NAVELEX
0101,114

NAVAL
SHORE ELECTRONICS
CRITERIA

NAVELEX CALIBRATION PROGRAM

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

NAVAL SHORE ELECTRONICS CRITERIA

NAVELEX CALIBRATION PROGRAM

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

FSN 0280—901—2000

JUNE 1972

LIST OF EFFECTIVE PAGES

Total number of pages in this manual is 195 consisting of the following.

Page Number	Effective Date
Title	June 1972
A, B	June 1972
Foreword	June 1972
i through v	June 1972
1-1 through 1-13	June 1972
2-1 through 2-17	June 1972
3-1 through 3-32	June 1972
4-1 through 4-20	June 1972
5-1 through 5-18	June 1972
6-1 through 6-6	June 1972
7-1 through 7-8	June 1972
8-1 through 8-13	June 1972
9-1 through 9-15	June 1972
A-1 through A-12	June 1972
B-1 through B-24	June 1972
C-1 through C-4	June 1972
Glossary-1 through Glossary-3	June 1972
FO 2-1	June 1972

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $2 (paper cover)
Stock Number 0859-0012

RECORD OF CHANGES

CHANGE NO.	DATE	TITLE OR BRIEF DESCRIPTION	ENTERED BY

FOREWORD

This handbook is published primarily as a means of documenting the current state-of-the-art of design and construction of electronic and electrical test equipment calibration laboratories. Its intent is to provide technical guidance to planners, engineers, and other personnel concerned with the planning, design, and construction of such laboratories to meet specific mission requirements.

This handbook is composed of familiarization material describing the Navy Calibration Program structure, including historical background, and a brief description is given of the basic operating characteristics of a Calibration Laboratory. The main portion of the handbook contains requirements for laboratory-type environments and recommendations, sample configurations, criteria, and ways and means of achieving the desired results. Since each Calibration Laboratory is usually designed to fulfill a specific mission, the material is presented in a general manner; that is, configurations are not standardized, but represent examples of possible solutions to various requirements. Similar material to that of the Navy Calibration Laboratory is presented for Fleet Electronic Calibration Laboratories emphasizing the shipboard environment. Finally, requirements for the Field Calibration (Qualification) Segment of the Navy Calibration Program is presented.

This manual may be used by all personnel concerned with new Calibration Laboratory design to achieve the following goals:

o To determine environmental requirements for a specific type laboratory, e.g., temperature, humidity, vibration.

o To determine the optimum configuration to achieve the specific mission goals.

o To select and/or design specific equipment, standards, supplies, furnishings, etc.

The material presented herein permits the achievement of these goals by giving the planner the technical tools required to select the optimum configuration in terms of such factors as mission requirements, projected workloads, operational efficiency, economy and other factors.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

CHAPTER 1

NAVY CALIBRATION PROGRAM STRUCTURE

1.1 HISTORICAL BACKGROUND

The establishment of a Navy Calibration Program resulted from problems generated by the lack of agreement on uniform measurement and calibration criteria between various activites; e.g., malfunctions and excessive return of equipment, high rejection rates, etc. The Bureau of Ordnance, in 1954, recognized the problem and initiated studies to determine the requirements for the establishment of a standardized measurements program. Such a calibration program was begun in 1956. In 1957, the Bureau of Ships initiated a similar program by establishing calibration facilities at various industrial activities and coordinating its program with that of the Bureau of Ordnance by a charter agreement to utilize the same technical guidance group (now known as Metrology Engineering Center (MEC) Pomona) to assure common standards, procedures, training, etc. In 1959, the Secretary of the Navy prescribed technical requirements for a Navy-wide calibration program. Installation of Fleet Electronic Calibration Laboratories (FECL) on Tenders and Repair Ships and at selected Shore Activities was initiated in 1960 by BUSHIPS to ensure that calibration intervals could be reasonably maintained and calibration services provided as near the end user as possible. As indicated in NAVELEX INST 9690.3, NAVELEX has the responsibility for the funding and technical direction of FECLs. NAVELEX also has the responsibility for the Field Calibration (Qualification) Segment of the Navy Calibration Program as it applies to the Fleet and shore activities for which NAVELEX has technical cognizance. At present, the Navy Calibration Program is managed and coordinated under the direction of the Chief of Naval Material (CNM). NAVELEX, by charter and by virtue of a joint agreement with NAVSHIPS, provides operational management, funding and technical direction for NAVSHIPS electronic-electrical calibration activities.

1.2 METROLOGY ORGANIZATIONAL STRUCTURE

1.2.1 Applicable Documents

Department of Defense (DOD) Directive 4155.18, entitled Improved Management of Metrology and Calibration Programs, states, in part, that metrology and calibration services and programs constitute a basic resource of the DOD. Objectives, responsibilities, and required action are outlined in order to maintain this resource. SECNAV Instruction 4355.11B, entitled Department of the Navy Metrology and Calibration Program, promulgates the DOD directive and assigns centralized management for the program to the Chief of Naval Material (CNM) under the Chief of Naval Operations (CNO). The CNM and the CNO documents pertinent to the Calibration Program are NAVMATINST 4355.66, NAVMATINST 4355.67, and NAVMATINST 4355.68. The CNM instructions assigns specific responsibilities to the various

Systems Commands which have, in turn, issued internal directives to their activities. The Naval Electronic Systems Command Electronic Test Equipment Calibration Program, NAVELEXINST 9690.3, is the guiding document for this command. It established policies and procedures in support of the NAVELEX portion of the Navy's Calibration Program and contains information covering:

- Program terminology and definitions
- NAVELEX Calibration Program Structure
- Listing of Navy Electronic Calibration Laboratories
- NAVELEX assigned responsibilities
- Field Calibration (Qualification) segment of the Navy Calibration Program
- Technical support functions of the Metrology Engineering Center (MEC)
- Navy calibration training program
- User considerations in determining calibration priority requirements
- Calibration labels and tags
- Use of other DOD/Government calibration activities
- Responsibilities of NAVELEX Field Calibration Technical Representatives (FCTRs)

Similarly, details of the Calibration Programs of the Naval Air, and Naval Ordnance Systems Commands may be found, respectively, in OPNAVINST 4790.2 and NAVORDINST 4855.14.

1.2.2 Program Structure and Traceability

The Navy Calibration Program is structured into various echelons or levels in which the capability of calibration services increases progressively with each higher echelons (see figures 1-1 and 1-2).

a. The National Bureau of Standards (NBS) and the Naval Observatory are the chartered agencies of the Federal Government having custody of the Nation's basic physical and time standards, respectively. They provide the common references for all measurements made within the scope of NAVELEXINST 9690.3, certify the Navy Standards maintained by the Navy Type I Standards Laboratories, and provide the basis for calibration of time and frequency standards.

The NBS and the Naval Observatory form the highest possible calibration level in the USA. NBS services, excluding precision time and time interval (PTTI) standards, are obtained by virtue of a Memorandum of Understanding between the

