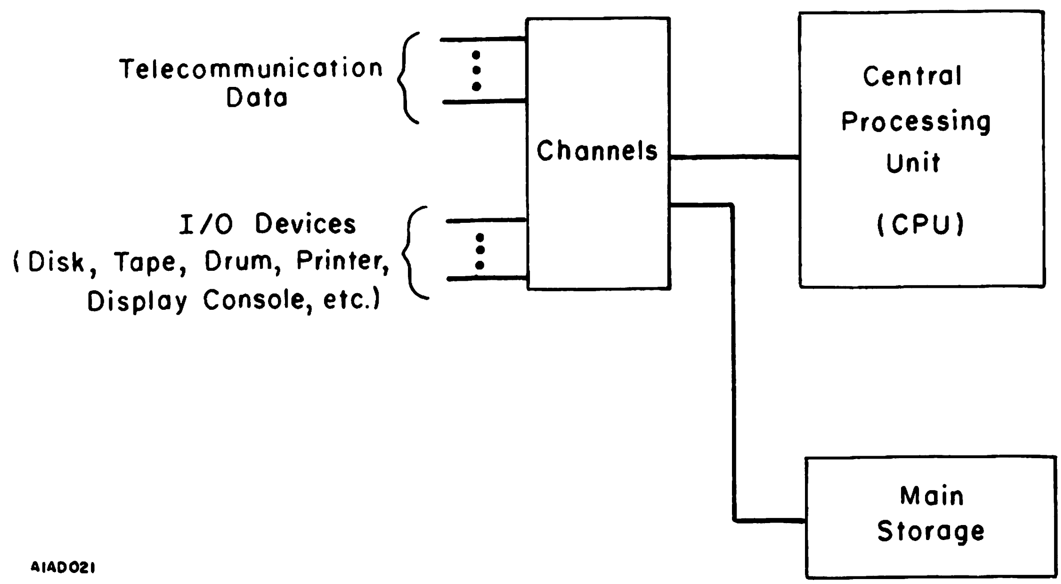



Figure 5 - 6. Single Processor, Simplified Block Diagram

Single Processor. The single processor (figure 5-7) may satisfy all equipment/software requirements within ocessing system.

ajor design considerations are:

o Main Storage Size – Determine memory size required to serve both communications-interface and data nanagement functions. (Memory size is a direct function of the maximum resident software requirement.) torage requirement depends on the size of the supervisory and application programs, buffer areas, and work required to serve worst-case conditions (maximum I/O devices, telecommunication data, and data base gement load).

o Central Processor Unit (CPU) Capability – The single CPU controls and processes both communication face and data base management in an apparently concurrent mode of operation.

o Channel – Both high speed (burst mode) and multiplex (low speed) I/O channels mus concurrently the required I/O and intermediate storage devices, log tapes, control consoles, disks for data base queing, and handle on-line data.

). Multiprocessor. The Multiprocessor (figure 5-8) requires substantially more equipment than the single essor. Both CPU's share one main storage; the system is controlled by the Processor Control Unit (PCU), h may be an integral part of each CPU. The PCU controls main storage use and inter-CPU timing. This iguration may be expanded into a shared-channel system (a pool of channels and I/O devices shared by both 's). This may result in more efficient equipment/software use, but is not a basic alternative because of the plexities of shared-channel/CPU interactions. Major design considerations include system reliability which be enhanced by CPU-function reapportionment upon a failure within one CPU. For example, if CPU A fails, ay be possible to use the I/O log tapes associated with the data being processed at the time of failure, in ert with disk resident programs, to restart the system using CPU B via appropriate disk packs and tapes and 'O channels and devices.

:. Dual Processor. The dual processor (figure 5-9) consists of two independent processing systems. During base input cycles, Processing System A (which primarily services the communications interface) is essentially /O device for Processing System B, which services data management functions. The redundancy in this iguration implies inefficient system operation during periods of low data traffic intensity, when Processing em A is idle except for routine maintenance and off-line processing (planning support information functions). same situation exists in the multiprocessor system where, for low traffic periods, CPU A and its associated devices are virtually idle. The multiprocessor system can reallocate CPU functions via software manipulation thus can operate as an efficient processing system (via PCU control) even when data-flow is low. In contrast, dual processor is a dedicated-function system, with Processing System A committed to communication face control and processing. Low-priority jobs may be stored on disk or drum, and activated by multi-ramming storage partioning techniques. Since portions of memory buffer areas are reserved for tele-munication processing, low-priority tasks are limited in scope. The configurations of Processing System A B are similar to that of the single processor, but communication interface and data base management are ed independently (separate main storage, etc.). The dual processor is the most versatile configuration. If a or component in either processing system fails, the remaining system can perform both system functions nmunications interface and data base management) in a deteriorated system mode.

I/O channels, regardless of system configuration, should fulfill at least a five to ten year time-frame face-requirement and allow orderly system upgrade and growth.

d. Major Interdependent Equipment-Design Areas. The functional areas which are directly dependent on the em software capability as well as the system configuration selected are:

o Data Transmission and Control Unit equipment/data communication software tradeoffs

o Logging function (system backup, restart, and recovery)

o Data buffering (including buffer size and number, and configuration tradeoffs)

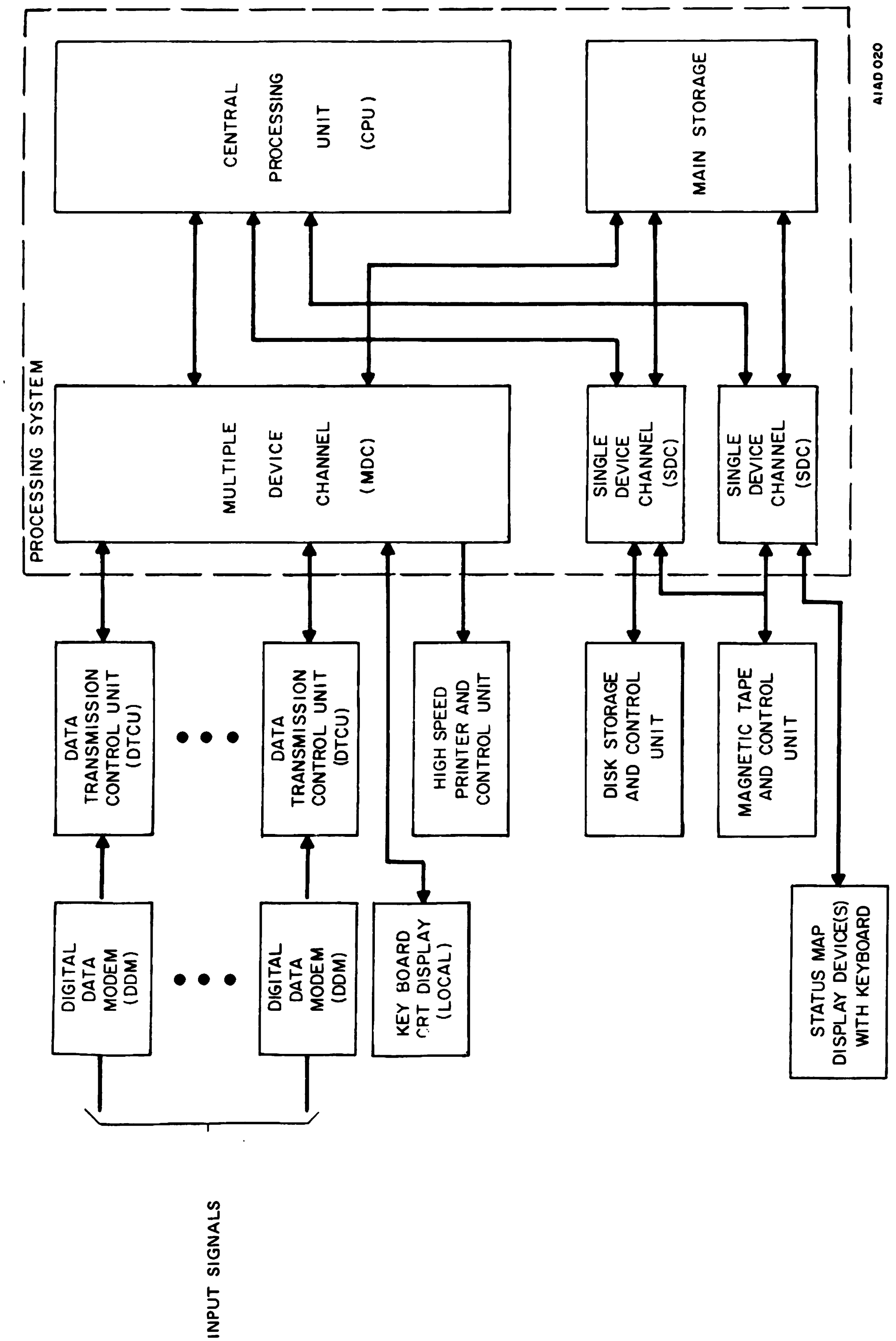



Figure 5-7. Single Processor, Detailed Block Diagram

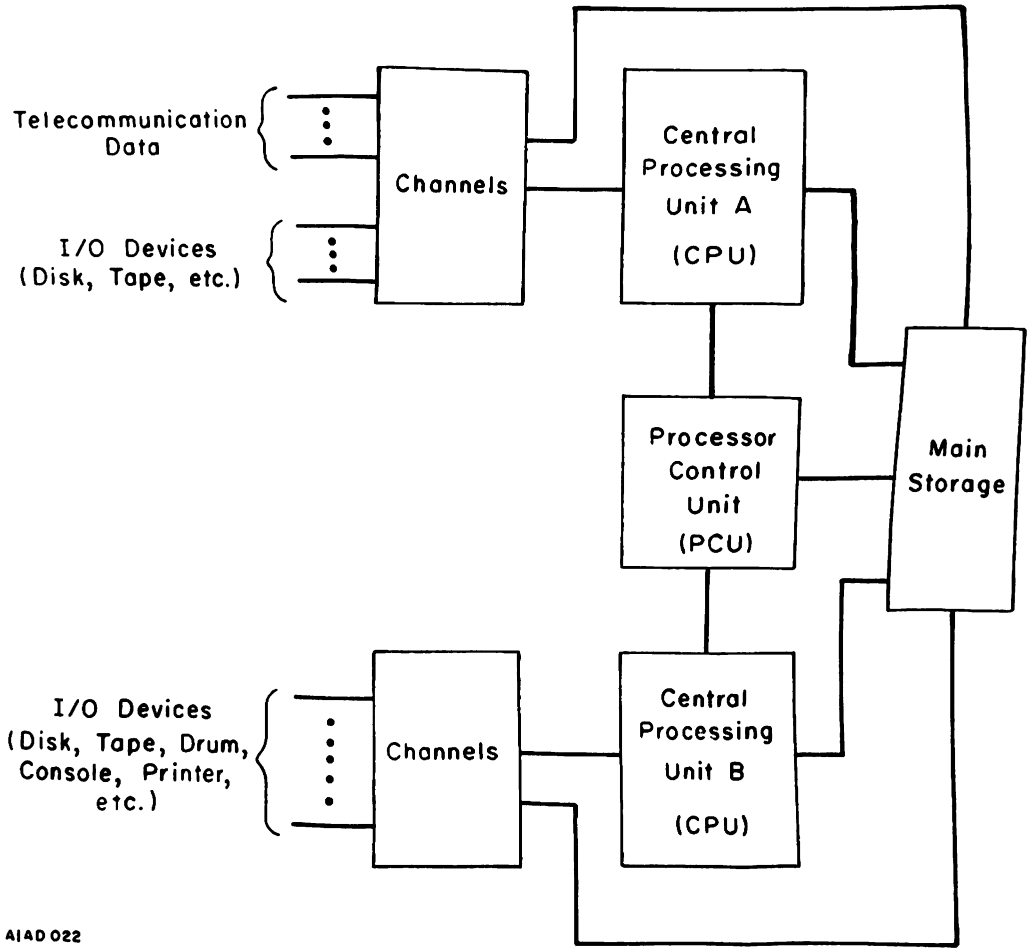



Figure 5 - 8. Multiprocessor Block Diagram

- o Queuing data for base management (disk organization and control with data-management software)
- o Main storage (modular expansion, optimization)
- o Intermediate storage devices (performance and cost characteristics)
- o Error detection and correction
- o Communication interface and data base management
- o Reliability including Mean Time Before Failure (MTBF) and Mean Time to Repair (MTTR)

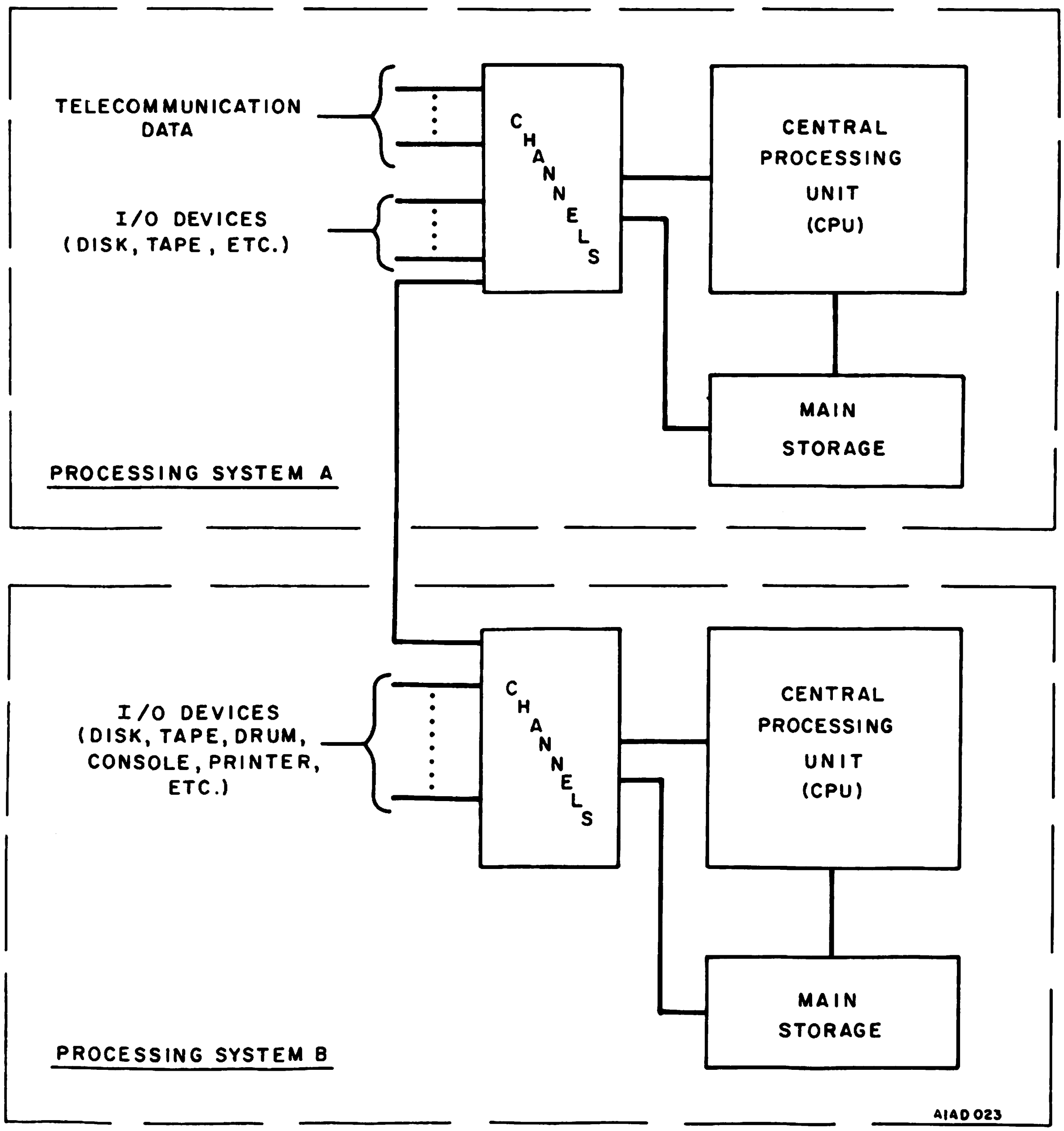



Figure 5-9. Dual Processor Block Diagram

nunications Subsystem Considerations

. Control System effectiveness is directly related to the communications-subsystem capabilities. jor system elements operate in a digital mode, major emphasis should be on development of ole digital communications. The message-switching subsystem should at least:

ny terminal to send a message to any other terminal

: "broadcast" and addressee-list capabilities so that messages may be sent to selected groups of

all messages for which the receiving terminal is not in a receptive state; forward the messages upon

n each terminal of the existence of its stored messages

t any terminal to explicitly request that an inquiry or message be sent to any other terminal

recall of messages received within the previous 48 hours.

rnative configurations can provide cost-effective communication service. The geographic location of al will dictate to a large extent the optimum configuration. Thus, in the early phases, the geographic d function of each terminal should be established. The following examples illustrate possible ns and methods for optimization.

ple 1 (figure 5-10). Each terminal is linked to the Central Processing Facility (CPF) which has tching capability. (Each terminal is connected full-time to the CPF by an individual communication etermine the total communications requirement to support each link based on the data rates needed k. Calculate instrumentation and monthly operating costs based on common carrier facilities and data terminal equipment (modems, equalizers, etc.) required.

ple 2 (figure 5-11). The communication channels associated with the terminals terminate at their eadquarters, where they are multiplexed for single-line transmission to the CPF. (All other system e connected to the CPF as described in Example 1). This configuration will not decrease the number cation channels required, but has the potential of decreasing the total cost for communication lines line mileage can be reduced significantly. The additional cost of multiplexers must be taken into n.

ple 3 (figure 5-12). The terminals associated with a headquarters are connected on a party-line or (a single communication link interconnects the CPF to headquarters and its associated terminals). All nals are connected to the CPF as in Example 1. This configuration can significantly reduce monthly ut at the expense of additional equipment.

ments of the data communications subsystem depend mainly on:

ty of tasks to be performed
execution rate
vable task-execution delay
ber of terminals
raphic extent of the network
rtance of uninterrupted service
ntial changeability of requirements.

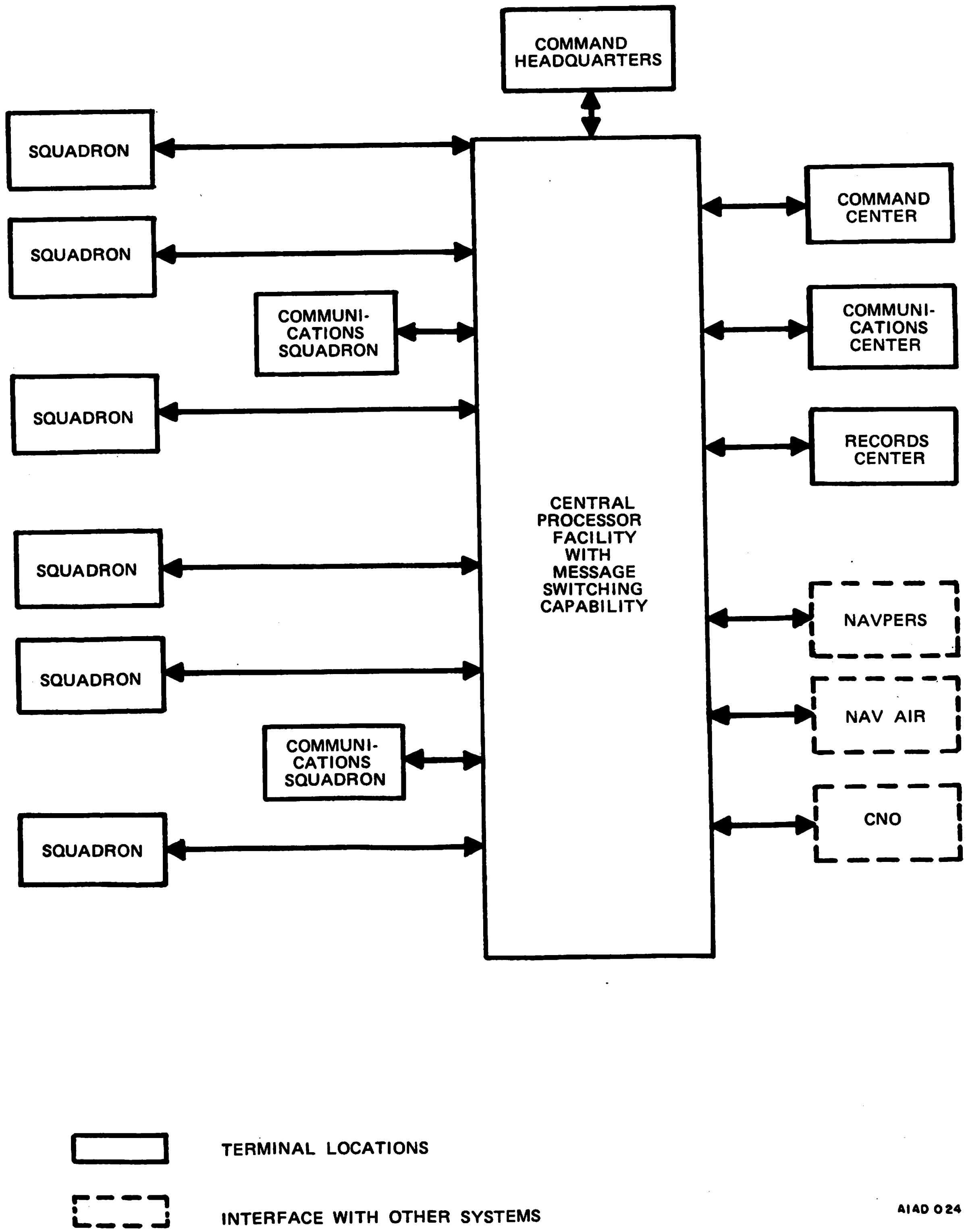



Figure 5 - 10. Network Configuration, Example 1

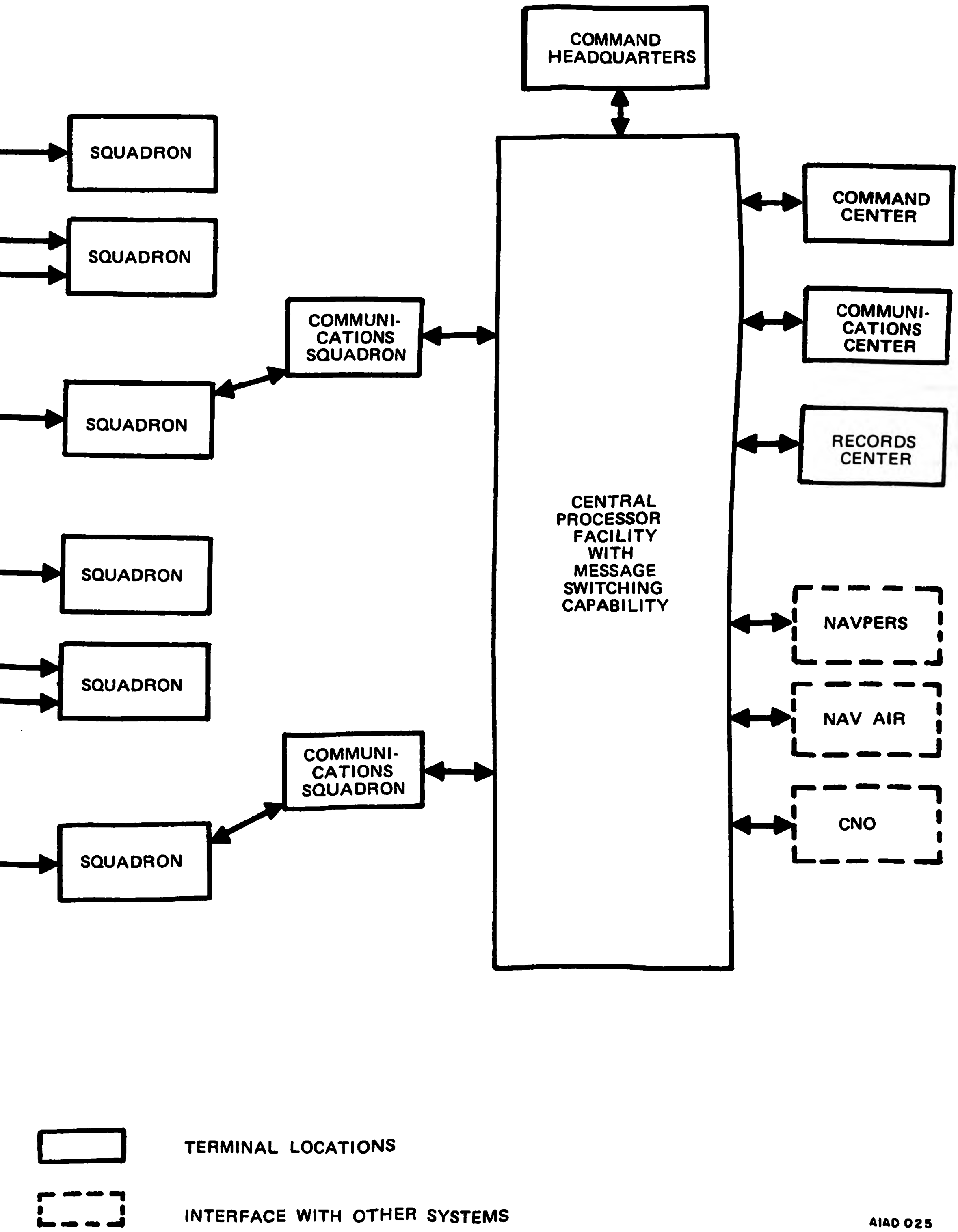



Figure 5-11. Network Configuration, Example 2

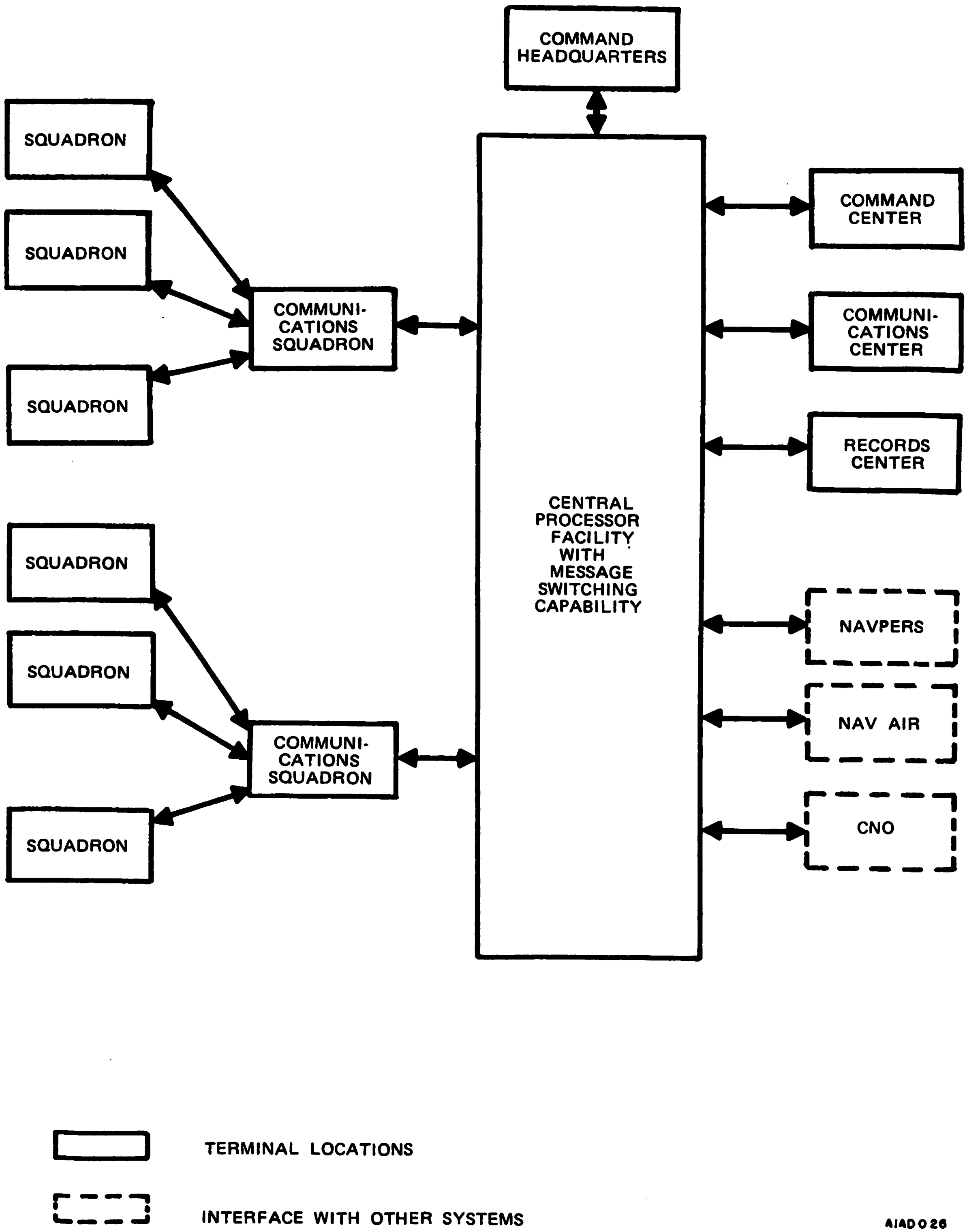



Figure 5 - 12. Network Configuration, Example 3

' the many data communication techniques available, the one to use depends on data characteristics (message ıgth, frequency of occurrence, urgency, priority, tolerance to errors, etc.). The variable parameters are:

- o Data transmission rate and bandwidth
- o Synchronization and timing
- o Scanning
- o Line buffering
- o Switching
- o Multiplexing
- o Parallel and serial transmission
- o Coding
- o Error control
- o Modulation and demodulation (MOD-DEMOD)
- o Channel control
- o Data block assembly and disassembly
- o Bulk data buffering

he alternatives most appropriate for a Command Information System (CIS) are discussed below. A typical ıta-system block diagram is shown in figure 5-13. Communications may be required to another computer or to mote peripheral I/O equipment. Peripheral Input/Output (I/O) equipment may be connected directly to a omputer, provided the unit is not too far from the computer (maximum distance without data sets is usually oout 1000 feet).

ommon carrier facilities (available with a wide range of characteristics) or special facilities can be used. ansmission-line and channel-termination equipment are provided by common carriers such as AT&T and estern Union; the rest of the equipment is normally user-furnished. Special facilities can be procured if unusual quirements or economic considerations make it favorable.

10.3 Equipment Considerations

a typical link (figure 5-14), the important components are:

a. Remote Peripheral I/O Equipment. Usually an input/output (I/O) unit (teletypewriter, card reader, paper oe punch, display scope, etc.), but may be another computer.

b. Remote I/O Equipment Controller. The interface between the remote peripheral I/O equipment discussed paragraph a above and the modem discussed in paragraph c below; its functions are normally:

- o Error control
- o Buffering
- o Synchronization
- o Code recognition and conversion
- o Data block assembly and disassembly
- o Generation of start and stop signals

ıll functions are not always required; some may be performed by the remote peripheral I/O equipment, in hich case the remote equipment may be connected directly to the modem and the controller eliminated.)

c. Line Terminal Unit and Data Set (Modem). Provides circuits for transmitting and receiving data over a ıannel. The modem performs functions pertaining to the transmission, signalling and control properties of the etwork. It provides modulation and demodulation of the digital data and may supply synchronization signals to ıe computer system. The modem performs no accuracy checking, such as parity checking; all such checking ıust be done by the remote peripheral I/O equipment.

d. Computer. The central processor unit (CPU) and the main memory form the other terminal. The main ınction is obviously data processing. However, at times, some functions pertain to data communications, which, an extreme case, can be all functions performed by the Line Terminal Control (LTC). Normally, a real-time

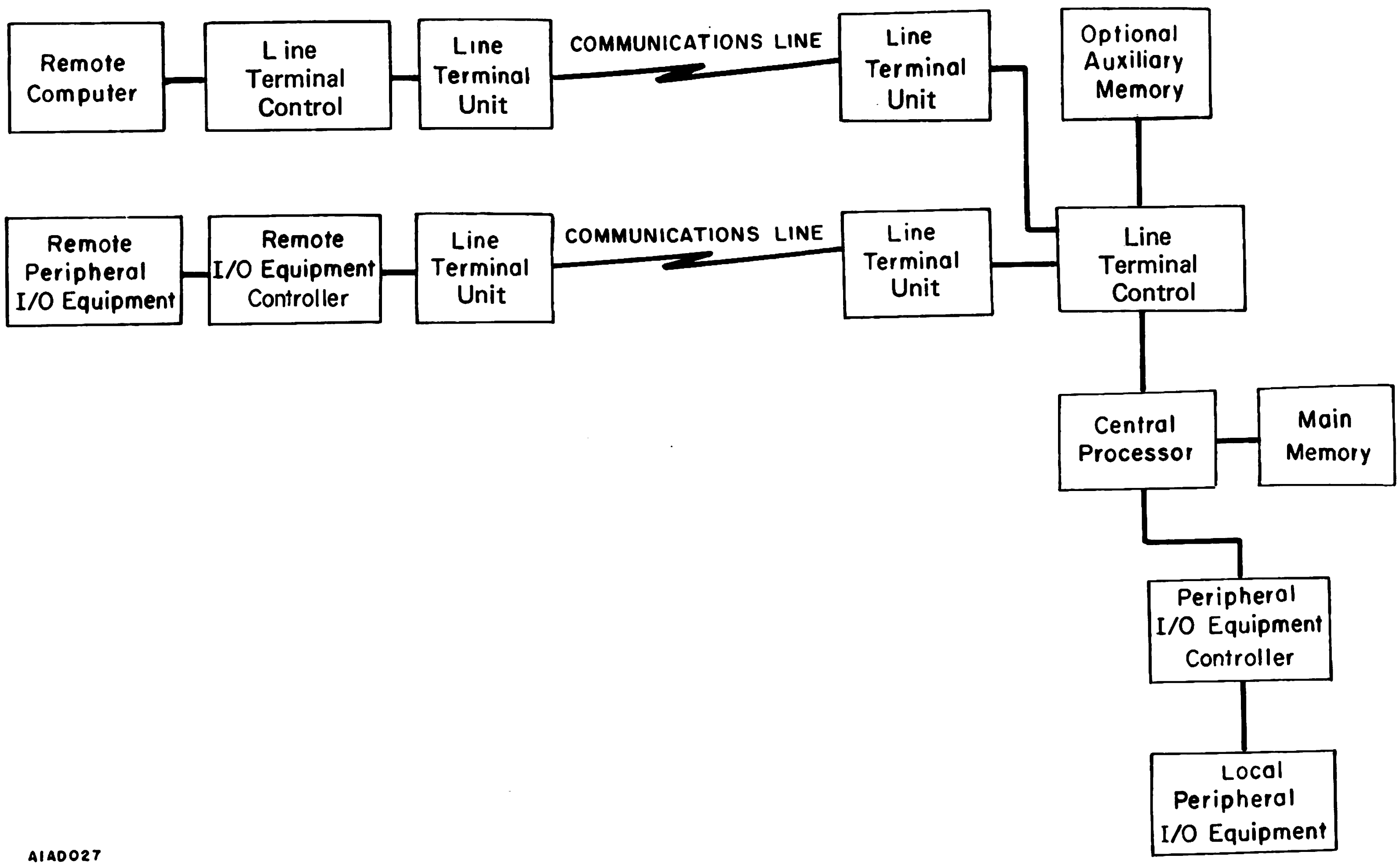



Figure 5 - 13. Typical Data Communications System, Block Diagram

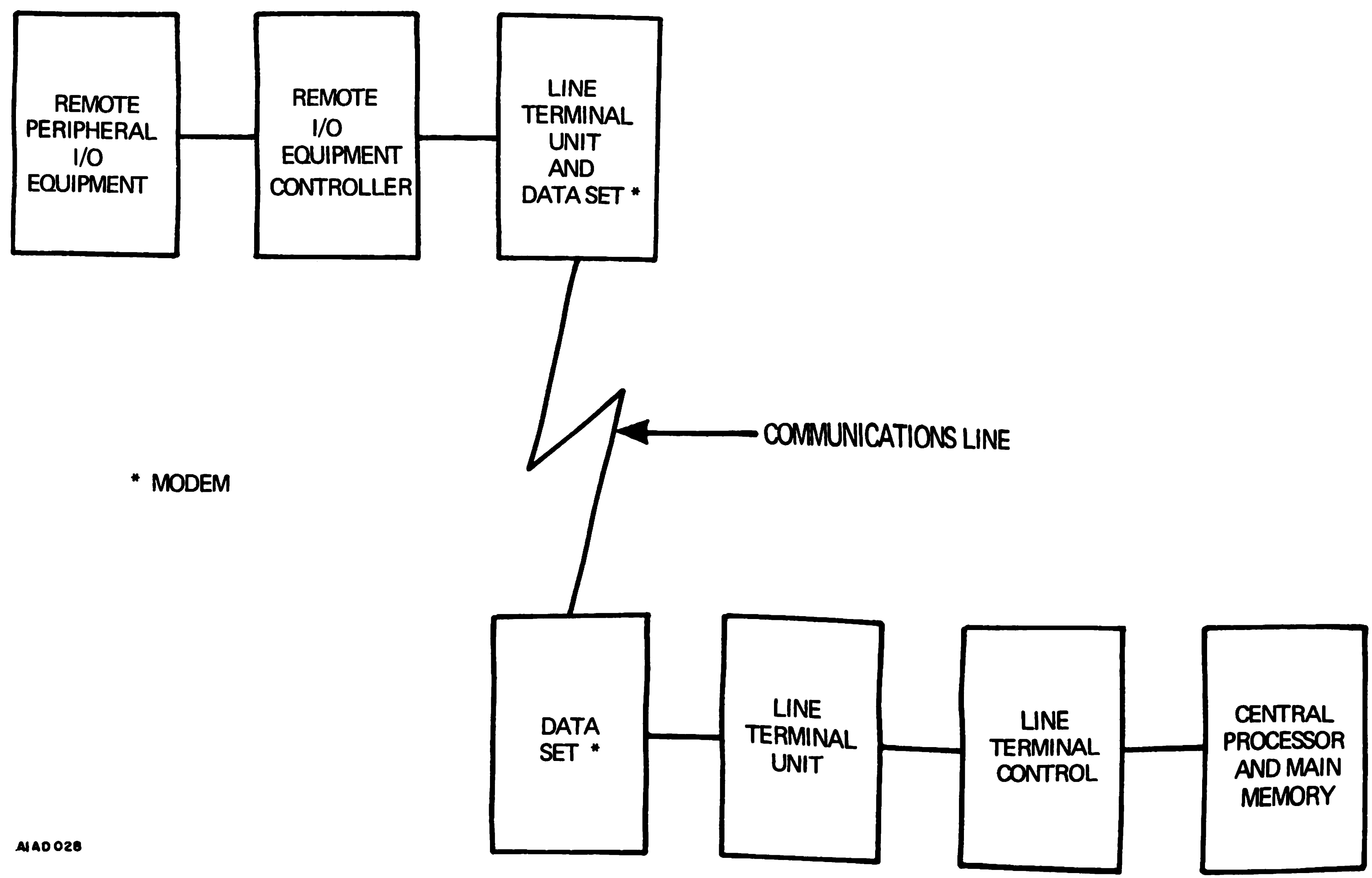



Figure 5 - 14. Data Communications Link, Block Diagram

multiprogrammed CPU is required, and time-sharing features are very desirable. Since many functions can be performed by various units in the system, base actual allocations on computer throughput requirements and economic considerations. If the LTC is simple and inexpensive (performing only the scanning function), the CPU must perform all the other functions listed for the LTC unless the line termination units assume some tasks. As a result, the CPU will spend considerable time performing communications duties and little time will remain for data processing. (This may be best if the CPU has light loading and idle time.) In another case, a complex (expensive) LTC could handle most communications functions, freeing the CPU for data processing. There is no general answer to equipment/software tradeoff. Consider each case separately to find the cost-effective solution.