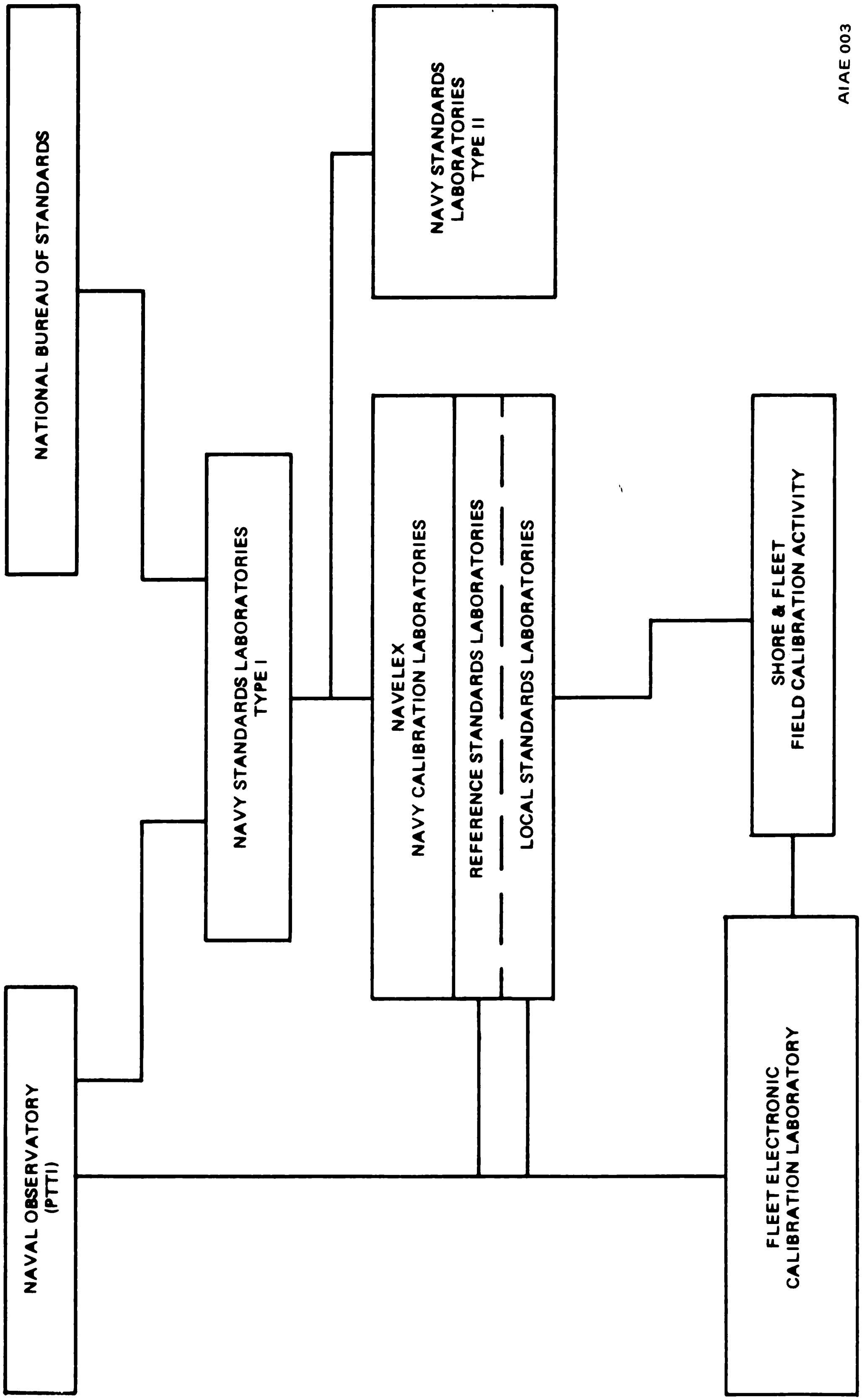


Figure 1-1. Traceability of Calibration Standards

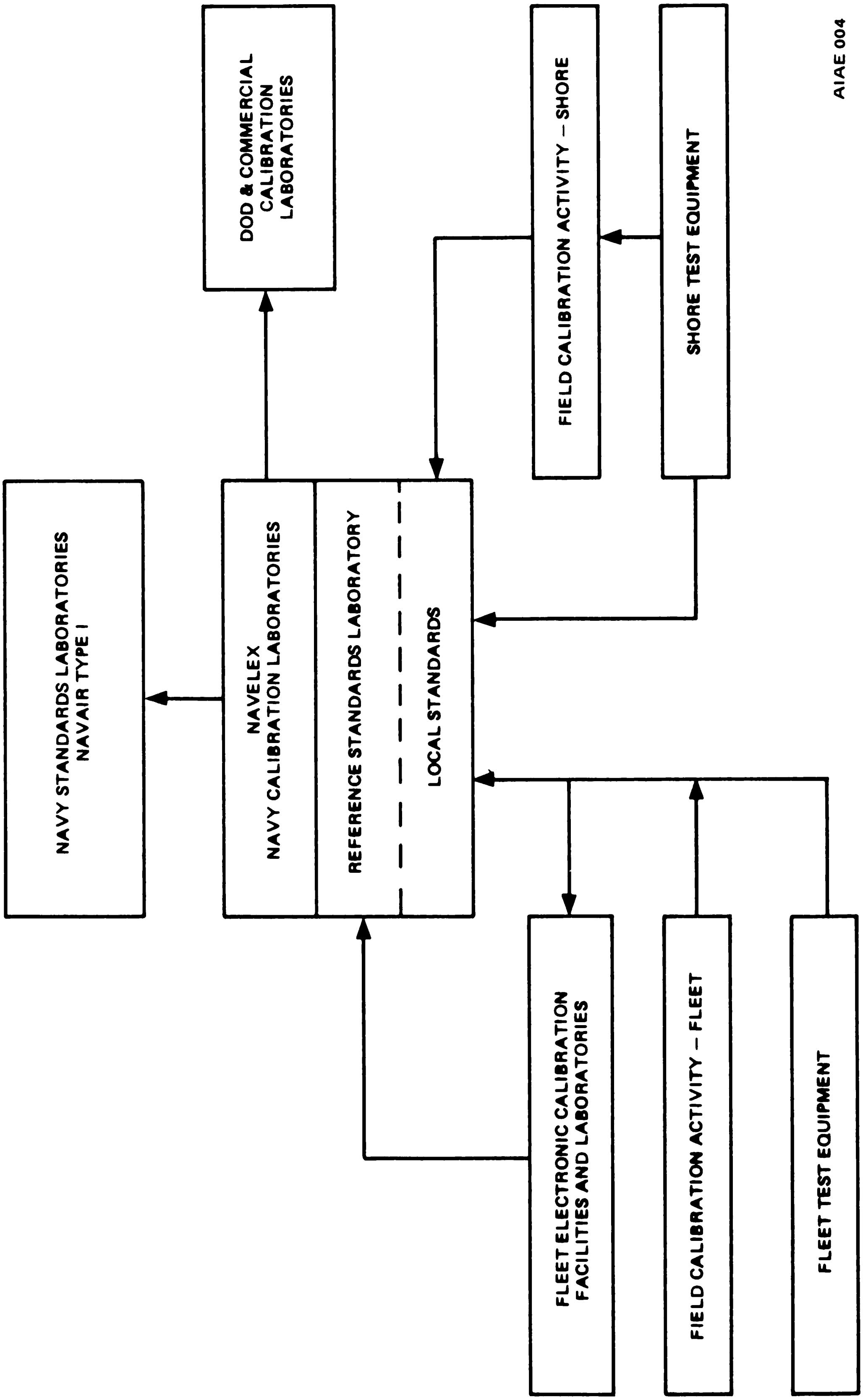


Figure 1-2. Test Equipment Flow

Department of Defense and the NBS, which establishes procedures for determining calibration requirements, joint requirements review and budget planning factors.

b. The Navy Standards Laboratories, Type I, maintain the highest standards within the Navy Calibration Program. They maintain and disseminate the most accurate units of measurements within the program, except for time and frequency. They obtain calibration services from the NBS and provide calibration of standards and associated measuring equipment received from Type II Standards and Reference Standards Laboratories.

c. The Navy Standards and Reference Standards Laboratories, Type II, provide the second highest calibration services for specific standards. They obtain standards calibration services from the cognizant Type I Navy Standards Laboratory, except for time and frequency, which they receive from the Naval Observatory, and calibrate standards and associated measurement equipment received from lower echelon Calibration Laboratories.

d. The Local Standards Laboratories (LSL) provide for the calibration and incidental repair of ship and shore test and measuring equipment. LSL calibration standards are calibrated by the cognizant Reference Standards Laboratory.

e. The Navy Calibration Laboratory (NCL) is a term describing the overall calibration effort in a Shipyard, SHIPREFAC or NAVELEXDIV or Activity. An NCL is usually comprised of a Reference Standards Laboratory and one or more Local Standards Laboratories.

f. Fleet Electronic Calibration Laboratories (FECL) have been established on board Tenders and Repair Ships, and at selected Shore Activities to assure calibration services and incidental repair of the Fleet's electronic and electrical test equipment. Calibration standards from these laboratories are submitted to RSLs for calibration.

g. Field Calibration (Qualification) Activities (FCA) are those ship and shore activities which have been authorized to perform field calibration functions and have been provided with Qualification Packages. Qualification standards are submitted to NCFs or FECFs for calibration.

1.2.3 Calibration Objectives

While the main objective of a calibration system is to attain a standardized measurements program, various other objectives are desirable for the attainment of a calibration system operating with a high degree of responsiveness to Navy requirements, economically and with self-sufficiency. Some of the objectives are:

o Identification of measurement requirements and development of calibration support plans concurrent with weapons system developments.

o Upgrading of facilities, equipment and personnel skills as required to maintain a continuous capability to satisfy increasing demands.

o Determining new capability requirements sufficiently in advance of support needs to permit timely acquisition of equipment, training of personnel, etc.

o Reduction of transportation of equipment and personnel through improved standards and equipment, and standardization of capabilities.

o Reduction of accuracy losses through elimination, wherever possible, of intermediary calibration echelons.

o Greater participation in tri-service operations profiting from maximum use of available information, elimination of duplication of development effort and maximum use of available resources.

o Investigation of feasibility of advanced measurement and calibration techniques, such as automatic test equipment and transmission of standard information by electromagnetic means, etc.

o Improved surveillance and auditing techniques aimed at maintaining high calibration proficiency.

1.3 LABORATORY OPERATION

1.3.1 Functions

The primary function of a calibration laboratory is to provide adequate, periodic calibration of metrology standards and/or test and measuring equipment used for quantitative measurements. Such calibration is performed at the lowest level of calibration commensurate with the use of the particular equipment involved.

Secondary functions include:

o Maintenance of its own standards.

o Training of personnel in the techniques and theory of calibration.

o Technical advisory services to parent activity with regard to calibration requirements, procedures, and equipments.

o Preparation of Local Calibration Procedures (LCP) when necessary.

o Calibration services for other government activities.

Other responsibilities will vary according to the type or level of the laboratory: e.g., a References Standards Laboratory may be recognized as the local authority in the measurements area and, as such, provide guidance, establish criteria, review techniques, etc. for the Local Standards Laboratories.

1.3.2 Workflow, Reporting and Control

Details of workflow, scheduling, paperwork, and control of test and measuring equipment vary with the activity within which the calibration laboratory is located, i.e., shipyard, air station, aboard ship, etc. In a shipyard, for example, the calibration program may be subject to, and operate by the procedures of the Quality Assurance office.

Reference Standards Laboratories and Local Standards Laboratories maintain a mandatory recall program for standards and test equipment which are included in the area of responsibility for each laboratory excluding transient workload. Such recall is performed monthly through the issuance of a Calibration Recall Notice, figure 1-3, by the laboratory to the coordinator or custodian of the equipment due for calibration the following month. Recalls are based on the calibration intervals established by the Metrology Requirements List (METRL), NAVAIR 17-35-MTL-1, NAVELEX 0967-133-2010. It may be accomplished manually or by an automated data processing (ADP) system. The latter is preferable since it may be used for a wide range of management activities, including scheduling workloads, failure reporting, inventory control, manhour control, etc.

The planning/scheduling sections within an activity issue calibration work or job orders which accompany the equipment to the cognizant laboratory and arrange for the scheduling of this equipment. Upon entering a laboratory, the equipment is logged in and tagged with any of the various forms used by the individual laboratory. Calibration is performed using the approved Navy Instrument Calibration Procedure (ICP) or Local Calibration Procedure (LCP) if a Navy ICP is not available; the Navy Calibration Checklist (figure 1-4) is executed during the calibration of each piece of equipment. In addition, laboratories must maintain a record for each piece of equipment, standard, etc. using a form similar to figure 1-5.

After calibration, all standards and test and measuring equipment are appropriately marked to indicate the calibration status. Calibration servicing labels and tags for this purpose are described in NAVELEX INST 9690.3 and NAVMATINST 4355.66 of 28 September 1970. Use in the Navy Calibration Program is mandatory.

In addition to the paperwork involved in the equipment flow and calibration process, laboratories are required to issue monthly status reports, calibration reports, etc. on a regular basis, or as requested by the Metrology Engineering Center (MEC), Pomona, California.

1.4 NAVELEX CALIBRATION PROGRAM PARTICIPANTS' RESPONSIBILITIES

Program participants have the following responsibilities for the effective utilization of calibration resources:

1.4.1 Ship and Shore Customers

a. Test equipment indicated in the Metrology Requirements List (METRL), NAVAIR 17-35MTL-1, NAVELEX 0967-133-2010, as requiring calibration servicing should be identified as to use:

FROM	DATE
TO	

Return below-listed items to this facility for calibration prior to recall date:

INSTRUMENT	MFG.	MODEL	SERIAL NO.	CONTROL NO.	DUE DATE
					AIAE 006

Figure 1-3. Calibration Recall Notice

IIND-GEN-13900-1

SECTION A

1. CALIBRATING ACTIVITY
2. SUBMITTING ACTIVITY
3. TEST INSTRUMENT *(Name of Item Calibrated)*
4. MANUFACTURER
5. MODEL NUMBER *(Commercial or Military)*
6. SERIAL NUMBER
7. REASON FOR SUBMISSION
   - CERTIFICATION/CALIBRATION 1
   - CROSSCHECK 2
   - FAILURE FROM DAMAGE OR ABUSE 3
   - OPERATIONAL FAILURE 4
8. DATE OF LAST SERVICING
9. SERVICING CYCLE (MONTHS)
   - CERTIFICATION/CALIBRATION
   - CROSSCHECK
10. CALIBRATION PROCEDURE

SECTION B

1. CALIBRATION TECHNICIAN
2. TEST DATE
3. CONDITION RECEIVED
   - WITHIN TOLERANCE 1
   - OUTSIDE TOLERANCE *Explain Below in 'REMARKS'* 2
4. CONDITION RETURNED
   - WITHIN TOLERANCE 1
   - OUTSIDE TOLERANCE *Explain Below in 'REMARKS'* 2
5. CERTIFICATED OR REPORTED VALUE, IF FIXED STANDARD
6. MAN-HOURS TO CALIBRATE
7. MAN-HOURS TO REPAIR *(List Repairs in 'REMARKS')*
8. SERVICING LABEL AFFIXED
   - CERTIFICATION/CALIBRATION 1
   - CROSSCHECK 2
   - LIMITED USE *(Explain Below in 'REMARKS')* 3
   - REJECT *(Explain Below in 'REMARKS')* 4
9. NEXT SERVICING DATE
   - CERTIFICATION/CALIBRATION
   - CROSSCHECK

SECTION C

REMARKS

☐ REPLY TO REMARKS REQUESTED

APPROVED ____________ LABORATORY SUPERVISOR

AIAE 007

Figure 1-4. Navy Calibration Checklist Form (Sheet 1 of 2)

11ND–GEN–13900–2

TEST INST(S):

PROC. NO. MFR MODEL SER.NO.

PROCEDURE STEP NO. (1)	FUNCTION TESTED (2)	NOMINAL (3)	MEASURED VALUES		OUT OF TOL ✓ (6)	CALIBRATION TOLERANCES (7)
			FIRST RUN (4)	SECOND RUN (5)		
						AIAE 008

Figure 1-4. Navy Calibration Checklist Form (Sheet 2 of 2)

INSTRUMENT CALIBRATION RECORD

IT IS THE RESPONSIBILITY OF EACH STANDARD AND LOCAL CALIBRATION LABORATORY TO MAINTAIN A CALIBRATION RECORD FOR EACH STANDARD, TOOL, OR PIECE OF TEST EQUIPMENT CALIBRATED WITHIN THE LABORATORY.

INSTRUMENT	MFG.	MODEL	SERIAL NO.	CONTROL NO.

ACTIVITY INSTRUMENT ASSIGNED TO

DATE CALIBRATED	CONDITION		NEXT CALIBRATION DUE	REMARKS
	WHEN REC.	WHEN RET.		

NOTES:

AIAE 009

Figure 1-5. Calibration Record Form

(1) Develop priority list for calibration to assure that those equipments considered most critical to the needs of the individual activity are calibrated. Highest priorities should be assigned to instruments used for highly accurate, quantitative measurements in performance monitoring, checkout and preventative maintenance.

(2) Apply a "Calibration Not Required" label if not used for critical measurements or adjustments.

(3) Identify ranges actually used on a multi-range instrument and request "Limited Use or Special Calibration" covering only those ranges. This will ensure that calibration facilities do not expend resources calibrating unused ranges.

(4) Label an instrument "Inactive" if it is used only during periods of prolonged technical availability (Tender or Shipyard). Do not submit it for calibration until it is to be used.

(5) If several instruments of a particular type are on board, determine a minimum number to be submitted for calibration. Those calibrated can then be used to verify the accuracy of the remaining ones by "cross checking."

(6) Clearly mark equipments known to be inoperable prior to submission, with the apparent malfunction explained on a tag attached to the instrument. <u>This is of utmost importance</u>. For example, in many instances, an equipment is submitted for calibration with one range intermittent. The calibration technician will start the calibration procedure and work through the instrument until he reaches the intermittent range. He then must stop, send the equipment to the repair area where the trouble is diagnosed, the customer contacted, and funds reouested for repair. Only after the funds are obtained can the parts be ordered and repair started. This process delays getting the instrument back and increases the cost of calibration. The operator of the equipment must have known the range was intermittent and could have identified it, or that it was a range which isn't used and "Limited Use or Special Calibration" should have been requested.

b. Customers should expend every effort to repair equipment to the best of their ability and, even more important, IDENTIFY THOSE EQUIPMENTS KNOWN (or SUSPECTED) TO BE MALFUNCTIONING and provide a brief description of the fault if possible.

c. Ensure that test equipment is properly protected in all phases of transit or storage to prevent damage or loss of calibration.

1.4.2 <u>Field Calibration (Qualification) Activities</u>

a. Service every equipment which can be supported by the Qualification Package which is held.

b. Provide service to other units in the area if possible.

c. Follow steps covered above in identifying malfunctions in equipments to be submitted to higher echelons.

1.4.3 Fleet Electronic Calibration Laboratories (FECL)

a. Screen and identify malfunctioning equipment as early as possible and return to the submitting unit for repair (if it is within their capability) or to the repair area for service, prior to attempting calibration.

b. Clearly identify, label, and tag inoperable equipments which obviously require shipyard servicing.

c. Submit metrology standards to the Navy Calibration Laboratory (NCL) which supports the FECL, in lieu of submitting directly to a Type I or Type II Navy Standards Laboratory. The NCL can support almost all FECL standards and is funded to accomplish repairs and calibration. FECLs should not attempt to repair FECL standards as NCLs have this responsibility. The NCL will forward only those standards requiring Type I or Type II Navy Standards Laboratory support to the higher echelon. Support at a level higher than is required increases costs.

d. Ensure that metrology standards and test equipment are properly protected in all phases of transit or storage.

1.4.4 Navy Calibration Laboratories (NCL)

a. Screen all incoming equipments as soon as possible to determine operability and notify the submitting activity, Type Commander or maintenance representative of funds required for repair. Initial contact by telephone, with paperwork follow up, is recommended.

b. Schedule work as far in advance as possible via the "180-day letter," pre-arrival conferences, etc.

CHAPTER 2

LABORATORY PLANNING CONSIDERATIONS

Planning Considerations in reference to the establishment of a Standards Laboratory are discussed in this chapter. The information contained in the chapter is general in nature and may be applied to all Standards Laboratories in the Navy Calibration Program.

2.1 NEW ACTIVITY ESTABLISHMENT

Establishment of a new Calibration Laboratory requires the approval of the Chief of Naval Material (CNM). Requests for establishing a new Calibration Laboratory, substantiated with detailed justification, should be submitted to CNM via the chain of command, the local Field Calibration Technical Representative and cognizant NAVSYSCOM HDQTRS. Justification for the new laboratory, or major expansion to an existing laboratory (i. e., an annex) should include the following factors:

- o Volume and consistency of workload in relation to present laboratory space.
- o Projection of future workload, including personnel and equipment budget forecast.
- o Availability of adequately trained personnel.
- o Availability of supporting funds.
- o Inadequacy of present facilities.
- o Geographic location and transportation factors.
- o Availability of other suitable calibration services.

When the direct workload exceeds the capability of an existing laboratory, it is recommended that a second shift be used, rather than initiating a request for additional space. Also, maximum use of other Navy (NAVORD, NAVAIR), DOD, or contracted facilities should be exercised, under negotiated inter- or intra-service agreements or contracts to resolve short term heavy workloads.

2.2 SITE SURVEYS

Surveys should be conducted during the initial planning stages of a new laboratory to determine the suitability of a physical site or plant for the location of the proposed laboratory. The following factors should be considered during such a survey:

a. Wherever possible, a laboratory should be:

o Located on the bottom floor of a building, isolated from heavily traveled areas, machine shops, etc., to minimize vibration and noise.

o Located away from dust areas and operations; e.g., sand-blasting paint shops, etc.

o Accessible to all operational organizations utilizing the calibration services.

o Serviced by a central shipping/receiving platform or area to preclude entry of unauthorized equipment into the laboratory.

b. An electromagnetic interference (EMI) survey should be conducted at a potential location to assure freedom from excess electromagnetic radiation (EMR), both natural and manmade, especially if the laboratory is expected to perform calibration of VLF Phase Tracking Systems or similar equipments.

c. Required antennas should be positioned so as to be free of line-of-sight obstructions.

d. Requirements for future expansion.

2.3 MEASUREMENT REQUIREMENTS

In order to expand an existing or implement a new laboratory it is necessary to identify the measurement requirements of all applicable test equipment; i.e., the true technical requirements of each item to be calibrated, range, accuracy, period, etc. To accomplish this, it will be necessary to analyze a complete inventory of test equipment, subdivided or grouped according to measurement area such as voltage, resistance, frequency, power, etc. Once the measurement requirements have been identified and specified, it is then possible to construct a chain of necessary standards, equipment and facilities required to support the standards and test and measuring equipment up to the highest echelon (NBS).

In addition, it is necessary to identify such items as calibration cycles, manhour workloads, facilities environments, requirements for new calibration procedures, etc.

In establishing the above requirements, the completion of the survey form shown in figure 2-1 may prove useful. This form provides for the listing of the item requiring calibration, nomenclature, manufacturer's code, model number, etc. of every item being surveyed.

2.4 NAVY CALIBRATION LABORATORY CAPABILITIES

2.4.1 Background Information

Standardized measurement capabilities for the various echelons of Navy Calibration Laboratories are not generally available. Past efforts have been directed toward

DATE OF SURVEY ________

SUBMITTING ACTIVITY ________

ACTIVITY/AREA/PROJECT BEING SURVEYED:

ITEM NO.	ITEM NOMENCLATURE	MFR CODE	MODEL NO.	QTY.	FREQUENCY RANGE	CHARACTERISTIC RANGE	CALIB LAB & PHASE CODE	ITEM NOS. REQUIRED
								AIAE 040

Figure 2-1. Measurement Requirements Survey Form

equipping each laboratory as necessary to meet specific mission requirements. Pertinent MEC documents which identify capabilities are discussed below.

a. "Navy Calibration Equipment List Electronic" (NAVAIR 17-35NCE-1) sets forth those instruments known to be available in Navy laboratories participating in the Navy Calibration Program. Individual instruments are listed by parameter with a brief capability statement. This document does not represent the inventory or capability of a particular laboratory or type of facility.

b. The Calibration Capability Listing for Fleet Electronic Calibration Laboratories and NAVELEX Calibration Facilities (CCL-1) indicates the support capability of NAVELEX calibration facilities in terms of test equipment and where it can be calibrated, listed by model number.

c. The "Minimum Equipment Requirements List" is an inventory listing for Fleet Electronic Calibration Facilities. It contains a preferred equipment listing for procurement consideration and models representing typical inventory of existing facilities. A brief capability statement is provided for each item. A copy of the MERL is presented as Appendix A.

2.4.2 Laboratory Standard Equipment

Appendix B supplements the above documents and lists the standards and key ancillary measurement equipment presently available, or scheduled, for NAVELEX Calibration Program participants. For clarity Appendix B lists only the major standards or measurement area. It is meant to be a capability chart, and as such, does not represent a complete preferred or typical inventory.

2.5 PERSONNEL REQUIREMENTS

While specific criteria relating personnel requirements to workload have not been developed for calibration laboratories, it is important that proper planning for staff be made to assure measurement quality and to achieve an efficient, well run operation.

2.5.1 Personnel Survey

The following factors should be examined in the determination of personnel requirements for each of the various types of laboratories:

a. Total quantity of customer equipment expected to fall under the laboratory's cognizance. This may be estimated from the survey conducted initially.

b. Expected number of internal standards and equipment to be maintained by the laboratory's own staff.

c. Calibration intervals of equipments included in workload.

d. Skills required for the areas of measurement to be encompassed, e.g., microwave, special test equipment, etc.

e. Other services to be provided, such as training, liaison, etc.

The expected total manhour requirements per month, or other unit of time, may be determined from a, b, and c by assuming that an average of 3 hours per instrument is required for calibration. More accurate manhour loading may be obtained from computer listings or checklists, if a sufficient quantity of completed checklists can be obtained for analysis. The number of personnel required for direct calibration activity is estimated by multiplying the total number of equipments to be calibrated per month by the average manhours per instrument and dividing the result by 160 (approximate available manhours per month, based on a 40-hour week, 48 weeks/year).

2.5.2 Supervisory and Support

In addition to the staff of direct workers, a number of supervisory and/or support personnel (production control, clerical, etc.) will be required.

2.5.3 Training

Technical personnel assigned to the calibration function must be properly trained in order to achieve a high operational quality. Supervisory personnel should be experienced and knowledgeable in all phases of calibration and be graduates of authorized calibration training or familiarization courses. Personnel training courses may be found in NAVELEXINST 9690.3 and other SYSCOM instructions.