Factors to consider in such a trade-off study are:

- o Expected data traffic
- o Functions to be performed
- o Load characteristics of each function
- o Subsequent load on each channel
- o Storage
- o Reliability
- o Language
- o Control
- o Speed and priority

### 5.10.4 Operational Considerations of the Interface

Common carrier channels can be classified into three general groups:

o Teletypewriter – capable of handling the load generated by a manually operated keyboard device, such as a teletypewriter (TTY); nominal data rate is 75 to 150 bits per second (baud).

o Voice-Grade – A switched voice circuit, without modifications to increase quality, can handle data at about 2000 baud. (It is difficult to increase switched voice circuit quality since the user has no control over the channels selected in the switching process.) If dedicated channels are used, quality can be increased substantially by equalization procedures. The following tabulation shows the increase in data transmission capacity as channel quality is improved:

| AT&T 4 KHz Channel Type | Transmission Rate (Baud) |
|---|---|
| 4 | 2000 |
| 4A | 2400 |
| 4B | 3600 |
| 4C | 4800 |

(Type 4 is the most commonly used ordinary switched-voice; 4A, 4B, and 4C are dedicated channels with increasing quality.)

o Broadband Channels – capable of handling data at speeds up to megabits per second.

### 5.10.5 Student-Training Criteria

In those cases where command and control systems are designated as dual-mission, take appropriate measures to ensure adequate system performance in both roles. For training purposes, the engineer must rely heavily on simulation, based primarily on appropriate on-line data interfaces. The nature of shore-training systems is such that usually there will be an interplay between special-purpose and digital subsystems to effect the desired goals.

Early in the planning phase, broadly outline the overall requirement in terms of definable segments, and then approach each segment (and the required interfaces) as an individual element of the configuration. From a criteria standpoint, consider:

a. Mock-up and Performance. Realism usually will be limited to the credibility of both input and output data as presented to the trainees. Precise, real-time computer interface with proper programming will necessitate considerable design-effort in the development of digital communiction links between trainees, instructors, umpires, and the computer.

b. Support. The preponderance of unique, special purpose interface devices, simulators, etc., can present a support problem unless constant vigil is maintained with regard to selection of standard equipment items wherever possible, and the entire system is thoroughly documented as it evolves.

## 5.11 SIMULATION SYSTEMS

### 5.11.1 Functional System Description

Simulation systems are usually one-of-a-kind, highly sophisticated configurations which encompass many common type subsystems (discussed separately in appropriate paragraphs), plus customized special training and interface devices. The nature of simulation systems is usually such that a major portion of the design effort must be devoted to digital segments (refer to paragraphs 5.6 and 5.10). There more than likely will also be high reliance on audio/visual training aids, including large-screen projection. There may also be a dual-mission role assigned to a portion of the overall system (refer to paragraph 5.13).

In each case, develop an understanding of the functional system by carefully reviewing and analyzing the specific training plan and other source documentation furnished for the program. (The uniqueness of each simulation system precludes any generalized discussion of function in this handbook.)

### 5.11.2 System Criteria

Because simulation systems usually carry a high priority, take particular care to adequately and accurately formulate the systems criteria, based on the documentation provided. Do not, however, overreact by selecting or developing equipment entities or subsystems which are far in excess of actual system needs. In the past, segmented overdesign has resulted in excessive program costs and delays. On the other hand, especially if there is a dual-mission assignment, try to select modular concepts whereby future needs can be efficiently met by relatively simple equipment augmentation.

### 5.11.3 Student-Training Criteria

In most cases the trainees will be high-ranking officers. Thus, design each training area with appropriate human-factors technology in mind. Also, the effectiveness and the reliability of the overall system must be greater than for most other shore-training systems due to the high value of the average trainee's time.

### 5.11.4 Special Training Devices

Of the many potential types of training and interface devices which may be necessary in a simulation installation, only one presents peculiar problems—the large-screen projection systems. It has been found, in actual installations, that elaborate vibration-isolation of projection equipment is not necessary to achieve a stable image unless ambient conditions are exceptionally poor (and in those cases, the screen might best be located elsewhere to avoid trainee-distraction).

If ultraviolet (UV) back-lighting will be used, then adequate protection must be ensured for trainees and instructors as well as for the operators. In this regard, clear as well as amber-colored UV-halt material is available for screen coating. Clear halt material is more effective than the amber for reducing UV emission, but it passes excessive visible blue light. If clear halt is chosen, consider incorporation of auxiliary filters on the lamps.

If the viewing screen (or a portion of it) is to be paper-backed, remember that all normally available paper fluoresces under ultraviolet illumination because of chemical whiteners added during mill processing. It is possible to procure un-whitened (non-fluorescing) paper on special order, but that means procuring an entire mill run. It would thus be advisable to contact existing installations such as WARCOL Newport to determine if a stock of special paper adequate for your needs is already available in storage. The viewing screen itself may be fabricated of several sections of clear plexiglass, chemically welded together. This affords a dividend in that, if the seams are properly located and left unburnished, the fabrication-process yields a built-in permanent reference-grid.

## 5.12 SPECIAL PURPOSE SYSTEMS

Special purpose systems are those one-of-a-kind systems created specifically in response to a non-repetitive training requirement. Whether or not NTDC is tasked to provide equipment, the cognizant EFA must oversee the entire equipment design phase as well as the training system development itself.

### 5.12.1 Functional System Description

It is impossible to predict what special-purpose needs will arise. The most effective approach is to first study the mission requirements, and correlate segmented elements of the desired system with portions of the more commonplace generic electronic systems/equipments covered elsewhere in this handbook. In many cases a special purpose system is a mix of standard electronic components, equipments, and systems configured in an unorthodox manner. Once the overall system is viewed in this perspective, the selection and innovation of interface devices can be effectively concentrated on.

### 5.12.2 Basic Considerations

As explained in the previous paragraph, the system criteria will dictate equipment configuration and interface. Depending on the degree of sophistication of the system, the master schedule should allow for adequate interim testing as well as one or more dry-runs prior to formal acceptance testing. It may be advisable in some cases to invite informal customer attendance at preliminary testing.

### 5.12.3 Operational Criteria

Performance evaluation must take into consideration not only the equipment parameters, but also the effectiveness of the training. Remember that the primary purpose of the equipment is not to function electronically in a tactical sense, but rather to be used as a tutorial aid to improve particular trainee proficiencies. On this basis, pay particular attention to the human factors segment of design.

### 5.12.4 Maintenance Criteria

Although particular segments of the system will usually be standard items in Navy inventory, portions will invariably be modified or even especially designed devices. Once completed, the system may function well as a cohesive entity, but may also be no better than a hodge-podge nightmare to maintenance technicians. Supportability and maintainability are equally as important as operability. Therefore, use extreme care in the development of complete, accurate logistics data for the system. The customer should be furnished with a data package including schematic and wiring diagrams, parts lists, troubleshooting guides, configuration management (CM) records, and all the other vital data which normally accompanies first-production-run equipment procured from commercial sources.

## 5.13 TRAINING SYSTEMS/COMPLEXES WITH ALTERNATE OPERATIONAL MISSIONS

### 5.13.1 Functional System Description

Most operator-training systems discussed in the preceding paragraphs could conceivably be designated as alternate-mission complexes. Such a situation is rare, but when it does occur special care in planning and implementation is necessary to preserve effective response to both missions. The system must be capable of performing satisfactorily in two configurations: tactical and training. Taken individually, each configuration must function (on demand) as well as if it were totally dedicated to that one mission.

5.13.2 System Criteria

During the early planning stages, carefully delineate two independent sets of system criteria – one for each mission. Then, proceed as required on a "worst case," item-by-item, basis in the translation of the criteria into resources. There may be instances of what appears to be overdesign regarding response to one system requirement, but in actuality such may be needed for ensured response to the alternate mission. Such factors should be clearly and concisely documented and substantiated.

5.13.3 Performance Criteria

The previous chapters emphasized cost-effective training-system design. But here the operational performance criteria must take precedence. In some cases it may even be advisable to provide items (such as heat exchangers) which exceed normal tactical-specification requirements. Remember that training equipment is often inadvertently over-used and even accidentally abused–but here, despite these drawbacks, the equipment must at all times be maintained in a state of operational readiness.

5.13.4 Support Criteria

It would obviously be inappropriate to make alternate-mission equipment available for maintenance training. But even operator and team training will result in some malfunctions. Therefore the anticipated duty cycle of the equipment must be cited and adequate information be provided so that appropriate on-board spares and test equipment will be available. Also, it should be noted that more stringent calibration will be required for both the prime and the test equipment involved.

5.13.5 Mission Transition

Prior to commencement of operation of a dual-mission system or complex, a detailed plan for transition to operation should be developed, coordinated, and approved. Effective implementation of the plan will be dependent to a large extent on the efficiency of the overall system design. The factors which must be carefully evaluated and considered include:

a. Interface/Cutover. Provide a means by which cutover to operation can be achieved quickly and accurately without loss of required synchronization and without degradation of equipment performance. Disabled antennas must be activated, transmitters connected to dummy loads must be transferred to appropriate antennas, receivers and indicators connected to simulators must be switched to their operational signal sources, etc. Configure all equipment so that orderly, rapid transition can be effected.

b. Security. Consider possible escalation of the security level required as a result of transition to an operational mission. Certain factors, such as actual in lieu of simulated red/black criteria will be inherent in the training configuration. In advance-planning, consider such factors as crypto areas or IFF equipments which use only unclassified signals for training purposes. Cipher locks and other forms of physical security may not be necessary (or even advisable) during training sessions, but they may be needed for use upon system transition.

c. Personnel Assignment. A review of personnel requirements may reveal the need for housing and other accommodations in excess of what would be expected at a similar single-mission installation. Note any such peculiarities in the BESEP as guidance for the NAVFAC designer.

d. Preparedness Criteria. Design the system on the primary basis of operational-mission needs. To ensure operational readiness, constantly monitor and record pertinent factors such as environmental conditions, chilled-water subsystem operation, primary power, etc., so that not only will failure or out-of-tolerance conditions actuate alarms, but more importantly slow degradation (indicative of ultimate failure) can be detected early.

# APPENDIX A

# ORGANIZATION

The organizational structure and chain of command which the EFA Engineer must be cognizant of and adhere to, will vary slightly from project to project, and may also be modified across-the-board from time to time. To understand the various office and command interrelationships the current issue of NAVPAC P-417 (NAVELEX-INST 10550.4), Shore Electronic Facilities Projects Handbook must be used as a basic guide. Additionally, the following documents provide standards for functional interface of program personnel in specific technical and/or administrative areas.

ASPR 1-2100, Advance Procurement Planning, Procedures for

ASPR 18-104, Performance of Work Contractor Clause

BUDOCKSINST 10550.1, Master Milestone Chart, Preparation of

DNCINST 5430.1, Management and Technical Cognizance of Electronic Systems and Equipment, Policies and Procedures for

NAVCOMMCOMINST 2300.1, Coordination Requirements, General

NAVCOMMINST 2300.1, Communications Equipment Installation/Reinstallations and Funding Procedures, Guidance Concerning

NAVELEXINST 4120.1, Electronic C/E, Standardization of

NAVELEXINST 4121.2, Suitability Status Classification for C/E, Procedures and Guidance for

NAVELEXINST 5100.4, Field Support of Electromagnetic Radiation (EMR) Hazards

NAVELEXINST 5200.7, Project Report, Requirements for NAVFLECSYSCOM Managed Projects

NAVELEXINST 5401.3, NAVFAC Support, Responsibilities

NAVELEXINST 7040.3, Funding

NAVELEXINST 11000.1, BESEP, Policy and Procedures for Utilization of

NAVELEXINST 11010.2, Implementation of NAVMATINST 11010.4

NAVELEXINST 11120.2, Procurement of Standard Installation Plans, Policy for

NAVFACINST 5401.1, Electronic Facilities and Installations, Implementation of Responsibilities and Functions Within NAVFAC Applicable to the Electronic Support Branch

NAVFACINST 7820.1, Funding Guidelines

NAVFACINST 8020.3, Site Approvals for Electromagnetic Wave Generating and Transmitting Equipment

NAVFACINST 11010.14, Coordination Requirements

AVELEX 0101,109

AVFACINST 11550.2, Transferring of Funds, Procedures for

AVFACNOTE 11012, Plans Approved, Requirements for

AVMATINST 2300.4, Inter-System Command Communications System Standards, Review and Control of

AVMATINST 4200.31, Advance Procurement Planning, Procedures for

AVMATINST 5101.1, Resolution of EMR Hazard Problems

AVMATINST 5430.21, Materiel Support of Shore Electronics, General Policies and Responsibilities for

AVMATINST 11010.4, Implementation of OPNAVINST 11010.1 Within NMC

AVMATNOTE 4200, Advance Procurement Planning, Procedures for

AVSECGRUINST 3520.1, Electronic Installation Procedures

PNAVINST 02552.1, Project Report, Requirements for NAVSECGRU Projects

PNAVINST 5000.36, Communications Equipment, Programming for

PNAVINST 8020.8, HERO Applications

PNAVINST 11010.1, Shore Facilities Planning and Programming Systems

PNAVINST 11010.2, Facilities Project Manual

PNAVINST 11010.20, Funding

PNAVINST 11120.5, Communications Requirements, Policy Concerning

CNAVINST 4200.18, Advance Procurement Planning, Procedures for

CNAVINST 7040.7, Collateral Equipment, Responsibility for

# APPENDIX B

# BASE ELECTRONIC SYSTEM ENGINEERING PLAN (BESEP)

This appendix is intended as an augmentation of NAVELEXINST 11000.1A. The scope and depth of coverage desired in both preliminary and final BESEP's is explained, along with cursory treatment of the more significant technical aspects, including references to appropriate criteria and informational sources. This appendix may be used as a broad checklist/guideline for the preparation of a BESEP for any shore electronics training facility. If more precise guidance is desired regarding a specific technical area, such data may be found in the basic handbook.

To facilitate reader cognition, this appendix is arranged in the format of an actual BESEP, with tutorial annotations instead of system-specific information.

## B.1 BESEP CONCEPT

The Base Electronic Systems Engineering Plan (BESEP) is a document translating a requirement concept into a resource concept. The BESEP is the basic technical reference governing electronics and other affected phases of shore electronics project planning and implementation. It provides required information on electronic systems, equipment and devices to be used, their pertinent technical, physical and environmental requirements, and complete system performance objectives.

The BESEP serves as a user/producer "contract." It therefore becomes a vital instrument in meeting the following project needs.

o Provides a means of obtaining sponsor approval of the plan developed to fulfill stated operational needs.

o Assures the central availability of a complete and authoritative engineering plan and major materiel requirements list for use as a project/program management tool.

o Provides a formally approved technical basis for preliminary and final design specifications.

o Provides a basis for evaluating performance of systems, or increments thereof, acquired under a project in terms of the degree to which approved design objectives are actually achieved.

o Provides a record document for use by operating, support, and management agencies after the project has been completed and turned over.

## B.2 TITLE PAGE

The form and layout of a BESEP title page should appear as that shown in figure B-1.

## B.3 REVIEW/COORDINATION SHEET

This sheet should be designed to fit the needs of the program, and be organized for a more or less sequential flow of signatures, top down on the page. A well planned sheet will also serve as a guide for the distribution cycle required for proper, expeditious processing of the BESEP. Use Appendix A as a guide to ensure inclusion of all appropriate codes in the review cycle.

FINAL (or PRELIMINARY)

BASE ELECTRONIC SYSTEM

ENGINEERING PLAN

FOR

(Specify Program)

AT

(Specify Facility)

Prepared by

NAVAL ELECTRONIC SYSTEMS COMMAND

(Specify Activity or Division)

DATE

A1AD060

Figure B-1. BESEP Title Page

## B.4 CHANGE OF RECORD

The inclusion and proper maintenance of the Change of Record page is one vital segment of the Configuration Management functions discussed in Chapter 2 of this handbook.

The format of the Change of Record Sheet is shown in figure B-2.

CHANGE RECORD

| CHANGE NO. | CHANGE DATE | DATE OF ENTRY | ENTERED BY (Signature/Title) | COMMENTS |
|---|---|---|---|---|
| | | | | |

AIAD 061

Figure B - 2. BESEP Change of Record Sheet

## B.5 TABLE OF CONTENTS

The format and layout of a BESEP Table of Contents is shown in figure B-3.

## B.6 LIST OF REFERENCES

The following instructions are provided to assist in preparing the BESEP List of References.

o List significant references which are described or specified in the BESEP. This list should include data to substantiate the inclusion of specific standard plans/criteria and to justify innovative specifications called out within the body of the BESEP. Inclusion of this bibliography is recommended to enable each user/receiver of the BESEP to be made aware of the utilized documentation early enough to permit his ordering and/or research of material not at hand. Use Appendix G as an guide if references to detailed technical data, standards, and/or criteria are desired.

TABLE OF CONTENTS



AIAD 062

Figure B - 3. BESEP Table of Contents

## B.7 GENERAL REQUIREMENTS

The General Requirements of the Project are included in Section 1 of the BESEP, the format of which is shown in figure B-4. Chapter 4 of this handbook provides general information and guidance for the preparation of BESEP, Section 1. However, specific instructions for the preparation of Section 1, on a requirement basis, are as follows:

1.1 Background. Provide brief historical data leading to the establishment of the project. This paragraph should clearly establish the who and when, and synopsize the why of program promulgation by reference to significant letters, instructions, plans, etc.

1.2 Objective. State brief overall mission objective of the training system to be provided. This paragraph may well be a refined extract from selected references recorded above.

1.3 Operational Requirement. Provide appropriate information obtained from the approved training plan or other appropriate documents which establishes the mission requirement. When appropriate, also list requirements developed on-site. Where known, list specific operating frequencies in addition to broad frequency range requirements, student loading, etc.

1.4 Project Site. Describe site; include room number, building number, street address, city, county, operating activity or command, etc., as appropriate.

1.5 Relationship to Existing and/or Planned Facilities. Briefly identify facilities affected or with which compatibility is required. Provide only general description. Give details in Sections 3 and/or 6 of the BESEP as required.

1.6 Phased Implementation. Briefly state general requirements for incremental or phased implementation. Also, state general requirements for continuity of operation of existing facilities. Give details in BESEP Sections 3 and/or 6 as required. Any critical time-phasing should be delineated here, with specific reference to the documentation citing the need for such time constraint. A brief statement of the envisioned total input on the program of any delay is advisable.

1.7 Special Clearance Requirements. State whether following items are applicable and provide information as indicated. Provide a general summary of each item below. Also state whether appropriate action is being taken for applicable site approval or granting of waivers as required. Coordinate as necessary with cognizant local field agencies in obtaining survey data. The non-applicability of any item should be so stated.

1.7.1 Hazards of Electromagnetic Radiation to Ordnance (HERO). Provide adequate on-site data on existing and planned facilities so that confirmation can be made that applicable criteria are being met. Data should include, but not be limited to: quantity/types of transmitters and antennas; operating frequencies; RF power output; emission, plot plan showing location of antennas, runways, parking aprons, and other ordnance loading, storage, and handling areas; types of ordnance involved, etc. If necessary, attach data as a separate supplement to keep the basic BESEP unclassified.

1.7.2 RF Hazards to Personnel and Fuel. Provide on-site data on RF-radiating equipment, both existing and planned under the project, so that confirmation can be made whether a hazard condition exists. Data should include items similar to that listed above on transmitting facilities; also include information on location and description of fuel and personnel involved. Pay particular attention to transmitters terminated in dummy loads, and to equipment which may be expected to be operated with covers removed or with plastic covers in lieu of standard covers.

1.7.3 Airspace Clearance Criteria. Provide on-site data so that confirmation can be made that applicable criteria are being met.

1.7.4 Security Clearance. State security clearance requirements for access to operating spaces or other areas where project work may be involved. Also, specify whether special requirements apply. If requirements vary within the facility, delineate the requirements for each room or area.

SECTION 1 - GENERAL REQUIREMENTS

1.1 BACKGROUND

1.2 OBJECTIVE

1.3 OPERATIONAL REQUIREMENTS

1.4 PROJECT SITE

1.5 RELATIONSHIP TO EXISTING AND/OR PLANNED FACILITIES

1.6 PHASED IMPLEMENTATION

1.7 SPECIAL CLEARANCE REQUIREMENTS

1.7.1 Hazards of Electromagnetic Radiation to Ordnance (HERO)

1.7.2 RF Hazards to Personnel and Fuel

1.7.3 Airspace Clearance Criteria

1.7.4 Security Clearance

1.8 SPECIAL CONSIDERATIONS

AIAD 063

Figure B-4. BESEP Section 1 Format

1.8 Special Considerations. Identify items such as requirements for operating flexibility and convenience, or items which may have significant impact (high cost or significant time factors) on project implementation. Among the items which should be highlighted for early consideration and action are: high-power dummy loads, multicouplers, shore cable electrically equivalent to ship cable, primary power transformers with 440-volt (nominal) taps, simulators and interface devices to be developed locally, and non-fluorescent paper for backing plot boards.

## B.8 SCOPE

Section 2, Scope of a BESEP states the overall scope of the Project and Physical Plant/Site Preparation. The information contained in this section (see figure B-5) are normally derived from Program Data provided by the sponsor. Instructions for the preparation of this section, on a requirement basis, are as follows:

2.1 Electronics System Design and Installation. Describe general scope of the project. List total number of circuits or systems to be provided and/or operational/support spaces involved and summarize removal and/or relocation of existing equipment. Provide details in Section 3 of the BESEP.

2.2 Physical Plant/Site Preparation. Describe general scope of the building construction and/or site preparation work to be accomplished. Define general parameters and limits of planned construction, alteration, expansion, addition, demolition, and/or disestablishment of physical plant facilities. Provide specific requirements and details in Section 6 of the BESEP.

SECTION 2 - SCOPE

2.1 ELECTRONICS SYSTEM DESIGN AND INSTALLATION

2.2 PHYSICAL PLANT/SITE PREPARATION

AIAD 064

Figure B - 5. BESEP Section 2 Format

## B.9 ELECTRONICS SYSTEM DESIGN AND INSTALLATION

The Electronics System Design and Installation requirements of a project are included in Section 3 of the BESEP, the format of which is shown in figure B-6. In order to ensure adequate coverage of all aspects of the classes of electronic equipment to be installed, it is suggested that Chapter 5 of this handbook be reviewed. In addition, specific instructions for the preparation of Section 3, on a requirement basis, are as follows:

3.1 General. State the general training system design concepts and objectives such as electronic system design and installation to meet the mission requirements, system reliability, flexibility, provision for optimum operation and maintenance, recommended provision for future expansion, etc.

3.2 System Design Criteria. List all applicable criteria such as NAVELEXINST 011120.1 Red/Black Criteria, MIL-STD-188 Low Level Specs, etc.

3.3 Electronics/Communications System. Provide a general description of the system that will be provided, the sub-paragraphs should clearly define the detailed requirements of design and installation. This paragraph should include, but not be limited to:

3.3.1 Existing Installation. Describe the existing facilities to the extent that they are related to the project. Where existing equipment is to be removed or relocated to provide space for new equipment, provide existing-equipment layouts. If existing patch modules, distribution frames, power panels, generators, etc., will be used, indicate location on floor plan and provide description of type/quantity of items to be used. The applicable as-built drawings should be verified during the site survey, to ensure accurate depiction of the existing plant in the BESEP.

3.3.2 Proposed Installation. Describe electronic system/facilities to be provided. Describe what is to be installed by rooms, systems or circuits. Refer to system block diagrams and equipment layouts which should be appended to the BESEP.

SECTION 3 - ELECTRONICS SYSTEM DESIGN AND INSTALLATION

3.1 GENERAL

3.2 SYSTEM DESIGN CRITERIA

3.3 ELECTRONICS/COMMUNICATIONS SYSTEM

3.3.1 Existing Installation

3.3.2 Proposed Installation

3.3.3 Interface Requirements

AIAD 065

Figure B - 6. BESEP Section 3 Format

3.3.3 Interface Requirements. Provide details on interface/compatibility with existing facilities, systems, and circuits. Include definitive data regarding required RF attenuation, primary power filtration, modem specifications, signalling levels, connector types and sizes, etc.

## B.10 ELECTRONIC EQUIPMENT

The Electronic Equipment requirements of a project are included in Section 4 of a BESEP, (see figure B-7 for format). Instructions for the preparation of this section are as follows:

4.1 General. Provide general equipment status, general condition of existing equipment, whether replacement is required, whether additional equipment is required for phased implementation, etc.

4.2 Equipment Tabulation. Provide a list of required electronics equipment to support the project. Sufficient breakdown should be provided to facilitate procurement. Figure B-8 illustrates a typical format for this tabulation. For the preparation of this tabulation, the following information are provided.

o List equipment required by rooms or areas; provide overall equipment list to clarify project requirements.

o The Operational Requirement (OP RQR) column should specify the minimum required equipment to satisfy the training requirement, including items for instructor positions; simulation, evaluation, and monitoring functions including computers, etc. Appropriate notes should be made to indicate quantity of equipment required to support such off-line functions.

o In the case of dual-mission facilities or systems, one spare equipment is generally provided for every five, full time operational equipments on active circuits, for use on a rotational maintenance basis. This should be taken into consideration.

SECTION 4 - ELECTRONIC EQUIPMENT

4.1 GENERAL

4.2 EQUIPMENT TABULATION

4.3 TEST EQUIPMENT

4.4 EQUIPMENT CHARACTERISTICS

AIAD 066

Figure B - 7. BESEP Section 4 Format

Table 4-1. Equipment Tabulation, Typical

| ITEM | NOMENCLATURE AND/OR SHORT DESCRIPTION | QUANTITY OF EQUIPMENT | | | | | |
|---|---|---|---|---|---|---|---|
| | | OP RQR | SPARE | TOTAL | EXIST | BAL REQD | NOTES |
| | | | | | | | |

AIAD 067

Figure B-8. BESEP Equipment Tabulation

o Normally, quantity in BAL REQD will be furnished by the appropriate Washington-level agency.

o Specify items that are installer-furnished.

4.3 Test Equipment. Provide a list of test equipment required to support a new facility. For an existing facility, provide a list of test equipment required to support only new equipment being installed that cannot be supported by existing test equipment. Refer to equipment instruction books to determine such requirements. Other requirements should be fulfilled through test equipment allowance changes.

4.4 Equipment Characteristics. In general, provide for only new equipment; if time permits, cover all equipment. Include nomenclature, short description, height, weight, electrical voltage, phase, frequency, regulation, and power required, water cooling and air circulation requirements, heat load, and maintenance and operational access space required. A typical format sheet is provided. (See figure B-9.)

## B.11 SYSTEM CHECKOUT AND ACCEPTANCE

System checkout and acceptance requirements are given in Section 5 of a Final BESEP, see figure B-10 for format. For a Preliminary BESEP, this section should be designated as "NOT APPLICABLE."

Specific information for the preparation of Section 5 of a BESEP are as follows:

5.1 General Requirements for System Checkout and Acceptance. The installation agency shall specify the applicable requirements in accordance with the provisions of appropriate Handbook of Naval Shore Station Electronics Criteria. Make reference to each specific procedure which has been published previously and which is applicable to the appraisal and acceptance of the installed electronic portion of the training system.

Table 4 - 2. Equipment Characteristics Tabulation

| ITEM | NOMENCLATURE & NOUN NAME | POWER REQUIREMENTS | | | | | | HEAT DISSIPATION (WATTS) | WT (LBS) | DIMENSIONS (INCHES) | | | SERVICE CLEARANCES (INCHES) | | | | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VOLTS | HZ | PHASE | REG | $P_f$ | AMPS | | | H | W | D | RIGHT | LEFT | FRONT | REAR | |
| | | | | | | | | | | | | | | | | | |

Note: In the case of 440-volt equipment, clearly indicate each absolute maximum tolerable input voltage as noted in the equipment specifications, and reference the data source.

AIAD 068

Figure B - 9. BESEP Equipment Characteristics Tabulation

SECTION 5 - SYSTEM CHECKOUT AND ACCEPTANCE

5.1 GENERAL REQUIREMENTS

5.2 SPECIAL REQUIREMENTS

5.2.1 TEMPEST

5.2.2 HERO

5.2.3 Special Documentation

AIAD 069

Figure B - 10. BESEP Section 5 Format

5.2 Special Requirements. This paragraph should include, as a minimum, the following:

5.2.1 TEMPEST. State whether visual inspection and/or instrumented survey is or is not required upon completion of installation.

5.2.2 HERO. State whether Hazards of Electromagnetic Radiation to Ordnance (HERO) measurements are or are not required upon completion of installation.

5.2.3 Special Documentation. Itemize all special documentation and procedures necessary to complete checkout and acceptance. That material which is available should be appended to the BESEP; all forthcoming material should be so designated, with appropriate annotations regarding the agency/office responsible for generation/procurement of the data as well as the date such material is required for initial review and evaluation. If no special documentation is required, so state.

## B.12 PHYSICAL PLANT

Physical Plant requirements of a project are included in Section 6 of BESEP (see figure B-11 for format). Specific instructions for the preparation of the Section 6, are as follows:

6.1 General. Provide general information on existing, planned, or future physical plant facilities. An area map, vicinity map, antenna field layout, and building floor plans should be provided, clearly indicating both existing and new facilities. The data should clearly differentiate between existing facilities and new items to be provided.

6.2 General Site Development. Provide information on existing and required new items such as land area and acquisition, clearing, grading, access roads, drainage and sewer systems, power lines, perimeter fences, highways, etc. Comment on the overall suitability of the site for electronics training.

SECTION 6 - PHYSICAL PLANT

6.1 GENERAL

6.2 SITE DEVELOPMENT

6.3 STRUCTURES

6.4 PHYSICAL SECURITY

6.5 POWER SYSTEMS

6.5.1 Normal Power System
6.5.2 Emergency Power System
6.5.3 No-Break Power
6.5.4 Power Panelboards

6.6 LIGHTING

6.7 AIR CONDITIONING

6.8 GROUNDING SYSTEM

6.8.1 Building Ground
6.8.2 Red/Black Criteria

6.9 TELEPHONE AND INTERCOMMS

6.10 FIRE PROTECTION

6.11 MISCELLANEOUS ITEMS

6.12 BUILDING CONSTRUCTION/SITE PREPARATION PLAN REVIEW

6.13 ANTENNAS

6.13.1 General
6.13.2 Location Plan
6.13.3 Siting
6.13.4 Site Preparation and Installation
6.13.5 Cable Installation
6.13.6 Ancillary Items
6.13.7 Test and Acceptance

AIAD 070

Figure B - 11. BESEP Section 6 Format

6.3 Structures. Provide information on existing and required new items. Include overall building size and height, total deck space requirements, deck construction and loading capacity, raised ceiling height, unistrut grid system in false ceiling for cable tray or duct support, types of interior bulkheads or partitions, supporting columns, acoustic treatment, roof and exterior wall construction, doors and emergency exits, cable access openings, cable entry tunnels and manholes, plenums, shielded enclosures, chase nipples, roof loading for antennas, etc.

6.4 Physical Security. Define controlled, limited, exclusion areas. Specify provisions needed to control access to such areas such as cipher-lock doors, alarms on emergency exit doors, barred windows and vent openings, etc. Also cite any required acoustic attenuation between walls and through transoms, windows, air ducts, etc.

6.5 Power Systems. Describe each power system required. Show location of and identify each power panel board. Specify quantities, number of poles and sizes of circuit breakers required for each power panelboard, estimated load, and special filter requirements. Specifically identify existing facilities and new items required. Clearly indicate the advisability of providing wall space, raceway space, etc., for future expansion of power feeders, panelboards, filters, etc.

6.5.1 Normal Power System. Establish need on the basis of a 100 percent coincidence factor, i.e., total utilization of the installed system, including a full complement of ancillary items connected to convenience outlets.

6.5.2 Emergency Power System. When required, reference the justifying documentation; when recommended, include analytic justification such as student turnaround time, gross manhours, by rank, per unit time of system in operation, etc.

6.5.3 No-Break Power System. When required, such as for computer and dual-mission facilities, specify the precise category of power required and reference the justifying documentation.

6.5.4 Power Panelboards. Include any requirements and/or recommendations regarding remote sub-controllers in lab areas. Refer to figure B-12 for a typical data format.

6.6 Lighting and Convenience Outlets. Describe luminaires, whether fluorescent or incandescent; whether recessed or hung type, etc. Specify quantities and indicate location of convenience outlets required. Specify emergency, battery operated lights, etc., for areas that require continuous service. Specify power-phase lamp-banking and/or dimmer requirements for lab/lecture and audio/visual presentation areas. Correlate this information with that in Paragraph 6.5 to ensure the provision of adequate, separate power sub-systems for equipment, lighting, and convenience outlets.

6.7 Air Conditioning System. Provide pertinent information for determining capacity of air conditioning system, such as electronics equipment heat load, personnel occupancy for each room and period of time involved, specifications for mean dry bulb temperature and mean relative humidity, etc. Describe existing systems by capacity of unit, location of ducts, grilles, and air diffusers as affecting electronics equipment location. For new construction, include recommendation for ducting adequate to handle future (increased) heat loads; cite known and anticipated facility expansion, and note the cost-differential of increasing duct-sizes only, with subsequent increase in heat-exchanger and blower capacity. Figure B-13 is a typical format for the presentation of such forecast data.

6.8 Grounding System. Provide information on existing or new items required for building and/or Red/Black ground system.

6.8.1 Building Ground

6.8.2 Red/Black Ground

Table 6 - 1. Electronic - Equipment Power Panelboard Requirements

| LOCATION ROOM, BLDG | EXIST/NEW PANELBOARD DESIGNATION | FILTERED OR UNFILTERED | NORMAL,EMERG NO-BRK SOURCE | QTY CKT BRKR | BRKR RATING | NO. OF POLES | CONN LOAD VOLT-AMPS | TYPE/QTY EQUIPMENT CONNECTED OR MISC. |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

Note: Unless otherwise noted, all panelboards are fed from a 120/208.volt, 3 phase, 4-wire, 60 hertz source.

AIAD 071

Figure B - 12. BESEP, Power Panelboard Requirements

Table 6 - 2. Electronics Equipment Heat Loads/Personnel Occupancy

| LOCATION (ROOM, BLDG) | TOTAL ELECTRONICS EQUIPMENT HEAT LOAD (WATTS) | TOTAL NO. PERSONNEL | NOTES |
|---|---|---|---|
| | | | |

Notes: 1. Unless otherwise specified, air environment within the vicinity of electronics equipment areas should be maintained at between 62° and 82° F and between 40 and 60% relative humidity.

2. Information on electronics equipment heat-loads given in this table is derived from the information contained in Table 6-1, electronics equipment power panelboard requirements. If convenient, electronics equipment heat-load data may be included with, or referenced back to, the power panelboard requirements.

AIAD 072

Figure B - 13. Air Conditioning Requirement

6.9 Telephone and Intercomms. Indicate location and quantity of telephones and intercomms required. Identify those in limited-exclusion areas and specify applicable installation criteria. Also specify the types and classes of service required and include recommendations for future-expansion/augmentation allowance.

6.10 Fire Protection. Specify requirement for fire protection facilities in accordance with applicable Design Manuals or other NAVFACENGCOM criteria.

6.11 Miscellaneous Items. Specify compressed air, hot and cold water, high-intensity illumination, and other such special requirements not appropriate for entry in other, more specific detail subparagraphs.

6.12 Building Construction/Site Preparation Plan Review. The applicable A&E, OICC, or PWC plans for building construction or site preparation must be submitted to the appropriate EFA for 30 percent and 90 percent review and comment. To expedite review, it is recommended that to the maximum extent practicable plans be in accordance with and correlated to NAVFAC DM-27. Justification for deviations, including references to Defense Communications Agency (DCA) and other standards and/or instructions, should be included with the plans.

6.13 Antennas. Most HF, VLF, and LF antennas are structures from the viewpoint that they must be properly designed, from both an electrical and mechanical aspect, constructed, and installed to withstand environmental conditions. Thus the installation of such antennas and associated items such as tuning units, RF transmission lines, RF connectors, etc., will be accomplished by the appropriate NAVFAC representative. Electronic technical assistance as required is provided by the cognizant NAVELEX EFA. The requirements to support such antennas installations should be contained in Section 6; normally, VHF and UHF antennas are part of the electronics installation covered in Section 3 of the BESEP.

6.13.1 General. Provide general description of work such as quantity/type of antennas to be installed, removal or relocation of existing antennas, etc. Also state whether other ancillary items such as RF transmission lines, dummy loads, baluns, dehydrators, patch panels, dummy loads, or switching matrices, etc., are to be installed. A specific list of items required should be provided in Section 4 of the BESEP.

6.13.2 Location Plan. Provide a proposed location plan for siting of applicable antennas. Show existing antennas, obstructions, buildings, etc., on a scaled drawing.

6.13.3 Siting Requirements. Specify general requirements such as separation from other antennas and obstructions/structures, need for relatively clear, level terrain (especially for vertical antennas with a ground plane), etc. Generally, vertical antennas require one wavelength separation, (based on the lower frequency limit of the antenna) from each other and from other vertical metallic obstructions. The same general rule applies to horizontal obstructions. Provide other pertinent information why proposed site was selected, such as to clear drainage canal, high voltage power transmission line, etc. Also state whether site-approval for antenna-structures is required.

6.13.4 Antenna Site Preparation and Installation. Specify requirements such as grading/slope, gravel for ground radials for soil erosion prevention, etc. State that antennas will be installed in accordance with applicable technical manual instruction book; any required or recommended deviations from published instructions should be appended to the BESEP.