2.6 THE BASE ELECTRONIC SYSTEM ENGINEERING PLAN

NAVELEX policy requires that the planning and execution of electronic projects, regardless of scope or complexity, be accompanied by an engineering plan called the Base Electronic System Engineering Plan (BESEP). The BESEP is the basic technical document governing electronics and other affected phases of shore electronic project planning and implementation. It equates a sponsor/user statement of operational needs to appropriate shore electronic systems and facilities concepts which will meet the need and includes such information as:

o Historical data leading to the establishment of the project.

o Reference to and appropriate paraphrasing of operational requirements and other guidance documents.

o Overall objectives of the systems to be provided.

o Identification of existing or other proposed systems/facilities affected or with which compatibility is required.

o Requirements or provisions for incremental implementation.

o Special requirements for continuity of operation of existing radiation hazards, security, etc.

- o General plan for selection of sites or identification and description of sites already selected.

- o System packaging guidance (i. e., transportable or fixed plant).

- o Special requirements of operational flexibility and convenience.

Within the Naval Material Command, electronics engineering capabilities are concentrated in the Naval Electronics Systems Command, while construction capabilities are assigned to the Naval Facilities Engineering Command. The BESEP is normally prepared by the Electronic Systems Command Field Technical Authority in cooperation with the Facilities Engineering Command Engineering Field Division.

Policy and procedures for BESEP utilization, as well as a detailed description of the BESEP, may be found in NAVELEXINST 11000. 1.

2. 7 LABORATORY FACILITIES CONFIGURATIONS

2. 7. 1 Space Requirements

The total area required for a particular laboratory depends on a number of factors, but it is governed primarily by the minimum working space necessary to perform the intended calibration and incidental repair and to accommodate the expected staff. Space must also be allocated for clerical and administrative functions, filing and storage cabinets, carts, bookcases, the shipping, receiving and cleaning functions, and for a utility area to contain the air-conditioning system, janitorial supplies, and the like. In addition, space should be allocated for a laboratory entrance of the double door, vestibule type, as recommended in EC-23 "Recommended Facility Requirements for Navy Calibration Laboratories (Shorebased)." Space requirements should be calculated to provide for all expected measurement areas. For those laboratories not anticipating all the various types of measurements, reduced space requirements exist. However, future measurement projections which allow for reasonable expansion should be included in the space planning stages.

Specialized floor space requirements should be handled on a "per case" basis. For example:

- o Laboratories with large workloads may require an office copying machine, extra cabinets, library spaces, administrative space for supervisory staff, etc.

- o Some shipyard located calibration laboratories may require additional space for a mercury work area.

2. 7. 2 Floor Plans and Laboratory Arrangements

Calibration laboratories are normally arranged according to measurement area and to achieve an efficient flow of equipment and personnel. Other modifying factors affecting the final layout include:

o Space and configuration available, if laboratory is being built at an existing facility

o Location of existing machinery, equipment, transformers, power lines, etc., which can contribute undesired vibration, noise electromagnetic fields, heat, etc.

o Availability and location of prime power

o Existing environmental conditions

o Human factors such as aisle clearances, safety considerations, etc.

The measurement areas expected to have the largest workload should be located for maximum convenience, usually close to the laboratory shipping/receiving/cleaning entrance. Other calibration stations may be separated according to function, e.g., DC voltage, current and resistance form a natural grouping; AC inductance, capacitance and resistance; oscilloscope calibration, signal generator calibration, etc. The exact arrangement will vary, of course, with each installation. Low frequency, waveform, frequency response and other measurements which may be affected by the stray fields found near transformers, cables and the like should be located so as to avoid possible electromagnetic coupling. Similarly, microwave and coaxial measurements should be placed so as to avoid possible coupling with high frequency stray electromagnetic radiation (EMR). Screen rooms or shielded enclosures used for this purpose must be justified on a per case basis. Experience has demonstrated that in many instances screen rooms are not required or are overdesigned, which greatly increases the expense of building a laboratory. An EMR survey should be conducted to determine requirements for shielded rooms. Other precautions for minimizing potential EMI are given in a later chapter.

Vibrations caused by door slamming, mobile carts, and general personnel traffic may be a problem for station using sensitive galvanometers or in the calibration and repair of meter movements. Such stations should be located away from heavily travelled aisles, doors, or other sources of disturbances.

Figure FO 2-1 and figures 2-2, 2-3 and 2-4 depict examples of arrangements which may be used for guidance during the planning stages of a new laboratory. The plans and illustrations shown generally reflect the recommendations previously listed those given in EC-23 and other Metrology Engineering Center documents. A discussion of those elements common to all arrangements follows.

a. Shipping and Receiving. An area immediately adjacent to the laboratory entrance should be provided with sufficient space to accommodate racks or cabinets to store eouipment awaiting disposition, pick-up by the customer, and spare parts. Separate racks should be provided for incoming and outgoing equipment. A cleaning area located outside the calibration effort is also necessary. This area should contain a pressurized air or nitrogen supply, sink, and if necessary, an ultrasonic or other specialized (neutral) cleansing system.

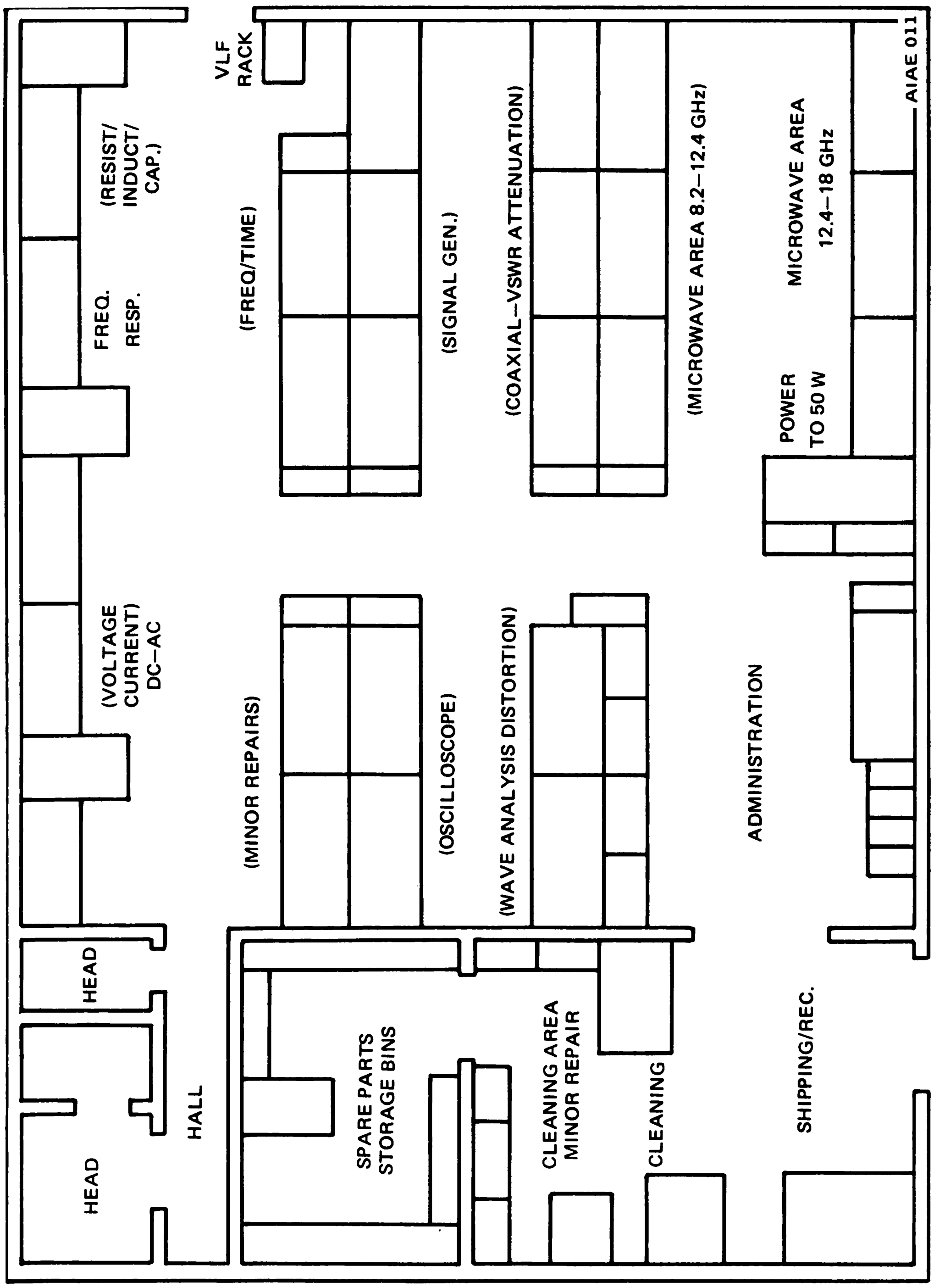


Figure 2-2. Sample Floor Plan "B"

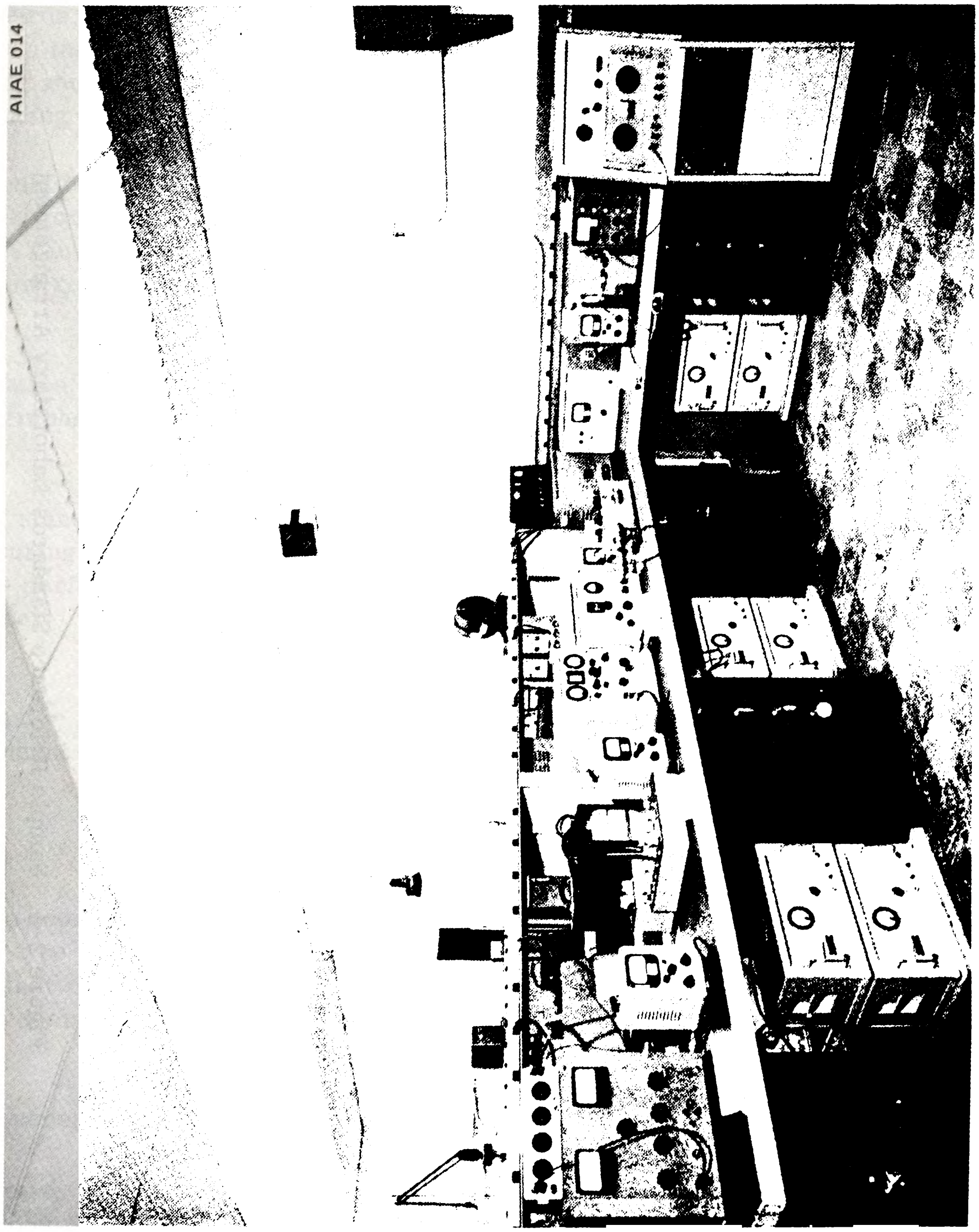


Figure 2-3. Sample Reference Standards Laboratory Arrangement

Figure 2-4. Sample Reference Standards Laboratory Arrangement

Such an area will most probably be required by Local Standards Laboratories operated at production or service type facilities, rather than Reference Standards Laboratories, which normally handle equipment originating in relatively clean environments.

b. Repair and Maintenance. Although Calibration Laboratories are limited to incidental repair of test and measuring equipment and repair of the laboratory's own standards, repair functions that are considered dirt producing should be confined to an area that is physically separated from the calibration effort. Soldering, wire-cutting and stripping, drilling and other machining operations are all contaminant producing activities which should be isolated.

It should be noted that while the Calibration Laboratory itself does not perform major repair work, it should be located adjacent to an Electronics Repair Shop, such as Shop 67 in a shipyard, whose function it is to repair test equipment. This will expedite any required major repair.

c. Storage. Storage space is necessary for equipment, administrative documentation, and technical literature; these are individually discussed in the following paragraphs.

(1) Equipment. Equipment requiring storage includes incoming and outgoing standards and test/measuring equipment, the laboratory's own standards/measuring equipment, tools used in incidental repair, and all accessories required in the performance of the calibration function. Available types of storage facilities include:

o Open racks or bins with adjustable shelving. These are the least expensive means of storage and may be used for temporary storage of customer equipment having, for example, a 2-week turnover time.

o Wall hung shelving which is similar to open racks.

o Fully enclosed cabinets. These include steel panel type units with double doors and adjustable shelves, sliding glass door type cabinets, and other laboratory type enclosures. They are ideal for dust-free storage of waveguides, standards, and other delicate instruments. However they are expensive, especially the sliding glass door type. (See figure 2-5.)

o Drawers built into bases of work benches. These may be used to store accessories, but should not be used for delicate equipment, e.g., meters, etc.

Whichever type of storage is used, adequate space for the anticipated (and future) workload, standards, etc. should be planned to avoid later "pile-ups" of equipment on floors and desk tops.

Special storage is required for microwave isolators having internal magnets. Clearances of 4 to 6 inches from metallic objects are usually necessary. This may be obtained by use of wooden boxes or cabinet drawers to store such equipment.

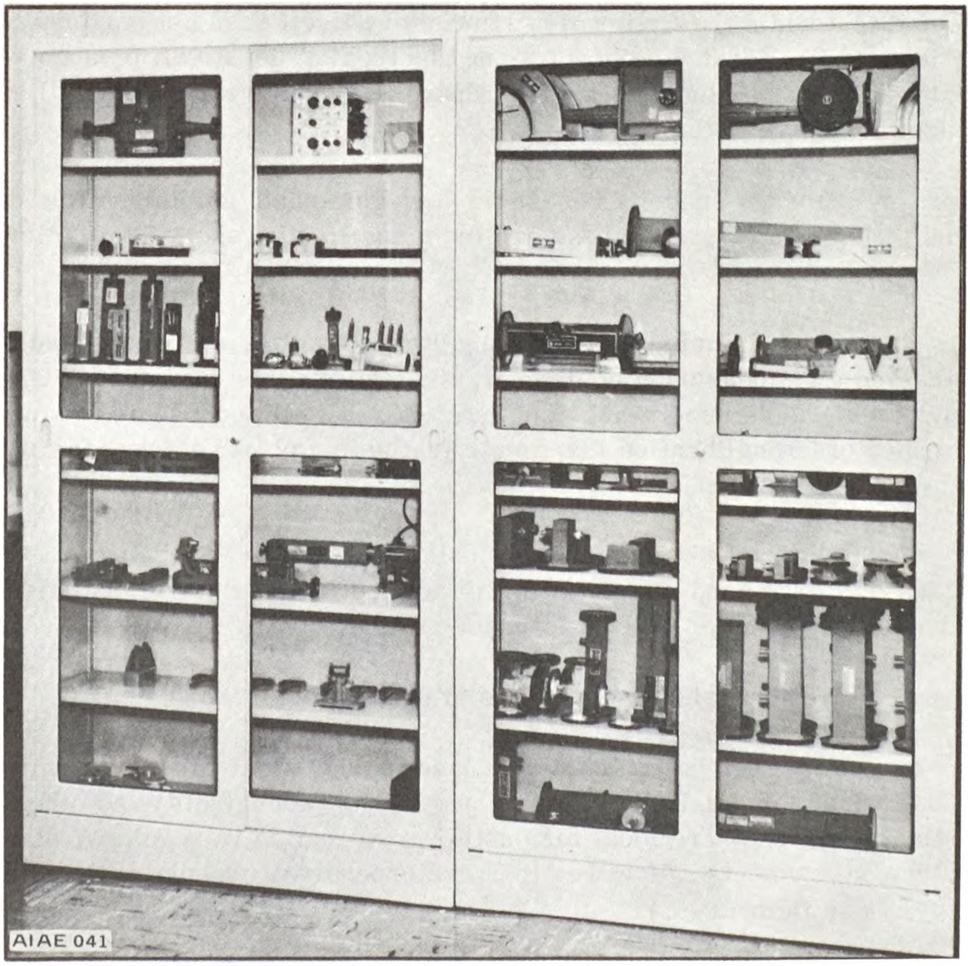


Figure 2-5. Wall Cabinet, Sliding Door

(2) Administrative Documentation. Adequate space should be provided for filing cabinets to store the quantities of paperwork generated by the laboratory. Checklists, recall notices, certificates, reporting forms, labels, tags, correspondence, and many other forms must all be kept on file for varying periods of time. The quantity of documentation requiring storage will be dependent on the laboratory's workload.

A secure filing cabinet will be required for storage of classified calibration procedures.

(3) Technical Literature. Technical Literature which must be stored includes calibration procedures, instruction books, operation and maintenance manuals, textbooks, manufacturers' brochures, and other documents. These may be stored in either open or enclosed type bookcases. The quantities to be stored may be significant, especially in production facilities which must store military and commercial operation manuals for large quantities and types of test equipment. Such operations may require a separate library area to accommodate the necessary material and to provide control of document flow.

d. Work Benches. Work Bench requirements are given in EC-23. In brief, benches should have the following properties:

o A minimum depth of 30 inches

o A height of approximately 37 inches from floor to bench top

o Have a non-metallic top (wood, masonite, etc.) fastened with non-metallic screws to avoid shock hazards

o Have bases with built in drawers and/or cabinets for additional storage space

o Provide adequate leg and knee clearances

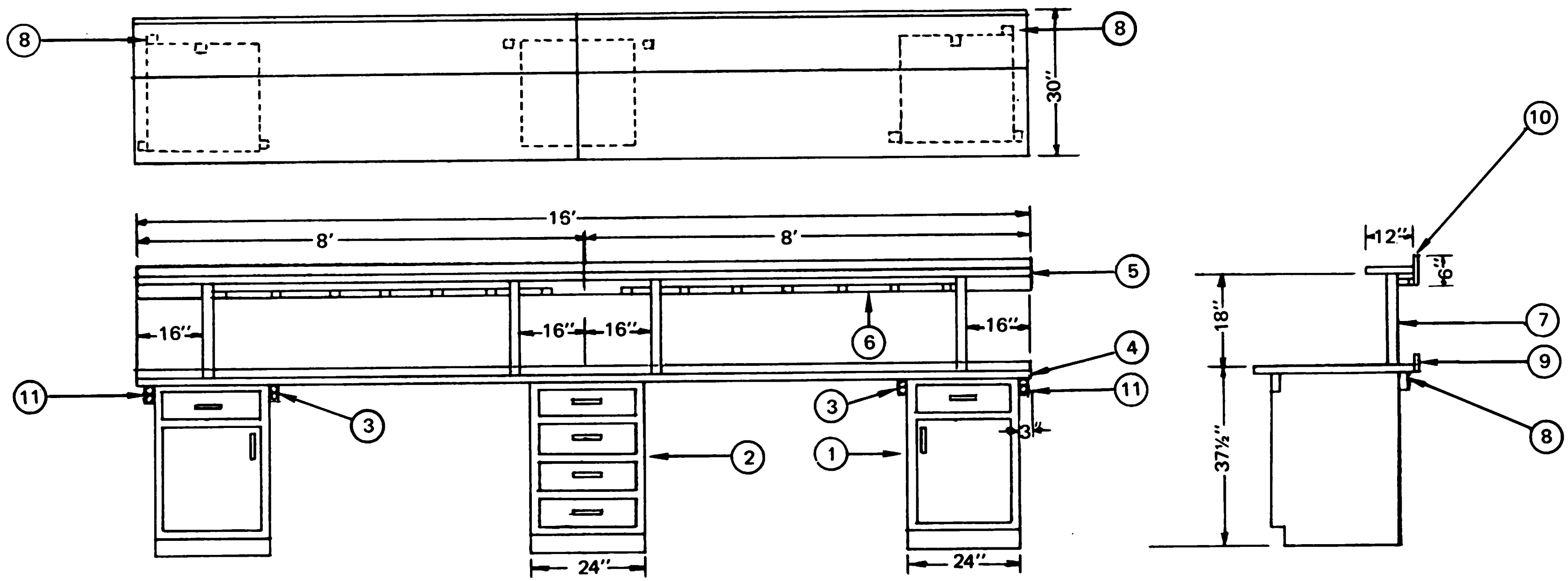
o Bench length is not critical. Overall laboratory working area and planned layout should determine the bench length. (See figure 2-6 for a typical 16-foot bench.)

o Have a leveling feature.

Non-metallic shelves mounted above benches, either on walls or on the benches themselves by means of a riser, provide additional space for test equipment. Such shelves can run along the length of the bench; however, they should be a minimum of 18 inches deep and be set back at least 12 inches from the bench front.