6.13.5 Cable Installation. Specify size, type, and quantity of RF, power, and control cables to be used. Detail the requirements for buried or overhead cable installation, building-entry information, cable-termination information on existing or new patch panels or switch matrix, pressurization of RF cables, minimum splicing requirements for RF cables. Trenching specifications for buried cable should stipulate that trenches not be backfilled unitl cable pressurization-tests have been successfully completed, that additional tests are required after backfilling, and that cable markers are required for cable-route and splice points.

6.13.6 Installation of Ancillary Items. Specify requirements for installation of RF patch panels or switch matrices, dehydrators and pressurization distribution system, remote control units for steerable antennas, ancillary tuning units, etc.

6.13.7 Special Antenna Tests and Acceptance. State the requirements for tests to be accomplished by the installing agency. The tests should include, but not be limited to, antenna impedance measurements at input to antenna over applicable frequency range measured at no less than 20 frequencies for an inverted cone antenna with a 15:1 bandwidth; inspection of support poles for straightness, electrical connections for continuity; testing tension of guy wires, catenaries, and radiators; testing cable pressurization before and after backfilling trenches. Necessary corrective action will be taken by the installing agency to provide an acceptable installation in accordance with the specifications. Acceptance will be in accordance with Section 5 of the BESEP.

# APPENDIX C

# INSTALLATION REFERENCE DATA

In the case of new construction (MILCON), the cognizant design activity is of course NAVFACENGCOM, with requests and recommendations furnished by the NAVELEX EFA. For non-MILCON projects, the EFA must assume total responsibility for the design elements encompassed in this appendix.

In planning a shore electronics training facility, consultation of applicable engineering handbooks is a must. However, in some specific areas it is recognized that much of the literature is obsolete, incomplete, or ambiguous. And, in some cases, there at least superficially appears to be inter-document conflict with regard to criterial disciplines. Thus this appendix has been assembled as a compendium of selected data, refined to eliminate ambiguity and/or inconsistency. The material included here is not all-inclusive; rather, it is intended as a guide toward better understanding of the technical areas discussed. Where more comprehensive treatment of a subject is desired, especially pursuant to non-MILCON projects, consult the pertinent references listed in Appendix G.

## C.1 ILLUMINATION

The primary considerations for facility-lighting are contained in DODINST 4270.29. Additional technical data may be found in DODINST 4270.28 and in the Illumination Engineering Society (IES) Lighting Handbook. The pertinent portions of DODINST 4270.29 are summarized for ready reference in the following paragraphs.

Interior lighting shall be in accordance with fundamentals and recommendations of the IES Lighting Handbook, subject to the following modifications and clarifications for implementing these criteria.

Lighting intensities, except as herein modified, shall conform to the intensities established in the latest edition of the IES Lighting Handbook. These intensities are the illumination required for specific visual tasks and may be provided by general area illumination combined with supplementary illumination for the task. The IES recommended intensities are not necessarily, to be considered as general illumination intensities for specific areas. (The ratios between general and supplementary illumination shall be, at least, those recommended by IES.) The intensity of general illumination for any area shall not exceed 150 footcandles; supplementary lighting where required will normally be provided by the user of the facility.

Design of electrical systems for lighting shall be in accordance with DODINST 4270.28.

Where fluorescent or mercury vapor lighting is prohibited, and intensity exceeds 50 footcandles, it is permissible to design the general lighting system for 50 footcandles as a practical limit. Where higher light levels are required on the task, supplementary incandescent lighting shall be used.

In large buildings, give full consideration to possible economies resulting from the use of higher voltages and frequencies for the lighting system.

Exits, exterior steps and ramps shall be adequately lighted to prevent accidents. Separate lighting will not be required if permanent lighting gives at least one footcandle on the exit, steps or ramp.

Crawl spaces with utility services, interior utility tunnels, and walk-in pipe chases shall be lighted as required for maintenance purposes. Switches for these lights shall be equipped with pilot lights and located in normally occupied areas.

lighting of communication-facilities shall be arranged parallel to the equipment aisles wherever possible in order to provide maximum illumination and to avoid overhead cable trays. In areas where manual equipment is used, operator efficiency must be maintained by carefully positioning luminaires to avoid glare and excessive light on the face of the equipment while maintaining a reasonable light level on the horizontal surface. Supplementary lighting may be provided over workbenches in maintenance and test areas.

Classroom lighting immediately in front of the lectern may be controlled from a point convenient to the speaker's platform and also at the entrance. Auditorium lighting may be controlled by motor-operated dimmers from the platform or stage and the main entrance to facilitate use of visual aids, or lighting may be controlled from those points by switches. Minimum lighting shall be provided so that notes may be taken during use of visual aids.

Weapons systems control area lighting shall be engineered for the conditions encountered. Low levels of lighting may be required to permit observation of luminous panels, without reflected glare or undesirable contrasts in brightness. Separately controlled luminaires shall be provided for normal maintenance and cleaning purposes.

Luminaires shall be the standard commercial types, and shall conform to Underwriters' Laboratories (UL), Inc., standard for Electric Lighting Fixtures, Publication No. 57. Where lighting levels exceed 100 footcandles in air-conditioned areas, an integrated air-conditioning and lighting system is required by DODINST 4270.7, and lighting fixtures shall conform to the requirement.

Special luminaires may be provided when required by the seeing task or architectural treatment of the building.

The number of different styles of luminaires installed in a single building or facility shall be the minimum consistent with the lighting requirements.

For specific areas, explosion-proof, dust-tight, dust-ignition-proof, or weatherproof luminaires shall be provided in accordance with the requirements of the National Electrical Code (NEC).

Special care shall be given to selection of luminaires to be used in halls and corridors of less than eight-foot clearance so as not to encroach on headroom. Flush mounted luminaires shall be used in halls and corridors where the building construction permits. Furred ceilings are not to be used for the specific purpose of installing flush luminaires. The selection of luminaires shall be integrated with the architecture of the room or area. The need for correct selection of luminaires is of special importance in large rooms or areas with high or sloping ceilings where the massed effect of the luminaires creates the impression of a lower ceiling level and may cancel the desired architectural effect. In rooms or areas where the overall building structure, or other valid reason, dictates a ceiling higher than required for the function, luminaires shall hang at the most economic height.

Light sources shall be selected in accordance with the type of lighting service, illumination level required, architectural treatment of building or structure, and from an economic standpoint. The only acceptable type of light sources are incandescent, fluorescent, and mercury vapor.

## C.2 TRANSMISSION LINES AND FITTINGS

### C.2.1 Radio Frequency Cables

Use RF cable types that employ a noncontaminating, low-temperature, synthetic resin jacket, as specified in MIL-HDBK-216(A).

C.2.2 Radio Frequency Connectors

Wherever practicable select RF connectors that conform to the following specifications:

| Series | Specification | Series | Specification |
|---|---|---|---|
| BNC | MIL-C-3608 | N | MIL-C-71 |
| HN | MIL-C-3643 | Pulse | MIL-C-3607 |
| LC | MIL-C-3650 | Twin | MIL-C-3655 |

A more comprehensive list of available connectors is contained in foldout C-1.

Commonly encountered RF coaxial connectors are:

a. BN Series. Small, light-weight, nonconstant impedance for use with the same cables which use BNC series. Not recommended for use above 200 MHz unless circuit electrical requirements are not critical. May be used at up to 250 volts peak.

b. BNC Series. Commonly used on small cable. Bayonet coupling; weatherproof. Besides regular and modified low-voltage types of nonconstant impedance, improved versions have constant 50-ohm impedance with excellent electrical performance up to 10,000 MHz.

c. C Series. Similar to 50-ohm Series N, but electrically superior with bayonet coupling and improved cable clamping mechanism for better cable grip with minimum cable indentation; for use up to 1,000 volts.

d. HN Series. Weatherproof, high-voltage, constant-impedance type for 50-ohm cables.

e. LC Series. Large, 50-ohm, weatherproof connectors for transmission of large amounts of power.

f. LT Series. Large, 50-ohm, 5000-volt type for use with RG-211/U cable. Very similar in appearance to LC Series, but differ in cable accommodation and are lighter.

g. Miniature. Have gold finish, screw-type coupling, and Teflon dielectric. Nominal impedance 50 ohms, sea-level breakdown voltage 1500 V rms, a practical frequency limit of 10,000 MHz, and operate at temperatures up to 200°C. Several different types are commercially available.

h. Series N. Most popular constant-impedance weatherproof type for medium-size cable. Can be used up through microwave frequencies with minimum line unbalance or increase in-standing-wave ratio. Series N 50-ohm and 70-ohm connectors do not mate, but 70-ohm cables may be used with 50-ohm connectors where impedance-matching is not critical.

i. Pulse. For high-voltage pulse or DC applications. Nearly all weatherproof and available in rubber-insert, ceramic-insert, and triaxial types. Rubber-insert, with a 5000-volt peak rating at 50,000 feet, for cables having an insulated Neoprene layer under the braid, such as RG-77/U and -78/U. May be used with cable employing conducting rubber under the braid (such as RG-25/U and -26/U), and with RG-64/U if special care is taken in assembling the connectors to these. Ceramic-insert type available in Type A (small) for use with 8000-volt RG-25/U and -26/U and Type B (large) size for 15,000-volt RG-27/U and -28/U cables. Corona does not damage the ceramic inserts; flash-over does not cause permanent damage. Insert-types tend to leak noise which may interfere with communications equipment. Triaxial type used where maximum shielding and minimum noise radiation are required. Commercially available in sizes of the same diameter as BNC and C Series.

j. QDL Series. Large-size, weatherproof, quick-connect and -disconnect types with five-ball locking coupling, metal-to-metal cable clamp, and polyethylene dielectric. Nominal impedance 50 ohms, 9000-volt peak rating, and a practical frequency limit of 1,000 MHz, for large-size cable.

k. QDS Series. Medium-size, weatherproof, quick-connect and -disconnect types with three-ball locking ipling, metal-to-metal cable clamp, and polytetrafluoroethylene dielectric. Nominal impedance 50 ohms, )0-volt peak rating, and a practical frequency limit of 10,000 MHz, for medium-size cable.

l. QL and QM Series. High-power, high-voltage, low-VSWR types for large-size cable where C, HN, LC, IT, l N series have been used in the past. Use QM with RG-217/U; use QL with RG-218, -219, -220, and -221/U.

m. SKL. Originally provided connection to a klystron tube. Modifications were subsequently designed to ovide general-purpose cable-to-cable connections and adapters. Newer klystrons use BNC series, therefore SKL pe should not be used for new applications.

n. SM Series. Nonweatherproof; for 1/4-inch overall diameter and smaller cables where electrical matching is ot required. Smaller and contain fewer parts than BNC series. Has female center-conductor contact on plugs and ale center-conductor contact on jacks and receptacles. However, for consistency in cataloging and usage, a plug still regarded as having a male mating end and a receptacle or jack as female. May replace BNC Series where eatherproofing is not required.

o. TNC Series. Basically BNC series with threaded instead of bayonet coupling. Preferred in applications ubject to extreme vibration.

p. TPS Series. Weatherproof; produce minimum electrical discontinuities in small size 50-ohm cable up to 0,000 MHz; rated at 1.5 kV rms at sea level; use governed by temperature-limitation of the cable.

q. TWIN. Similar to UHF Series except have twin center conductors; for use with small- and medium-sized win-conductor cable. Available in small (weatherproof and nonweatherproof) and large (nonweatherproof) types.

r. UHF Series. Low-cost, general-purpose, nonconstant impedance. Small and large types for small- and nedium-size cable where line unbalance or increased VSWR is not important. Where impedance-match is ecessary, use C, N, or BNC series. Can be weatherproofed.

.2.3 Waveguide Assemblies

o not use aluminum waveguide assemblies where they will come in contact with silver or copper alloy aveguides or fittings. When copper alloy frames are assembled to silver waveguide tubing, silver plate the frame ter assembly. In addition, use components which meet the following requirements:

o Rigid rectangular waveguide tubing conforming to MIL-W-85(1A). Provided that all other requirements of ie specification are met, bimetallic waveguide tubing will be acceptable, with the specific approval of the sponsible engineering office.

o Flanges and fittings conforming to MIL-F-3922.

o Coaxial, air dielectric, RF transmission lines conforming to MIL-L-3890(1A).

.3 AIR CONDITIONING

lectronic equipment cooling, as delineated in NTDC Specification 3231-220, falls into three classes:

o Class I. Room air intake; natural, or forced circulation in enclosure by fans within the enclosure, exhaust f heated air to room.

o Class II. Air-conditioned air intake from ducts supplying chilled air; circulation through enclosure by static ead of conditioned air; exhaust of heated air to room.

o Class III. Air-conditioned air intake from ducts supplying chilled air; circulation through enclosure by static ead of conditioned air; exhaust of heated air to ducts which return directly to conditioner (closed system).

Class I is preferred for cooling small, constant-heat load which will not materially affect room ambient.

Class II is preferred for cooling simulation equipment. Class II or III shall be used for all equipment enclosures containing transistors or electronic data-processing equipment.

Class III shall be used for large, fluctuating heat loads which would cause undue room temperature variations during turn-on or equipment operation.

## C.4 ANTENNA MASTS/TOWERS

When an antenna tower is indicated, consider such alternatives as dummy-loading and/or simulation, piggy-backing on existing towers, etc. If a new tower is indeed required, then consider use of existing, available excess equipment such as portable towers, ships masts, etc. In those cases where new construction is needed, the particular situation must be evaluated carefully in order to devise a truly cost-effective recommendation to NAVFACENGCOM. Any one of a number of commercial available, prefabricated self-supporting (or guyed) towers may be considered or, especially if maintenance training is involved, a more elaborate structure may be indicated. For complete-structure design, consider the following.

### C.4.1 Height

The height of the tower as measured from the ground line to the top of the upper platform is to be as specified. Generally the tower should be capable of being erected on top of a 25-, 50-, or 75-foot length of tower which may be similar to that detailed in figure C-1. All parts necessary to connect the two towers should be provided.

### C.4.2 Weight

Keep the weight of the tower to a minimum consistent with specified requirements.

### C.4.3 Service Life

Design and construct the tower to meet the specified minimum life expectancy requirements under the following climatic and mechanical service conditions.

### C.4.4 Service Conditions (Climatic)

Design the tower to withstand any probable combination of the following service conditions without mechanical or electrical damage or any degradation in performance:

- o Relative humidity up to 100 percent (including condensation due to temperature changes)
- o Salt atmosphere as encountered in coastal regions
- o Sand and dust as encountered in the area.

### C.4.5 Loads

The dead weight load applied to the upper platform is the weight of the antenna system for which the tower is being designed. The dead weight load applied to the lower platform is the weight of the specified component equipment. Make sure that the erected tower is capable of withstanding this load.

### C.4.6 Stress

Design the tower to withstand the specified maximum instantaneous torque which may result from failure of the electrical torque-limiting system on reversal of the antenna drive. (This torque need not be considered in the determination for deflection.) Proportion the tower structure and all the parts thereof so that the working stresses do not exceed basic values consistent with sound engineering practices. For combined stresses due to

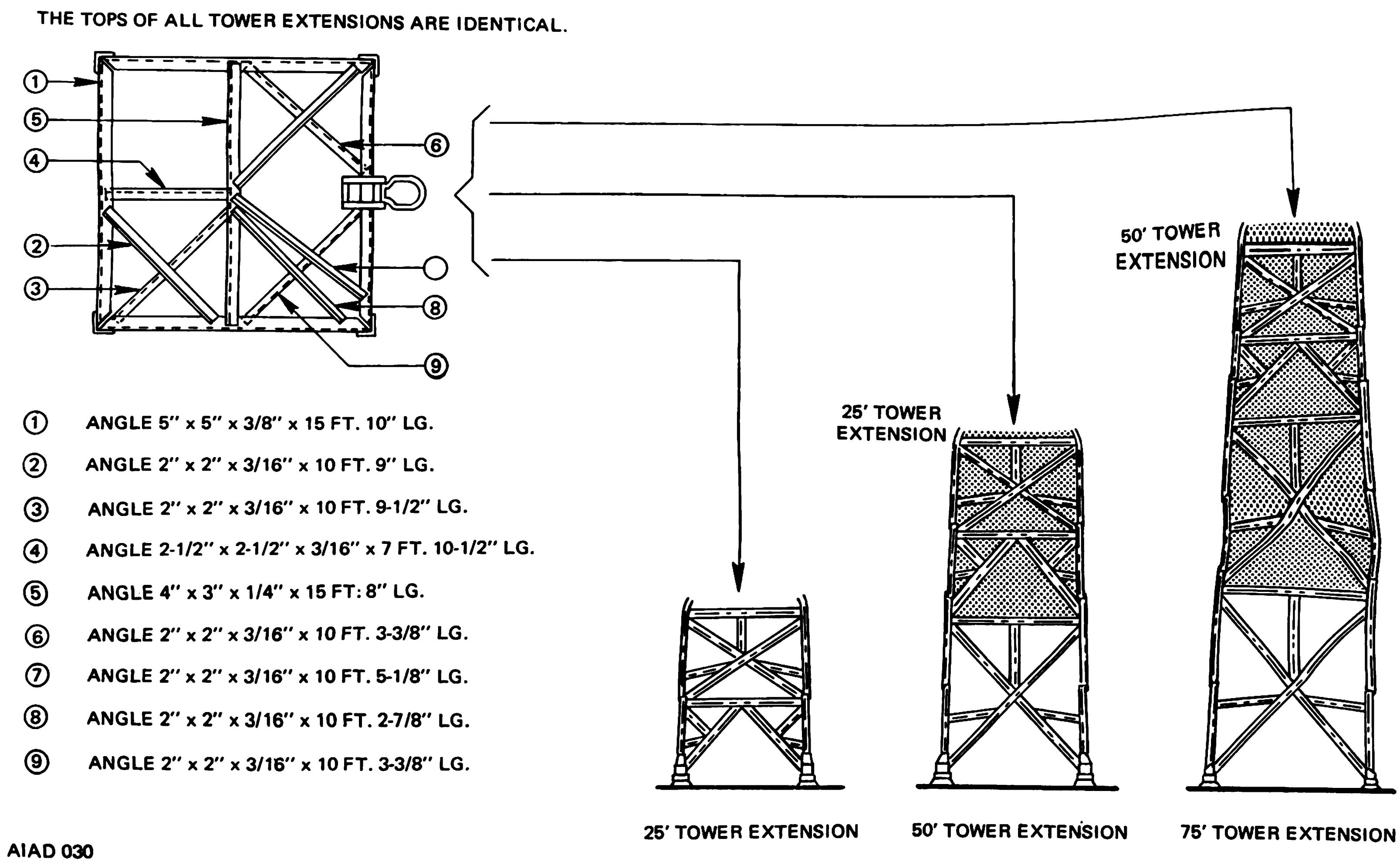



Figure C-1. Representative Tower Extension wind and other loading, the allowable working stresses may not be increased. With the above exception, follow a NAVFAC-recognized code for the material used.

C.4.7 Deflection

Determine limits by referring to the requirements of the individual radar sets.

C.4.8 Foundation

As part of the tower, provide the column shoes and anchoring material required for attaching the tower to concrete foundations. Provide engineering information only on concrete foundations and anchor bolts. Provide complete design and working drawings for foundations based upon the granular content and the bearing capability of the soil for three conditions, covering a range of good, medium, and poor. State the bearing values for each type of soil on the applicable drawings. Furnish sufficient data and information to permit engineers in charge of a particular installation to prepare an alternative design, in the event that soil conditions do not lend themselves to use of any of the original designs. Design mudsills capable of supporting the tower, and the materials required for attaching the mudsills to the tower legs. Base mudsill design on a maximum bearing value of 1000 psf.

C.4.9 Components

Splice stressed members so that a minimum of work will be necessary to erect the tower in the field. Design the tower structure so as to prohibit ambiguity in the determination of stresses and to minimize secondary stresses from rigidity of connections or other causes.

C.4.10 Connections

Accomplish structural connections with securely locked bolts or drive bolts of a material compatible with the tower structure. Make holes for bolts with a diameter 1/16-inch larger than the diameter of the bolt.

C.4.11 Identification of Members

Depth-stamp all structural members to permit ready identification by reference to erection and assembly drawing provided with the tower.

C.4.12 Upper Platform

Ensure that the tower upper platform will provide the necessary strength required to mount the antenna system. Details of the antenna system will normally be specified. Allow adequate space to enable personnel to assemble, install, and maintain the antenna equipment. Incorporate sufficient platform overhang for raising the antenna assembly from the ground level to the platform level by means of the antenna hoist.

o Upper-Platform Flooring. Make the upper-platform flooring capable of withstanding a load of 300 psf over the area within the antenna or pedestal base mounting plates, and 125 psf over the remainder of the platform area. In addition, make the floor capable of supporting a 400-pound load at any point. Provide openings for waveguide and cable as directed by the responsible engineering office. Make the floor and openings watertight only if the tower includes an equipment enclosure.

o Antenna System Mounting. Make provision on the upper platform to mount the specified antenna system, and to keep it firmly in place.

o Waveguide Openings. Supply waveguide openings in the upper platform, to permit connection of the antenna system waveguides to the RF components that will be housed in the equipment enclosure.

o Railing. Provide the upper platform with a non-metallic dismountable railing approximately three feet high, to completely enclose the platform area.

o Trap Door. Furnish a trap door in the upper platform to permit access from the latter. Design the trap or to provide a watertight seal when closed.

.13 Antenna Pedestal Adapter

en specified, supply an antenna pedestal adapter to mount the antenna pedestal at the requisite height above e floor level of the upper platform.

.4.14 Lower Platform

esign a lower platform to support the equipment cabinets. Provide an extension on one side of the tower for se as a loading platform for the cabinets. Enclose the extension with a hand rail having a removable section to ermit access to the equipment enclosure doors. Make provision for cable entrance from a cable trough.

o Lower Platform Flooring. Design the lower platform flooring and extension to carry the specified dead and ive load. Fabricate the top surface of the flooring of sheet-steel sections coated with nonskid material or of commercial floor plate. The recommended size for the sections is 3 by 6 feet, although other size sections may be used, subject to responsible engineering office approval.

C.4.15 Equipment Enclosure

When specified, form an equipment enclosure by attaching wall panels to the sides of the tower between the upper and lower platforms, and make the enclosure walls splashproof.

o Doors. When specified, incorporate two sliding, independently-operated doors, each approximately 3 feet wide by 9 feet high, on the loading-platform side of the enclosure. Design the two doors to come together at the center line of the enclosure wall and slide to the outside, leaving a maximum opening of approximately 6 feet when both doors are open.

o Monorail and Hoist. On the underside of the upper platform, attach a monorail and hoist extending beyond the projection of the loading platform extension of the lower platform, positioning the monorail above the center of the door opening when specified by the responsible engineering office. Determine the hoist capacity required from the weight of individual equipments.

o Wall Panels. Fashion the equipment enclosure wall panels of sheet steel.

o Lighting Circuit. Within the enclosure, provide lighting and convenience outlets with necessary circuit breakers in the number and location specified. Provide for obstruction-light circuits.

o Protective Equipment. To prevent damage to the equipment due to overload, protect the complete lighting system by circuit breakers or fuses of adequate capacity.

o Convenience Outlets. Along each of the four enclosure walls furnish a series of convenience outlets, positioned with regard to equipment location. Use conductors adequate for a 20-ampere load at 115 volts AC.

o Cable Ducts and Sleeving. Cover the specified cables installed in the equipment enclosure by cable ducts, so that a minimum number of cables are exposed. Using suitable sleeving, protect the cables that will enter the enclosure from the point where they leave the cable trough to the point where they enter the enclosure.

o Component Cabinets. The component cabinets to be mounted in the equipment enclosure will be specified by the responsible engineering office.

o Air Exhaust Blowers. Near the underside of the upper platform, locate two reversible blowers and louvers on opposite enclosure walls.

o Electric Air Heater. Provide an electric air heater approved by the procuring activity in the equipment enclosure.

o Fire Extinguisher. In the equipment enclosure, install a hand-type fire extinguisher, carbon dioxide, 10-pound capacity according to Fed Spec 0-E-910. Attach the mounting bracket and hardware required to mount the fire extinguisher on a wall of the enclosure.

o Work Bench. Supply a collapsible work bench equipped with safety locks when the tower has equipment. Design the work bench to be approximately 2 feet wide by 4 feet long by 3-1/2 feet high in its open position. Hinge one side of the bench to a equipment enclosure wall and support the other side by legs or by a permanently located equipment cabinet. Furnish all hardware necessary for attaching the bench to a wall as part of the bench. So that the work bench will occupy minimum space when not in use, make the legs capable of folding under the top of the bench and ensure that the bench top, with the folded legs underneath, will lie flat against the wall. Construct the bench of one-inch plywood and cover its working surface with asbestos sheet.

### C.4.16 Ladder

Supply a steel, exposed ladder that will extend from the ground to the lower platform and from there to the upper platform. Design the ladder to conform with safety regulations in regard to the clearance, width, and distance between rungs. Design so that it will connect with the ladder in the extension tower, if one is used. Make provisions on the ladder structure for mounting a safety cage, but a safety cage will not be required as part of the tower.

### C.4.17 Cable Trough

Provide a cable trough extending from the ground to the tower upper platform. Design the cable trough to contain the cables used to connect the ground installation and the components mounted atop the tower. Be sure the cable trough can be attached to the tower in such a way that it can be serviced from the ladder furnished with the tower. Include supports for the cables that connect the antenna system and associated equipment mounted on the tower to the ground installations. Mount the cable supports within the cable trough and space them at approximately six-foot intervals.

### C.4.18 Antenna Hoist

At one corner of the upper platform, compatible to the electronic equipment, locate a dismountable hoist assembly. Devise the hoist to raise the antenna assembly from the ground to the upper platform level, and make it capable of raising components of the antenna from the upper platform to a specified height above the upper platform.

### C.4.19 Guying Equipment

Furnish guying equipment with mudsills including guy wires, guy anchors and anchor rods, and associated clamps, turnbuckles and brackets to anchor the tower to the ground and take the side and vertical uplift loads on the tower.

## C.5 FLOOR CONSTRUCTION

The floor must be capable of supporting the equipment weights specified for the system. The floor under the equipment should be true and level. For fire preventive reasons, areas with wooden floors should not, if at all possible, be used. The flooring should be one of two types, raceway or false, in order to facilitate cabling.

### C.5.1 Raceway Flooring

Raceway flooring is a solid concrete floor with trenches at appropriate locations for wiring and cables. (See figure C-2.) The main advantages of the raceway floor are that it is solid and virtually vibration-free. However, it is very inflexible. For this reason, the raceway floor is not often used.

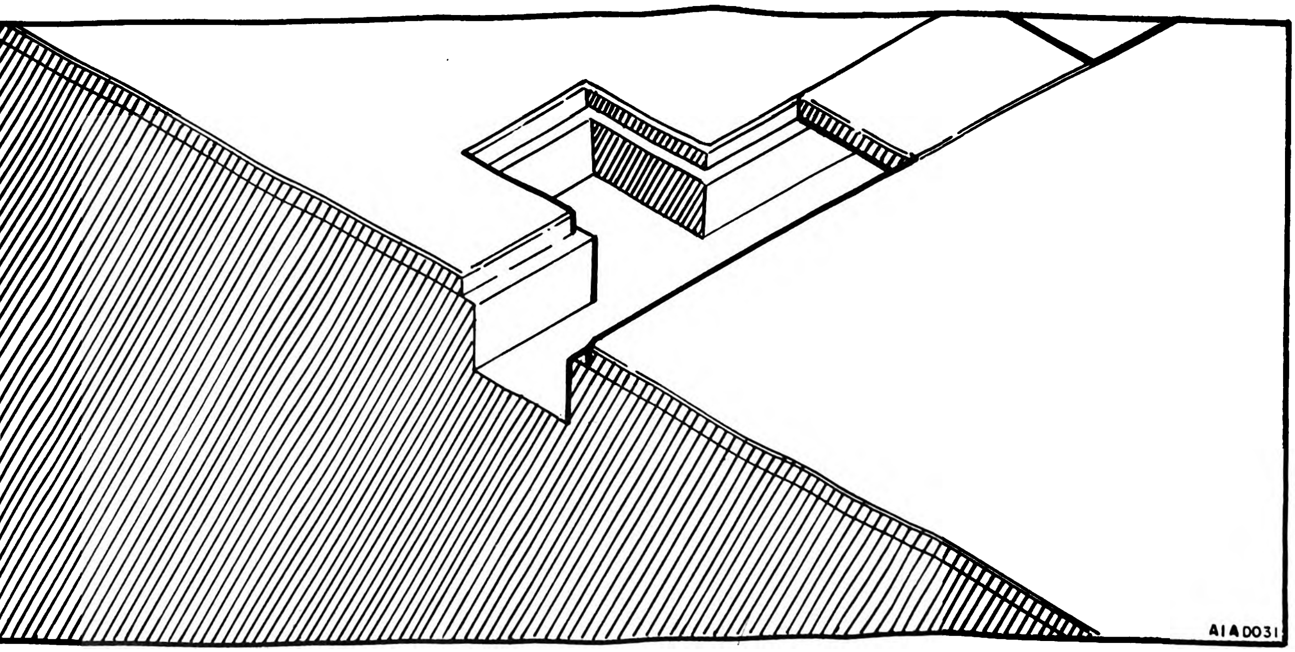



Figure C - 2. Raceway Floor (Covers Removable, Cutouts in Covers)

C.5.2 Raised Flooring

Raised or false floors are used mostly for installation. Some advantages afforded by a raised floor are:

- o Facilitates routing of and conceals signal cables and power wiring
- o Greater flexibility in locating initial equipment
- o Greater flexibility in equipment relocation or expansion

Details of typical raised-floor configurations are provided in figures C-3 through C-8.

C.6 WIRE-GAGE UTILIZATION

There are a number of wire gages in use, the principal one being the American or Brown and Sharpe Wire Gage. This gage is the one commonly used for copper, aluminum, and resistance wires. The gage is designated by either of the abbreviations AWG or B&S.

Basis of the AWG or B&S Gage. The diameters of wires having successive numbers on this gage are in the ratio of $\sqrt[39]{92}$ (=1.1229 approx.) to 1, and the No. 36 wire has a diameter of 5 mils. No. 35 AWG, therefore, has a diameter of 5 X 1.1229 = 5.61 mils and so on until No. 0000 is reached, having a diameter of 460 mils.

The ratio $\sqrt[39]{92}$ is approximately equal to $\sqrt[6]{2}$, which is 1.1225. This makes it possible to have a group of wires of regular gage size with an aggregate area approximately equal to that of another regular gage size. For example, a reduction of three gage numbers (as from gage No. 36 to No. 33) results in a new gage number