Bench installations should include:

o A copper grounding bar running along the length of all benches and fastened at the bench rear or on back of overhead shelves. Size of the bar should be



LEGEND

1. CABINET – 1 RIGHT HAND DOOR & 1 LEFT HAND DOOR REQ
2. CABINET WITH DRAWERS – 1 REQ
3. DUPLEX RECEPTACLE & BOX, 15 AMP 125 VOLT – 2 REQ
4. 1¾" HARDWOOD MAPLE TOP – 2 REQ
5. 1¼" HARDWOOD MAPLE SHELF – 2 REQ
6. PLUGMOLD 2000 NO. 20G606 WIREMOLD COMPANY – 2 REQ
7. 2¼" X 2¼" SHELF SUPPORT – 4 REQ
8. ELECTRICAL JUNCTION BOX WITH 6' CORD ATTACHED/WITHOUT PLUG – 2 REQ
9. ¾" X 2½" RETAINING EDGE – 2 REQ
10. ¼" X 6" RETAINING EDGE – 2 REQ
11. DUPLEX RECEPTACLE & BOX, 15 AMP 125 VOLT – 2 REQ

NOTES

1. ALL WIRING TO BE CONCEALED WITHIN BASE CABINET OR SHELF SUPPORT.
2. WORKBENCHES MUST BE CONSTRUCTED OF NON–CONDUCTING MATERIAL OR MUST BE INSULATED TO PREVENT THE TECHNICIANS FROM THE POSSIBILITY OF GROUNDING WHEN WORKING AROUND HIGH VOLTAGES.

AIAE 042

Figure 2-6. Bench, 16-Foot, Laboratory

1/4 X 3/4 inch bar minimum. The bar should be connected to the earth ground at the laboratories tie-point by use of an approved bonding technique (see NAVELEX 0101, 106) at one end only in order to prevent ground loops. Resistance to earth ground should be 0.25 Ω maximum.

o Receptacles for 115-volt, 60-Hz power should be installed at least every foot at the rear of all benches. Further details for power requirements are provided in a later chapter. Additional receptacles should be provided for 400 Hz.

e. Other Requirements. In addition to the above, space should be provided for:

o Mobile Service. Carts used for storage of oscilloscope and other instruments and to move equipment around the laboratory. A number of these may be used in a laboratory. If possible, they should be equipped with pneumatic tires to prevent floor damage and to protect the instruments from vibration. In addition, padding should be placed on the carts to isolate the instrument from the cart.

o Special Facilities. Some laboratories may handle calibration of specialized instruments or employ techniques which require special facilities, such as equipment from nuclear submarines. Where mercury is used in calibration, a mercury room or special work area must be available to avoid possible mercury contamination of the equipment. Special "mercury free" tags are attached to such equipment.

2.8 ARCHITECTURAL CONSIDERATIONS

Although construction of shore facilities is the responsibility of the Naval Facilities Engineering Command, NAVELEX personnel concerned with the planning of new laboratories should be acquainted with the basic types and principles of construction, as well as those architectural features which may be specified by requirements peculiar to a calibration laboratory. The latter includes floor coverings, materials, wall finishes and similar details which should be selected specifically for a laboratory type environment.

2.8.1 Design Philosophy

In general, the objectives of military construction are the same as that of good commercial practice, i.e., emphasis is placed on scale, balance of elements, simple functional layouts, and low cost in both initial construction and future maintenance. Other objectives include selection of good materials, methods and details of construction, mechanical and electrical systems, and fire-safe, hazard free design.

The architectural design should be harmonious with existing construction within the area. Such design should:

o Be based on the actual project requirements with special attention given to configuration, structural system, selection of interior and exterior (if applicable) finishes, and extent and type of services provided.

o Meet the operational requirements of the using activity and, at the same time, provide enough flexibility to accommodate future requirements changes.

o Provide a functional facility at lowest possible cost, with regard for economy of operation and maintenance.

o Place emphasis on quality of the design, including the attractiveness of both interior and exterior. High quality, simple, functional designs are achieved through the expert use of economical basic design concepts rather than the use of superficial, piecemeal features.

Further details may be found in NAVDOCKS DM-1 and other manuals in the DM series, as well as commercial documents and texts on architecture and construction.

2.8.2 Fenestration

The term, fenestration, refers to the arrangement of openings in a building wall for windows. The traditional use of windows is to admit light and permit a view. However, where advantageous to functional use or special need, (as in a calibration laboratory), fenestration should be eliminated. The absence of windows will lessen their possible influence on the lighting, heating and cooling systems required to establish the desired environment, and will contribute to the achievement of a glare-free, dust-free area without the need for special sealed windows, draperies, etc. For additional information on laboratory environments and lighting requirements, refer to subsequent chapters.

2.8.3 Floor and Ceiling Treatments

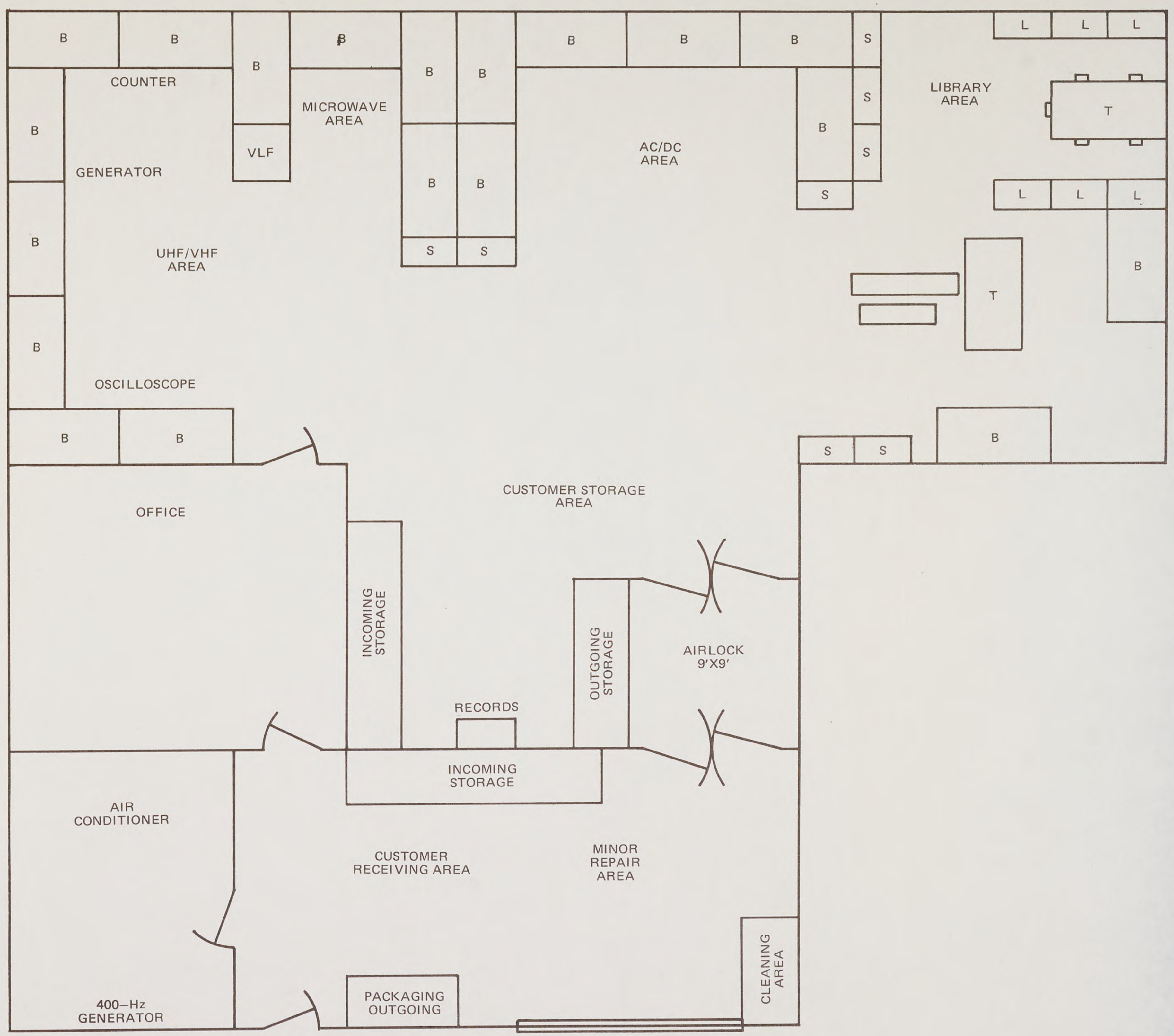
a. Floors. Floor finishes for laboratories are selected for their electrical insulation properties, durability, ease of maintenance and their resilience. The deck of the entire laboratory area should be covered with continuous lengths of vinyl sheeting capable of withstanding 10,000 volts without dielectric breakdown when tested by method 8211 of Federal Test Method Standard No. 501. Examples of suitable floor covering are sheet vinyl 9Q7220-728-3028 under Federal Specification LF-00450A (GSA-FSS) which will test for dielectric strength of at least 30,000 volts. However, any qualified grade of sheet vinyl will do. Light colors are encouraged due to their reflective and cleanliness characteristics.

b. Ceilings. Acoustical tile ceilings installed on a metal suspension system or on metal ceiling furring, are recommended for laboratory areas. Suspended ceilings should be installed to conceal unsightly piping and duct work which, if exposed, can cause condensation to fall on electronic equipment, and to lower existing high ceilings to standard 8-foot heights. The lower ceiling permits the design and installation of more efficient, less costly lighting, heating and cooling systems. The tile used on such ceilings should be made of noncombustible inorganic acoustical materials. A number of suspension systems are available which permit the combination of sound-absorptive ceiling surfaces with lighting, air-conditioning, and sometimes radiant-heating elements in any desired arrangement. These are further discussed in chapter 3 and details of acoustical noise treatment are given in chapter 7.

Selection factors for paints and other interior finishes include durability, reflectance, esthetic factors (color, texture), and special requirements such as resistance to mildew and fungus, freedom from lead or mercury, etc.

The ceiling and side walls down to a distance of 3 feet from the ceiling should be flat white with a reflectance of 60 percent, minimum. The remaining wall surface should be non-glossy and finished in non-saturated colors such as tints or pastels, having a reflectance of 40 percent, minimum. Such a painting scheme will add to overall room illumination and, at the same time, reduce undesirable specular glare. Colors may be selected from Federal Standard 595 which presents a collection of standard colors in current use, or from other applicable specifications. Monotonous repetition should be avoided while selecting colors. However, the number of different colors should be kept within reasonable economic bounds.

AIAE 010



NOTES:

1. TOTAL AREA – 2748 SQ FT (APPROX)
2. AIRCONDITIONER HOUSING 180 SQ FT
3. OFFICE 270
4. RECEIVING AREA 450
5. CUSTOMER STORAGE 279
6. AIRLOCK 81
7. LABORATORY 1488
8. "B" – 6' X 3' WORKBENCH
9. "S" – 1.5 X 3' X 6.5' CABINET
10. "L" – 3–SHELVE BOOK CASE
11. "T" – 3' X 6' TABLE
12. BARRIER WALL AT POINTS A ↔ A. CUSTOMER RECEIVING AREA AND AIR CONDITIONER COMPARTMENTS NOT AIR CONDITIONED
13. OFFICE WALLS COMPLETE TO CEILING
14. FACILITY SPECIFICATIONS – REFERENCE RECOMMENDED FACILITY SPECIFICATIONS FOR NAVY CALIBRATION LABORATORIES (SHOREBASED) OF 1 MAY 1965 (MEC DOCUMENT)

Figure FO 2-1. Laboratory Floor Plan "A," Typical

CHAPTER 3

ENVIRONMENTAL REQUIREMENTS AND CONTROL

Environmental requirements depend, primarily, on the effects of the various environmental factors on the measurement process, coupled with the accuracy and precision needed for a particular measurement. For the daily, routine measurements encountered within the Navy Calibration function, special controls or equipment may not be required, and the normal air-conditioning, heating, and air flow systems and controls will usually be sufficient. In higher echelon laboratories using reference standards having greater accuracies, the environmental requirements are more demanding and special facilities are usually necessary.

Presently accepted criteria for the various environmental factors are listed in table 3-1, in which Type I and Type II laboratories are included for comparision. Each of the listed factors is discussed separately since numerous methods and techniques are available to achieve the criteria identified in the table. However, since each laboratory is unique in location, size, layout, and other details, standardization is possible only to a limited extent. Therefore, general information applicable to most laboratories will be stated here and the various parameters contributing to the control of the particular environmental factor will be discussed.

3.1 TEMPERATURE

Temperature values for laboratories are chosen on the bases of assuring the stability of the laboratory standards and instruments and maintaining the desired accuracies. The 73° F ± 4° F nominal specification is considered adequate for daily NCL electronic and electrical requirements. Special provisions, as outlined in the following paragraph, may be used to achieve specific workload requirements deviating from the nominal laboratory condition.

Rate of change of temperature may be more important than the nominal temperature, since many measurements are adversely affected by high rates of change. This may be especially true if the measurements are projected over a considerable period, or where rapid excursions beyond narrow limits (microchanges) can affect a precision measurement. Microwave bolometers, for example, must be calibrated within limits of ± .005 degrees C. Even though the calibration can be performed within 15 seconds (equivalent to a rate of change of about 1.0 degrees C/HR), rapid microchanges can far exceed this rate, with adverse effects. Rather than attempt to control the entire laboratory area, the bolometer may be housed in an isothermal enclosure consisting of thick slabs of insulating material. Other cases, e.g., saturated standard cells, may require a temperature regulated enclosure such as an oil or air bath. For DC and low frequency measurements, variations about a static temperature should be minimized. A 2-minute maximum duration is recommended since a 2-minute exposure for temperature sensitive measuring equipment is usually required to stabilize any deviation from the calibrated temperature. If a longer exposure is used, the

Table 3-1. Criteria for Various Environmental Factors

ENVIRONMENTAL FACTOR	N.C.L. REF	N.C.L. LOCAL	QUALIFICATION ACTIVITY	DIMENSIONAL AND OPTICAL	TYPE I ELECTRICAL D.C., LOW FREQ.	HIGH FREQUENCY MICROWAVE	DIMENSIONAL AND OPTICAL	TYPE II ELECTRICAL, D.C., LOW FREQ.	HIGH FREQUENCY MICROWAVE
Temperature	$73.5^{\circ}F \pm 1.5^{\circ}F$	$73^{\circ}F \pm 4^{\circ}F$	65° to $90^{\circ}F$ ideally $75^{\circ} \pm 5^{\circ}F$	$68^{\circ} \pm 32.5^{\circ}F$	$73.4^{\circ} \pm 33.8^{\circ}F$	$73.4^{\circ} \pm 33.8^{\circ}$ to $50.9^{\circ}F$	$68^{\circ} \pm 33.8^{\circ}F$	$73.4^{\circ} \pm 50.9^{\circ}F$	$73.4^{\circ} \pm 33.8^{\circ}$ to $50.9^{\circ}F$
Rate of Change of Temperature	$1^{\circ}F/HR$ Max.	$2^{\circ}F/HR$ Max.	No Criteria	$33.1^{\circ}F/HR$ Max.	$33.8^{\circ}F/HR$ Max.	$33.8^{\circ}F/HR$ Max.	$33.1^{\circ}F/HR$ Max.	$33.8^{\circ}F/HR$Max.	$33.8^{\circ}F/HR$ Max.
Relative Humidity	←		LESS THAN 60%	30 – 45% ALL LABORATORIES (EXCEPT QUALIFICATION)					→
Air Pressure	Positive Pressure of 0.62 Millibar, Min		No Criteria	Positive Pressure of 0.2 millibar		Positive Pressure of 0.08 Millibar, Min	Positive Pressure of 0.8 Millibar		Positive Pressure of 0.08 Millibar, Min.
Vibration	.01 g Max. Below 200 Hz at Instrument Base		No Criteria	.001 g Max.	.002 g Max.	.005 g Max.		SAME AS TYPE I	
Acoustic Noise	←			Noise Criterion (NC) of 35 Between 20 and 9600 Hz					→
Lighting	←				100 Foot Candles At Bench level				→
Electromagnetic Fields	←			NO GENERAL CRITERIA					→

measuring equipment will tend to follow the variations. However, the maximum deviation cycle of 2 minutes can be a stringent requirement for commercial air-conditioning systems because of sensor and controller response time. To minimize the effects of temperature fluctuations, the amplitude of the fluctuations should be balanced with the recommended rates of change.

Temperature control may be achieved by implementing the following techniques, methods, and recommendations:

a. Air-conditioning/heating systems must have sufficient capacity and regulation to establish and maintain the desired temperature requirements. Required capacity is a function of room volume, heat producing equipment, insulation, location, number of personnel, and other factors. Selection of air-conditioning equipment for various applications is given in NAVDOCKS DM-3 and the Guide of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).

b. The system should be in continuous operation, 24 hours a day, including weekends. Control of the system should be completely automatic.

c. The system should have the capability of air ventilating, filtering and circulating, humidifying/dehumidifying the laboratory, as well as cooling and heating.

d. Ideally, the laboratory should have its own air-conditioning and control system, independent of other facilities located within the same building. However, the laboratory should, if possible, be placed adjacent to areas having the same temperature.

e. Insulating materials should be used in construction of outside walls and other walls to thermally isolate the laboratory from areas with significantly different temperature levels. EC-23 gives a coefficient of heat transfer of 0.15 BTU per hour, per square foot, per degree Fahrenheit as a goal for walls, ceilings, and floors. (See ASHRAE Guide for tables and methods of computing overall coefficient for building material.) Entrances which must open between such areas should be of the double door, vestibule type. Conditioned air should be introduced into the vestibule to maintain the slight positive pressure requirement (see table 3-1).

f. To avoid uneven temperature distribution, a maximum of 10,000 cubic feet of space should be allotted for each control point. If possible, multi-zone thermostat control systems should be used to avoid interaction between separate areas.

g. A duct system should be used to introduce the conditioned air into the laboratory. The ducts should be equipped with dampers or louvers which can be adjusted to compensate for local temperature variations and provide a uniform air flow. Return duct openings should be positioned to achieve uniform circulation and distribution of air within the laboratory.

h. Temperature throughout the laboratory should be measured and recorded continuously to determine indications of drift or out-of-control periods. A thermo-humidigraph type instrument can be used for this purpose.

i. Special techniques can be used to obtain more stringent controls. These include room-within-a-room construction, isothermal enclosures, ovens, oil and air baths, and the like, having individual, separate control and monitoring systems.

j. Coordinated or integrated cooling, heating, and lighting systems can provide the desired environmental requirements, with the benefits of lower overall operating or maintenance costs. Such systems use heat transfer lighting fixtures, or luminaires, in which room air is exhausted through the lamp compartment of the luminaire. This method causes the heat produced by the lighting equipment to be removed before it can contribute to the room heat load. Water tube heat exchanges located within the luminaire body may be used to reclaim the heat, which can then be used to reduce the heating requirements of the building. In addition, such systems can reduce air changes, duct size, headroom requirements, and fan horsepower. Fluorescent lamps will provide more light in heat transfer luminaires than in static units and the life of their ballasts will be enhanced.

3.2 RELATIVE HUMIDITY

Humidity affects the measurement process through corrosion and changes of electrical conductivity and dielectric constants during periods of high humidity (above 50 percent), while low humidity (below 30 percent) can cause deterioration of materials and affect measurements by the accumulation of static charges. Selection of humidity value represents a compromise between these effects and the requirement for personnel comfort. In either case, the relative humidity (RH) should be maintained below the condensation point: tables or charts in the ASHRAE Guide should be consulted to determine the inside temperature and relative humidity that can be maintained without forming condensation on windows, walls, and equipment at various outside temperatures.

It is believed that corrosion of iron and steel in laboratories operating at 50 percent RH presents a problem only under conditions of zoning or stratification of temperature that would cause localized high humidity conditions. Corrosion can also occur if contaminants become deposited upon unprotected iron surfaces. Steel, for example, will corrode at a fairly low humidity if subjected to perspiration from fingerprints, corrosive vapors, certain atmospheric gases, or dust. None of these conditions should exist in a well-designed, well-maintained laboratory having adequate wall insulation.

Humidity control involves the addition (humidification) or removal (dehumidification) of moisture (water vapor) in the air to obtain the desired relative humidity. The following suggestions for RH control may prove helpful.

a. Outside winter conditions for most regions of the United States show the moisture content of outside air is relatively low even if the air is saturated. To obtain winter indoor humidities of 30 percent or above, it is therefore necessary to humidify or add moisture to the air.

b. A 45 percent RH is recommended, where practical, because of a problem that has been observed in humidity control systems; i.e., the failure of the system reheat cycle which can result in the system producing a relative humidity condition near 90 percent. A value of 45 percent RH allows time to shut off the system spray pump and keep the RH level well below the critical oxidizing humidity of 60 to 65 percent.

c. Dehumidification and cooling may be accomplished simultaneously by a single apparatus. However, dehumidification in the hot, humid sections of the United States or in tropical regions may be very expensive. See NAVDOCKS DM-3 for further criteria.

d. Humidifiers may be attached to the air-conditioning system, in which case water vapor is introduced directly into the laboratory via the duct system, or a separate humidifier may be used. In either case, the humidification equipment should not be located directly inside the space to be conditioned. See NAVDOCKS DM-3 for further information on humidification equipment.

e. Humidity should be monitored continuously; a hygrothermograph may be used for this purpose.

3.3 VENTILATION

Ventilation systems are designed to remove odors, fumes, heat, and dust, and to provide a supply of fresh air for personnel. Mechanical ventilation employs fans combined with a supply air and/or exhaust duct system to induce positive air circulation within buildings or spaces.

The relation between supply air and exhaust air depends on the function of the area to be ventilated. In the case of calibration laboratories, where a dust free atmosphere is required, a slight positive pressure (see table 3-1) is necessary to prevent infiltration of unfiltered outside air. In this case, supply or makeup air quantity should be 10 to 20 percent more than the exhaust and exfiltration air.

In addition to effects on measurements, local temperature variations and drafts caused by uneven air distribution can contribute to personnel discomfort. Specifications for air freshness have not been standardized since the matter seems to include psychological, as well as physiological, effects; i.e., a low supply air volume can cause a stuffy, oppressed feeling on the part of the occupants. Many factors, including room volume, number of personnel present, and the amount of traffic, influence the requirements for fresh air (as fresh air and outside air are not necessarily synonymous terms). For cooling load calculations, NAVDOCKS DM-3 states that minimum ventilation air supply shall be one air change per hour. At the National Bureau of Standards Electronic Calibration Center at Boulder, Colorado, air intake is a function of outside air temperature and ranges from approximately 1.5 to 7.5 air changes per hour.