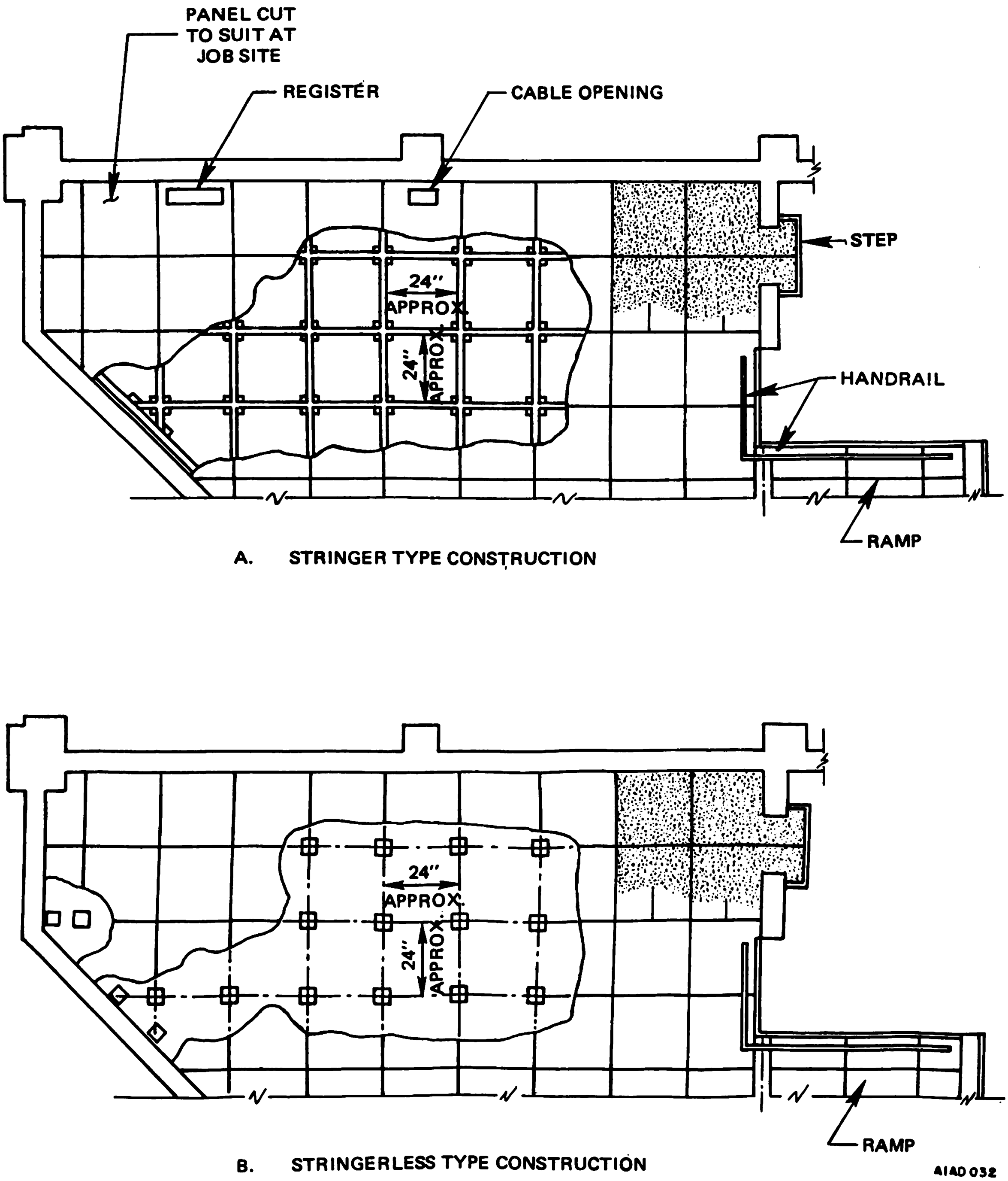



Figure C - 3. Typical Raised-Floor Suspension Systems

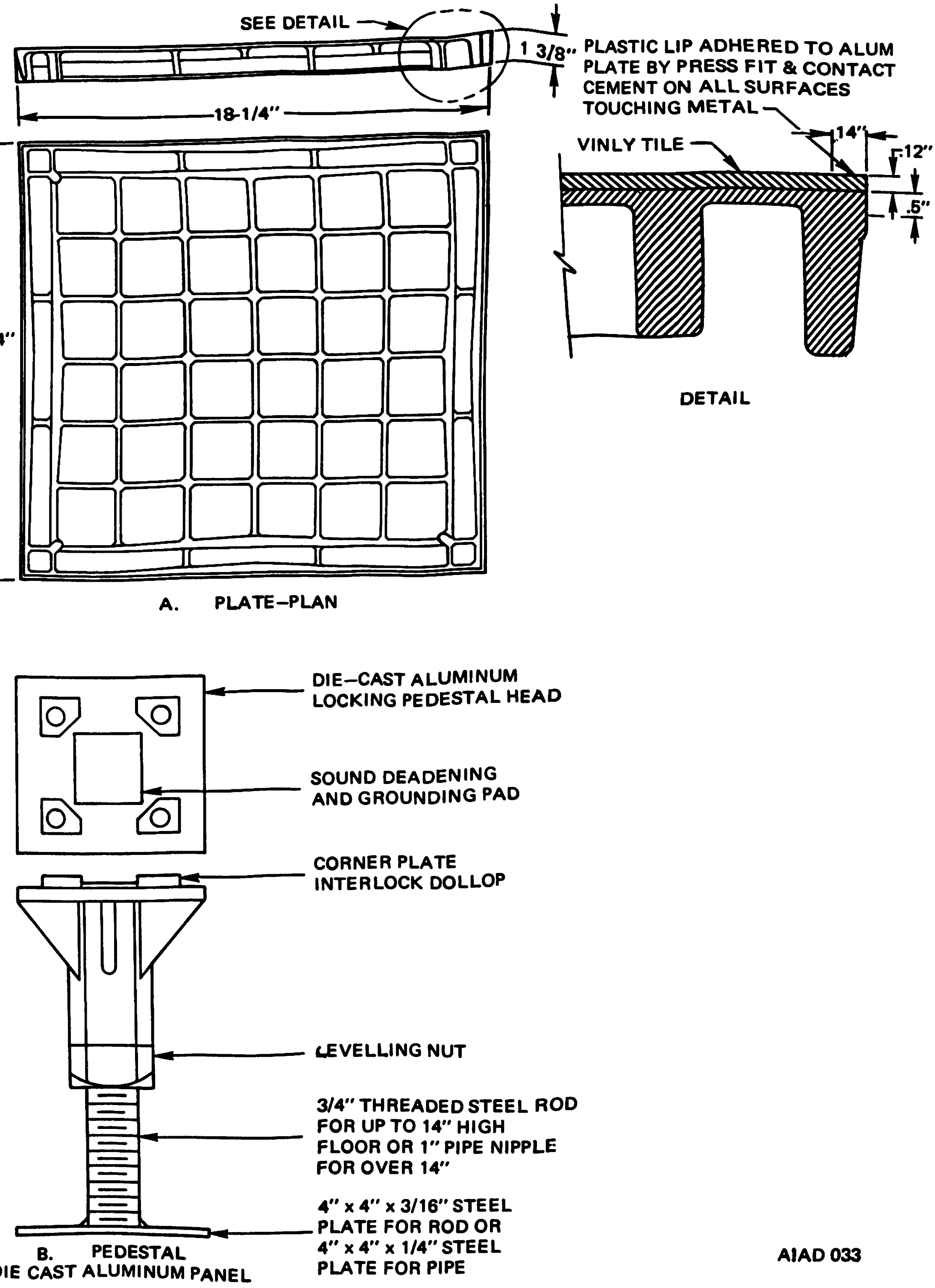



Figure C-4. Typical Raised-Floor Panel Details

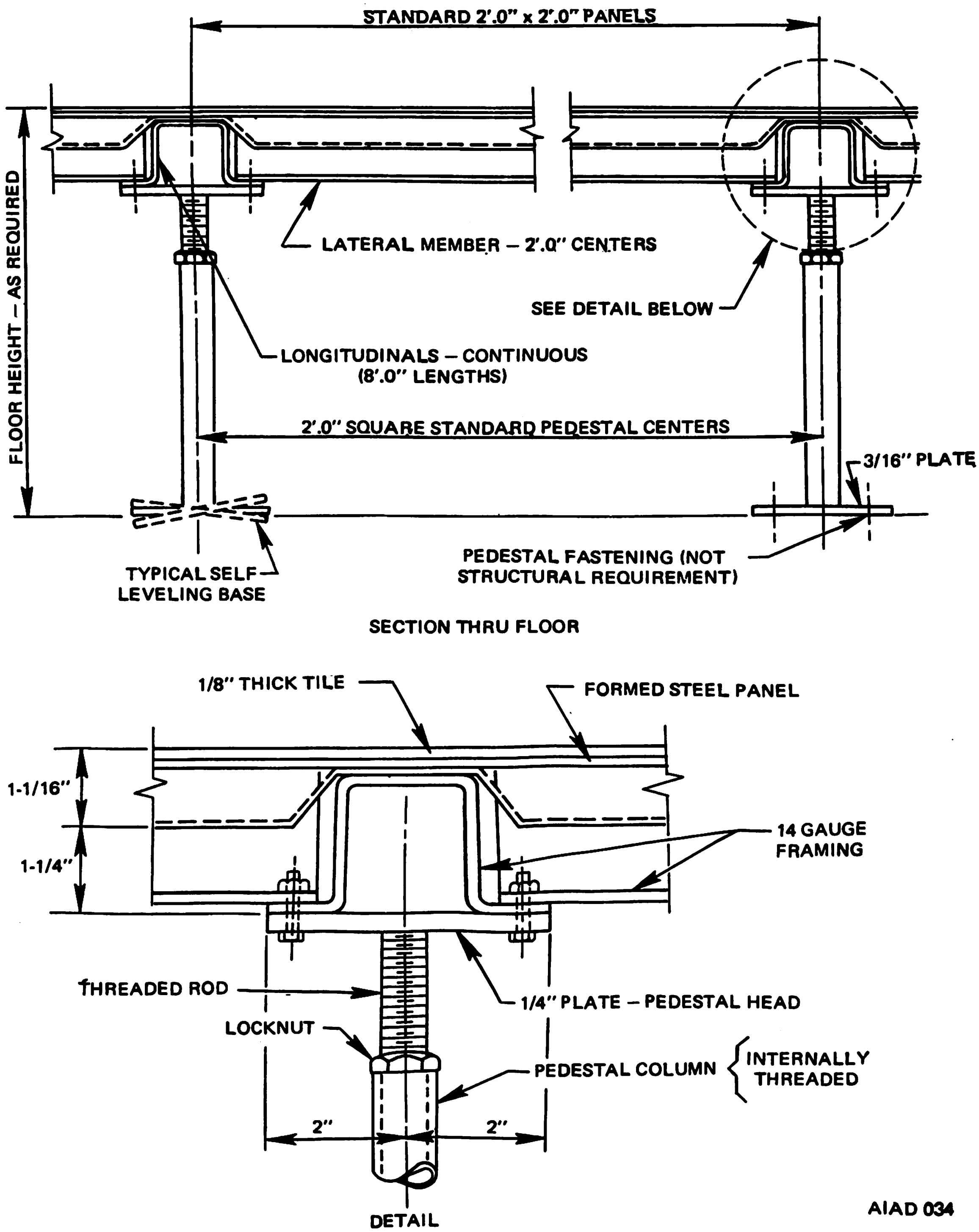
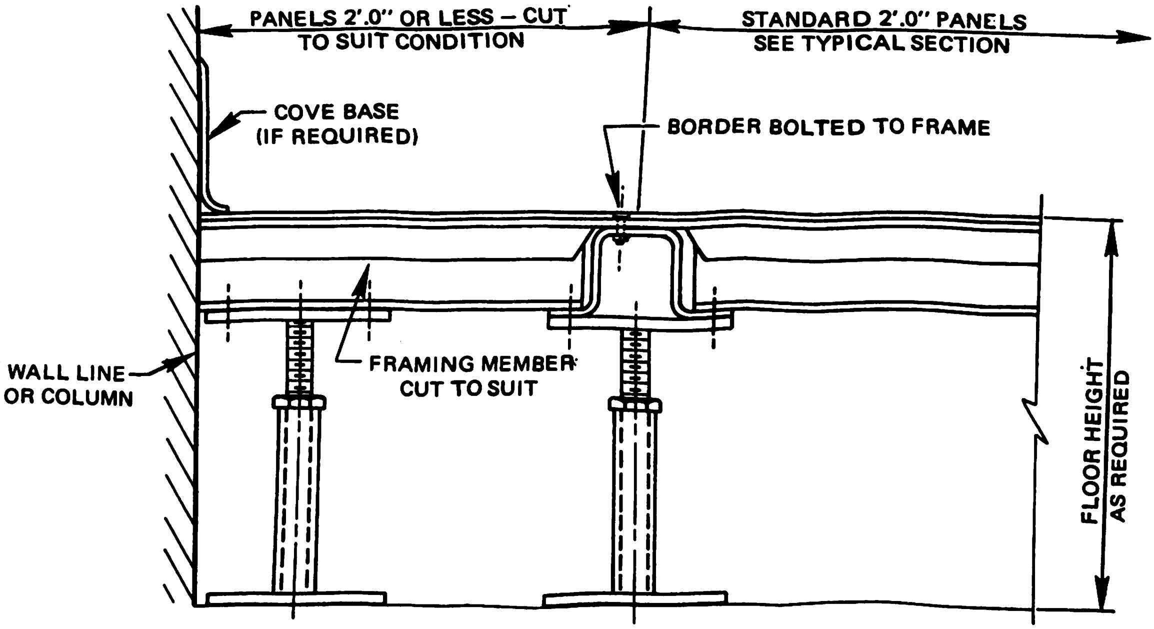
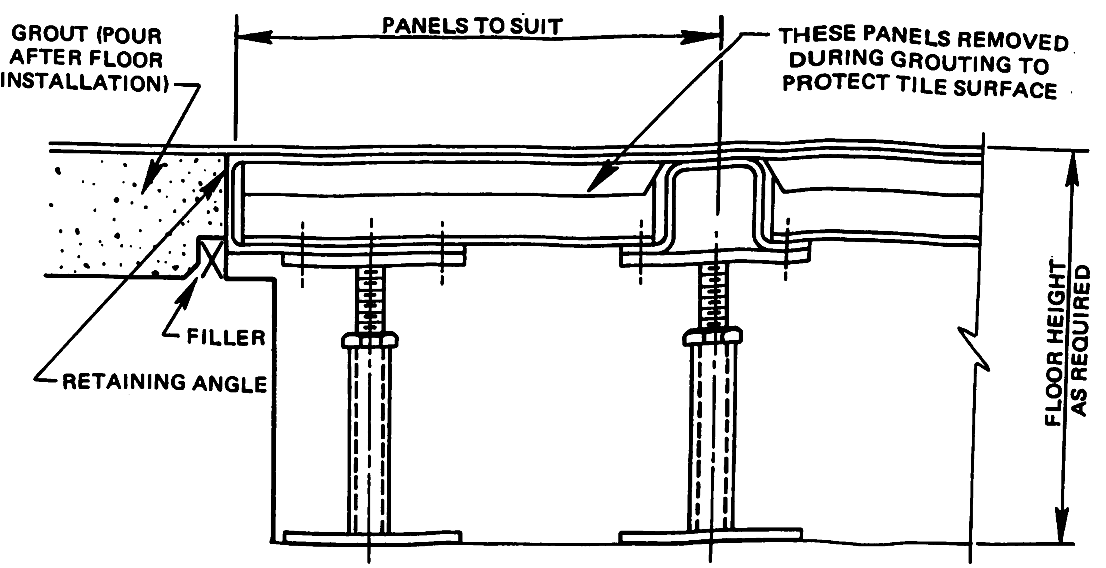



Figure C - 5. Typical Raised Floor, Cross-Sectional View




A. SECTION AT BORDERS




B. SECTION AT DEPRESSED SLABS

AIAD 035

Figure C - 6. Typical Raised Floor, Perimeter Treatment

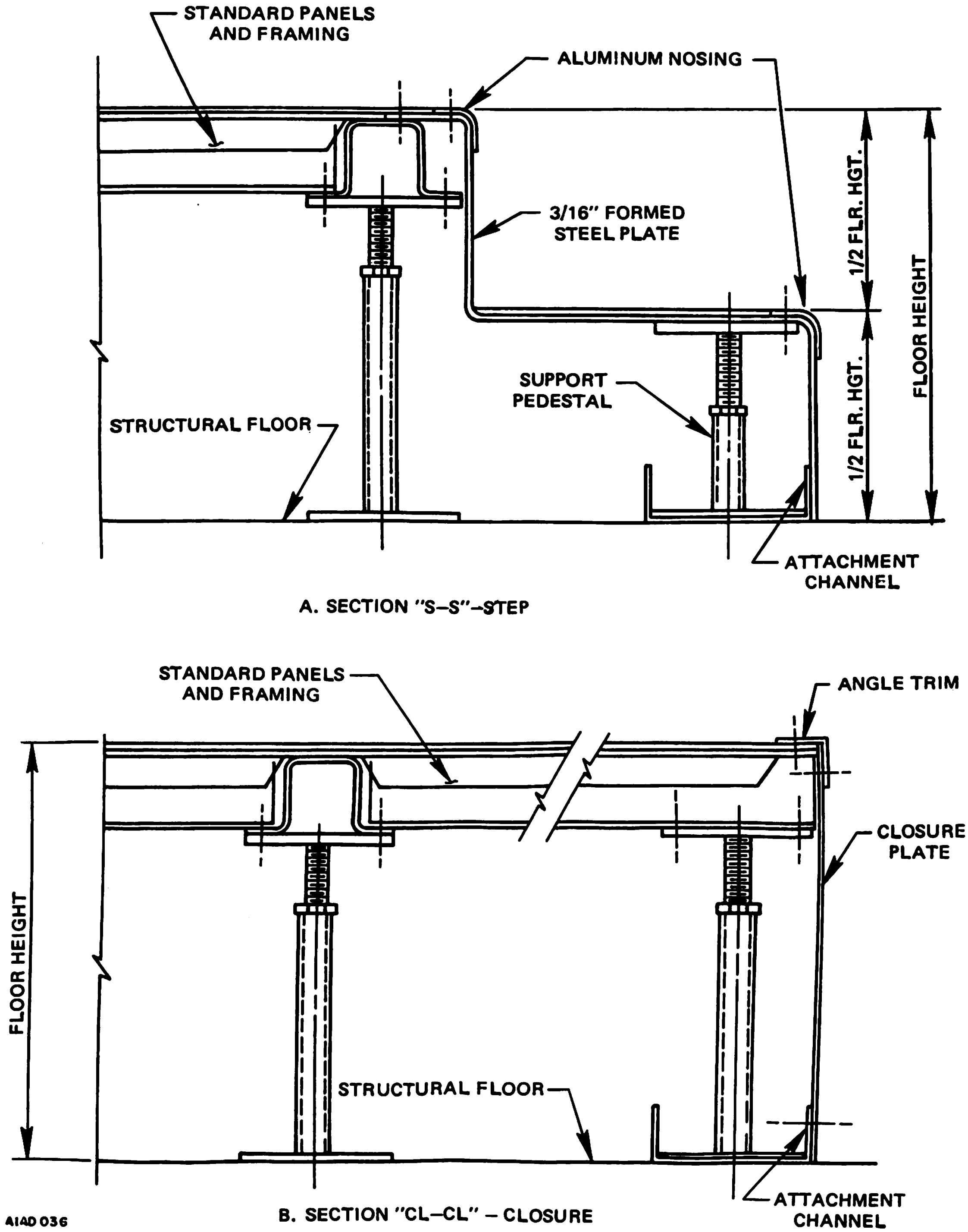



Figure C - 7. Typical Raised Floor, Depth Transition Treatment

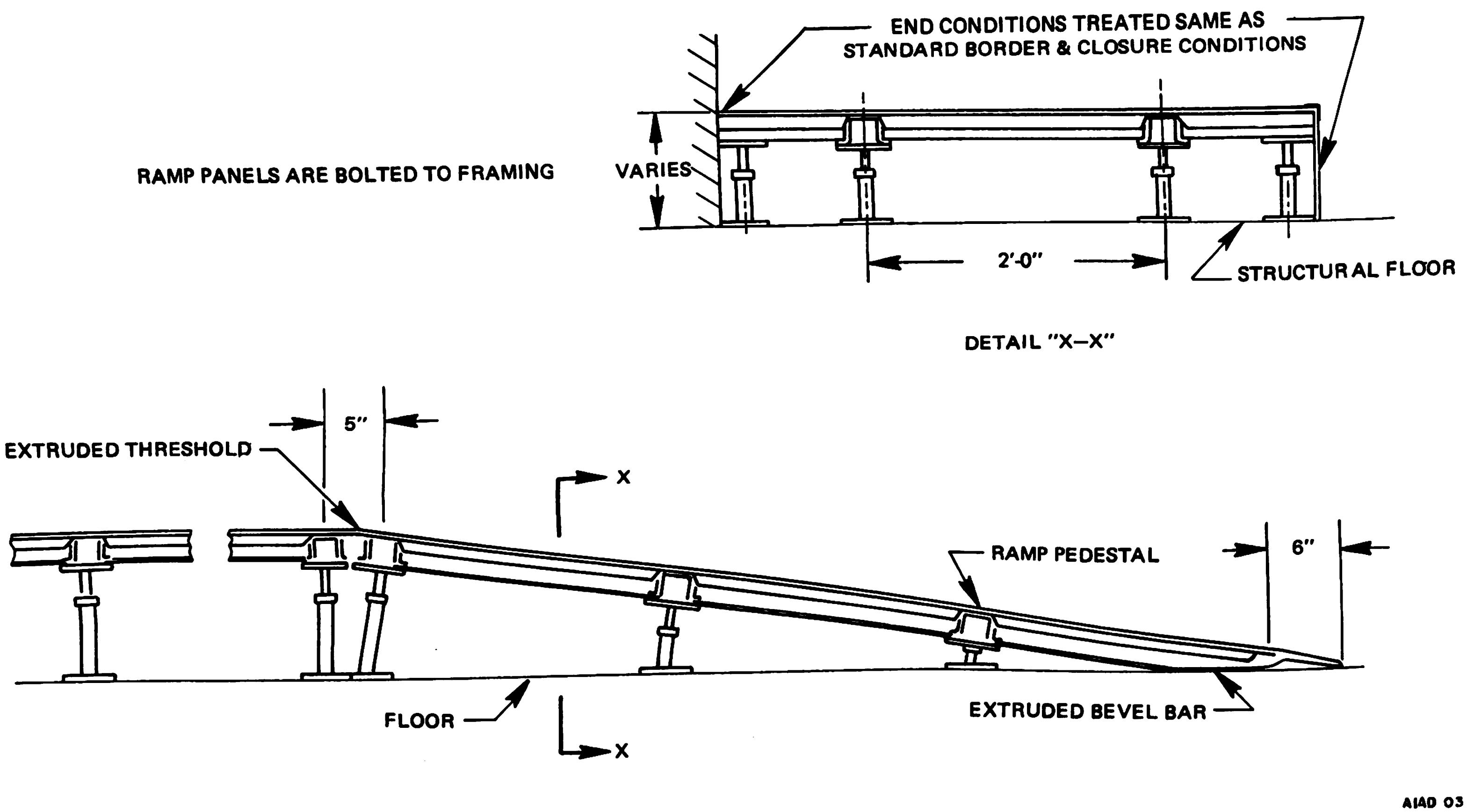



Figure C - 8. Typical Raised Floor, Ramp Configuration representing a diameter approximately $\sqrt{2}$ times that represented by the original gage number, or an area approximately two times as great.

The following approximate relations are also useful:

An increase of 1 in the number increases the resistance 25 percent.
An increase of 2 in the number increases the resistance 60 percent.
An increase of 3 in the number increases the resistance 100 percent.
An increase of 10 in the number increases the resistance 10 times.

A No. 10 AWG copper wire has the following approximate characteristics:

| | |
|---|---|
| Ohms per 1000 feet | 1 |
| Circular mils area | 10,000 |
| Weight, pounds per 1000 feet | 32 |

A No. 10 AWG aluminum wire has the following approximate characteristics:

| | |
|---|---|
| Ohms per 1000 feet | 1.6 |
| Circular mils area | 10,000 |
| Weights, pounds per 1000 feet | 9.5 |

Remembering these rules it is easy to find the approximate size, resistance, area, or weight of any size wire. For example, a No. 12 AWG copper wire has a resistance of 1 plus 60 percent = 1.6 ohms per 1000 feet approximately. Its area, being inversely as its resistance, is 10,000/1.6 = 6250 circular mils, its diameter is therefore $\sqrt{6250}$ = 79 mils, and its weight 32/1.6 = 20 pounds per 1000 feet.

## C.7 WIRE AND CABLE SPECIFICATIONS

A tabulation of the most frequently referenced criterial documents is presented in table C-1.

## C.8 CABLES AND CONNECTORS REFERENCE DATA

The following tables provide a compilation, in ready-reference form, of pertinent data to facilitate selection of cable and connectors.

o Table C-2. Coaxial-cable conversion chart, listing new, preferred cables against obsolete items and also listing non-armored cables which are electrically equivalent to armored versions.

o Table C-3. Standard to High-Temperature Cable Conversion Chart and High-Temperature to Standard Cable Conversion Chart which provide a two-way reference to facilitate selection of the most appropriate temperature-range cable for a given installation.

o Table C-4. Standard-to-Angled Connector Conversion Chart, which indexes angled connectors which can be used instead of standard connectors to ease the mechanical stresses caused with shipboard-equipment cabling is routed vertically into trenches, under computer decking, or into Q-cell configurations.

o Table C-5. Special Cable Factors, a summary of special features such as extra-rigidity or flexibility, ultra-compactness, etc., of nomenclatured cables.

o Table C-6. Coaxial Cable Comparison Guide.

Table C - 1. Commonly Used Wire and Cable Specifications

| | |
|---|---|
| ANC-68 | Covers 2 and 3 conductor 18 AWG through 6 AWG flexible portable power cord |
| ANC-161 | Covers low tension, single aluminum conductor, insulated avionics cable |
| ANC-168 | Covers wire with 78 percent coverage TC shield; identified by BC tracer braided in shield |
| ANJC-48A | Covers low-tension, single copper conductor, insulated aircraft cable |
| ASTM B-174 | Covers stranding of conductors |
| ASTM D-752 | Covers jackets |
| ASTM D-754 | Covers insulation and heat-resistance |
| ASTM D-755 | Covers insulation |
| JAN-C-17A | Covers coax cable for HF applications in radio, TV, radar |
| JAN-C-76A | Covers radio hookup wire, types SRIR, SPHV, WL, and SRRF |
| MIL-C-17 | Covers many coax cables |
| MIL-C-915A | Covers conductor color-coding |
| MIL-C-2194 | Covers silicone rubber insulated armored shipboard cable |
| MIL-C-3432 | Covers light, medium, and heavy duty, 300- and 600-volt wire and multi-conductor cables, shielded and unshielded, with extruded and vulcanized jackets |
| MIL-C-5898B(USAF) | Covers miniature, flexible, multi-conductor cable |
| MIL-C-7078A | Covers color-coded, shielded, 600-volt aircraft power cable; specifies inner conductor per MIL-W-5086A |
| MIL-C-8721(USAF) | Covers RG 178/U and 180/U cables |
| MIL-C-10392B | Covers miniature, flexible, multi-conductor cable |
| MIL-C-25038(USAF) | Covers high-temperature avionics cable. NCC conductors, maximum temperature 750°C(1375°F); outer braids and protective coverings, as needed, are usually TFE, asbestos, and glass |
| MIL-C-27072 | Covers non-portable multi-conductor unshielded and shielded cables |
| MIL-C-27500 | Covers shielded and unshielded avionic and missile type cable |
| MIL-C-55021 | Covers shielded and unshielded twisted pair and triad combinations for internal equipment-wiring |
| MIL-C-55134 | Covers types I, II, and III inside telephone cables |
| MIL-C-55446 | Covers 22 AWG plastic-insulated, plastic jacketed telephone cable in combinations of pairs and singles from 4 pairs to 201 pairs |
| MIL-E-9085A | Replaced by MIL-C-5898 |
| MIL-E-9088A | Replaced by MIL-C-5898B |
| MIL-I-22129B | Covers TFE tubing |
| MIL-L-3890 | Covers bead-supported coax line |

Table C - 1. Commonly Used Wire and Cable Specifications (Continued)

| | |
|---|---|
| MIL-STD-104 | Covers colors for jacketing |
| MIL-W-76 | Covers plastic-insulated hookup wire rated at 80°C(176°F). Four basic types: LW, rated at 300 volts; MW, rated at 1kV; HW, rated at 2.5kV; and HF, rated at 1kV. |
| MIL-W-3861 | Covers BC and TC solid soft-drawn wire |
| MIL-W-5086A | Covers aircraft 600-volt wire, 150°C(302°F) maximum temperature rating constructed as follows:<br><br>Type I. First, stranded TCC conductor; second, primary insulation, PVC; third, extruded clear nylon.<br><br>Type II. First, stranded TCC conductor, second, primary insulation, PVC, third, glass fiber braid treated with suitable saturants; fourth, extruded clear nylon on 22 through 12 AWG, and braided nylon impregnated with nylon lacquer on 10 through 4/0 AWG.<br><br>Type III. First, stranded TCC conductor; second, primary insulation, PVC; third, glass fiber braid, treated with suitable saturants; fourth, secondary insulation, PVC; fifth, extruded clear nylon on 22 through 12 AWG, and braided nylon impregnated with nylon lacquer on 10 through 4/0 AWG. |
| MIL-W-5274 | Cancelled; use MIL-W-5086A |
| MIL-W-5845 | Covers iron and constantan thermocouple wire |
| MIL-W-5846 | Covers Chromel and Alumel thermocouple wire |
| MIL-W-5908 | Covers copper and Constantan thermocouple wire |
| MIL-W-6370C | Covers solid hard-drawn copper-covered steel antenna wire |
| MIL-W-7139B | Covers 600-volt high-temperature avionics wire<br><br>Class I. SPC stranded conductor, then laminates of TFE and glass, 200°C (392°F)<br><br>Class II. NPC stranded conductor, laminates of TFE and glass, 260°C (492°F) |
| MIL-W-8777B(ASG) | Covers 600-volt, 150°C(302°F) power and lighting wire, SPC conductor, silicone rubber insulation with raided or extruded-material protective cover. Additional coatings as needed |
| MIL-W-12995(Sig. C) | Covers stranded silicon-bronze antenna wire |
| MIL-W-16878D | Covers wire and insulation for internal equipment wiring: |

| TYPE | AWG SIZES | INSULATION | OPERATING VOLTS | TEMPERATURE RATING °C | TEMPERATURE RATING °F. |
|---|---|---|---|---|---|
| B | 32-14 | PVC | 600 | 105 | 219 |
| C | 26-12 | PVC | 1000 | 105 | 219 |
| D | 24-1/0 | PVC | 3000 | 105 | 219 |
| E | 32-10 | TFE | 600 | 200* | 392* |
| EE | 32-8 | TFE | 1000 | 200* | 392* |
| ET | 32-20 | TFE | 250 | 200* | 392* |
| F | 24-12 | SR | 600 | 200 | 392 |
| FF | 24-3/0 | SR | 1000 | 200 | 392 |
| J | 24-3/0 | Poly | 600 | 75 | 167 |
| K | 32-10 | FEP | 600 | 200 | 392 |
| KK | 32-4/0 | FEP | 1000 | 200 | 392 |
| KT | 32-20 | FEP | 250 | 200 | 392 |
| N | 32-20 | Nylon | 75 | 80 | 176 |

*Temperature rating is 260°C(492°F) with NPC conductor.

Table C - 1. Commonly Used Wire and Cable Specifications (Continued)

| | |
|---|---|
| MIL-W-22759B | Covers fluorocarbon-insulated copper and copper-alloy high-temperature wire |
| MIL-W-25038B(ASG) | Same as MS27125(USAF) |
| MIL-W-25136(USAF) | Covers solid hard-drawn copper-covered steel antenna wire |
| MIL-W-81044 | Covers single-conductor cross-linked Polyalkene-insulated wire; conductor can be tin-coated, SPC, or NPC |
| MIL-W-81381 | Covers polyimide-insulated single-conductor SPC and NPC wire |
| MS25471(ASG) | See MIL-W-8777B(ASG) |
| MS27110(ASG) | Covers same type wire as MIL-W-8777B(ASG), but with FEP jacket |
| MS27125(USAF) | Covers same type cable as MIL-C-25038(USAF), but adds requirement for resistance to open flame of 1180°C(2000°F) |
| MC90294(AS) | See MIL-W-22759B |
| QQ-B-575 | Covers TC and BC flexible braid |
| QQ-W-343 | Covers BC and TC solid soft-drawn wire |
| USAS C-1-( ) | National Electric Code (NEC) |
| USAS C-42 | Definitions of Electrical Terms |

Table C - 2. Coaxial Cable Conversion Chart

| BASIC CABLE | | | REPLACED BY | | UNARMORED EQUIVALENT | | REMARKS |
|---|---|---|---|---|---|---|---|
| RG-_/U | ARMOR | OBS | RG-_/U | FSN 6145- | RG-_/U | FSN 6145- | |
| 4 | | x | 58C | 542-6092 | - | - | |
| 5, 5A, 5B | | x | 212 | 945-6429 | - | - | |
| 6 | | x | 6A | 812-3943 | - | - | |
| 7 | | x | 63B | 542-6087 | - | - | |
| 8, 8A | | x | 213 | 660-8711 | - | - | |
| 9, 9A, 9B | | x | 214 | 660-8054 | - | - | |
| 10, 10A | x | x | 215 | 660-8712 | 213 | 660-8711 | |
| 12 | x | x | 12A | 500-0794 | 11A | 161-0885 | |
| 12A | x | | - | - | 11A | 161-0885 | |
| 13, 13A | | x | 216 | - | - | - | |
| 14, 14A | | x | 217 | 843-7878 | - | - | |
| 15 | | x | 11A | 161-0885 | - | - | |
| 17, 17A | | x | 218 | 577-8113 | - | - | |
| 17B | | x | 177 | 519-2820 | - | - | |
| 18 | x | | - | - | 17 | - | |
| 18A | x | x | 219 | 660-8714 | 218 | 577-8113 | |
| 19A | | x | 220 | 000-8715 | - | - | |
| 20, 20A | x | x | 221 | | 220 | 660-8715 | |
| 21, 21A | | x | 222 | | - | - | |
| 22, 22A | | x | 22B | 553-7822 | - | - | |
| 23 | | x | 23A | 539-8508 | - | - | |
| 24 | x | x | 24A | 542-6089 | 23A | 539-8508 | |
| 24A | x | | - | - | 23A | 539-8508 | |
| 25 | x | x | - | - | 25A | - | |
| 26, 26A | x | | - | - | 25A | 160-6193 | |
| 27 | x | | - | - | 28 | - | |
| 27A | x | | - | - | 28B | 660-8958 | |
| 28A | x | | - | - | | | |
| 29 | | x | 58C | 542-6092 | - | - | |
| 30 | | x | 58C | 542-6092 | - | - | |
| 31 | | x | 213 | 660-8711 | - | - | |
| 32 | x | x | 215 | 660-8712 | 213 | 660-8711 | |
| 34, 34A | | x | 34B | 661-0192 | - | - | |
| 35, 35A | x | x | 35B | 957-9963 | 164 | | |
| 35B | x | | - | - | 164 | | |
| 36 | x | | - | - | | | |
| 37 | | x | 58C | 542-6092 | - | - | |
| 38 | | x | 212 | 945-6429 | - | - | |
| 39 | | x | 59B | 661-0191 | - | - | |
| 40 | | x | 6A | 812-3943 | - | - | |
| 42 | | x | 222 | | - | - | |
| 43 | | x | 57A | 978-8056 | - | - | same as RG-130/U except more rigid |
| 54 | | x | 54A | | - | - | |
| 55, 55A, 55B | | x | 223 | 681-7849 | - | - | |
| 57 | | x | 57A | 577-8423 | - | - | same as RG-130/U except more rigid |
| 59A | | x | 59B | 661-0191 | - | - | |
| 62C | | x | 210 | 543-9322 | - | - | |
| 63, 63A | | x | 63B | 542-0007 | - | - | |
| 71 | | x | 64A | | | | |
| 71 | | x | 71B | 683-5353 | - | - | |
| 74, 74A | x | x | 224 | 660-8717 | 217 | 843-7878 | |
| 77 | | x | 88A | - | - | - | |
| 79, 79A | x | x | 79B | 171-3057 | 63B | 542-6087 | |

Table C - 4. Standard-to-Angled Coaxial-Connector Conversion Chart

| STD UG- /U | 90° | | STD UG- /U | 90° | |
|---|---|---|---|---|---|
| | UG- /U | FSN 5935- | | UG- /U | FSN 5935- |
| 21 | 594 | 722-3190 | 925 | 212* | 201-8151 |
| 58 | 27* | 323-0267 | 943 | 945<br>567* | 834-2893<br>201-2755 |
| 38 | 913 | 682-0501 | 943B | 945B | |
| 38D, E | 913A | | 944 | 567* | 201-2755 |
| 154 | 216B* | 549-7577 | 982 | 27* | 323-0267 |
| 180A | 1085 | | 1094A | 1098A | |
| 181A | 1086 | 549-1703 | 1292 | 1293 | |
| 245 | 342 | | 1392 | 1395 | |
| 260 | 306*<br>306B | 847-2600 | 1393 | 1396 | |
| 261 | 306B | 847-2600 | 1460 | 1461 | |
| 352 | 216B | 549-7577 | 1465 | 1466 | |
| 532A | 534B* | 581-4628 | 1681 | 1708 | |
| 573, 573B | 710B | 702-1207 | | | |

* Denotes male/female adapter

Table C - 5. Special Cable Factors

| RG- /U | REMARKS |
|---|---|
| 11 | Use RG-144/U (FSN 6145-577-3478) for low noise |
| 58A | Electrically equivalent to RG-122/U (FSN 6145-583-9268), but is thicker and heavier in weight |
| 77A | Double-braid; RG-78/U is single-braid equivalent |
| 122 | Thin, lightweight version of RG-58A/U (FSN 6145-771-3336) |
| 126 | FEP-jacketed version of RG-301/U |
| 130 | More flexible version of RG-57A/U (FSN 6145-978-8056) |
| 140 | FEP-jacketed version of RG-302/U |
| 141A | FEP-jacketed version of RG-303/U (FSN 6145-080-6517) |
| 143A | FEP-jacketed version of RG-304/U |
| 144 | Low-noise version of RG-11/U (FSN 6145-161-0919) |

Table C-6. Coaxial Cable Comparison Guide

| RG-/U | NOTES | Z NOM | CAP ($\mu\mu$f/FT) | MAX OPER KV | EQUIV. CABLE RG-/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 5A, 5B, 6, 6A, 8 | 1* | 52* | 29.5 | 4* | 213, 215 | | 297 | 250 | 6 |
| 9A, 9B | 1 | 50 | 30* | 4* | 214 | C, HN, N* | | | |
| 11 | 1* | 75 | 20.5 | 4* | 11A, 12, 12A 13, 13A, 216 | MC, N. UHF, Splice, Term* | 297 | 250 | 6 |
| 11A | 1* | | | 5* | See 11 | C, HN, N, QDL, QDS* | 297 | 250 | 6 |
| 12, 12A | 1*, 9 | | | 5* | See 11 | C, HN, N, QDL, QDS* | 297 | 250 | 6 |
| 13, 13A | 1* | | | - | See 11 | C, N, UHF, Term* | | | |
| 17, 17A | 1* | 52* | 29.5* | 11 | 18, 177, 218, 219 | C, HN, LC, N, UHF, Splice, Term | | | |
| 18, 18A | 1*, 9 | 52* | 29.5* | | See 17 | HN, LC, N* | | | |
| 19, 19A | 1* | 52* | 29.5 | 14 | 220,221 | - | | | |
| 21, 21A | 4 | 53* | 29 | 2.7* | 222 | C N* | | | |
| 22B | 4* | 95 | 16 | 1 | 111, 111A | Twin | | | |
| 23, 23A | 4* | 125 | 12 | 3 | 24A | - | | | |

Table C - 2. Coaxial Cable Conversion Chart (Continued)

| BASIC CABLE | | | REPLACED BY | | UNARMORED EQUIVALENT | | REMARKS |
|---|---|---|---|---|---|---|---|
| RG-_/U | ARMOR | OBS | RG-_/U | FSN 6145- | RG-_/U | FSN 6145- | |
| 79B | x | | - | - | 63B | 542-6087 | |
| 84A | x | | - | - | 164 | | RG-84A/U has lead sheath instead of armor |
| 85A | x | | - | - | 164 | | RG-85A/U is RG-84A/ with special armor |
| 87, 87A | | x | 225 | 660-8718 | - | - | |
| 88B | | x | 88A | | - | - | |
| 93 | | x | 221 | | - | - | |
| 93A | | x | 211A | | - | - | |
| 94, 94A | | x | 226 | | - | - | |
| 108 | | x | 108A | 553-7823 | - | - | |
| 115 | | x | 115A | | - | - | |
| 111. 111A | x | | - | - | 22B | 553-7822 | |
| 116 | x | x | 227 | 660-8824 | 225 | 660-8718 | |
| 117 | | x | 211 | | - | - | |
| 117A | | x | 211A | | - | - | |
| 118 | x | x | 228 | | 211 | | |
| 118A | x | x | 228A | | 211A | | |
| 120 | x | | - | - | 119 | 548-0720 | |
| 124 | | x | 140 | 643-2172 | - | - | Hi-temp version of RG-59B/U (FSN 6145-661-0191); same as RG-302/U with FEP jacket |
| 131 | x | | - | - | 130 | | |
| 147 | x | | - | - | 19 | | |
| 148 | x | | - | - | 8 | 299-7752 | |
| 150 | x | | - | - | 149 | 577-3478 | |
| 159 | | x | 142 | 643-2174 | - | - | Hi-temp version of RG-223/U (FSN 6145-681-7849) |
| 166 | x | | - | - | 165 | | |
| 178, 178A | | x | 179B | 959-4490 | - | - | |
| 179, 179A | | x | 179B | 984-6262 | - | - | |
| 180, 180A | | x | 180B | 835-5840 | - | - | |
| 187A | | x | 188A | | - | - | |
| 188 | | x | 188A | | - | - | |
| 189 | | x | 389 | | - | - | |
| 194 | x | | - | - | 193 | | |
| 195 | | x | 195A | | - | - | |
| 196 | | x | 196A | 814-1209 | - | - | |
| 215 | x | | - | - | 213 | 660-8711 | |
| 219 | x | | - | - | 218 | 577-8113 | |
| 221 | x | | - | - | 220 | 660-8715 | |
| 224 | x | | - | - | 217 | 843-7878 | |
| 227 | x | | - | - | 225 | 660-8718 | |
| 228 | x | | - | - | 211 | | |
| 228A | x | | - | - | 211A | | |
| 229 | x | x | 227 | 660-8824 | 225 | 660-8710 | |
| 238 | | x | 197 | | - | - | |
| 239 | | x | 232 | | - | - | |
| 241 | | x | 233 | | - | - | |
| 243 | | x | 234 | | - | - | |
| 392 | x | | - | - | 391 | | |

Table C - 3. Standard Versus High-Temperature Cable Conversion Matrix Chart

| STANDARD CABLE RG /U | STANDARD CABLE FSN 6145- | HIGH TEMPERATURE CABLE 87A | 94A | 115 | 115A | 117 | 118 548-0718 | 118B | 140 643-2172 | 141 | 141A 655-2728 | 142 643-2174 | 142A | 143 | 143A 845-1855 | 144 635-9342 | 146 | 159 | 165 | 166 | 211 | 225 660-8718 | 226 | 228 | 264A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | | | | | | | | | | | | | | | *2 | | | | | | | | | | |
| 5A | | | | | | | | | | | | | | | *2 | | | | | | | | | | |
| 5B | | | | | | | | | | | | | | | *2 | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | *3 | | | | | | | | | |
| 11A*1 | 161-0885 | | | | | | | | | | | | | | | *3,10 | | | | | | | | | |
| 55 | | | | | | | | | | | | X | | | | | | | | | | | | | |
| 55A | | | | | | | | | | | | | *4 | | | | | | | | | | | | |
| 55B | | | | | | | | | | | | | *4 | | | | | | | | | | | | |
| 58C | 542-6092 | | | | | | | | | *8 | *5,8 | | | | | | | | | | | | | | |
| 59A | | | | | | | | | X | | | | | | | | | | | | | | | | |
| 59B | 661-0191 | | | | | | | | X | | | | | | | | | | | | | | | | |
| 114A | 725-9360 | | | | | | | | | | | | | | | | X | | | | | | | | |
| 212 | 945-6429 | | | | | | | | | | | | | *9 | *2,9 | | | | | | | | | | |
| 213 | 660-8711 | | | *7 | *6,7 | | | | | | | | | | | | | | X | | | | | | |
| 214 | 660-8054 | X | X | | | | | | | | | | | | | | | | | | | X | | | |
| 215 | 660-8712 | | | | | | | | | | | | | | | | | | | X | | | | | |
| 217 | 843-7878 | | | | | | | | | | | | | | | | | | | | | | X | | |
| 218 | 577-8113 | | | | | X | | | | | | | | | | | | | | | X | | | | |
| 219 | 660-8714 | | | | | | X | X | | | | | | | | | | | | | | | | X | |
| 223 | 681-7849 | | | | | | | | | | | *4 | *4 | | | | | X | | | | | | | |
| 264 | 080-8701 | | | | | | | | | | | | | | | | | | | | | | | | X |

Notes (*) :

1. For low noise at 400 MHz, RG- 149/U ( FSN 6145-577-3478 ) may be used, but attenuation is more than double.
2. RG- 143A/U has about 0.5% higher attenuation at all frequencies.
3. RG- 144/U has less attenuation in the 100-3000 MHz band.
4. RG- 142A/U has less attenuation at all frequencies.
5. RG- 141A has much lower attenuation at all frequencies.
6. RG- 115A/U has higher attenuation at 1-100 MHz; less at 200-10,000 MHz.
7. RG-213/U has less attenuation in the 1-100 MHz band, and higher attenuation in the 200-5000 MHz band.
8. RG- 58C/U has much higher attenuation at all frequencies.
9. RG- 212/U has slightly less attenuation at all frequencies.
10. RG- 11A/U has higher attenuation in the 0.1 to 3.0 GHz band.

Table C - 4. Standard-to-Angled Coaxial-Connector Conversion Chart

| STD UG- /U | 90° UG- /U | 90° FSN 5935- | STD UG- /U | 90° UG- /U | 90° FSN 5935- |
|---|---|---|---|---|---|
| 21 | 594 | 722-3190 | 925 | 212* | 201-8151 |
| 58 | 27* | 323-0267 | 943 | 945<br>567* | 834-2893<br>201-2755 |
| 38 | 913 | 682-0501 | 943B | 945B | |
| 38D, E | 913A | | 944 | 567* | 201-2755 |
| 154 | 216B* | 549-7577 | 982 | 27* | 323-0267 |
| 180A | 1085 | | 1094A | 1098A | |
| 181A | 1086 | 549-1703 | 1292 | 1293 | |
| 245 | 342 | | 1392 | 1395 | |
| 260 | 306*<br>306B | 847-2600 | 1393 | 1396 | |
| 261 | 306B | 847-2600 | 1460 | 1461 | |
| 352 | 216B | 549-7577 | 1465 | 1466 | |
| 532A | 534B* | 581-4628 | 1681 | 1708 | |
| 573, 573B | 710B | 702-1207 | | | |

* Denotes male/female adapter

Table C - 5. Special Cable Factors

| RG- /U | REMARKS |
|---|---|
| 11 | Use RG-144/U (FSN 6145-577-3478) for low noise |
| 58A | Electrically equivalent to RG-122/U (FSN 6145-583-9268), but is thicker and heavier in weight |
| 77A | Double-braid; RG-78/U is single-braid equivalent |
| 122 | Thin, lightweight version of RG-58A/U (FSN 6145-771-3336) |
| 126 | FEP-jacketed version of RG-301/U |
| 130 | More flexible version of RG-57A/U (FSN 6145-978-8056) |
| 140 | FEP-jacketed version of RG-302/U |
| 141A | FEP-jacketed version of RG-303/U (FSN 6145-080-6517) |
| 143A | FEP-jacketed version of RG-304/U |
| 144 | Low-noise version of RG-11/U (FSN 6145-161-0919) |

Table C-6. Coaxial Cable Comparison Guide

| RG-/U | NOTES | Z NOM | CAP ($\mu\mu$f/FT) | MAX OPER KV | EQUIV. CABLE RG-/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 5A, 5B, 6, 6A, 8 | 1* | 52* | 29.5 | 4* | 213, 215 | | 297 | 250 | 6 |
| 9A, 9B | 1 | 50 | 30* | 4* | 214 | C, HN, N* | | | |
| 11 | 1* | 75 | 20.5 | 4* | 11A, 12, 12A 13, 13A, 216 | MC, N. UHF, Splice, Term* | 297 | 250 | 6 |
| 11A | 1* | | | 5* | See 11 | C, HN, N, QDL, QDS* | 297 | 250 | 6 |
| 12, 12A | 1*, 9 | | | 5* | See 11 | C, HN, N, QDL, QDS* | 297 | 250 | 6 |
| 13, 13A | 1* | | | - | See 11 | C, N, UHF, Term* | | | |
| 17, 17A | 1* | 52* | 29.5* | 11 | 18, 177, 218, 219 | C, HN, LC, N, UHF, Splice, Term | | | |
| 18, 18A | 1*, 9 | 52* | 29.5* | | See 17 | HN, LC, N* | | | |
| 19, 19A | 1* | 52* | 29.5 | 14 | 220,221 | - | | | |
| 21, 21A | 4 | 53* | 29 | 2.7* | 222 | C N* | | | |
| 22B | 4* | 95 | 16 | 1 | 111, 111A | Twin | | | |
| 23, 23A | 4* | 125 | 12 | 3 | 24A | - | | | |

Table C - 6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP (μμf./FT) | MAX. OPER KV | EQUIV. CABLE RG-_/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 24A | 4*, 9 | | | | 23 | | | | |
| 25 | 3* | 48 | 50 | 10* | 25A, 26, 26A, 27A, 28B, 64, 64A, 77, 77A, 88, 88A | Pulse | | | |
| 25A | 3* | | | 8*Peak | See 25 | Pulse | | | |
| 26 | 3*, 9 | | | 10* | See 25 | Pulse | | | |
| 26A | 3*, 9 | | | 8* Peak | See 25 | Pulse | 297 | 250 | 6 |
| 27A | 3*, 9 | | | 15* Peak | See 25 | - | | | |
| 28B | 3* | | | 15* Peak | See 25 | - | | | |
| 35B | 1*, 9 | 75 | 21.5 | 10 | 164 | - | | | |
| 57A | 4* | 95 | 17 | 3* | 130, 131 | Twin | | | |
| 58A | 1 | 50 | 30 | 1.9 | 58C | BNC, MB, MHF, UHF* | 124 | 128 | S, 1S |
| 58C | | | | | See 58A | BNC, MB, MHV, C, N, TNC, UHF* | 124 | 130 | S, 1S, 10S |
| 59, 59A | 1 | 73* | 21 | 2.3 | 59B | BN, BNC, C, MB, MC, MHV, N, SM, TNC, TRIAX, UHF Plug-in, Space, Term* | 156 | 160 | 2 |

Table C-6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP (μμf/FT) | MAX. OPER KV | EQUIV. CABLE RG-/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 59B | | 75* | | | See 59 | BNC, C, TERM* | 156 | 160 | 2 |
| 62 | 4 | 93 | 13.5* | .75 | 62A, 71A, 71B | BN, BNC, C, MB, MHV, N, SM, TNC, UHF, Plug-in splice, Term* | 156 | 160 | 2 |
| 62A | | | 13.5* | | See 62 | BNC* | 156 | 160 | 2 |
| 63, 63B | 4* | 125 | 10* | 1 | 79B | - | 297 | 250 | 6 |
| 64 | 3* | | | 10* | See 25 | - | | | |
| 64A | 3* | | | 8* Peak | See 25 | - | | | |
| 71A | | | 13.5* | | See 62 | BNC, C, HN* | | | |
| 71B | | | 14.5 Max* | See 231 | See 62 | BNC, C* | 156 | 180 | 2 |
| 77, 77A | 3* | | | | See 25 | - | | | |
| 79, 79B | 4*, 9 | | 11 Max.* | | See 63 | | 297 | 250 | 6 |
| 84, 84A | 1, 9 | 75 | 21.5 | 10 | 85, 85A | - | | | |
| 85, 85A | | | | | See 84 | - | | | |
| 88 | 3* | | | 10* | See 25 | - | | | |
| 88A | 3* | | | 10* | See 25 | - | | | |

Table C-6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP (μμf/FT) | MAX. OPER KV | EQUIV. CABLE RG-_/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 111 | 4*, 9 | | | | See 22B | - | | | |
| 111A | 4*, 9 | | | | See 22B | Twin | | | |
| 114 | 4 | 185 | 6.5 | 1 | 114A | C, N* | | | |
| 114A | | | | | See 114 | BNC, C, HN, N* | | | |
| 115A | 2 | 50 | 29.5 | 5* | 235 | - | | | |
| 119 | 2* | 50 | 29 | 6 | 120 | - | | | |
| 120 | 2*, 9 | | | | See 119 | - | | | |
| 126 | 4 | 50 | 29 | 3 | 301 | - | 194 | 190 | 2 |
| 130 | 4* | | | 8* | See 57A | | | | |
| 131 | 4*, 9 | | | 8* | See 57A | | | | |
| 140 | 2 | 75 | 21 | 2.3 | 302 | BNC, TERM | 156 | 160 | 2 |
| 141 | 2 | 50 | 28.5 | 1.9* | 141A, 142, 142A, 142B 303 | BNC, MB, MAV, C, N, TNC, UHF, TERM* | | | |
| 141A | | | | 1.9* | See 141 | - * | 134 | 130 | S, 1S, 10S |
| 142 | | | | 1.9* | See 141 | BNC, MB, MHV, TNC, UHF, C, TERM* | | | |

Table C-6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP (µµf/FT) | MAX. OPER KV | EQUIV. CABLE RG-/U | CONNECTOR SERIES | HYRING (NOTE 10) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
| 142A | | | | 2.7* | See 141 | - * | 124 | 150 | 2 |
| 142B | | | | 1.9* | See 141 | - * | | | |
| 143 | 2 | 50 | 28.5 | 3 | 143A, 304 | C, N | | | |
| 143A | | | | | See 143 | - | 194 | 200 | 3 |
| 149 | - | 75 | 20.5 | 5 | 150 | - | | | |
| 150 | 9 | | | | See 149 | TERM | | | |
| 164 | 1* | | | | See 35B | LC, QDC, C, HN, N | | | |
| 165 | 2* | 50 | 29.5 | 5 | 166, 225, 227 | N | | | |
| 166 | 2*, 9 | | | | See 165 | | | | |
| 177 | -* | 50* | 30* | | See 17 | - * | | | |
| 178A | 4* | 50 | 27.9* | 1 | 196 | SUB 5116* | | | |
| 179 | 4* | 70* | 20.4* | 0.750* | 179A, 187 | MB* | | | |
| 179A | 4* | 75* | 20.4* | 1.2* | See 179 | SUB 5116* | | | |
| 180 | 4 | 93* | 15.3* | 1.5 | 180A | BNC, TNC, SUB 5116* | | | |

Table C-6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP ( $\mu\mu f$/FT) | MAX. OPER KV | EQUIV. CABLE RG-_/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 180A | | 95* | 14.5* | | See 180 | BNC, SUB 27, SUB 5116, TERM* | | | |
| 187 | 2*, 4 | 75* | 19.5* | 1.2* | See 179 | BNC, MB, SUB 27, SUB 5116, TERM* | 71 | 100 | S, 1S |
| 188A | 4* | 50 | 29 | 1.2 | 316 | SUB 5116 | | | |
| 190 | 3 | 50 | 50 | 15 | 329 | - | | | |
| 191 | 3 | 25 | 85* | 25* | 230, 328 | - | | | |
| 193 | 3* | 12.5 | 159 | 30 Peak | 194 | - | | | |
| 194 | 3*, 9 | | | | See 193 | - | | | |
| 196 | 2*, 4 | | 28.5* | | See 178A | MB, SUB 27, SUB 5116* | 46 | 80 | S |
| 197 | 6 | 50 | 22 | 2.4 | 232 | - | | | |
| 211 | 2* | 50 | 29 | 9.9 | 228 | - | | | |
| 211A | 2* | 50 | - | 9.9 | 228A | - | | | |
| 213 | 1* | 50* | | 5* | See 8 | N* | 297 | 250 | 6 |
| 214 | | | 29.5* | 5* | See 9A | N* | | | |
| 215 | 1*, 9 | 50* | | 5* | See 8 | C, N* | | | |

Table C-6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP ($\mu\mu f$/FT) | MAX. OPER KV | EQUIV. CABLE RG-/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 216 | 1* | | | 5* | See 11 | - * | | | |
| 217 | 1 | 50 | 29.5 | 7 | 224 | - | | | |
| 218 | 1* | 50* | 29.5* | | See 17 | N* | | | |
| 219 | 1*, 9 | 50* | 29.5* | | See 17 | - | | | |
| 220 | 1* | 50* | | | See 19 | - | | | |
| 221 | 1*, 9 | 50* | | | See 19 | - | | | |
| 222 | | 50* | | 7* | See 21 | N* | | | |
| 224 | | | | | See 217 | - | | | |
| 225 | 2* | | | | See 165 | | | | |
| 227 | 2*, 9 | | | | See 165 | | | | |
| 228 | 2*, 9 | | | | See 211 | - | | | |
| 228A | 2*, 9 | | | | See 211A | - | | | |
| 230 | 3 | | 100* | 15* | See 191 | - | | | |
| 231 | 8 | 50* | 25* | 2.5 | 331, 334, 335 | - | | | |
| 232 | | 50 | 22 | | 197 | - | | | |
| 233 | 6 | 50 | 22 | 4.65 | 240 | - | | | |

Table C - 6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP ( $\mu\mu f$/FT ) | MAX. OPER KV | EQUIV. CABLE RG-_/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 234 | 6 | 50 | 22 | 8.7 | 242 | - | | | |
| 235 | | | | 1.3* | See 115A | - | | | |
| 236 | 6 | 50 | 24 | 1.3 | 237 | - | | | |
| 237 | | | | | See 236 | - | | | |
| 240 | | | | | See 233 | - | | | |
| 242 | | | | | See 234 | - | | | |
| 244 | 6 | 75 | 15.5 | 1.2 | 245 | - | | | |
| 245 | | | | | See 244 | - | | | |
| 246 | 6 | 75 | 15.5 | 2.25 | 247 | - | | | |
| 247 | | | | | See 246 | - | | | |
| 248 | 6 | 75 | 15 | 4.2 | 249 | - | | | |
| 249 | | | | | See 248 | - | | | |
| 250 | 6 | 75 | 15 | 8.5 | 251 | - | | | |
| 251 | | | | | See 250 | - | | | |
| 252 | 7 | 75 | 24.4 | 0.850 | 253 | - | | | |

Table C-6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP ( $\mu\mu f$/FT ) | MAX. OPER KV | EQUIV. CABLE RG-_/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 253 | | | | | See 252 | - | | | |
| 254 | 7 | 50 | 24.4 | 1.8 | 255 | - | | | |
| 255 | 7* | 50 | 24.4* | 4.2* | 258, 270, 319 | - | | | |
| 258 | 7* | | 24.4* | 4.2 | See 257 | - | | | |
| 264B | | 40 | 42 max. | 2* | 264C | - | | | |
| 264C | | | | 5* | See 264B | - | | | |
| 269 | 5 | 50 | 22.2 | 6* | 318 | - | | | |
| 270 | 5* | | 22.3* | 11* | See 257 | - | | | |
| 294 | - | 95 | 16.3 | 5* | 294A | - | | | |
| 294A | - | | | 10* | See 294 | - | | | |
| 301 | | | | | See 126 | | | | |
| 302 | | | | | See 140 | - | | | |
| 303 | | | | 1.9* | See 141 | - | | | |
| 304 | | | | | See 143 | - | | | |
| 306A | | 75* | 16.5* | -* | 332, 333, 336 | | | | |
| 316 | 2*, 4 | | | | See 188A | | | | |

Table C - 6. Coaxial Cable Comparison Guide (Continued)

| RG-/U | NOTES | Z NOM | CAP ($\mu\mu$f/FT) | MAX. OPER KV | EQUIV. CABLE RG-/U | CONNECTOR SERIES | HYRING (NOTE 10) INNER YIC- | OUTER YOC- | CRIMP TOOL MR8 PV- |
|---|---|---|---|---|---|---|---|---|---|
| 318 | - | | | 2.2* | See 269 | - | | | |
| 319 | -* | | 22.3* | 2.72* | See 257 | - | | | |
| 328 | - | | 85* | 15* | See 191 | - | | | |
| 329 | - | | | | See 190 | - | | | |
| 331 | - | 50* | 25* | 1.4* | See 231 | - | | | |
| 332 | - | 50* | 25* | 2.7* | See 306A | - | | | |
| 333 | - | 50* | 25* | 2.1* | See 306A | - | | | |
| 334 | - | 75* | 17* | 1.6* | See 231 | - | | | |
| 335 | - | 75* | 17* | 1.4* | See 231 | - | | | |
| 336 | - | 75* | 16.5* | 2.7* | See 306A | - | | | |

NOTES

1. General Purpose
2. High-temperature
3. Pulse
4. Special Characteristics
5. Helia® 
6. Styroflex®
7. Spir-O-Line®
8. Foamflex®
9. Armored
10. Hyrings® are Burndy products

*The listed datum element varies from cable-to-cable with the group referenced in the Equiv. Cable column. Absence of the asterisk indicates that the datum element is identical for all listed cables.

# APPENDIX D

## INDUSTRIAL CABLE/WIRE/CONNECTOR DEFINITIONS

### A

A - Denotes general family of asbestos-insulated wire.

AA - Felted asbestos, asbestos-braid, 300-volt motion picture cable. Extra-flexible stranding.

ABC - BX armored bushing 600-volt building wire; PVC insulation.

ACA - Asbestos avionics wire per MIL SPEC ANJC-48A 1000-volt; rated with cotton braid at 90°C (194°F), with glass braid at 125°C (258°F).

ACR - Cable with corona-resisting insulation.

ACSR - Aluminum Conductor, Steel Reinforced aluminum wires stranded around steel core; for high-voltage cross-country transmission lines. (See also ALUMOWELD.)

AIRCRAFT WIRE - Avionics wire for extreme conditions (temperature, altitude, solvents, fuels, etc.)

AL - Aluminum.

ALUMEL - Hoskins Mfg. Co. trademark for a highly magnetic alloy of nickel manganese, aluminum, silicon, and nine other elements. Used as the negative lead for thermocouple extension wire. (See also CHROMEL.)

AMPACITY - Current-carrying capacity in amperes.

ALUMOWELD - Copperweld Steel Co. trademark for wire composed of a thick aluminum covering welded to a steel core. (See also ACSR.)

ASESA - Armed Services Electro Standards Agency.

ASKAREL - Synthetic nonflammable insulating liquid which, when decomposed by an electric arc emits only nonflammable gases.

ASTM - American Society for Testing Materials (tests materials and attempts to set standards on various materials for industry).

AVA - Asbestos, Varnished cambric, Asbestos-braided.

AVB - Asbestos, Varnished cambric, cotton-braided.

AVL - Asbestos, Varnished cambric, and Lead.

AWAC - Copperweld Steel Co. trademark for cable composed of strands of EC-grade aluminum wire. Used primarily for power transmission lines.

G - American Wire Gauge (formerly B&S Gauge). The system most commonly used in the U.S. to describe copper wire sizes, based on the circular mil (one mil equals 0.001 inch). Gauge sizes are each 20.6 percent apart based on cross-sectional area.

M - Appliance Wiring Material (various types).

B

LCO - Wilbur Driver Co. trademark for resistance-wire, nickel-iron alloy used in devices where temperature self-regulation is required.

NDED CABLE - Two or more cables banded together by stainless steel strapping.

. or BC - Bare Copper.

LT (BELTED TYPE CABLE) - Refers to number of layers of insulation on a conductor or number of layers of jacket on a cable.

: S Gauge - See AWG.

NDABLE WIRE - Wire whose insulated surface has been etched to permit adherence to other material such as potting compounds. Usually refers to extruded TFE insulated wires.

NDED CONSTRUCTION - Insulation in which glass braid and nylon jacket are bonded together as in certain wire sizes of MIL-W-5086 Type II.

LDING WIRE - Commercial wire such as types RR, RH, RL, and TW used in building trades.

NA RUBBER - A synthetic replacement for natural rubber.

NCH STRAND - A conductor in which all individual wires are twisted in the same direction with no regard for geometrical arrangement.

- Common 600-volt armored building-wire.

C

A pair twisted together, using stranded conductor and cotton braid, commonly known as lamp cord, for pendant or portable use in dry locations, rated at 300 or 600 volts, depending on insulation thickness; $60^{o}C$ ($140^{o}F$).

WELD - A low-cost alternative to brazing to effect low-impedance electrical joints. Measured amounts of copper oxide and powdered aluminum are placed in a preformed graphite mold. The mold is clumped around the pieces to be connected, and the powder ignited. The high temperature generated can join two 1/4 inch by 2-inch bus bars within two minutes.

ED ARMOR - Armor-wires within a polyethylene jacket; often used in submarine cables.

OC MAGNET WIRE - Sprague Electric Co. trade name for copper wire coated with ceramic for high-temperature use.

OC T - Sprague Electric Co. trade name for Ceroc magnet wire coated with TFE.

CF - Cotton insulated wire impregnated with moisture-resisting, flame-retarding compound; used in lighting fixtures up to 90°C (194°F).

CFPO - Parallel CF wires with overall braid, 300-volt, 90°C (194°F).

CHROMAX - Driver Harris Co. trade name for resistance-wire alloy of nickel, chromium, and iron. A less expensive substitute for nichrome.

CHROMEL - Hoskins Mfg. Co. trademark for a non-magnetic alloy of nickel, chromium, and nine other elements used as the positive lead for thermocouple and thermocouple-extension wire. (See also ALUMEL.)

CIGARETTE WRAP TAPE - TFE insulation wrapped longitudinally rather than spirally over a conductor.

CIRCULAR MIL (CM) - Defines cross-sectional areas of conductors. An area equal to the area of a 0.001 inch diameter circle.

CM - See CIRCULAR MIL.

COMET C - Driver Harris Co. trade name of a resistance-wire alloy of nickel, chromium, and iron; use for low to medium temperatures.

COMPACT CONDUCTOR - Stranded conductor which is rolled to deform the round wires to fill the normal space between the wires in a strand.

CONCENTRIC LAY CONDUCTOR - A single conductor composed of a central core surrounded by one or more sets of six helically laid wires. Each succeeding layer consists of six additional wires applied with an opposite direction of twist.

CONCENTRIC STRAND - A central wire or core surrounded by one or more layers of spirally laid wires. Each layer after the first has six more strands than the preceding layer, and is applied in a direction opposite to that of the layer under it.

CONSTANTAN - An alloy of mainly copper and nickel used in making thermocouple wires. Iron or pure copper is the positive wire and constant is the negative wire.

CONTINUOUS DUTY - In some portable cords there are two standard number of strands of a given wire size. The one with the greater number (more flexible) is called continuous duty and the other is called stationary duty.

COPO - COPOLENE.

COPOLENE - An obsolete coax-cable dielectric material. Developed as a substitute for polystyrene, but due to undesirable characteristics it has been replaced by POLYETHYLENE.

COPPERWELD - Copperweld Steel Co. trademark for wire composed of a thick copper covering welded to a steel core. Hot rolling, cold drawing, pounding, or temperature changes do not adversely affect it.

CORD - Small, flexible insulated conductor or conductors, usually 10 AWG or smaller. Jacketed to protect the conductors. Most often used for portable applications.

C POLY - Conductive polyethlene.

CROSS-LINKED POLYETHYLENE - A dielectric material used for insulating and jacketing.

CUFIL - Phelps Dodge trademark for Spirafil coax cable with a corrugated-copper outer conductor.

UFLEX - Phelps Dodge trademark for Foamflex coax cable with a corrugated-copper outer conductor.

CV - Continuous Vulcanization. Mass-production for applying and curing rubber and rubber-like material.

CW - Copperweld conductor.

CX - Christmas-tree wire.

CXT - Christmas-tree wire.

D

DHOF - Two-conductor, heat, oil, and flame-resistant Navy-type small boat cable per MIL-C-915A.

DIRECTION OF LAY - The lateral direction in which strands run over the top of a cable as they recede from view along the cable axis.

DOUBLE SHIELD - Two shields, one over the other (maximum coverage 98 percent).

DRAIN WIRE - Uninsulated, solid or stranded, TC wire directly under and touching the shield throughout a cable. May be used in terminating the shield to ground. A labor-saver in terminating shielded cables, it is necessary only on spiral-shielded cables to eliminate the possibility of induction in the shield.

DUPLEX - Two conductors twisted together, usually with no outer covering. This word has a double meaning and it is possible to have parallel wires and jacketed parallel wires, and still refer to them as duplex.

DURACORD - Anaconda trade name for a thinner-than-normal rubber jacket and a fire-hose type knitted-cotton jacket overall.

E

- Elevator control cable, rubber insulation and braid on conductors, with or without steel supporting strand, 300-volt, braided jacket.

DS - Everyday Stress; refers to sag and tension factors for exterior horizontal-line spans.

.H.S. or EHS - Extra High Strength.

IA - Electronics Industries Association. Formerly RETMA (Radio-Electronic-Television Manufacturers Association).

NAMELED WIRE - Conductor with baked-on varnish enamel; may be 7 through 50 AWG. For winding motors, coils, transformers, etc.

O - Same as E, but with neoprene jacket.

TCHED WIRE - See BONDABLE WIRE.

F

FATIGUE RESISTANCE - Resistance to metal-crystalization that causes conductors or wires to break from flexing.

FEP or F.E.P. - DuPont trademark for extruded Fluorinated Ethylene Propylene (formerly called X-100 or FEP-100).

FERRITE - Compound of bivalent iron and carbon used in computer memory cores, transformers, etc.

FF - Two types, commercial and military:

o Commercial - UL-approved fixture-wire with stranded copper conductor, rubber insulation, cotton braid.

o Military - (MIL-W-16878D) - Voltage 1000. Temperature 200°C (392°F). Sizes 24 to 4/0 AWG. Construction: stranded T/C conductor, SR insulation with or without outer glass braid.

FHOF - Shipboard cable per MIL-C-915A. A 4-conductor, heat and oil resistant flexible cable. 600-volt, 16 AWG to 250 MCM. Rubber insulation, impervious sheath overall.

FLEXOPRENE - Standard Wire & Cable Co. trade name for neoprene-jacketed portable cord and cable.

FL POL - Fluorocarbon/Polyimide.

FOAMFLEX - Phelps Dodge trademark for lightweight low-loss coax cable consisting of a copper clad aluminum, or a hollow copper, inner conductor, foamed polyethylene dielectric, and tubular outer conductor.

FUSED SPIRAL TAPE - TFE-insulated hookup wire run through a taping head so that each successive wrap overlaps the previous wrap. The spiral-wrapped conductor is passed through an oven where the overlaps are fused together. The wire is then sized and polished.

FX - Christmas-tree wire.

FXT - Christmas-tree wire.

G

G CABLE - Type W cable with ground wires. The total CM area of the ground wires is approximately 50-75 percent of the CM area of one conductor.

GAS FILLED CABLE - Paper-insulated lead-sheath cable filled with gas which provides a self-supervised alarm system. There are three pressure types: low, medium, and high. May be installed in ducts, in air, or buried directly.

GAS PRESSURE COMPENSATED - Saturated-paper insulated cable containing tubes for the transmission of gas pressure along a cable, and with external gas fed to the tubes.

GLASS BRAID - Provides thermal and/or mechanical protection to underlying insulation of certain types of conductors.

GLYPTAL - Trade name for an insulating varnish, such as coil-coating. Resistant to heat, oil, and corrosive conditions.

RS - Government Rubber Synthetic. Government standard for BUNA-S Rubber for jacketing and insulating compounds for military wires and cables.

TO - Gas tube, sign, and oil-burner ignition cable. Stranded TC conductor, Pole E insulation, PVC jacket overall. Available in 14 AWG for 10 KV and 15 KV service.

W - Galvanized Steel.

## H

H FILM - DuPont trademark for high-temperature polyimide resin film.

HARD DRAWN - Refers to the temper of conductors drawn without annealing or that may harden in the drawing process.

HDP - High Density Polyethylene.

HELIAX - Andrew Corp. trademark for low-loss pressurized-air and polyethylene-foam dielectric coax cable with convoluted copper or aluminum outer conductors. Air dielectric cables use a polyethylene-strip helically-wound insulator.

HF - Heavy Formvar magnet wire. Soft BC wire with baked synthetic insulation overall.

HI-VOLTAGE - Operating voltage over 600 volts.

IPD - Heater cord, rubber and asbestos insulated, with overall braid.

IPN - Heater cord, neoprene, parallel, two-conductor.

.S. or HS - High Strength.

SJ - Rubber jacketed heater cord; 300-volt 18 and 16 AWG 2 and 3 conductor, BC conductor, rubber insulation, asbestos cotton braid, rubber jacket overall.

SJO - HSJ with neoprene jacket.

T - High Temperature.

W - Heavy-Wall, 2500-volt hookup wire per MIL-W-76.

YPALON - A DuPont product resistant to oxidation by ozone, sun, weather, heat, and chemicals.

## I

.S.A. or IMSA - International Municipal Signal Association (fire-alarm cable specifications).

TERCALATED TAPES - Two or more tapes, generally of different composition, applied simultaneously so that a portion of each tape overlays a portion of the other tape.

TERSTICES - Space between things closely set, as between round wires in a strand of a conductor.

IPCEA - Insulated Power Cable Engineers Association. (Association of power-cable engineers from many companies.) Their object is to establish standards in the insulated power cable industry.

I POLY - Irradiated Polyethylene.

IRRADIATED POLYOLEFIN - A dielectric compound which has been exposed to electron-beam radiation.

K

K - KARMA

KAPTON - DuPont trademark for polyimide resin.

KARMA - Driver Harris Co. trade name for a resistance-wire alloy of nickel, chromium, aluminum, and copper.

KEL F - Polymonochlorotrifluoroethylene per MIL-W-12340. High temperature insulation $-55^{o}$ to $+135^{o}C$ ($-68^{o}$ to $+275^{o}F$) used on hookup wire and for tubing where temperatures are beyond the range of PVC, and where resistance to solvents is needed.

KOVAR - Alloy of iron, nickel, and cobalt.

KYNAR - Pennwalt Corp. trademark for $VF_2$ Vinylidene fluoride resin. Has high dielectric strength and abrasion-resistant characteristics.

L

LAMINATES - A build-up of layers of material to increase thickness as in VCB.

LAMP CORD - Flexible stranded-conductor cord, rubber or plastic insulated, used in wiring lamps, household fans, and similar appliances not subject to hard usage. UL approved.

LEACHING AND NON-LEACHING - In a leaching wire the plasticizer will migrate (leave the vinyl compound) when exposed to the heat of baking. Wire so treated becomes brittle and hard. Non-leaching wire is desirable for use as motor lead wire.

LEAD CURED - Cured or vulcanized in a lead mold.

LITZ WIRE - Fine individually-insulated strands specially woven or braided together to reduce skin effect.

L.T. - Low Temperature non-contaminating jacket.

LW - Light Wall, 300-volt hookup wire per MIL-W-76.

M

MAGNET WIRE - Insulated copper wire for winding coils, motors, and transformers.

MAG. OX. - Magnesium Oxide.

ARKER TAPE - Tape laid parallel to the conductors under the cable sheath, imprinted with manufacturer's name and specification to which cable is made.

IARKER THREAD - Colored thread laid parallel and adjacent to the strand in an insulated conductor which identifies the manufacturer and sometimes the specification to which the wire is made.

ICM - One thousand circular mils, e.g., 500 MCM = 500,000 CM.

ICOP - Multiple conductor (16 AWG) oil resistant, portable, synthetic-insulation cable with fillers, binder, and impervious sheath overall per MIL-C-915A.

IELAMINE - A thermosetting resin (melamin formaldehyde) with excellent resistance to acids and alkalies, good resistance to water and solvents, high strength, and high insulation resistance relative to plastics.

IFT - Abbreviation for 1000 feet.

IHD - Medium Hard Drawn.

HFF - Multiple conductor (16 AWG) heat and flame resistant, flexible synthetic-resin and felted-asbestos insulation-rayon braid, cabled with fillers, binder, and impervious sheath overall per MIL-C-915A.

I - Cable of one or more conductors using mineral for insulation and overall solid-metal tube sheath.

IGRATING OR MIGRATION - Movement of non-resinous plasticizer in PVC which takes place at extreme temperatures. Jacket plasticizer will contaminate the polyethylene core of a coax cable and thus change its electrical characteristics.

IL - One one-thousandth of an inch. The unit used in measuring wire diameter and insulation thickness. (See CIRCULAR MIL.)

NIATURE WIRE - Insulated conductors of about 20 to 34 AWG with smaller than usual overall diameter.

- Two types:

o Type A-600-volt, UL-approved AVC Mine locomotive cable. Will not carry flame or support combustion.

o Type B - Used as lead-wire for electric motors. Stranded-copper conductor; PVC, rubber, or rubber and braid insulation.

- Machine-Tool wire used for internal wiring of appliances or tools. Solid or stranded conductor, thermoplastic insulation.

W - Machine-Tool Wire, plastic insulated, 600-volt; varies 90°C (194°F) to 105°C (219°F).

- 1000-volt plastic-insulated wire per MIL-W-76.

LAR - A DuPont synthetic compound with high dielectric qualities.

N

Nichrome

C - Nickel Clad Copper

N.E.C. or NEC - National Electric Code, which stipulates the use of wire and cable in building and factories. Most city electrical codes are derived from it. Compiled by fire underwriters and wire and cable manufacturers.

N.E.M.A. or NEMA - National Electric Manufacturers Association. Known for standardization of electrical motors and gear reducers and for wire and cable specifications.

NEOPRENE - DuPont trade name for polychloroprene, a rubber-like compound notable for resistance to the effects of oil and solvents.

N.E.S.C. or NESC - National Electrical Safety Code.

NICHROME - Driver Harris Co. trade name for a nickel, chromium, and steel resistance-wire alloy.

NICKEL CLAD COPPER WIRE - Wire with a layer of nickel rolled and fused to a copper core before drawing, with the nickel area about 30 percent of the conductor area.

NON-CONTAMINATING - Refers to PVC jacketing material whose plasticizer will not migrate.

NON-LEACHING - See LEACHING.

NON-MIGRATING - Same as NON-CONTAMINATING.

NPC - Nickel Plated Copper.

## O

OIL FILLED CABLE - Paper-insulated, lead-sheathed cable, into which high grade mineral oil is forced under pressure, saturating the insulation to prevent moisture and gases from entering. Easier to detect flaws due to leakage, as the oil is kept under constant pressure.

OIL FILLED PIPE CABLE - Oil-filled cable in rigid pipe instead of lead sheath; sometimes a standard oil filled cable inserted into rigid pipe, under pressure, both units being oil-filled. (Usually for much higher voltage; kept under constant pressure.)

OKOCORD - Okonite Co. trade name for portable power cable.

OKOPRENE - Okonite Co. trade name for neoprene-covered wire and cable.

OUTGASSING - Dissipation of gas from a dielectric, evidencing decomposition.

## P

P - Reinforced portable cord. Stranded-copper conductor. Separator, rubber insulation, cotton braid, twisted conductor, and rubber jacket cotton braid overall. For drop-cords and portable lines in dry places.

PAN CURED - Method of vulcanizing in which insulated wires are coiled in pans and vulcanized under pressure with live steam.

PAPER INSULATION - Used for telephone cable, hi-voltage cable, and magnet wire. Has high dielectric strength. Widely used in telephone cable, but generally being replaced because of new developments.

M-109 - Trailing mine cable with outer sheath of flame-resistant neoprene. Conforms to requirements of Pa. Bureau of Mines and Federal Bureau of Mines.

TROL WIRE - Wire insulated to withstand immersion in gas and oil. Usually thermoplastic, with or without nylon jacket.

'E TYPE CABLE - Pressure cable. Pressure-medium is a loose rigid metal pipe.

AIN ENAMEL - Type of magnet wire; dip-coated with varnish and then baked.

SJ - Light duty, all rubber, parallel, two-conductor, 300-volt cord.

T - Same as PLSJ except plastic.

R - Control cable using Polyethylene and Nylon on the conductors and PVC jacket.

- (1) Rayon parallel lamp-cord stranded copper conductor, separator, rubber insulation, cotton braid, rayon braid overall. Used in dry places, on small appliances.

(2) Lamp cord insulated with rubber and braid, parallel laid and overall cotton braid.

OY - Polyethylene.

LYAMIDE - Same as Nylon.

LYCHLOROPRENE - Chemical name for Neoprene. Used for jacketing wire and cable subject to rough usage, moisture, oil, grease, solvents and/or chemicals. Also used as low-voltage insulating material.

LYETHYLENE - Family of basically pure hydrocarbon-resin insulating materials, often with small amounts of additives to impart special properties. All members are electrically superior to any other extrudable solid dielectric in use. All have high insulation resistance, high dielectric strength, low dielectric constant, low dielectric loss at all frequencies, excellent resistance to cold flow, and good abrasion-resistance. Some are resistant to sunlight, weathering, chemicals, and flame. Widely used on telephone, signal, and control cables, high-frequency cables, high-and-low-voltage power cables, line wire, neutral supported secondary and service drop cables. Suitable for direct earth burial. Ratings vary from 75°C (167°F) up.

.Y F - Polyethylene Foam.

.Y FC - Polyethylene Flooding Compound.

.YIMIDE - A relatively high-temperature plastic dielectric or jacketing material.

.YOLEFINS - Family of plastics including cross-linked polyethylene and various ethylene copolymers.

.YPROPYLENE - A thermoplastic with good electric characteristics, high tensile strength, and heat-resistance.

YSULFONE - A polymer highly resistant to mineral acid, alkali, and salt solutions. Good dielectric properties up to 178°C (350°F).

Y U - Polyurethane.

.YURETHANE - Enamel that has excellent moisture resistance, easily soldered, also has excellent winding properties. Used as a magnet-wire dielectric.

POLYVINYLCHLORIDE - Also known as PVC or Vinyl. A family of insulating compounds. Can be compounded to provide resistance to moisture, cold, heat, flame, oils, chemicals, ozone for low-voltage applications. Temperature ratings up to 105°C (219°F) recognized by UL for certain applications. Widely used for T and TW wire, series street-lighting cable, MTW, hookup and appliance wiring, overhead line wire, control and signal cables.

POSJ - Also known as Type SP. Rubber parallel lamp cord. Stranded copper conductor, cotton separator, rubber insulation. Mid-Rip (Ripcord) used on small appliances not subject to hard usage.

POT - Also known as Type SPT. Plastic parallel lamp cord; stranded-copper conductor, plastic insulation with Mid-Rip (Ripcord) for small appliances.

POTTED - Cemented with special compound to make moisture proof or air tight.

PRESSURE CABLE - Oil-impregnated, paper-insulated conductors. Lead or steel pipe outer covering, in which positive pressure is maintained constantly. Has higher dielectric strength, greater insulation stability, and increased ampacapacity. Saves space.

PS - Polystyrene.

PSH - Three-conductor cable. Each conductor has PS tape over the insulation and contains ground wires. Extra-heavy insulation. Recommended for intermediate voltage where extra safety factor is needed.

PS TAPE - Non-metallic shielding, very flexible. Remains in positive contact with insulation. Prevents formation of air gaps between conductor and insulation.

PVC - See POLYVINYLCHLORIDE.

PVC-105°C - High-temperature Vinyl.

PW - Moistureproof, reinforced portable cord (formerly PWP). Stranded-copper conductor, separator, rubber insulation, cotton braid, twisted conductors, rubber drop cords. Jacket is cotton braid overall with moistureproof finish. Used in damp places for drop-cords, portable lines.

PWP - See PW.

R

R - 600-volt stranded or solid copper conductor, rubber-insulated, cotton braid (rubber filled tape, 6 AWG and larger). Cotton braid saturated with moisture-resisting, flame-retarding compound smoothly finished. Used for power wiring.

RESIN - A solid or semi-solid organic substance, originally of plant origin but usually synthesized now. Non-conductor of electricity, soluble in organic solvents, but not in water. Used in insulating, potting, encapsulating, etc.

RETMA - See EIA.

RF - TC conductors, rubber insulation, cotton braid saturated with moisture-resisting flame-retarding compound, smoothly finished in white, black, red, green, blue, and yellow. Lubricated-surface finish permits easy pulling through conduit.

RHRW - TC conductors, rubber insulation, saturated braid, flame and moisture resistant finish for moist locations.

/ - 75°C (167°F), rubber insulated, heat and moisture resistant insulation with moisture-resistant, flame-retardant non-metallic outer covering. Generally used in wet locations.

GE-MARKER - One or more ridges running laterally along outer surface of plastic wire for identification.

M. - Resin-Insulated Magnet Wire.

- 600-volt TC conductors, solid or stranded, rubber insulation, rubber-filled tape (cotton braid on small sizes only) with lead sheath. Used in moist locations.

JFJ - Denotes Rubber-Lead-Jute-Flat-Armor-Jute. Metallic parkway cable for earth burial without additional protection, except at points of extreme mechanical hazard. Provides economical, easy to install, dependable underground system, well protected from mechanical injury. Used for underground street lighting circuits, railroad yard lighting and signal systems, airport power and lighting circuits, and in industrial plants and mines.

)MEX - Trade name for non-metallic sheathed cable (N) Romex UF multi-conductor non-metallic sheathed cable.

PE LAY STRAND - A conductor made of multiple groups of filaments. A 7 x 9 rope lay strand has 19 wires laid into a group and then 7 such groups laid cabled into a conductor.

- All-rubber non-metallic underground cable for direct burial in the earth or in conduit. Has heat and moisture resistant insulation and outer neoprene jacket.

3. - Rubber.

S

600-volt senior-service rubber-insulated portable cord available in 18 AWG 2-conductor through 6 AWG 4-conductor.

- SR insulation with asbestos or glass braid overall for use up to 125°C (258°F).

3 - Silver-plated Cadmium Bronze.

C - Silver-Coated Copper.

W - Silver-plated copperweld conductor.

CTOR STRAND - A group of wires laid in triangular shape with rounded corners, for use as one conductor of 3-conductor cable with a 120-degree angle between faces, and with a 90-degree angle for 4-conductor cable.

GMENTAL CONDUCTOR - In single-conductor cables 1,000 MCM or more, the conductors are divided into three or four segments insulated from each other by paper tape to reduce impedance in AC circuits.

LENIUM CURE - Process used on neoprene and rubber jacketed wires and cables to make a dense, tough, durable jacket.

LF-SUPPORTING AERIAL CABLE - One or more insulated conductors assembled or cabled with a steel core or attached to a separate steel cable, which supports the weight of the cable. May be from pole to pole or vertical in a tower.

SELF-SUPPORTING CABLE - Cable with steel support-strand capable of supporting its own weight across spans.

SEMI-CONDUCTING JACKET - Jacket of sufficiently low resistance so that its outer surface can be kept at substantially ground potential by a grounded conductor in contact with it at frequent intervals.

SERVE - A separator applied directly over a conductor; consists of one or a combination of materials such as paper, cotton, silk, nylon, or rayon.

SF - Solid or stranded SR-insulated fixture wire.

SFF - Flexible grade SF.

SH-A - Portable power cable rated 5 kV, commonly known as shovel cable; neoprene jacket, usually three or four individually shielded conductors.

SH-B - Similar to SH-A except shield over all conductors.

SH-C - Similar to SH-B except with ground.

SH-D - Similar to SH-A except with ground.

SHFS - Nomenclature for 600-volt switchboard wire per MIL-C-915A, insulated with PVC and felted asbestos, overall flameproof cotton braid.

SHOF - Navy-type single conductor, heat and oil resistant, flexible shipboard cable.

SHOVEL CABLE - See SH-A.

SILICONE IMPREGNATED - Saturation of insulating tapes or braids with a silicone varnish compound (process may be performed under a vacuum). The compound serves as a heat and flame retardant and as a binder.

SINTERED - Usually refers to curing of TFE.

SJ - 300-volt junior-service rubber-insulated UL-approved portable cord, rubber jacket in 18 AWG 2-conductor through 16 AWG 4-conductor.

SJO - 300-volt junior-service rubber-insulated UL-approved portable cord, neoprene jacket.

SJT - 300-volt junior-service PVC-insulated UL-approved portable cord, PVC jacket. (See also ST.)

SK - Dielectric constant of insulation material.

SKELETON BRAID - Widely separated braid of fiber, copper, or steel used to hold core together, for reinforcing jacket, or for shielding.

SKIN EFFECT - The natural tendancy for alternating-current to concentrate near the surface of a conductor.

SO - 600-volt senior-service neoprene-jacket UL-approved portable cord. Available in 18 AWG 2-conductor through 10 AWG 4-conductor.

SOLDERABLE NYLON LITZ - Litz wire made up of SOLDEREZE strands with a nylon serve overall.

SOLDEREZE - Trade name for magnet wire insulated with Polyurethane base enamel.

SP - See POSJ.

E FACTOR - Given values in coil-winding for amount of space available.

- Silver Plated Copper.

AFIL - Phelps Dodge trademark for low-loss pressurized air-dielectric coax cable consisting of a solid copper center conductor covered with a solid-polyethylene continuous helix and a tubular outer conductor.

AL SHIELD - A shield of fine stranded wires applied spirally rather than braided.

HIELD - Silver-Plated shield.

- Lamp cord, parallel, all rubber, two-conductor, 300-volt, no ground.

- Similar to SP-1; heavier insulation.

- Similar to SP-2; heavier insulation; may have ground.

CIFIC INDUCTANCE CAPACITY (SK) - Dielectric constant of insulation material.

- See POT.

1 - Same as SP-1 except in plastic.

2 - Same as SP-2 except in plastic.

3 - Same as SP-3 except in plastic.

(1) Silicone rubber. (2) Silicone Rubber, 600-volt insulated cable.

W - Silicone rubber insulated, overall glass braid, with NPC conductor, flexible stranding, 600-volt.

V - 2500-volt insulated hookup wire per JAN-C-76.

F - 1000-volt RF-wire; polyethylene, glass braid per JAN-C-76.

(1) Semi-solid. (2) Stainless Steel.

Same as SJT, except 600-volt.

NCOTE - Standard Wire & Cable Co. trade name for plastic-insulated wire.

NFLEX - Standard Wire & Cable Co. trade name for rubber-jacketed portable cords and cables.

NFLEX TWIN - Duplex laid parallel cable, may have waxed-braid or PVC jacket. Used for trailer and trunk electric brakes and in drive-in theaters to hook up speakers.

TIONARY DUTY - See CONTINUOUS DUTY.

ANDED CONDUCTOR - Conductor made with a specified number of strands. Rope lay strand, for example, is a conductor made of multiple groups of strands (filaments). A 7 x 19 rope lay strand has 19 wires laid into a group and then 7 such groups cabled laid into a conductor.

IP INSULATIONS - One or more longitudinal strips of thermosetting material folded around a conductor and vulcanized after application.

STYROFLEX - Phelps Dodge trademark for coax cable similar to Spirafil but with a polyethylene-tape helix and an aluminum sheath overall.

SV - Vacuum cleaner cord.

SVO - Same as SV except neoprene jacket.

SVT - Same as SV except non-marking plastic jacket.

SWEEP TEST - Oscilloscope-test given to check attenuation, as in coax cable.

SWEPT COAX - Coax cable which has been sweep-tested and certified.

SWITCHBOARD WIRE - Asbestos-insulated wire such as TA or AVB, used to wire switchboards and control apparatus. Heat, flame, and corrosive-vapor resistant.

SYN. RUB. - Synthetic conductive rubber.

## T

T - Old UL designation for switchboard wire insulated with thermoplastic lead wire.

TA - UL designation for switchboard wire insulated with thermoplastic felted asbestos.

T.C. or TC - Tinned copper.

TCW - Tinned copperweld.

TEFLON - DuPont trademark for TFE.

TEFLON COAXIAL CABLE - DuPont trademark for coax cable with TFE dielectric.

TEFLON IMPREGNATED - DuPont trade name for saturation of heat-resistant fibrous glass braid with TFE suspensoid. After saturation, the TFE is cured.

TELEPHONE WIRE - A general term, referring to communication wire. Refers to a class of wires and cables, rather than a specific type.

TELLURIUM CURE - A curing process similar to selenium cure, except tellurium is used.

TEW - Canadian Standards Association nomenclature for appliance-wire plastic insulated, solid or stranded conductor, 600-volt.

TEXTILE BRAID - Braid of cotton, silk, or synthetic-fiber threads.

TF - UL designation for fixture wire, solid soft-copper conductor, insulated with thermoplastic lead wire.

TFE - Polytetrafluoroethylene, a fluorocarbon resin.

TFF - Same as TF, except stranded-copper conductor.

TG - TFE tape with overall glass braid, stranded NCC conductor.

THERMOCOUPLE WIRE - Wire drawn from special metals or alloys and calibrated to U.S. Bureau of Standards or Instruments Society of American Standards specifications.

ERMOSTAT WIRE - Single or multi-conductor wire, soft solid BC conductor, usually PVC-insulated. May be twisted and/or jacketed. May have enameled or nylon-covered conductors and may have metal armor covering. May also have asbestos insulation. Used to transmit electrical signals between the thermostat and the heating or cooling unit.

IOF - Navy designation for triple conductor, heat, oil, and flame resistant, portable flexible cable per MIL-C-915A.

HW - Building wire, plastic insulated, heat, flame, and moisture resistant, 75°C (167°F).

HWN - THW with overall nylon jacket.

INSEL CORD - Cord made with tinsel conductors for maximum flexibility. Used mostly on headsets, handsets, etc., where repeated flexing is necessary.

INSEL WIRE - Low voltage, stranded wire where each strand is very thin copper ribbon spirally wrapped around textile yarn. Insulation is generally textile braid. Intended for severe flexing.

PA - A 125-volt, 204°C (400°F) wire. Stranded tinned conductor, glass braid or tape, impregnated felted asbestos, and asbestos braid.

RANSITE - Johns-Manville trade name for Asbestos-Cement in pipe and fitting form, for use in the building industry as electrical conduit.

RAP WIRE - Low-voltage wire used at hinge points, where severe flexing occurs, such as in burglar alarm systems. Made with tinsel conductor.

RIAD - See TRIPLEX.

RIAXIAL - Three-conductor cable with one conductor in the center, a second circular conductor concentric with the first and a third circular conductor insulated from and concentric with the first and second, usually with insulation, and a braid or impervious sheath overall.

RIPLEX - A group of three insulated conductors twisted and/or sheathed or held together mechanically. Usually color-coded or ridge-marked.

RPA - A 125-volt, 342°C (650°F) wire. Stranded NCC conductor, glass braid or tape, impregnated felted asbestos, and asbestos braid.

TOP - U.S. Navy designation for twisted-pair telephone, oil-resistant, portable, synthetic insulation, binder, jacketed with an impervious sheath. A dash-number suffix indicates the number of pairs. Per MIL-C-915A.

TRS - Navy designation for twisted-pair, telephone, radio, shielded, binder, jacketed with impervious sheath. A dash-number suffix indicates the number of pairs. Per MIL-C-915A.

TRSA - Navy designation for twisted-pair, telephone, radio, each pair shielded; armored. A dash-number suffix indicates the number of pairs. Per MIL-C-915A.

TW - UL designation for thermoplastic-insulated wire for use in conduit and underground and wet locations. A common building wire having a soft, solid or stranded BC conductor.

TWIN CABLE - A pair of insulated conductors of 8 AWG or larger, twisted and/or sheathed or held together mechanically and not identifiable from each other.

TWIN WIRE - A pair of insulated conductors, 9 AWG or smaller, twisted or bonded together and not identifiable from each other.

U

UF - Single or multi-conductor, with or without ground, used for direct-burial. Underground feeders and branch circuits between buildings, yard lights, and similar installations.

UL - Underwriters Laboratories, Inc. (Maintains and operates laboratories for the examination and testing of devices, systems, and materials relative to life, fire and casualty, hazards, and crime prevention. Sponsored by the National Board of Fire Underwriters.)

UNILAY CONDUCTOR - A central core surrounded by one or more concentric layers of helically wound strands in a fixed geometrical arrangement with the direction of lay the same for each layer (and the central core).

UNSINTERED - Uncured (usually to differentiate between cured and uncured TFE tape).

URC - Nomenclature for weatherproof wire.

USE - Underground-Service Entrance, neoprene-jacketed cable.

V

VCB - Varnished Cambric with flame and moisture resistant cotton braided jacket.

VCL - Varnished-Cambric conductor-insulation, lead-jacketed cable.

VINYL - See POLYVINYLCHLORIDE; also known as PVC.

W

W - Heavy-duty portable power cable, neoprene jacket, single or multiple conductors, 600-volt.

WIRE - A slender rod or filament of drawn metal; a single conductor. If larger than 9 AWG, or multiple-conductor, it is usually called cable.

WIRE BRAID - Flexible wire of small-size strands woven together in tubular form. Used for shielding or connections where constant flexing is required.

WIRE GAUGE AWG - See AWG.

X

X-100 - See FEP.

2BC - Double bare copper shield.

2S - Silver plated copper double shield.

2TC - Tinned copper double shield.

3TC - Tinned copper triple shield.

4TC - Tinned copper quadruple shield.

# APPENDIX E

# LIGHTNING PROTECTION

Due to certain atmospheric processes, charges collect in clouds; equal and opposite charges are induced on the ground. As the charges build up, the potential gradient in the air increases until the gradient exceeds the dielectric strength of the air between cloud and ground, the air breaks down. A streamer starts from cloud to earth with a potential from 5 to 20 megavolts between cloud and earth. Lightning currents are 85 percent negative, varying in crest magnitude from less than 1,000 amperes to more than 160,000 amperes.

Lightning behaves in terms of a complete electrical circuit. The charge in a cloud wants to reach and distribute itself through the ground and tends to use tall objects. Good conductors such as metal mast often carry lightning current without being damaged. Nonmetallic objects such as trees are poor conductors, but are still better conductors than air. The danger with nonmetallic objects is that lightning currents will heat them to the point they will explode.

The lightning charge tends to distribute itself when it reaches ground. Since current travels more easily in wet than in dry ground, there is more danger from ground voltages in high-resistance soil than in low-resistance soil. A secondary danger occurs through voltages induced in large metal objects near a lightning strike. No known form of protection can prevent a lightning discharge. Damage comes from electromagnetic fields caused by the lightning stroke, voltage drops in the ground system, structural damage from heat and mechanical forces. The goal of protection is to provide a path by which a discharge can be conducted to earth without entering a vulnerable part of the equipment and without inducing voltages in nearby metal objects.

## E.1 LIGHTNING AS A SOURCE OF EMI

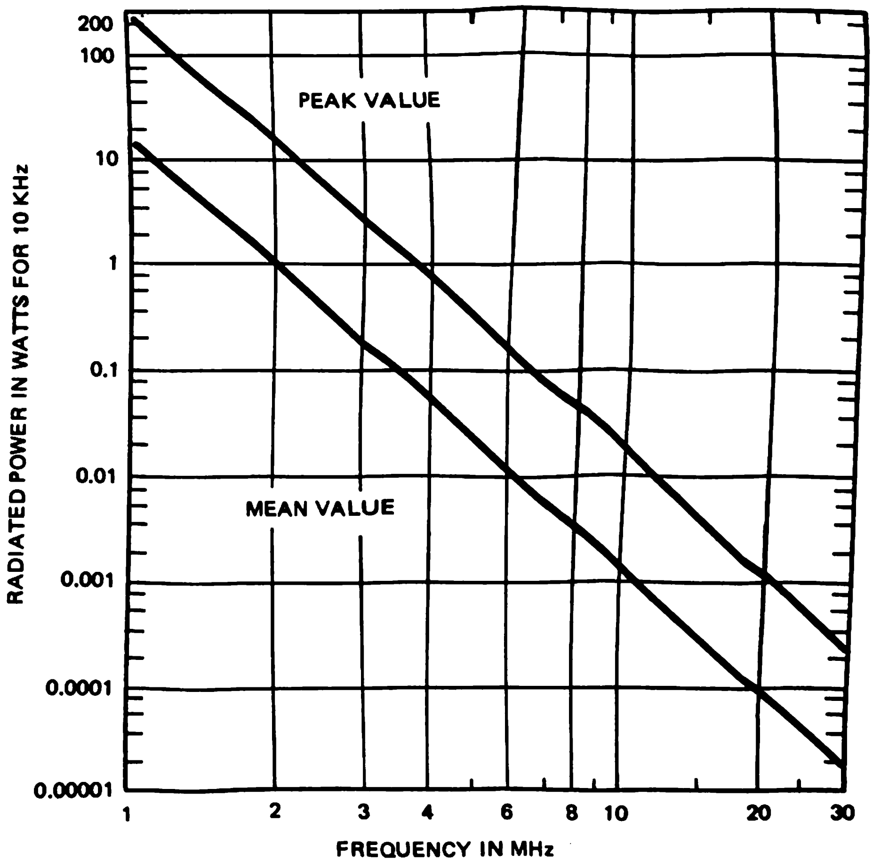
To better understand the cause of Electromagnetic Interference (EMI) resulting from lightning discharge, see figure E-1. Radiated voltage levels produced by lightning discharge are significant. At 400 MHz, an average field strength of 397 $\mu$V/m, at a 1-kHz bandwidth was measured for 37 flashes at a distance of one statute mile.

The major sources of damage to electronic systems are the coupled surge-voltages and overvoltages in sensitive circuits. Such damage can be prevented by using protective devices. Many EMI control specifications require that equipment not sustain damage when a voltage transient of plus and minus 50 volts is placed on the power lines, and MIL-STD-461 requires transients at twice the line voltage or 100 volts. This is not enough to prevent damage due to lightning surges on power lines.

## E.2 SHIELDING AGAINST LIGHTNING

Shielding is the interception of lightning strokes by good, well-grounded conductors such as lightning rods and overhead ground wires.

There is no evidence that a mast or rod less than 500 feet high contributes to lightning-stroke formation. Whether the lightning rod is blunt or sharp is inconsequential. A typical shielding mast offers protection against direct strokes within a cone as shown in figure E-2.




NOTE: THE PEAK EQUIVALENT RADIATED POWER FROM A TYPICAL DISCHARGE, WHICH IS COMPOSED OF A NUMBER OF STROKES AVERAGING ABOUT 4 OR 5, RANGES FROM 200 W. AT 1 GHz TO MW AT 20 GHz.

AIAD 047

Figure E - 1. Effective Radiation Power of a Single Stroke

## E.3 LIGHTNING ARRESTERS

Lightning arresters provide by-passes around insulation. If lightning strikes a circuit, very high transient-currents tend to flow. If there is a high impedance or insulation between point of entry and ground, very high and dangerous voltages are created. A lightning arrester must perform as an insulator under normal conditions but must be a good conductor for lightning currents and afterwards must return to the insulator state to prevent system current from opening circuit breakers or fuses.

The closing-mechanism in a lightning arrester is usually a spark gap which is normally insulating, but conducts by sparking when transient voltages reach the spark-potential of the gap. This sparking forms the circuit for the lightning current. After the circuit is established, system current continues to flow after lightning current ceases. Lightning arresters must be designed to interrupt these system currents. Simple spark gaps are unable to interrupt system currents, but depend on circuit breakers or fuses in the system to prevent power outages.

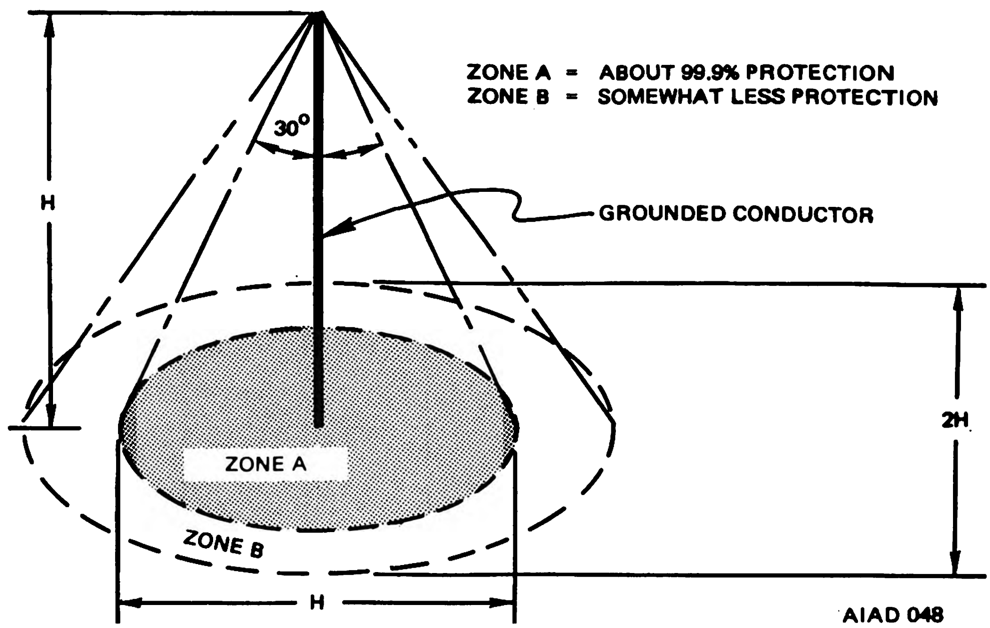



Figure E - 2. Cone of Protection Provided by a Vertical Grounded Conductor

## E.4 SPARK GAPS

Simple spark gaps are more economical than lightning arresters. Circuits with very low voltages, and those that are normally unenergized, are ideal for application of air gaps for lightning overvoltage-protection. Figure E-3 shows the operating ranges of some generic protective devices.

## E.5 TYPES OF LIGHTNING ARRESTERS FOR LOW VOLTAGE CIRCUITS

Lightning arresters are generally classified as DC or AC arresters, depending on the circuit which is used. (It is more difficult to interrupt system follow-currents in DC than in AC circuits, mainly because the DC current never passes through zero magnitude.)

Generally, valve or gap arresters are used on low voltage signal and control circuits. Valve arresters limit the system current by the action of the arrester itself, making the system current independent of short circuit currents.

A valve arrester of a particular voltage rating can be applied to any system operating on the same voltage frequency; valve arresters have no system-current ratings. The voltage rating defines the maximum voltage applied across the arrester's line and ground terminals against which it will interrupt system current reliably and restore itself to an insulator after it has been discharged by a surge. The normal rating for 120/208 volt AC system arrester is a 175-volt AC valve type. A typical DC valve type arrester rating is 75 volts for high short-circuit capacity.

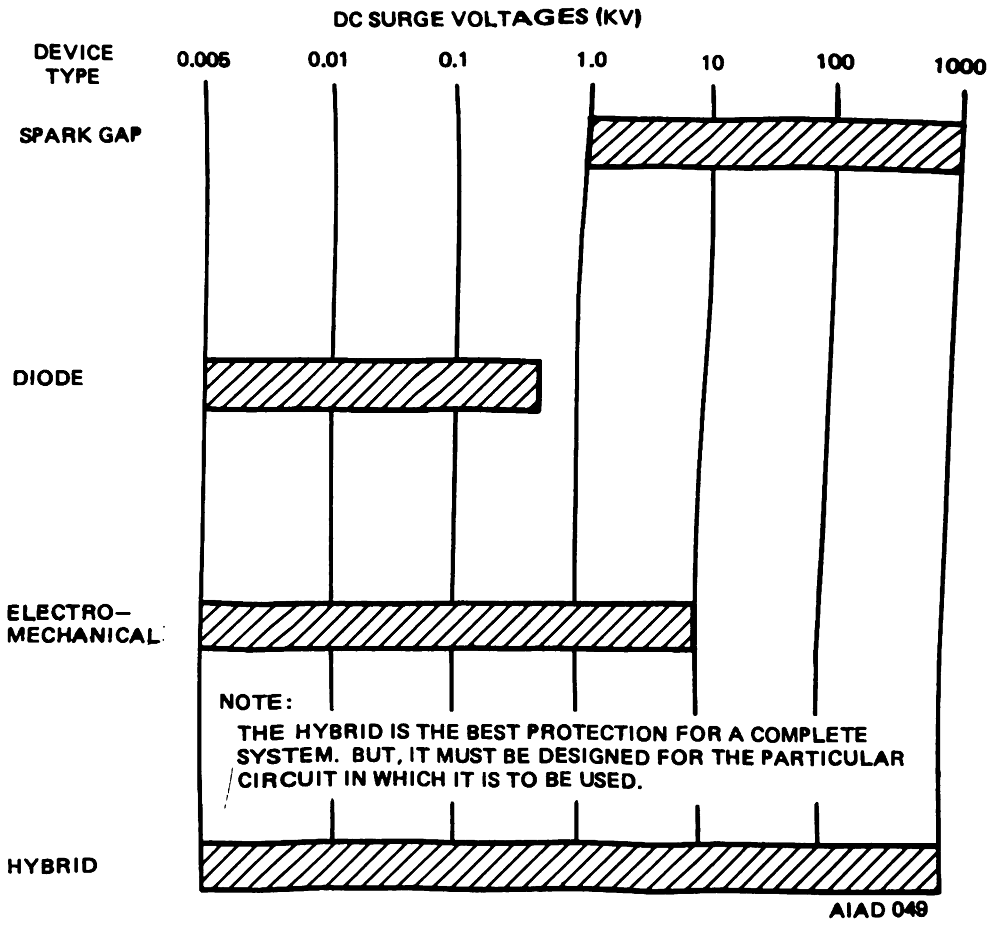



Figure E - 3. Operating Ranges of Generic Protective Devices

The frequency of occurrence of discharge-current crest of arresters connected to unshielded lines in areas of 30 to 40 thunderstorm days/year has been measured and recorded as follows:

| Amperes | Frequency |
|---|---|
| 100K | Once in 14,300 yrs |
| 65K | Once in 4,000 yrs |
| 20K | Once in 200 yrs |
| 10K | Once in 45 yrs |
| 5K | Once in 13 yrs |
| 1.5K | Once in 3.5 yrs |
| .830 | Once in 2 yrs |
| .100 | Once in 1 yr |

## E.6 GROUNDING

To have an effective lightning protection system, proper grounding from equipment ground to earth ground is essential. Earth resistivity depends on the moisture and mineral-salt content of the soil. There is a marked difference between ordinary resistance and resistance to high surges because of sparking between particles of low-resistivity soil under surge conditions. There is a definite limit in the number of parallel grounding rods that will appreciably lower the ground resistance from that of a single grounding rod over a particular land area. For example, if a single 10-foot rod has a resistance of 25 ohms; in order to reduce this to 5 ohms, eight rods would be required over an area of 1000 square feet. An infinite number of rods in that area would be required to lower the ground resistance to approximately four ohms.

## E.7 LIGHTNING ARRESTER GROUND

o Coordinate the lightning-arrester ground subsystem and ground subsystem for noncurrent carrying parts.

o Structure ground to earth ground resistance should be less than the NEC-required 25 ohms.

Lightning Protection

| Size of Largest Conductor | AWG No. of Copper Grounding Conductor |
|---|---|
| AWG 2 or larger | 8 |
| AWG 1 or 0 | 6 |
| AWG 2/0 or 3/0 | 4 |
| Over AWG 3/0 to 250 MCM | 2 |
| Over 250 to 600 MCM | 1/0 |
| Over 600 to 1,100 MCM | 2/0 |
| Over 1,100 MCM | 3/0 |

## E.8 LIGHTNING PROTECTION FOR BUILDINGS

### E.8.1 Conductors

Protection-system materials shall be resistant to, or protected against, corrosion. Use no combination of materials that forms an electrolytic couple except where moisture is permanently excluded from the junction. In aluminum systems, use only aluminum or aluminum-alloy fixtures and fittings except for ground connections (galvanized iron ground rods and clamps, protected against corrosion, may be used). Copper or copper-covered ground rods and leads may be used only if clamps connecting the down conductors to the grounding equipment are designed for connecting the two dissimilar metals. Make connection of aluminum down conductors to grounding equipment at least one foot above grade.

### E.8.2 Air Terminals (Points)

a. Form. Points may be of any solid or tubular cross-section.

b. Height. Point tips shall be at least ten inches above the object to be protected. (On flat surfaces a height greater than ten inches is desirable. Proper height depends on the contour of the object being protected; a spire, for instance, does not require so high a point as a silo having a peaked but much less sloping roof.)

c. Attachment. Points shall be substantially constructed and be part of or secured to the roof saddle or base by screw or slip joints. The conducting cross-sectional area of the base shall be at least equal to the conducting cross-sectional area of the point.

d. Supports. Secure points against overturning either by attachment to the object to be protected or by means of braces rigidly attached to the object. Points may be secured to chimneys with expansion-screw fasteners or a band surrounding the chimney. On masonry, holes should be made in the brick or stone rather than in the mortar joint. On woodwork, lag-screws or strap fasteners may be used.

e. Corrosion. Protect any part of a copper system exposed to direct chimney or other corrosive gases with a continuous hot-dip lead coating extending at least two feet below the top of the chimney. Protect other metals by appropriate means. Protect aluminum parts, including fasteners and anchors, from direct contact with masonry which is, or may become wet or damp.

E.8.3 Location of Air Terminals and Conductors

a. Provide points for all structural parts likely to be struck, and damaged by, lightning.

b. Nonmetallic Projections. In the case of nonmetallic projections such as chimneys, place the point on or attached to the object to be protected, where practicable, otherwise within two feet of it.

c. Ridges, Parapets, and Edges of Flat Roofs. Along ridges, parapets, and edges of flat roofs, place 24-inch or longer points 25 feet or less apart (more closely spaced, shorter points are not recommended).

d. Metal Projections and Parts of Buildings. Metal projections and parts of buildings (ventilators, smoke-stacks, etc.) likely to be struck, but not appreciably damaged by lightning need not be provided with points, but shall be bonded to the main conductor with metal of the same weight per unit length as the main cable. Projecting parts (chimneys, towers, water-tanks, etc.) are most likely to be struck. The roof edge is the part most likely to be struck on flat-roofed buildings. On large, flat or gently sloping roof areas, it is desirable to erect additional points so that there is 50 feet or less between adjacent points. Additional conductors are required to provide at least two paths to ground for each point. (See figure E-4.)

In some buildings relatively thin layers of brick, stone, tile, or similar materials have been laid on top of structural steel. To avoid lightning damage, such construction should be protected by conductors run along exposed corners or edges and connected to the structural steel or to the protection system. (See paragraph E.8.7.)

e. Coursing of Conductors. Course conductors over roofs and down corners and sides of structures so as to constitute (as nearly as possible) an enclosing network. Course roof conductors along contours, such as ridges, parapets, and edges of flat roofs, and where necessary over flat surfaces, so as to interconnect all points. Form a closed loop with conductors surrounding decks, flat surfaces, and flat roofs.

f. Down Conductors. Course down conductors over the outer portions of structures, such as corners, consideration begin given to the best places for making ground connections and to the location of points.

g. Obstructions. Course horizontal conductors horizontally around chimneys and similar obstructions.

h. Bends. Each bend in a conductor shall have a radius of eight inches or more. Turns shall not exceed 90 degrees, and conductors shall maintain a downward or horizontal course.

i. Guards. Protect down conductors in driveways, walks, or similar locations with securely fastened wood or metal laid over the conductor for a distance of at least six feet above grade level to prevent physical damage.

(1) Conductor should not be run through iron or steel pipe.

(2) Bond conductors run through metal pipe to the top and the bottom of the pipe.

(3) Encase down conductors entering acidic soil in lead sleeves, or the equivalent, extending at least three feet above and three feet below grade.

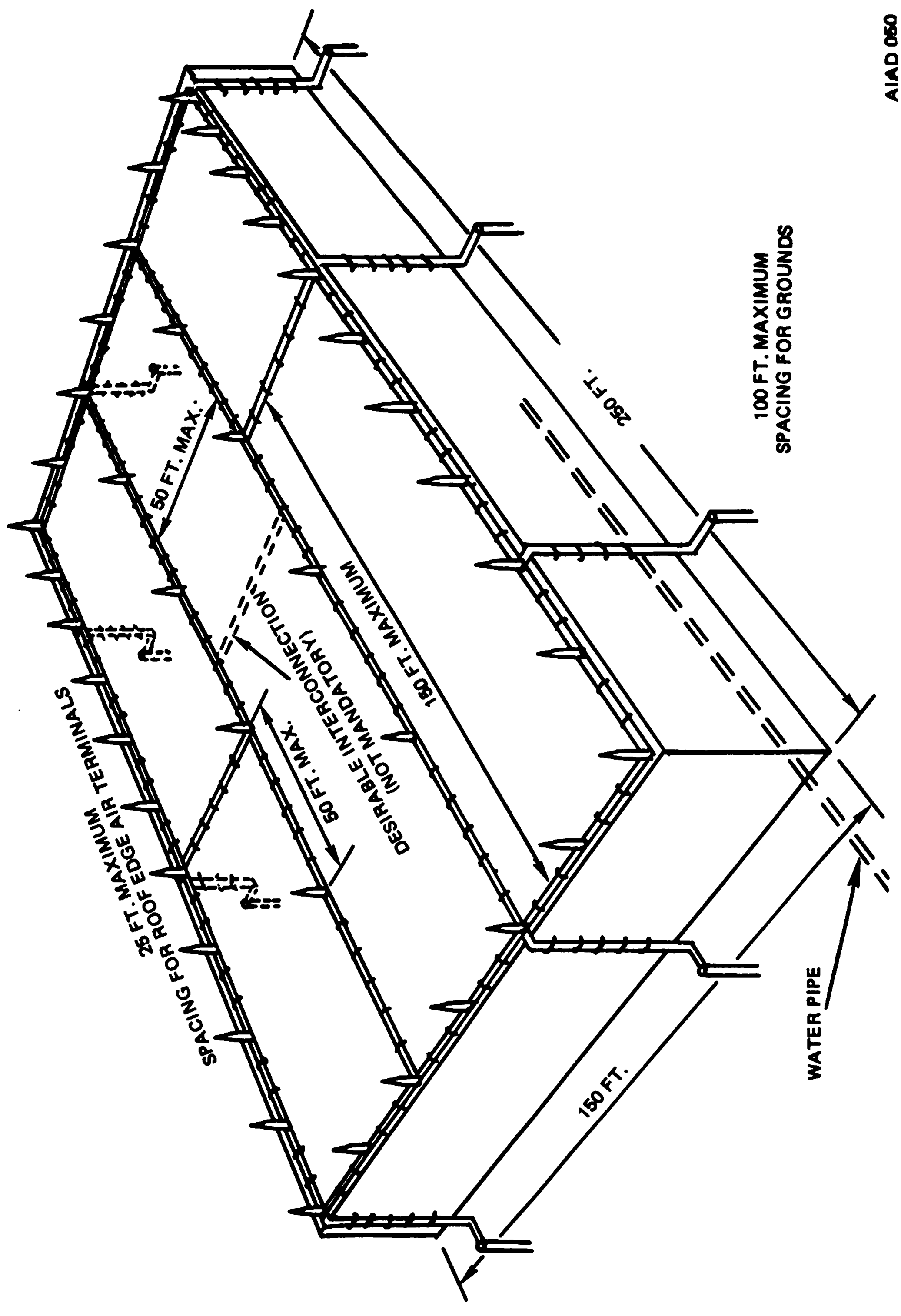



Figure E - 4. Typical Installation on Flat-Roofed Building

## E.8.4 Metal-Roofed and Metal-Clad Buildings

Buildings with metal siding but not equipped with standard lightning protection or continuous metal roofs are not considered protected even if the siding is bonded and grounded.

Metal-roofed or metal-roofed and clad buildings are partially self-protecting, depending on the construction. Equipment for protection of metal-roofed or metal-roofed and clad buildings shall comply with the requirements of paragraphs E.8.1, E.8.2, and E.8.3.

a. Metal Not Continuous. Use separate lightning-protection conductors for buildings which are roofed, or roofed and clad, with metal in sections that are not in electrical contact.

b. Metal Continuous. When buildings are roofed or roofed-and-clad, with all-metal sheets at least 3/16 inch thick made electrically continuous by contact acceptable to the code-enforcing authority, or by bonding, the following modifications may be made to the requirements of paragraphs E.8.2 through E.8.7.

(1) Provide points on chimneys and other projections likely to be struck and damaged by lightning. Projections likely to be struck, but not damaged, need not be provided with points, but shall be bonded to the roof.

(2) Roof conductors may be dispensed with, and points (if used) connected to the roof by securely bolted joints, having a contact area of at least three square inches. If the roof metal is in small sections, make connection to at least four sections.

(3) Connect down conductors to the edges of roofs, or to the lower-edge of metal siding, by bolted joints having at least three square inches of contact area. If the metal is in small sections, make connection to at least four sections.

c. Metal Roof Not Electrically Continuous with Metal Siding. Bond the siding to the roof at each corner, and bond down conductors to the lower part of the metal siding with a connection between roof and siding directly above each down conductor and the down conductor grounded.

## E.8.5 Number of Down Conductors

a. Separate down conductors as widely as practicable, preferably at diagonally opposite corners on rectangular structures and diametrically opposite sides on cylindrical structures.

Down conductor location is contingent on the location of points, size of structure, most direct coursing, security against displacement, location of metallic bodies which require bonding thereto, location of water pipes, and where ground conditions are most favorable.

b. Provide at least two down conductors (with groundings) on any structure except flagpoles, spires, and similar structures which are adjuncts of buildings and require only one down conductor. Structures having a perimeter exceeding 250 feet shall have one additional down conductor for each additional 100 feet of perimeter or fraction thereof. (Measure the perimeter at ground level, but exclude sheds and other small projections not requiring protection.)

c. On structures having flat or gently sloping roofs, and on irregular-shaped structures, make the average distance between down conductors 100 feet or less.

d. Metal-Roofed and Metal-Clad Buildings. Determine the number of down conductors and ground connections in the same manner as for buildings composed of nonconducting materials, except where paragraph E.8.4.b permits partial omission of down conductors.

e. Dead Ends. Install additional down conductors to avoid dead ends (branch conductors ending at points) which exceed 16 feet in length, except that single down conductors descending flagpoles, spires, and similar adjuncts of buildings which shall be treated as points. A dead end arises where a point on the peak of a dormer, or in some similar situation, is connected only to the nearest conductor, which usually is at the nearest ridge. A stroke on such a point must traverse a single conductor until it reaches the ridge conductor where the path divides. The length of this single conductor must not exceed 16 feet. Where greater lengths are encountered the conductor must be extended from the point to ground. Additional down conductors should be installed at places where the roof conductor descends into low places between parts of buildings, as in the base of H-shaped structures where the end wings are as high as or higher than the center portion.

E.8.6 Interconnection of Metallic Masses

a. Exterior Bodies of Metal. Bond metal wholly on a structure exterior (radio masts, gutters, down spouts, structural iron, etc.) to the conductor at its upper (or nearest) end, and if of considerable size or length, also bond it to the conductor at its lower (or farthest) end.

A metal gutter with no down spout may be connected at one point only. A metal down spout should be grounded at its bottom end. Any extensive vertical metal object with its lower end within six feet of the ground should be grounded at the lower end. Metal objects wholly on the roof need be grounded at only one point.

b. Interior Bodies of Metal. Metal wholly in the interior of buildings (piping systems, cable armor, conduits, tanks, stationary machinery, structural metal, etc.) which at any place comes within six feet of a lightning conductor, or metal connected thereto, shall be bonded to it, and if of considerable size or length, also shall be bonded to it at its lower or farther extremity within the building.

c. Metal Bodies Projecting Through Roofs. Bond metal which projects through roofs (soil pipes, flues, ventilators, etc.) to the nearest conductor. If such a body extends to or near grade level, also bond it to the protection system at its lower end.

d. Interconnection of Metals on or Within Metal-Roofed and Metal-Clad Buildings. Bond all parts of metal roofs and sides together. All interior metal parts or contents of considerable size that are permanently installed, if within six feet of metal sides, roof, or a down conductor, shall be bonded thereto.

e. Substitution for Conductors. Do not use extended metal parts of buildings for conductors, except where they are permanently electrically continuous, and have a conducting cross-sectional area at least double that of the conductor that would otherwise be used.

E.8.7 Ground Connections

a. Number. Provide a ground connection for each down conductor; give preference to metal water pipes and other large underground metallic structures.

b. Permanency. Make every ground connection permanent, with due regard to the character of the surrounding soil.

c. Water Pipe Grounds

(1) Where metallic water pipe enters a building, connect at least one down conductor to it, preferably immediately outside of the foundation wall, by means of a substantial clamp.

(2) Make no connections to nonmetallic water pipes. If such pipes serve metal pipes within the structure, treat the metal pipes as interior bodies of metal.

(3) If a building is served by plastic pipe leading from a metal well casing or metal pipe within 25 feet of the protected building, bond the protection system to the well casing or metal pipe.

(4) In the case of metal pipe systems that are connected together with a section of plastic pipe, bridge the section of plastic pipe with a length of main-size conductor terminating in accepted type grounding fittings.

(5) If nonmetallic water storage tanks are located within a building, make a connection between the supply and the outlet pipe using main-size conductor and accepted-type grounding fittings.

d. Grounding Electrodes in Deep Soil. Where soil is sufficiently deep, grounding electrodes may be made by driving pipes or rods or extending the conductor itself into the ground a depth of at least 10 feet. Permanently mark the length of each driven rod or pipe on it at the top.

e. Grounding Electrodes in Shallow Soil. Where soil is of insufficient depth to drive 10-foot rods or pipes, or is largely sand, gravel or stone, make more extensive electrodes with driven rods or pipes or strips, plates, or lengths of conductors buried in trenches. Where bed rock is near the surface, grounds may be made by digging trenches radially from the building and burying in them the lowest ends of the down conductors or their equivalent in the form of metal strips or wires. Where soil is very dry or will not permit digging to a depth of more than one foot, in addition to the conductors laid radially, bury a similar conductor which encircles the structure to be protected and connects all down conductors together.

f. Trenches. Trenches shall accommodate 12 feet of conductor laid straight, but need not be more than three feet deep.

Low resistance to ground is desirable, but not essential, as may be shown by the extreme case on the one hand of a building resting on moist clay soil, and on the other by a building resting on bare solid rock. In the first case if the soil is of normal resistivity (200 to 5000 ohm-centimeters), the resistance of a ground connection made by extending the conductor 10 feet into the ground will be from 20 to 50 ohms, and two such ground connections on a small rectangular building are sufficient. In the second case it would be impossible to make a ground connection in the ordinary sense because most kinds of rocks are of high resistivity; to obtain effective grounding more elaborate means are necessary. The most effective means would be an extensive wire network laid on the surface of the rock surrounding the building, similar to an antenna counterpoise; to which down conductors could be connected. The resistance to earth at some distant point of such an arrangement would be high, but the potential distribution about the building would be substantially the same as though it were resting on conducting soil and the resulting protective effect also substantially the same.

The extent of the grounding arrangements will depend on the character of the soil, ranging from simple extension of the conductor into the ground (where the soil is deep and of high conductivity), to an elaborate buried network (where the soil is very dry or of very poor conductivity). Where a network is required it should be buried if there is soil enough to permit it, as this adds to its effectiveness. Its extent will be determined largely by judgment with due regard to the minimum requirements of this provision, which is intended to cover ordinary cases likely to be encountered, keeping in mind that as a rule, the more extensive the underground metal available, the more effective the protection. Some essential features of good grounding practice are:

o Where practicable each connection should extend, or have a branch which extends, below and at least two feet away from, the structure foundation walls.

o The metal composing the connection should make contact with the soil from the surface downwards to prevent flashing at the surface with danger of burning off the conductor.

o During a lightning stroke on a system of conductors, the grounding electrodes are the points through which the heavy current flows between the air terminals and the surface of the earth about the structure and should, therefore, be distributed to carry this flow of current in the most advantageous manner. This will be generally realized by placing them at the outer extremities, such as the corners, and avoiding as far as possible current flow under the structure.

g. Installation. Install the grounding system in accordance with guidelines contained in NAVELEX 0101,110, Electronic Installation Practices.

E.8.8 Electric and Telephone Service, Radio

a. Make sure wires entering buildings conform to the National Electrical Code (NEC). A system installed to provide building-protection does not provide protection to electric service conductors and antenna systems. Buildings equipped with approved lightning protection should also be provided with protective devices where electric service conductors and antenna wires enter the building.

b. If electric or telephone service using driven ground electrodes enters a protected structure, interconnect the ground electrodes with the protection system, using main-size cable. (Such interconnections, to obtain common grounding, are permitted by the NEC.) If the services are grounded through the water pipe system, interconnection with the pipe is adequate.

c. Common grounding is the most effective method of preventing side flashes. Bond all grounding mediums together, including electric and telephone service grounds and all underground metallic piping systems (water service, gas, conduits, liquified petroleum-gas, etc.) which enter the structure. (Avoid bonding to systems which have sections of plastic pipe unless each such section is bridged by a length of main-size cable.)

d. Bond metal radio masts, regardless of location on or near a building, to the main cable with main-size cable and approved fittings.

E.8.9 Concealed Installations

a. All requirements for exposed systems also apply to concealed systems except that conductors may be under the roof or roofing material, behind the exterior wall facing, or between wall studs.

b. Groundings may be carried to the exterior at or below grade level and then made conventionally. Groundings may also be placed in the basement below the slab, but on outside walls only.

c. Chimney points and conductors may be built into the masonry, or attached to the exterior, of the chimney and then carried through the roof to the interior main cable.

d. Use approved fittings and flashings in making all through-roof and through-wall connections. Use particular care on concealed installations to insure common grounding of all extended metallic parts such as the electric system, water system, furnace pipes or ducts, gas pipes, soil pipes, metal lathing, metal foil insulation, etc.

e. The structural steel framework or reinforcing rods of a building may be used as the main cable if it is made electrically continuous by bonding of all noncontinuous sections. (Continuity may be measured by comparing resistance to ground at grade level and at the top and other elevations of the structure.)

f. Points may be individually bonded to the framework through the roof or parapets or they may be joined together with an exterior conductor bonded to the framework in not less than the same number of places as there are groundings.

g. Make groundings from approximately every other steel column around the perimeter; in no case shall they average more than 60 feet apart.

h. Make all bonding of points, branch conductors, and grounding tails to the steel with bonding plates having a contact surface of at least 8 square inches. They shall be bolted, welded, brazed, or clamped to a cleaned section of the steel.

i. If the grounding locations are dry (such as in sand, gravel, or rock), install a counterpoise, interconnected with each ground terminal.

E.8.10 Masts

a. Air Terminals. For masts, a single point may be used, which extends at least 10 inches above the uppermost part of the structure.

). Down Conductors. If the mast is isolated, extend down conductors directly to a ground connection. If the is near, or touching the perimeter of a building, extend the down conductors directly to a ground ection, and also bond them to the lightning-conductor system on the building. If the mast is within the neter, bond the down conductors to the nearest roof conductors.

:. Grounding of Metallic Masts. Masts composed entirely of, or covered entirely with, metal and resting on dations of nonconducting material with the top so constructed as to receive a stroke of lightning without eciable damage, need not be provided with points or down conductors, but shall be grounded directly or led to the nearest main cable, in accordance with the previous paragraph. On masts over 75 feet high it is able to use more massive conductors and fastenings than on ordinary types of buildings.

1 Masts and Overhead Ground Wires

. The cone of protection of a grounded mast of conducting material is the space enclosed by a cone with ex at the highest point of the mast. No part of the structure to be protected should ever extend outside the of protection illustrated in Zone B of figure E-2. If more than one mast is used, the shielded region is what greater than the total of the shielded regions of all masts considered individually.

. Masts separate from the structure to be protected should be at least six feet from the structure, and the nce should be increased by one foot for every ten feet of structure height above 50 feet. The masts shall be ided and bonded at ground level to the grounding system of the structure. Where suitable underground lic water pipe serves the structure, the pipe is ordinarily the common grounding electrode for all services acilities. If there is no water pipe or if the pipe is not accessible, bond the separate grounding electrodes of arious services and facilities together and to the masts. If separate grounding electrodes are not accessible, inimum separation between the mast and the structure shall be 10 feet for mast ground-resistance of 10 or less. As an alternative, a buried conductor around the outside of the structure may be used and bonded e mast ground to avoid larger separations.

. The zone of protection of overhead ground wires (see figure E-5) is a triangular prism or wedge. One-half e base of the wedge equal to the height of lowest point of the overhead ground wire (HM) in important , or up to twice the height in less important cases, is satisfactory. Each mast should have a clearance from tructure in accordance with the preceding paragraphs and the requirements of E.8.1 should be observed.

.. Minimum clearance between overhead ground wires and the highest projection on the protected structure be six feet. For each 10 feet of lead between a point on the ground wire midway between the masts and nd in excess of 60 feet, the clearance should be increased by one foot. Various ground-wire configurations hown in figure E-6.

. Masts used either separately or with ground wires may be of wood only if a point is mounted to the top e mast extending at least two feet above the top of the mast and connected to ground electrodes. In an ead ground-wire system, the guy wire may be used as the down conductor (see figure E-7). For metallic s, the point and the down conductor are not required, but the masts shall be grounded.

2 Ground Resistance

resistance of driven ground rods 10 feet or more apart will be reduced in approximate proportion to the er of rods. The resistance of a buried conductor decreases almost directly in proportion to the increase in 1 of the buried conductor. Such conductors are usually 1 to 3 feet beneath, and run parallel with, the ce. Refer to NAVELEX 0101,106, Electromagnetic Compatibility and Electromagnetic Radiation Hazards, lditional details regarding ground resistance.

3 Electrostatic Shielding

ostatically induced voltage on isolated objects in the field of a storm cloud may cause sparks to ground a lightning discharge occurs to some adjacent object. Isolated objects within an adequately shielded re will themselves be electrostatically shielded. If the structure is not (or is only partially) shielded, then lated objects should be grounded to prevent electrostatic sparks (refer to paragraph E.8.6.b).

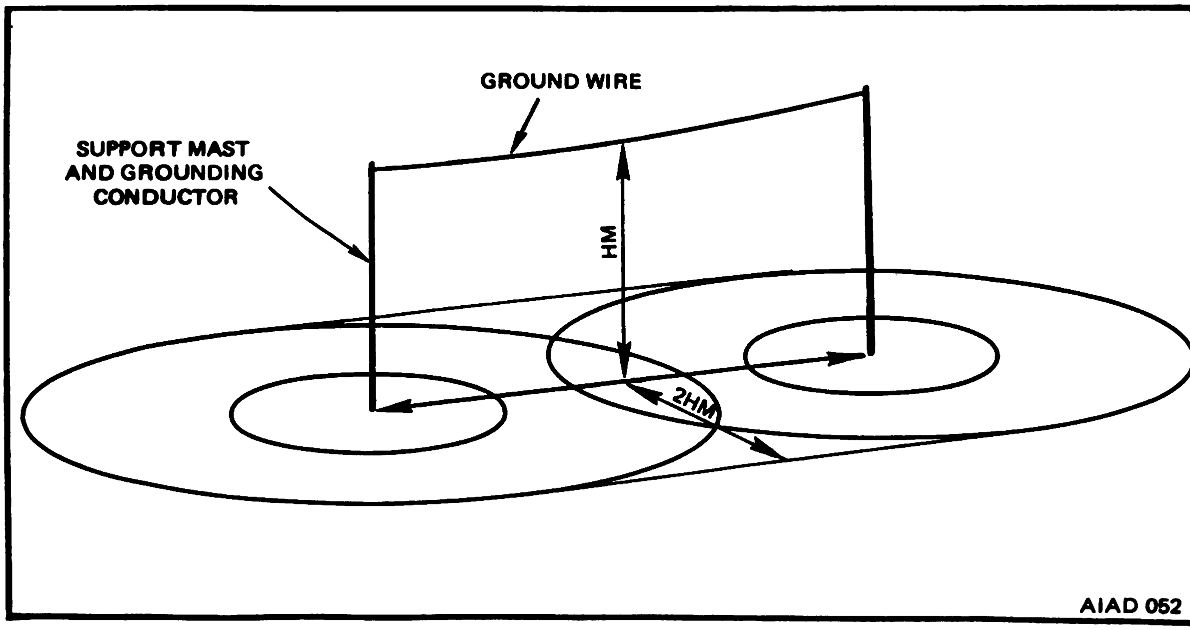



Figure E-5. Zone of Protection Provided by a Horizontal Aerial Ground Wire

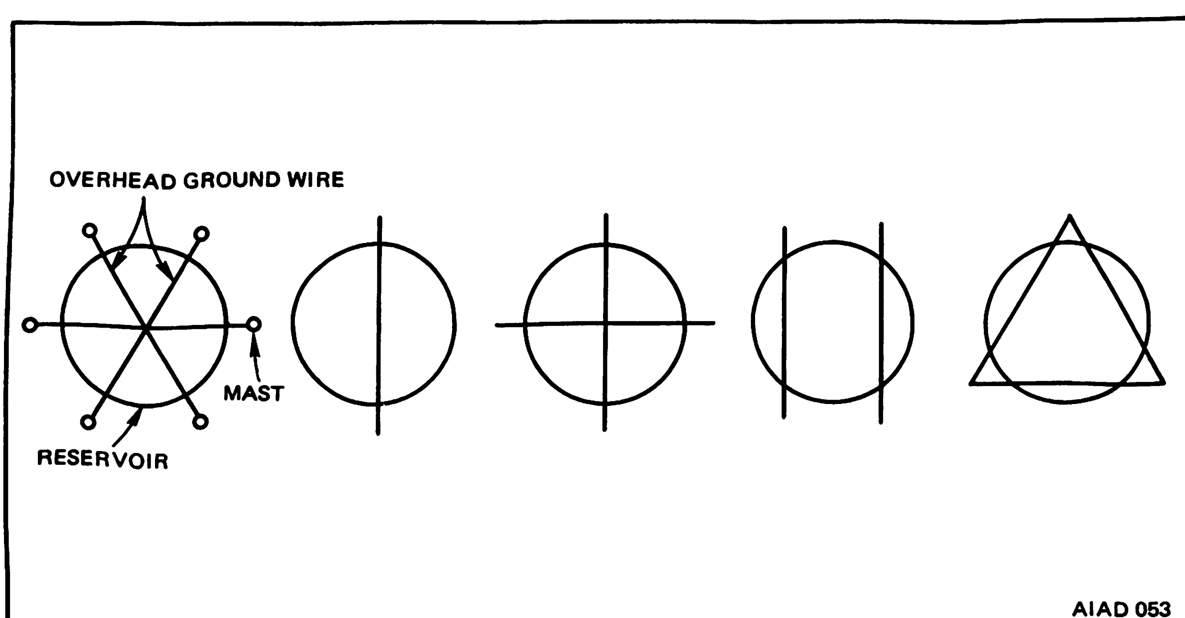



Figure E-6. Overhead Ground Wire Configurations

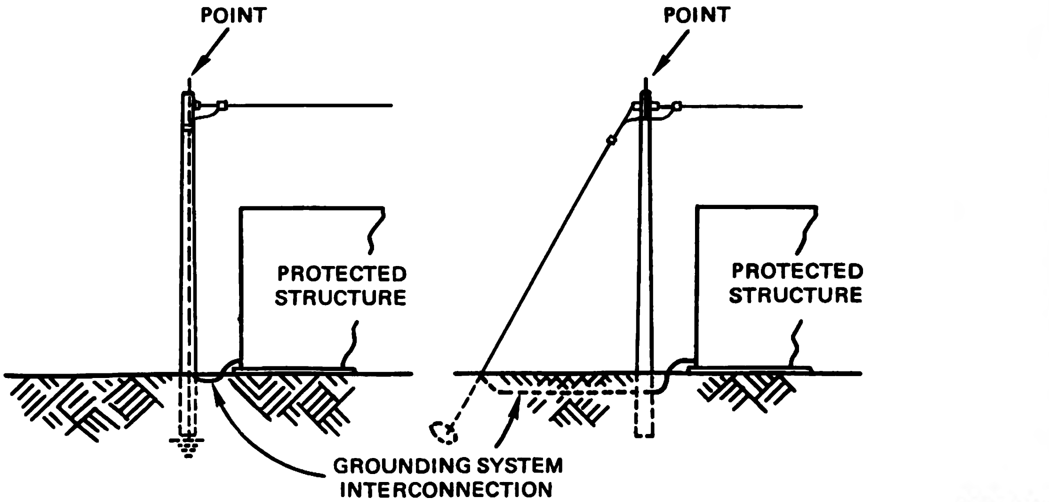



Figure E - 7. Alternate Grounding Method for Aerial Ground Wire Protection

# APPENDIX F

# RF GROUNDING CONSIDERATIONS

The evaluation and preparation of a site, in reference to the electronic groundings, is the responsibility of the Naval Facilities Engineering Command (NAVFAC) who will determine and install the required grounding system. Naval Electronics System Command personnel are responsible only for the grounding of the electronic equipment to the site's overall grounding system.

This appendix presents generic information on some criteria and considerations in reference to the grounding of electronic equipments.

It is strongly recommended that personnel concerned with grounding of electronic equipment, consult the following publications for more precise information.

o NAVELEX 0101,106 – Electromagnetic Compatibility and Electromagnetic Radiation Hazards.

o NAVELEX INSTR. 011120.1 – Shore Electronics Engineering Installation Guidance for Equipments and System Processing Classified Information.

o MIL-STD – Military Communication System, Technical Standards

o NAVFAC DM-23 – Communications, Navigational Aids, and Airfield Lighting

o NAVELEX 0101,102 – Naval Communication Station Design

o NAVELEX 0101,104 – HF Radio Antenna Systems

## F.1 SKIN EFFECT

A high-frequency field in a conductor causes current to concentrate on the surface, the decay into the conductor being approximately exponential. This concentration increases as frequency, conductivity, or permeability increases. The result is increasing resistance and decreasing internal inductance as frequency increases. Skin depth is that distance below the surface of a conductor where current-density has diminished to 1/e (about 37%) of its surface value. (The thickness of the conductor is assumed to be at least three times the skin depth.) Imagine the conductor replaced by a cylindrical shell of the same surface shape but of thickness equal to skin depth, with uniform current density equal to that which exists at the surface of the actual conductor. Then the total current in the shell and its resistance are equal to the corresponding values in the actual conductor.

By using low-permeability materials of maximum diameter and minimum length, inductive reactance can be kept low. Figure F-1 illustrates how the inductance of solid cylindrical copper conductors varies with length and gauge. The graph is also valid for rectangular copper strap if the thickness is very small relative to the width.

In addition to resistance and inductance, solid conductors also possess stray capacitance to adjacent conductive surfaces. The capacitance associated with cables whose height varies from a conductive plane or earth ground can be very difficult to evaluate. However, as long as capacitive reactance ($X_C$) is much less than inductive reactance ($X_L$), and the frequency of interest is much less than the resonant frequency, then $X_C$ can be neglected.

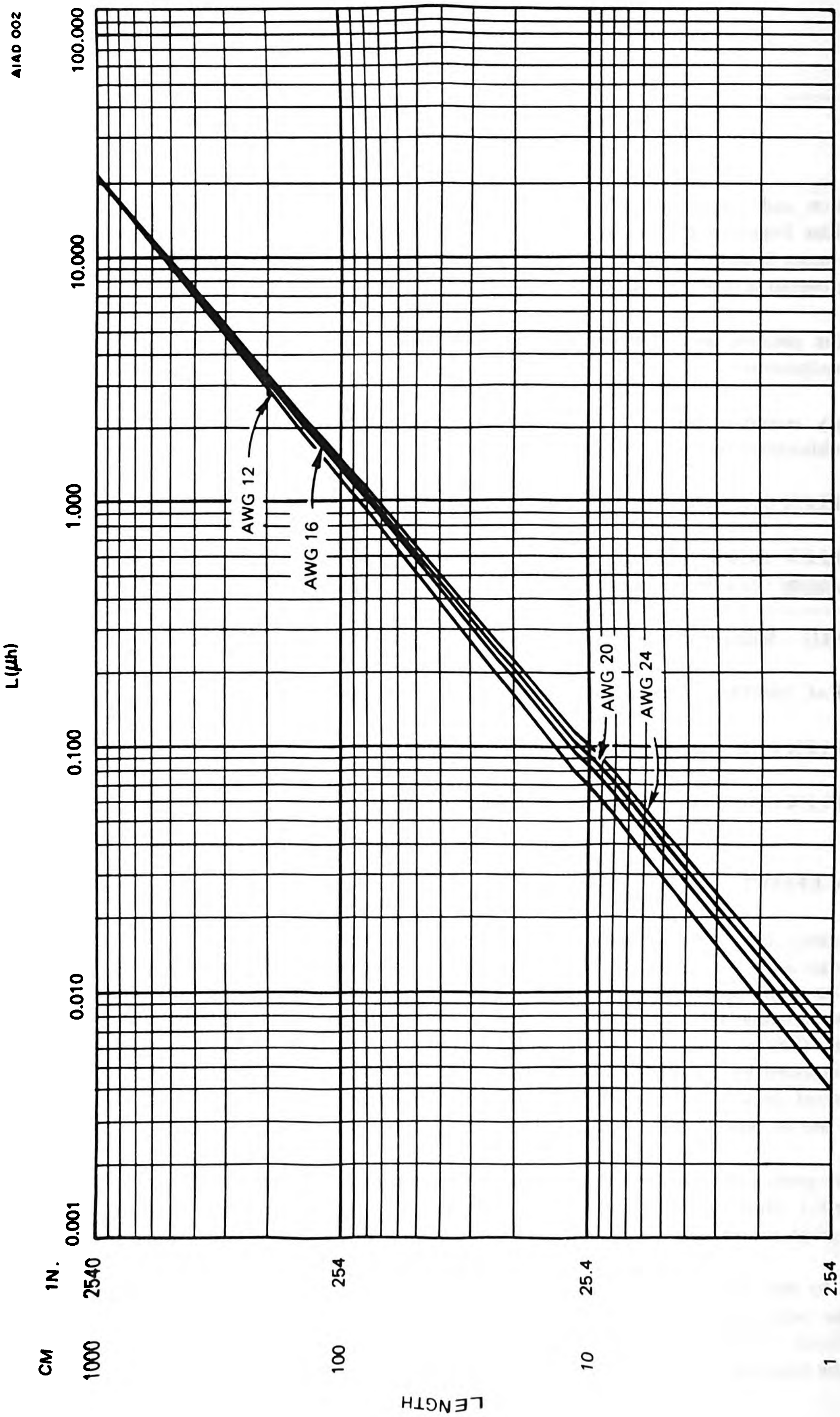



Figure F - 1. Inductance of Copper Conductors

The ratio of AC to DC resistance ($R_{AC}/R_{DC}$) for straight round wires is given in figure F-2 and table F-1 *in* terms of parameter X, which is defined as:

$$X = \frac{8 \pi f \mu}{R X 10^9} \qquad \text{(F-1)}$$

where: X for copper = $0.271 \, d \sqrt{f X 10^{-9}}$

d = diameter in mils

f = frequency in Hertz

$\mu$ = conductor permeability ($\mu$ = 1 for air)

R = DC resistance in ohms for 1 cm of conductor

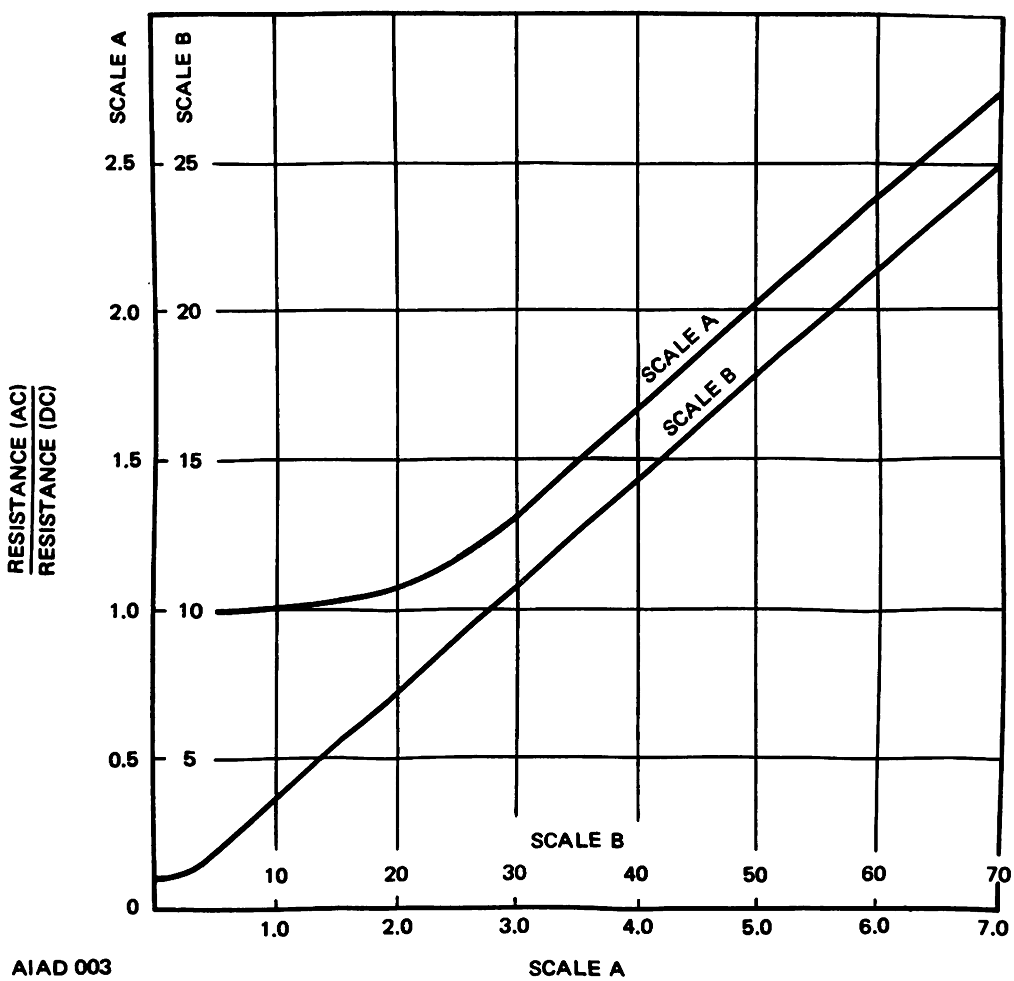



Figure F - 2. Resistance Ratio in Isolated Round Wires as a Function of Parameter X

Table F - 1. Ratio of AC to DC Resistance for Solid Round Wire

| X | $R_{AC}/R_{DC}$ | X | $R_{AC}/R_{DC}$ | X | $R_{AC}/R_{DC}$ |
|---|---|---|---|---|---|
| 0 | 1.0000 | 5.2 | 2.114 | 14.0 | 5.209 |
| 0.5 | 1.0003 | 5.4 | 2.184 | 14.5 | 5.386 |
| 0.6 | 1.0007 | 5.6 | 2.254 | 15.0 | 5.562 |
| 0.7 | 1.0012 | 5.8 | 2.324 | 16.0 | 5.915 |
| 0.8 | 1.0021 | 6.0 | 2.394 | 17.0 | 6.268 |
| 0.9 | 1.0034 | 6.2 | 2.463 | 18.0 | 6.621 |
| 1.0 | 1.005 | 6.4 | 2.533 | 19.0 | 6.974 |
| 1.1 | 1.008 | 6.6 | 2.603 | 20.0 | 7.328 |
| 1.2 | 1.011 | 6.8 | 2.673 | 21.0 | 7.681 |
| 1.3 | 1.015 | 7.0 | 2.743 | 22.0 | 8.034 |
| 1.4 | 1.020 | 7.2 | 2.813 | 23.0 | 8.387 |
| 1.5 | 1.026 | 7.4 | 2.884 | 24.0 | 8.741 |
| 1.6 | 1.033 | 7.6 | 2.954 | 25.0 | 9.004 |
| 1.7 | 1.042 | 7.8 | 3.024 | 26.0 | 9.447 |
| 1.8 | 1.052 | 8.0 | 3.094 | 28.0 | 10.15 |
| 1.9 | 1.064 | 8.2 | 3.165 | 30.0 | 10.86 |
| 2.0 | 1.078 | 8.4 | 3.235 | 32.0 | 11.57 |
| 2.2 | 1.111 | 8.6 | 3.306 | 34.0 | 12.27 |
| 2.4 | 1.152 | 8.8 | 3.376 | 36.0 | 12.98 |
| 2.6 | 1.201 | 9.0 | 3.446 | 38.0 | 13.69 |
| 2.8 | 1.256 | 9.2 | 3.517 | 40.0 | 14.40 |
| 3.0 | 1.318 | 9.4 | 3.587 | 42.0 | 15.10 |
| 3.2 | 1.385 | 9.6 | 3.658 | 44.0 | 15.81 |
| 3.4 | 1.456 | 9.8 | 3.728 | 46.0 | 16.52 |
| 3.6 | 1.529 | 10.0 | 3.799 | 48.0 | 17.22 |
| 3.8 | 1.603 | 10.5 | 3.975 | 50.0 | 17.93 |
| 4.0 | 1.678 | 11.0 | 4.151 | 60.0 | 21.47 |
| 4.2 | 1.752 | 11.5 | 4.327 | 70.0 | 25.00 |
| 4.4 | 1.826 | 12.0 | 4.504 | 80.0 | 28.54 |
| 4.6 | 1.899 | 12.5 | 4.680 | 90.0 | 32.07 |
| 4.8 | 1.971 | 13.0 | 4.856 | 100.0 | 35.61 |
| 5.0 | 2.043 | 13.5 | 5.033 | ∞ | ∞ |

The largest diameter permissible at various frequencies for selected resistance ratios is tabulated in table F-2 for copper.

Table F - 2. Wire-Diameter Versus Skin-Effect Ratio

| FREQUENCY (MHz) | SKIN-EFFECT RATIO | | | |
|---|---|---|---|---|
| | 1.100 | 1.010 | 1.001 | |
| 0.1 | 24.9 | 14.0 | 7.7 | |
| 0.2 | 17.6 | 9.9 | 5.4 | |
| 0.5 | 11.2 | 6.3 | 3.5 | |
| 1.0 | 7.8 | 4.4 | 2.4 | MAXIMUM WIRE DIAMETER IN MILS |
| 2.0 | 5.5 | 3.1 | 1.7 | |
| 5.0 | 3.6 | 2.0 | 1.1 | |
| 10.0 | 2.5 | 1.4 | 0.8 | |
| 20.0 | 1.8 | 1.0 | 0.6 | |
| 50.0 | 1.1 | 0.6 | 0.3 | |

In the case of isolated tubular conductors, the resistance ratio is always closer to unity than for a solid conductor of the same outside diameter. This is because the center of a solid wire does not do its full share in the carrying of current; so if the center is removed to form a tube, the resistance ratio will be improved. However, removing the center to form a tube increases the DC resistance sufficiently so that the AC resistance of the tube is greater than for the corresponding solid wire, even though the resistance-ratio is less. Resistance-ratio values for isolated nonmagnetic tubular conductors are given in figure F-3.

A conductor consisting of a flat rectangular strip (ribbon) will have a lower resistance ratio than a solid round wire of the same cross-section when the frequency is high enough to make the resistance ratio appreciable, but has a higher resistance ratio than would be obtained by forming the ribbon into a tube of the same cross-sectional area and the same wall thickness. This is because the current in a ribbon tends to concentrate more at the edges than at the sides, since the edges are circled by the fewest flux lines. Information on the resistance ratio of rectangular conductors of various shapes is given in figure F-4. For shape ratios exceeding about 2:1, the ribbon has lower AC resistance than a solid round wire of the same cross-section except when the resistance ratio approaches unity.

### F.1.1 Skin Depth and Resistance at Very High Frequencies

At frequencies so great that the resistance-ratio is large, most of the current carried by the conductor is concentrated very close to the surface. Under these conditions, the AC resistance of a conductor is approximately the same as the DC resistance of a hollow conductor having a thickness equal to skin depth.

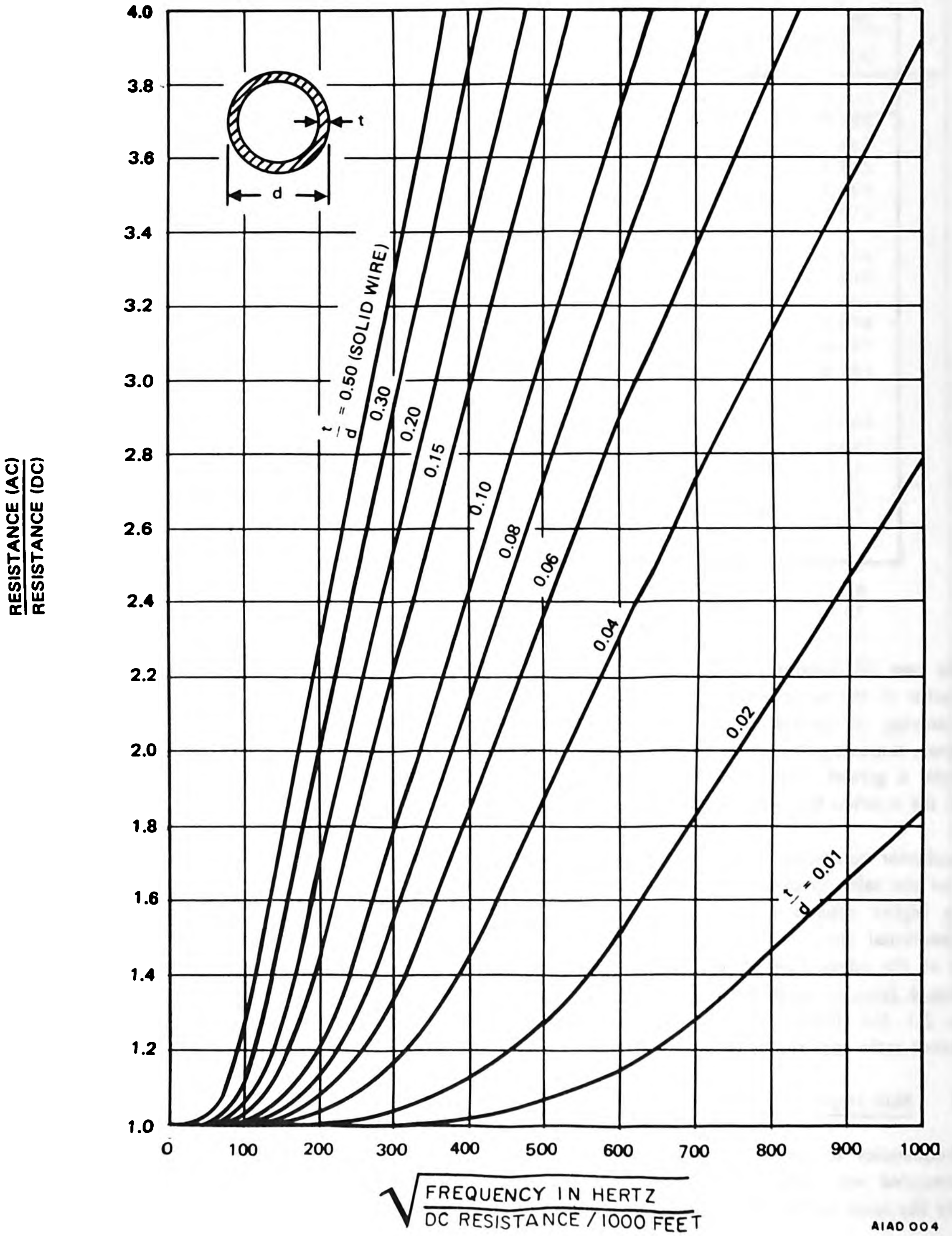



Figure F-3. Resistance Ratio of Isolated Nonmagnetic Tubular Conductors in Terms of Frequency

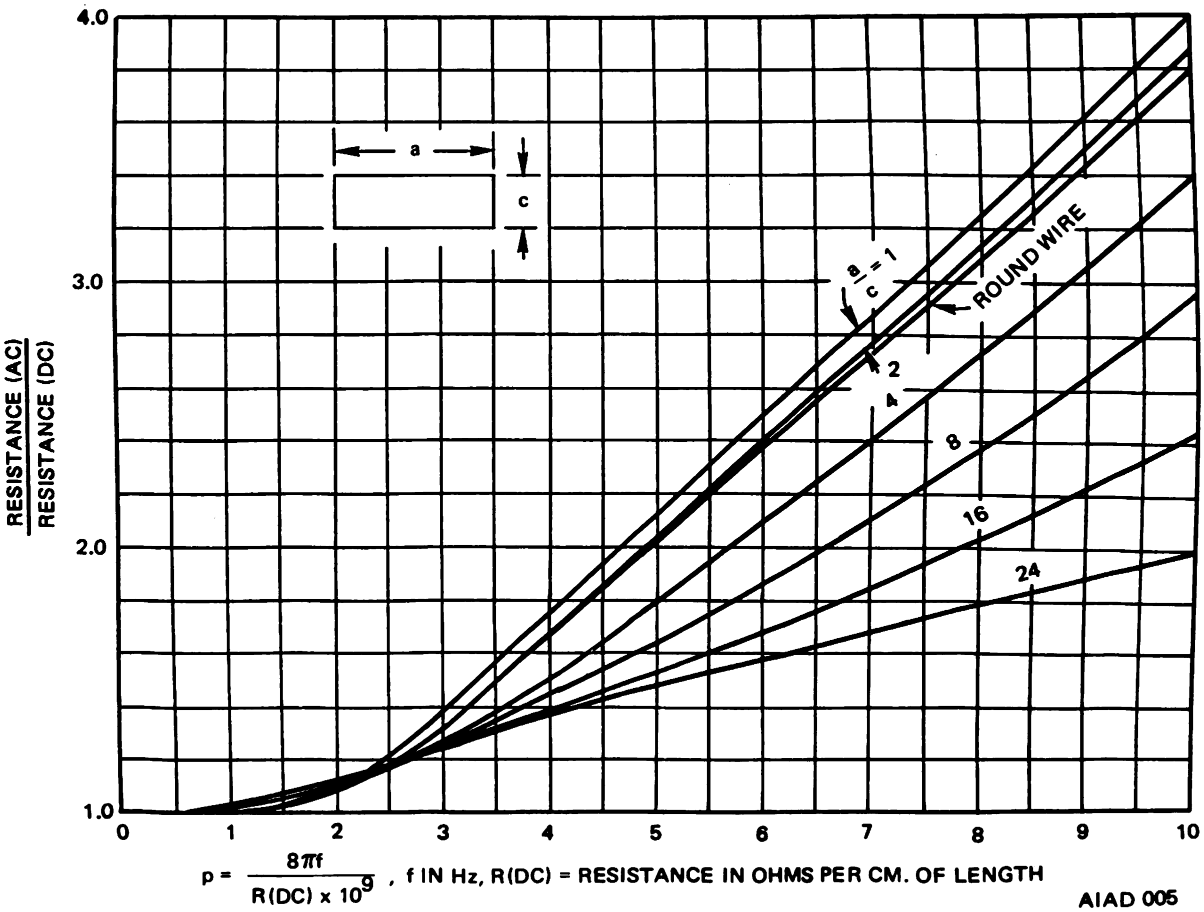



Figure F - 4. Resistance Ratio of Conductors in Terms of Parameter p

When the thickness and the radius of curvature of the surface of a copper conductor are both much greater than the skin depth, the high-frequency resistance ($R_{HF}$) in ohms/cm$^2$ is calculated as follows:

$$R_{HF} = \frac{26\sqrt{f \times 10^{-9}}}{P} \qquad \text{(F-2)}$$

Where:

P = perimeter in cm

f = frequency in Hertz

This expression is plotted in figure F-5.

Equation F-2 holds reasonably well for resistance ratios exceeding 2, and quite closely when the ratio is of the order of 5 or more. If the radius of curvature varies too rapidly around the periphery, the AC resistance is greater than given by Equation F-2 by a factor that depends on the shape. Note also that AC resistance is

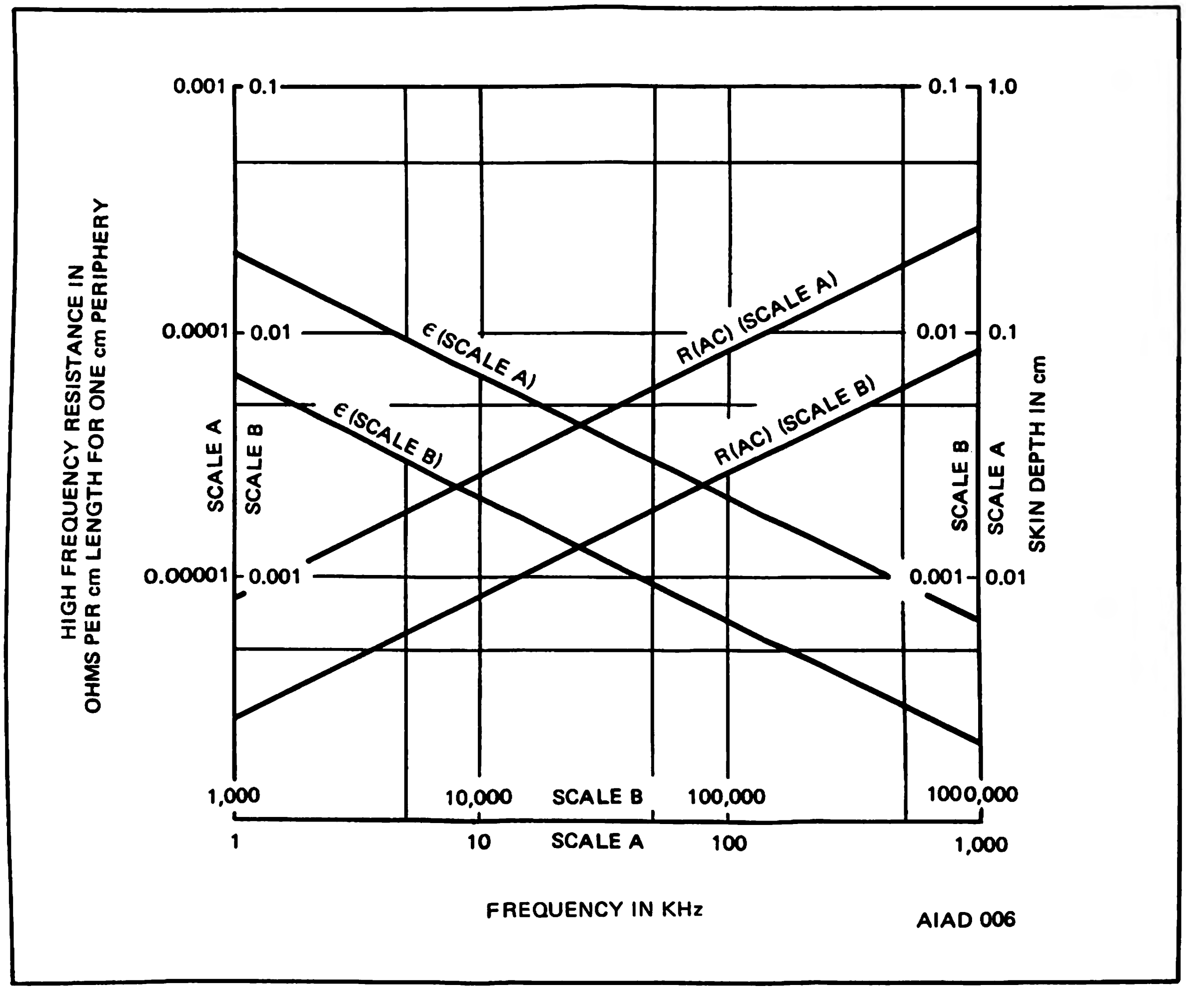



Figure F - 5. Skin Depth and Resistance of Copper at Frequencies so High that Most of the Current is Concentrated Near the Conductor Surface

directly proportional to the square root of the frequency, and inversely proportional to the conductor size (or perimeter).

When current flows through ground paths at frequencies above 400 Hertz, metal straps are usually required and normally meet the following specifications:

- o Maximum DC resistance of 0.0025 ohm
- o Length-to-width ratio 5:1 or less
- o Selection of metals which will result in minimum corrosion.

In the case of a rectangular conductor, the radius of curvature varies so rapidly at the corners that the resistance values obtained from figure F-5 must be modified by a factor K, obtained from figure F-6, where a and c are conductor width and thickness in cm.

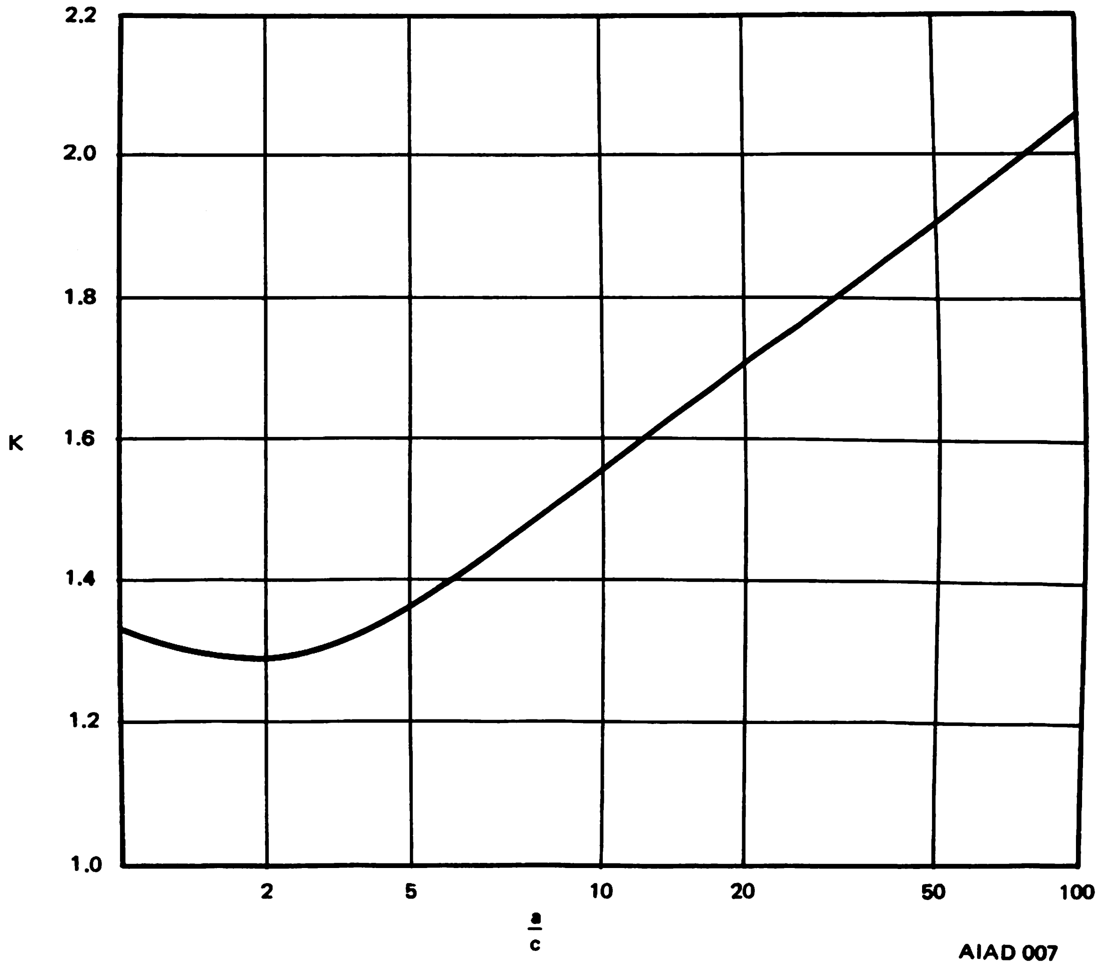



Figure F - 6. Factor K for Rectangular Conductors

F.1.2 Self Inductance

Use figure F-7 to determine the self-inductance of round straight copper conductors at high frequencies. Low-frequency inductance ($L_0$) in microhenries may be calculated as follows:

$$L_0 = 0.05081 \left(2.303 \log_{10} \frac{4\ell}{d} - 0.75\right) \qquad \text{(F-3)}$$

where $\ell$ (length) and d (diameter) are in inches. (For such very short lengths of wire that $\ell$ is less than 100d, a term $d/2\ell$ should be inserted within the parentheses above instead of $4\ell/d$.)

F.2 TRANSMISSION LINE EFFECTS OF ROUND GROUND CONDUCTORS

Another factor which can increase impedance is transmission-line effect. At high frequencies every conductor of appreciable length compared to the wavelength radiates energy. The energy radiated can be much greater than the losses caused by conductor resistance, if the terminating impedance is not equal to the conductor

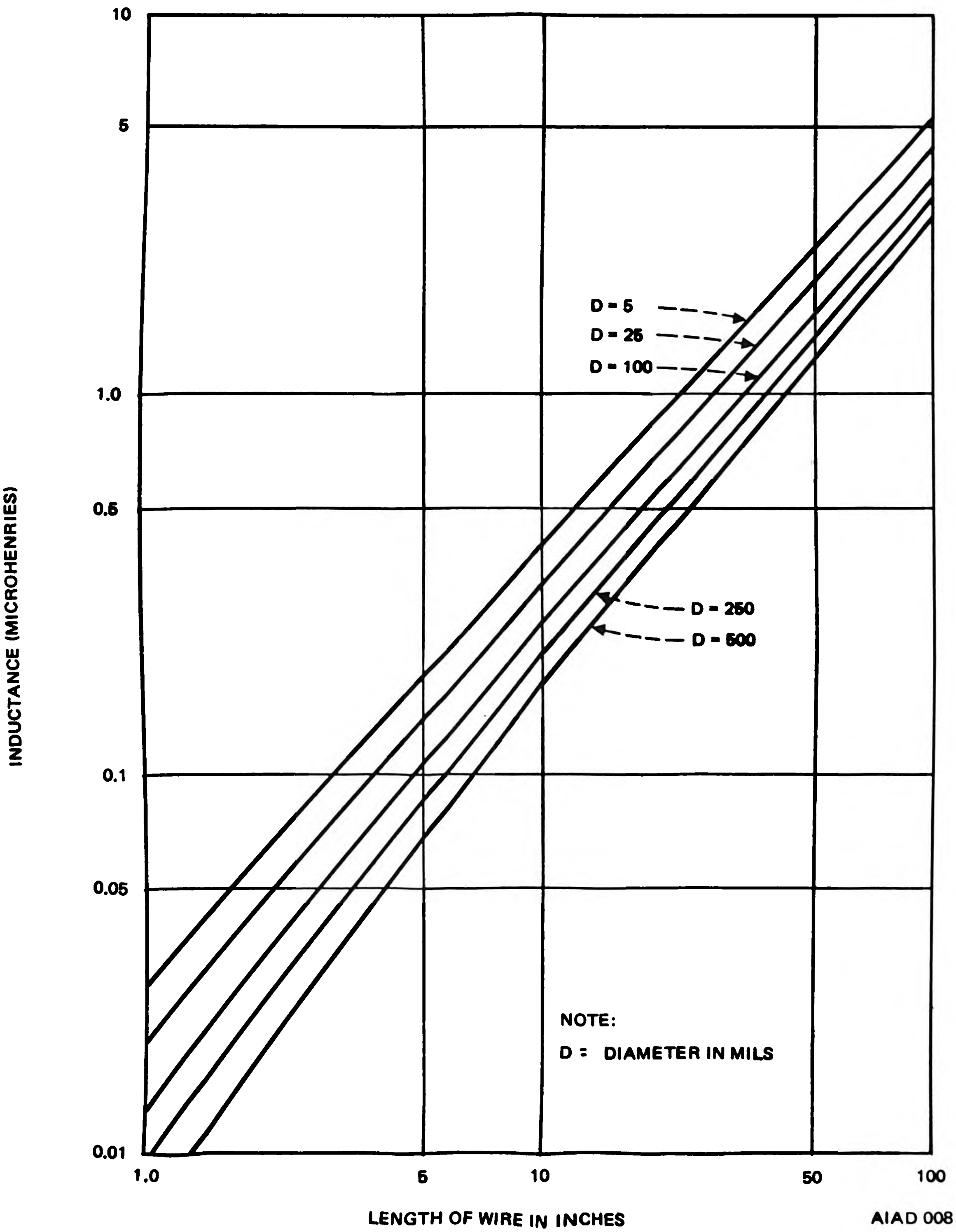



Figure F-7. Self-Inductance of Straight Round Wire at High Frequencies characteristic impedance. In normal transmission, the radiation problem is solved by using a second conduct with an electromagnetic field equal and opposite to that of the first conductor; the net field is thus zero. (Th second conductor is usually parallel or coaxial to the first.) If the two conductors had zero resistance, and di not possess inductance and capacitance, infinite current would flow. But distributive capacitance and inductanc establish a relationship between current and voltage which gives the conductor an effective impedance, calle characteristic impedance, $Z_o$.

In a perfect conductor, where resistance is zero or $R/X_L$ is much less than 1, R is the resistance in ohms per uni length and $X_L$ is the inductive resistance in ohms per unit length. The value of characteristic impedance is equa to L/C, where L and C are the inductance and capacitance per unit length of line.

## F.3 TERMINATED LINES

For current to travel from the source end to the terminating end of a conductor, the terminating impedan should equal the characteristic impedance. The current then will be completely absorbed at the terminated en and the current in the conductor will equal the applied voltage divided by the characteristic impedance.

When the terminating resistance ($R_t$) is not zero, only part of the power is absorbed; the balance is reflecte back. In extreme cases ($R_t = 0$ or $\infty$) all power is reflected back. When $R_t = 0$, current is maximum and voltage minimum (the voltage being $180^o$ out of phase); when $R_t = \infty$, current is minimum and voltage is maximur Transmission-line conditions are easily understood for parallel and coaxial lines where distributive capacitance well defined, but ground-conductor distributive capacitance is not always so well defined. If a round conductor close to a metallic surface, its capacitance and its characteristic impedance can be determined. Where only or conductor is used, the current is returned by an apparent conductor formed from the image of the groun conductor.

Single-wire transmission lines have a characteristic impedance of about 500 ohms, which is too high for a groun conductor when both the source and the terminating impedances are low, and causes a large mismatch. Whe ground conductors are long compared to the wavelength, the characteristic impedance should approximate th terminating impedance between the conductor and the ground reference.

The impedance characteristics of round conductors limits their use as high frequency ground conductors. T lower the impedance, use conductor configurations of larger surface area. Paralleling a number of roun conductors is one way to provide additional surface area; another way is to use a strap. Flag straps, often use for RF ground paths because of their low impedance compared to wires, are mechanically easy to install. Th major electrical drawbacks are the unknown effects of voltage fringing, the unknown contact impedance of th mating surfaces, the probability of corrosion at points of contact, and difficulty in determining characteristi impedance. Ground straps possess DC resistance ($R_{DC}$) given by:

$$R_{DC} = \frac{l}{(w + t)\sigma} \qquad \text{(F-4}$$

where l is the length, w the width, and t the thickness of the strap in inches, and $\sigma$ is the conducto conductivity in mhos per inch.

Inductance (L) in microhenries is given by:

$$L = 0.21\ (2.303 \log_{10} \frac{2l}{w + t} + 0.5 + 0.2235 \frac{w + t}{l}) \qquad \text{(F-5}$$

where l is the length, w the width, and t the thickness of the strap in meters.

igure F-3 shows how the inductance per unit length varies with the length-to-width ratio of a strap. As with ound conductors, the resistance given in Equation F-4 is valid only for DC currents. Because of skin effect, the urface impedance Re(Z) of a strap is given by:

$$Re(Z) = \frac{1}{2(w + t)\,\sigma\delta} \qquad (F\text{-}6)$$

vhere $\sigma$ is the conductivity in mhos per cm and $\delta$ is the skin depth when $t << w$, the equation becomes:

$$Re(Z) = \frac{1}{2w\sigma\delta} \qquad (F\text{-}7)$$

'or round conductors Equation F-7 becomes:

$$Re(Z) = \frac{\ell}{2\pi r\delta\sigma} \qquad (F\text{-}8)$$

/hen the strap length approaches the wavelength of the current, the strap will also act as a single-conductor ansmission-line with a given characteristic impedance which, except in a few special cases, will be difficult to alculate because of its capacitance. However, if the source and load impedances do not match the characteristic npedance, the strap will act as a radiator. Since the effort involved in matching impedances could be enormous, usually is advantageous to restrict the length of ground straps to less than 1/15 of the wavelength of the ighest frequency of interest.

## .4 SELECTION OF GROUND CONDUCTORS

o design a ground conductor, consider the major frequencies for which a ground path must be provided, the aximum current expected at these frequencies, and the maximum voltage drop permissible at these frequencies nd currents.

'he given theoretical information can be used to obtain:

o The real part of the surface impedance Re(Z) of the conductor at the frequencies (f) of interest Equations F-7 and F-8)

o The length of the conductor required compared to the wavelength of the frequencies (f) of interest, or the esonant frequency ($f_r$) of a given conductor (Equations F-3, F-5, and F-8)

o The DC resistance of the ground configuration, including contact resistance and DC resistance ($R_{DC}$) of he conductor (Equation F-4)

o The inductive reactance ($X_L$) of the conductor (Equations F-3 and F-5).

### '.4.1 Contact Versus Conductor Resistance

'he DC contact resistance is a major portion of the total DC resistance of ground conductors, and the reactive npedance is significantly higher at relatively low frequencies. To visualize how contact resistance becomes isignificant, consider a flat copper strap-type ground conductor, where the length-to-width ratio is 5:1, with a idth of 1.00 centimeter and a thickness of 0.15 centimeter. Suppose that the highest frequency is 50 MHz. ecause the conductivity ($\sigma$) copper = $5.8 \times 10^5$, the DC resistance ($R_{DC}$) of the strap (from Equation F-4) will e:

$$R_{DC} = \frac{5\text{ cm}}{(1 + .15) \times 5.8 \times 10^5} \quad \text{or} \quad R_{DC} = 6.66 \times 10^{-6}\text{ ohms} \qquad (F\text{-}9)$$

The real part of the surface impedance (Re(Z)) is equal to the DC resistance ($R_{DC}$) divided by two times skin depth ($\delta$) for flat conductors (compare Equations F-4 and F-7). Using the same value for conductivity ($\sigma$) above, the skin depth of copper is calculated as follows:

$$\delta = \frac{504}{(\sigma k m f)^{1/2}} \text{ meters} \quad \text{(F-1}$$

and is equal to 0.00093 cm at a frequency (f) of 50 MHz. Therefore, the characteristic impedance ($Z_o$) at MHz may be calculated as follows:

$$Z_o = \frac{R_{DC}}{2 \times 9.3 \times 10^{-4}}$$

$$= 3.5 \times 10^{-3} \text{ ohms}$$

which is 3.5 times greater than the normal DC contact resistance.

F.4.2 Complex Impedance

To obtain the inductance (L) of the strap described above, use figure F-1. The inductive reactance ($X_L$) of t conductor then will be given by $X_L = 2\pi f L$, which equals 10 ohms at a frequency (f) of 50 MHz. The resu indicates that the inductive reactance of the strap is much more significant than the impedance caused by sk effect. Capacitance between the strap and the adjacent metal surfaces also affects strap impedance, causing t strap to possess a characteristic impedance (given by $\sqrt{L/C}$), providing both L and C are approximately consta over the length of the conductor. However, unlike inductance, capacitance per unit length is rarely constant.

One exception is that of two parallel plates. The general equation for calculating the capacitance (C) picofarads of a parallel-plate capacitor, neglecting fringe effects, is:

$$C = 0.0885\, \epsilon\, [(N - 1)A]/t \quad \text{(F-1}$$

where N is the number of plates, A is the area of one side of the plate in square centimeters, t is the thickne of the dielectric in centimeters and $\epsilon$ is the dielectric constant relative to air.

In the case of two parallel circular plates of equal radius a, and thickness b (in meters), the capacitance (C) farads is calculated as follows:

$$C = \epsilon_o \frac{A}{d} + \epsilon_o\, a \left(\log \frac{16\pi(d + b)a}{d^2} + \frac{b}{d} \log \frac{d + b}{b} - 1\right) \quad \text{(F-1}$$

where A is the area of one side of a plate in square meters, d is the separation of the two plates in meters, ar $\epsilon_o$ is $8.85 \times 10^{-12}$ farad per meter.

Using Equation F-11, and assuming that t = 1 cm, the capacitance of a 5 cm strap will be equal to 0.4 picofarad. Thus, the characteristic impedance ($Z_o$) will be 256 ohms and the resonant frequency ($f_r$) will be 1.4 GHz.

If we examine a case where the strap is 17.70 centimeters long and the width is 1/5 of the length (3.55 centimeters), the following can be calculated:

- o Inductance, from Equation F-5, $L = 0.1\mu h$
- o Capacitance, from Equation F-11, $C = 5.6 \times 10^{-10}$ farads
- o Impedance, from $Z = \sqrt{L/C}$, $Z_o = 13.3$ ohms
- o Resonant frequency, from $f_r = \frac{1}{2\pi\ LC}$, $f_r = 21.3$ MHz
- o Inductive reactance from $X_L = 2\pi fL$, $X_L = 30.1$ ohms at 50 MHz.

In the examples above, the basic rule of maintaining arbitrarily-selected length-to-width ratios in constructing flat ground conductors can result in higher impedance than can be tolerated in a ground path. Bonding straps tend to lose their effectiveness at frequencies above parallel resonance (the 7-inch strap would not be effective above 21.3 MHz, while the 2-inch strap would be effective, but both straps have a length-to-width ratio of 5:1). Consider total conductor length in terms of the wavelength of interest and the strap self-resonance, as well as its length-to-width ratio. Arbitrary values, such as a 5:1 length-to-width ratio, can cause a bond strap to act as an open circuit instead of a short circuit. To ensure a low impedance ground path, account for variables such as inductance, capacitance, surface impedance, dissimilar metals, and transmission-line effects.

# APPENDIX G

## REFERENCES


1. NAVSANDA Pub 2002 Navy Stock List of Forms and Publications
2. NAVELEX 0101,102 Naval Communication Station Design
3. NAVELEX 0101,103 HF Radio Propagation and Facility Site Selection
4. NAVELEX 0101,108 Naval Security Communication Systems
5. NAVELEX 0101,110 Installation Standards and Practices
6. NAVELEX 0101,111 Digital Computer Systems, Vol. I of II
7. NAVELEX 0101,115 Digital Computer Systems, Vol. II of II
8. NAVDOCKS DM-4 Design Manual, Electrical Engineering
9. NAVDOCKS MO-201 Operation of Electric Power Distribution Systems
10. NAVDOCKS P-349 Index of Bureau of Yards and Docks Publications
11. NAVELEXINST 011120.1 Shore Electronics Engineering Installation Guidance for Equipments and Systems Processing Classified Information
12. NAVELEX 0101,106 Electromagnetic Compatibility and Electromagnetic Radiation Hazards
13. NAVMAT P3910 Guide for the Preparation of Technical Development Plans
14. NAVMAT P3940 Navy Systems Design Guidelines Manual, Electronic Packaging
15. NAVMAT P-5100 Safety Precautions for Shore Activities
16. NAVMAT P-3941-A Navy Systems Performance Effectiveness Manual
17. NAVMATINST 4000.20( ) Integrated Logistic Support Planning Procedures
18. NAVSHIPS 900,000.103 Test Methods and Practices
19. NAVSHIPS 900,000.105 RFI Reduction
20. NAVSHIPS 0967-000-0040 EIMB, Test Equipment
21. NAVSHIPS 0967-000-0100 EIMB, General
22. NAVSHIPS 0967-000-0110 EIMB, Installation Standards
23. NAVSHIPS 0967-000-0140 EIMB, Reference Data
24. OPNAVINST 1500.8 Preparation and Implementation of Navy Training Plans for New Developments
25. OPNAVINST 11010.1D Shore Facilities Planning and Programming System
26. SECNAVINST 4120.3B Defense Standardization Program
27. TM11-483/TO31-3-9 Radio Interference Suppression
28. MIL-HDBK-172A Military Standardization Handbook, Electronic Test Equipment
29. DCAC 160-1 Site Survey Manual
30. (no number) Handbook for Systems Engineers, USAF/ESD
31. (no number) Instructions for Preparation of Facilities Design Criteria, AFSC/ESD
32. T.O. 31-1-01 LOAP, Ground Communications, Electronic and Meteorological Equipment
33. T.O. 31-1-62 Handbook, Installation Practice Manual—Tables
34. T.O. 31-1-80 Handbook, Radio Frequency Radiation Hazards
35. T.O. 31-1-141 Basic Electronics Technology and Testing Practices
36. T.O. 31-10-24 GEEIA-Standard Theory, Principles, and Practices of Grounding Procedures and Lightning Protection for C-E Equipment, Facilities, and Systems
37. T.O. 43-1-1 Maintenance, Inspection, Storage, and Shipment-Training Devices and Trainer Maintenance Parts
38. ARDC M80-5 Handbook of Instructions for Ground Equipment Designers
39. EIA/EMC Bulletin No. 3 – Designer's Guide on EMC-Testing and Measurement Techniques for Electronic Equipment
40. MIL-STD-8B Dimensioning and Tolerancing
41. MIL-STD-12B Abbreviations for use on Drawings and in Technical Publications
42. MIL-STD-15-1A Graphic Symbols for Electrical and Electronics Diagrams
43. MIL-STD-15-3 Electrical Wiring Symbols for Architectural and Electrical Layout Drawings
44. MIL-STD-16B Electrical and Electronic Reference Designations

45. MIL-STD-17B-1 Mechanical Symbols (Other than Aeronautical, Aerospacecraft and Spacecraft Use)
46. MIL-STD-27 Designations for Electric Switchgear and Control Devices
47. MIL-STD-100 Engineering Drawing Practices
48. MIL-STD-108D Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment
49. MIL-STD-143A Specifications and Standards Order of Precedence for the Selection of
50. MIL-STD-210A Climatic Extremes for Military Equipment
51. MIL-STD-255A Electrical Voltages, Alternating and Direct Current
52. MIL-STD-285 Attenuation Measurements for Enclosures, Electromagnetic Shielding, For Electronic Test Purposes, Method of
53. MIL-STD-415B Test Point and Test Facilities For Electronic Systems and Associated Equipment, Design Standard For
54. MIL-STD-439B Electronic Circuits
55. MIL-STD-446A Environments For Electronic Parts, Tubes and Solid State Devices
56. MIL-STD-454A Standard General Requirements For Electronic Equipment
57. MIL-STD-469 Radar Engineering Design Requirements, EMC
58. MIL-STD-490 Specification Practices
59. MIL-STD-721B Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety
60. MIL-STD-826A EMI Test Requirements and Test Methods
61. MIL-STD-882 System Safety Program for Systems and Associated Subsystems and Equipment; Requirements for
62. 4120.3-M DOD Standardization Policies, Procedures and Instructions
63. MIL-D-1000 Drawings, Engineering and Associated Lists
64. MIL-E-4158C Electronic Equipment Ground; General Requirements For
65. MIL-T-4860C Trainers, Operational Procedure, General Requirements For
66. MIL-H-4978 Handbook: Standard Installation Instructions, Preparation of
67. MIL-A-9094C Arrester, Lightning, General Specification for Design of
68. MIL-I-11748E Interference Reduction For Electrical and Electronic Equipment
69. MIL-E-15685 Electronic Equipment For Service Test (Ship and Shore): General Specification
70. MIL-F-15733D Filters, Radio Interference, General Specification For
71. MIL-D-16415A Drawings, Installation, and Preliminary Data (For Electronic and Related Equipment)
72. MIL-I-16910C Interference Measurement, Electromagnetic, Methods and Limits
73. MIL-STD-847 Preparation of Technical Reports
74. NAVFAC P-127 Index of Design Standards and Criteria
75. NAVSO P-1480 Naval Training Device Center Index of Publications
76. AFM 86-4 Standard Facility Requirements
77. AFM 88-15 Standard Outline Specifications For Air Force Facilities
78. MIL-HDBK-300A Technical Information File of Aerospace Ground Equipment
79. MIL-E-16400F Electronic Equipment, Naval Ship and Shore, General Specification
80. MIL-S-26640 Specifications, Electronic Support Systems, Preparation of
81. MIL-T-27382 Training Equipment, Subsystem, Technical Data, Preparation Of
82. NAVPUBINST 5215.4D Navy Directives System Consolidated Index of Unclassified Instructions
83. American Institute of Physics Handbook by McGraw-Hill Co., Inc.
84. Electrical Engineers Handbook, Electric Power, by Wiley Engineering Handbook Series
85. Electrical Interference by Rocco F. Ficchi, Hayden Book Co., Inc., New York
86. Fields and Waves in Modern Radio by Simon Ramo, John Wiley & Sons, Inc., New York
87. Reference Data for Radio Engineers by International Telephone and Telegraph Corporation
88. Radio Engineers' Handbook by Frederick Emmons Terman, McGraw-Hill Book Company, Inc.
89. 1970 IEEE International Symposium on Electromagnetic Compatibility, The Design and Selection of Ground Conductors by Chris M. Kendall
90. MIL-STD-1472A Human Engineering Design Criteria For Military Systems, Equipment and Facilities
91. Human Engineering Guide to Equipment Design sponsored by JANAF Steering Committee and edited by Clifford T. Morgan, Jesse S. Cook, Alphonse Chapanis, and Max W. Land; McGraw-Hill Book Co., Inc.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 468-015

**WITHIN–SERIES ADAPTERS**

| Adapter type | BN | BNC | C | HN | LC | LN | LT | N | QDL | QDS | QL | PULSE RUB | PULSE A** | PULSE B** | SM | TPS | TWIN | UHF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FEMALE TO BANANA JACK | | 97B | | | | | | | | | | | | | | | | |
| FEMALE TO BANANA PLUG | | 1035 | | | | | | | | | | | | | | | | |
| FEMALE TO BINDING POST | | 1090 | | | | | | | | | | | | | | | | |
| MALE TO BANANA JACK | | | | | | | | | | | | | | | | | | 1017‡ |
| MALE TO BINDING POST | | 2B2B, 641 | | | | | | | | | | | | | | | | 332‡ |
| RIGHT ANGLE (F–M) | 243 | 306B | 567A | 212C | 208*, 208B**, 219*, 219B** | 97B | 534B, 1264, 1422* | 27C | 1061A | 1221 | | | | | | | 140*, 981*, 105B** | M–353A*, 247A*, 646*, 359** |
| STRAIGHT (F–F) | | 414A, 914 | 643 | | 155*, 155B**, 157**, 157B** | 109A | 533B | 29B, 1018, 1308 | 934A | 976 | 1373 | | 221 | | | 1367 | 105‡ | PL–258*, 299**, 360‡‡ |
| STRAIGHT (M–M) | | 491B | 642A | | | | | 57B, 1281, 1282, 1283 | | | | | | | 695 | | | |
| STRAIGHT PRES. BLKHD OR PNL MT. (F–F) | 244 | 492D | 701, 113B | 1019 | 287B* | 293 | | 30E | | 1145 | | | | 222B | | | PL–275, 493‡ | 224*, 300*, 307‡, 363‡ |
| STRAIGHT PRES. BLKHD OR PNL MT. (M–F) | | | | | | | | | | | | 336A | | | | | | |
| STRAIGHT PRES. BLKHD OR PNL MT. (M–M) | | | | | | | | 1018 | | | | | | | | | | |
| TEE (F–F–F) | | | | 413 | | 555 | | 28A, 1309 | | | | | | | | | | |
| TEE (F–M–F) | 242 | 2748 | 566A | | | | | 107B, 464 | 1249 | 1173 | | 1084 | | | | | 196‡ | 298‡, M–35B‡ |
| TEE (M–F–M) | | | | 1109 | | | | | | | | | | | | | | |

**BETWEEN–SERIES ADAPTERS**

| | BN | BNC F | BNC M | C F | C M | HN F | HN M | LC F | LC M | LN F | LN M | LT–M | N F | N M | QDL–M | QDS F | QDS M | QL–M | R–M | SKL F | SKL M | SM F | SM M | TPS F | TPS M | TWIN–F | UHF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BN–F | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| BNC F | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| BNC M | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C F | | | 636A | | | | | | | | | | | | | | | | | | | | | | | | |
| C M | | 635 | | | | | | | | | | | | | | | | | | | | | | | | | |
| HN F | | | 309 | | 702 | | | | | | | | | | | | | | | | | | | | | | |
| HN M | | 559B | | 703A | | | | | | | | | | | | | | | | | | | | | | | |
| LC F | | | | | | | 218A, 252, 497A | | | | | | | | | | | | | | | | | | | | |
| LC M (1) | | | | | 1287, 1288 | | 217A, 259A, 327A | | | | | | | | | | | | | | | | | | | | |
| LN F | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| LN M | | | | | | | | 998 | | | | | | | | | | | | | | | | | | | |
| LT–M | | | | | 1250, 1306 | | | 1168 | 586B, 587B | 1166, 1167 | | | | | | | | | | | | | | | | | |
| N F | | 1034 | 201A | | 564 | | | | | | 516A | | | | | | | | | | | | | | | | |
| N M | 605 | 335, 349B | 606 | 565A | | 1108 | 1107 | 999A | 270A, 271A | 213A | 108A | | | | | | | | | | | | | | | | |
| QDL–M | | | | | | | | | | | | | | 1013A | | | | | | | | | | | | | |
| QDS F | | 1136 | 1146 | | 1142 | | 1143 | | | | | | | 1144 | | | | | | | | | | | | | |
| QDS M | | | | | | 1137 | | | | | | | 966 | | 977A | | | | | | | | | | | | |
| QL–M | | | | | 1374, 1375 | | | | | | | | | | | | | | | | | | | | | | |
| R–M | | | 1260 | | | | | | | | | | | | | | | | | | | | | | | | |
| SKL F | | | | | | | | | | | | | | 131 | | | | | | | | | | | | | |
| SKL M | | | | | | | | | | | | | 110 | | | | | | | | | | | | | | |
| SM F | | | 690 | | | | | | | | | | | | | | | | | | | | | | | | |
| SM M | | | 691 | | | | | | | | | | | | | | | | | | | | | | | | |
| TPS F | | 1368 | | | | | | | | | | | 1426 | 1427 | | | | | | | | | | | | | |
| TPS M | | | 136B | | | | | | | | | | 1428 | 1429 | | | | | | | | | | | | | |
| TWIN–F | | | | | 971 | | | | | | | | | | | | | | | | | | | | | | |
| UHF F (2) | | | 273 | | 637 | | | | | | | | 318 | 838 | | | | | | | | | | | | | |
| UHF M (3) | | 255 | | | | | | | | | | | 146A | | | | | | | | | | | | | 970 | |
| UHF M (4) | 241 | | | | | | | | | | | | | | | | | | | | | | | | | | |

LEGEND:
- * UG–1422/U IS A 45° ADAPTER; MATES WITH PLUG UG–1305/U
- ** TO ADAPT PULSE A PLUG TO PULSE B PLUG, USE UG–1110/U
- ‡ SMALL SERIES ONLY
- ‡‡ LARGE SERIES ONLY
- F FEMALE
- M MALE

EXAMPLE 1: TO MATE A QDL MALE CONNECTOR TO A QDS MALE CONNECTOR, USE A 977A ADAPTER; TO ACHIEVE A RIGHT–ANGLE CONNECTION, USE A 1061A QDL CONNECTOR OR A 1221 QDS CONNECTOR AS APPROPRIATE.

EXAMPLE 2: TO MATE AN SKL MALE CONNECTOR TO AN N–SERIES FEMALE, USE A 110 ADAPTER; WITHIN–SERIES SKL ADAPTERS ARE UN–AVAILABLE, BUT A CONSIDERABLE SELECTION EXISTS FOR THE N SERIES.

NOTES:
1. UG–154 OR EQUIVALENT (SMALL)
2. 49194, SO–239 OR EQUIVALENT
3. 49190, PL–259 OR EQUIVALENT
4. 49195, PL–259A OR EQUIVALENT

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Foldout C - 1. Coaxial Connectors Interrelationships