3.4 CONTAMINATION CONTROL

Specifications for dust particle count are based mainly on good housekeeping considerations, since dust levels in laboratory areas are difficult to determine quantitatively. It is known that dust accumulation on insulating or conducting surfaces can influence measurements. Dust can also promote rust and corrosion and contaminate oil baths and other open-air systems. Control of contamination includes the following factors:

- o Pressurize the laboratory and all entrance vestibules.

- o Avoid access to the laboratory through dirty areas such as machine shops, sandblasting operations, etc.

- o Place mats at all entries for shoe cleaning.

- o Equip the air conditioning/ventilating system with mechanical and/or electrostatic traps and filters which can filter salt air as well as particulate matter (includes hair, clothing fiber, skin flakes, dust, etc.).

Filter selection depends on required efficiency, type of air conditioning equipment, economy, and other factors. For dust free atmospheres, filters should have an efficiency of 80 to 90 percent on the basis of the NBS Dust Spot Method, using Cottrell precipitate. More critical applications requiring filtration efficiencies exceeding 90 percent should be equipped with two sets of filters: a prefilter of the viscous or dry throwaway type, having an NBS efficiency of 60 percent minimum, and a main filter of the absolute dry media type or electrostatic precipitators. Prefilters, afterfilters, and other speical precautions, as given in NAVDOCKS DM-3, are necessary when using an electrostatic type filter to prevent arcing and other undesirable effects.

Super critical requirements, such as "clean rooms," use high efficiency particulate air filter (HEPA) type units having efficiencies better than 99.97 percent for 0.3-micron diameter particles.

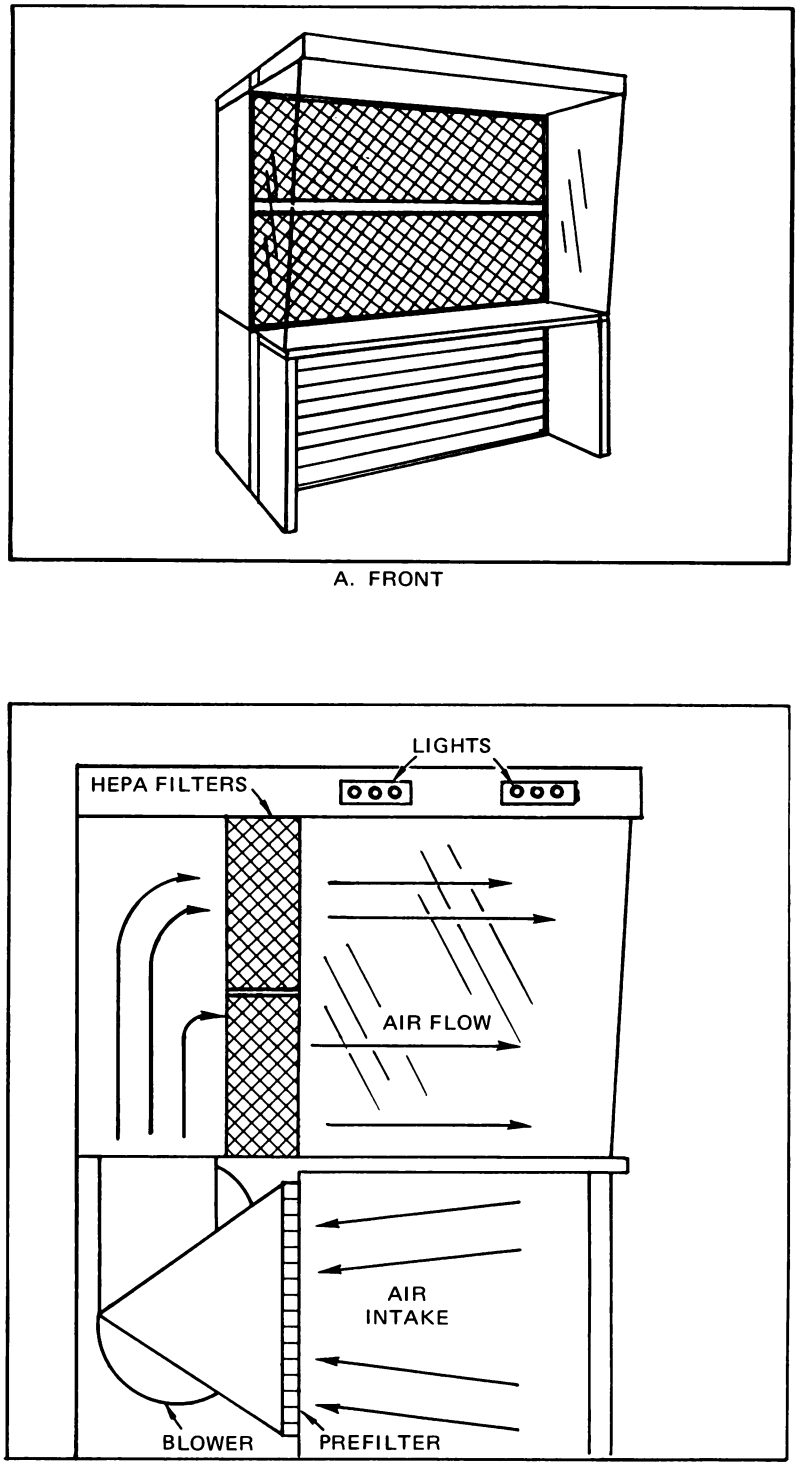
Horizontal laminar airflow benches such as shown in figure 3-1 may be used to provide a clean work station in lieu of constructing an entire clean room (laminar airflow occurs when the entire body of air within a confined area moves with uniform velocity along parallel flow lines with a minimum of eddies). Such benches contain their own air-movers, filters, and lighting so as to make them independent of the room characteristics.

3.5 VIBRATION AND ACOUSTICAL NOISE

3.5.1 Vibration Levels

Vibration tolerance requirements vary greatly among individual instruments. Therefore, the single values given in table 3-1 expressed in units of acceleration due to gravity are useful only as a guide to the maximum acceptable levels. Some equipments, such as galvanometers and pointer-type instruments, are more sensitive to vibration and shock. Other instruments may respond violently to disturbances having a frequency range which includes the natural frequencies of the instrument. In the case of shock, or impulse type disturbance, there are additional complicating factors of amplitude, waveshape, and pulse duration. It has been stated in the literature that in using pointer-type instruments, the threshold of error determination is exceeded when a disturbance induces a deviation equivalent to one-tenth of a scale division.

Thus, measurements should be conducted to determine tolerable vibration and shock levels for individual instruments. The optimum, most economical means of control may then be selected based upon the individual requirements.



B. SIDE ELEVATION

AIAE 013

Figure 3-1. Typical Horizontal Laminar Air Flow, Work Station

3.5.2 Vibration Control

The following methods and techniques may be applied toward the control of vibrations in both new designs and existing structures. In existing structures where vibrations stem from geographic and other sources, the best approach probably involves isolation of the sensitive instruments, rather than attempts to eliminate the source of disturbance.

As a general rule, whenever possible, use equipment that is self-damped, or otherwise less sensitive to external disturbances. In recent years, for example, there has been a trend toward use of electronic and oil-damped equipment, of a type that is relatively immune to moderate vibration, to replace galvanometers and other shock and vibration sensitive instruments.

Effective isolation may be achieved by interposing a resilient member between equipment and support such that the natural frequency of the equipment plus isolator is substantially below the lowest frequency of excitation. Construct such special isolation pads of either polyurethane foam, cork, rubberized hair, partially inflated innertubes, or other similar materials to locally isolate individual equipments. Heavy steel blocks (40-50 pounds) supported by air-inflated tubes resting on a bench top are especially effective. Special isolation tables using air pistons or other devices to "float" the table top are available in various sizes. However, these are relatively expensive.

Reciprocating, high speed, or other machinery of vibration-producing tendencies such as generators, pumps, fans, motors, and compressors should be mounted on supports designed to reduce vibration to a minimum (these equipments should be located outside of the laboratory). Such vibration mounts must also support the static load of the machine. The principal exciting frequencies of vibrations generated by a machine should be at least two to three times the natural resonant frequency of the machine and its mount. If this rule is not followed, vibrations transmitted to the support may be coupled rather than reduced. See the ASHRAE Guide on Sound Control for additional details and methods for calculation of resonant frequency.

Selection of vibration mounts may be made from the following:

- Cork and Felt. For isolation of machinery generating mostly high-frequency vibrations, use cork, felt, or ribbed rubber, etc., with static deflection less than 0.1 inches corresponding to a resonant frequency greater than about 10 cycles per second.

- Rubber-in-shear. Most other machines require rubber-in-shear mounts, with a static deflection about 1/4 inch, corresponding to a resonant frequency of about 7 cycles per second.

- Steel Springs. Steel springs may be designed for larger static deflections where large slow-moving machinery is to be isolated. Use steel springs in conjunction with ribbed rubber pads or similar material to furnish adequate isolation at high frequencies.

o Vibration Damping. Dashpots or other viscous damping devices may be used in conjunction with steel springs to furnish damping near troublesome resonances.

o Resilient Foundation. Vibration isolation and resonant frequencies calculated on the basis of an assumed infinitely still foundation may be seriously in error if the foundation is resilient near the frequencies of the equipment. For additional criteria, see ASHRAE Guide, Sound Control, and Beranek, Noise Reduction, Isolation of Vibrations.

Sources of disturbances within the laboratory, or within a collocated laboratory, such as acceleration calibrating equipment, shakers, pumps, and the like, require isolation. Shock mounts and local devices as listed or special enclosures may be used for this purpose.

When designing new laboratories, locate the laboratory away from heavy machinery, trains, shop operations, and all other potential sources of acoustical noise.

In cases of high vibration where the use of isolation mounts on fixed floors or benches is inadequate, isolation can be effected by use of a floating floor, floating slab, or a floating inertia block design. Refer to figure 3-2 and NAVDOCKS DM-3 for construction details.

3.5.3 Acoustical Noise Levels and Control

Acoustical noise specifications for laboratories stem from the effects of such noise upon equipment and personnel. A level of 45 dB when measured on a sound level meter using the A or 40-dB weighing network represents a balance between the level which induces microphonics in electronic equipment and that which causes personal irritation or discomfort. Work in the acoustical field, however, has concentrated on the physiological, psychological, and speech interference aspects, rather than on effects to equipment. Since criteria for satisfactory speech communication and telephone use are generally lower than the levels which affect equipment, attainment of the former will normally satisfy both requirements. Noise criteria details and personnel effects are discussed in a later chapter.

a. Acoustical Noise Control. Noise control may be defined as the technology of obtaining an acceptable noise environment, at a receiver, consistent with economic and operational considerations. The receiver may be a person or a piece of equipment whose operation is affected by noise. Methods for control of noise may include noise reduction at the source, control of the transmission path, use of protective measures at the receiver, or some combination of the three. Regardless of which specific measures are finally selected, a number of general methods can be applied, including:

o Segregating noisy areas from quiet ones.

o Interposing unoccupied rooms (e.g., storage) between occupied rooms and rooms with noisy equipment.

o Grouping together rooms where quiet is important, rooms where noise is about average, and rooms where operations are noisy.

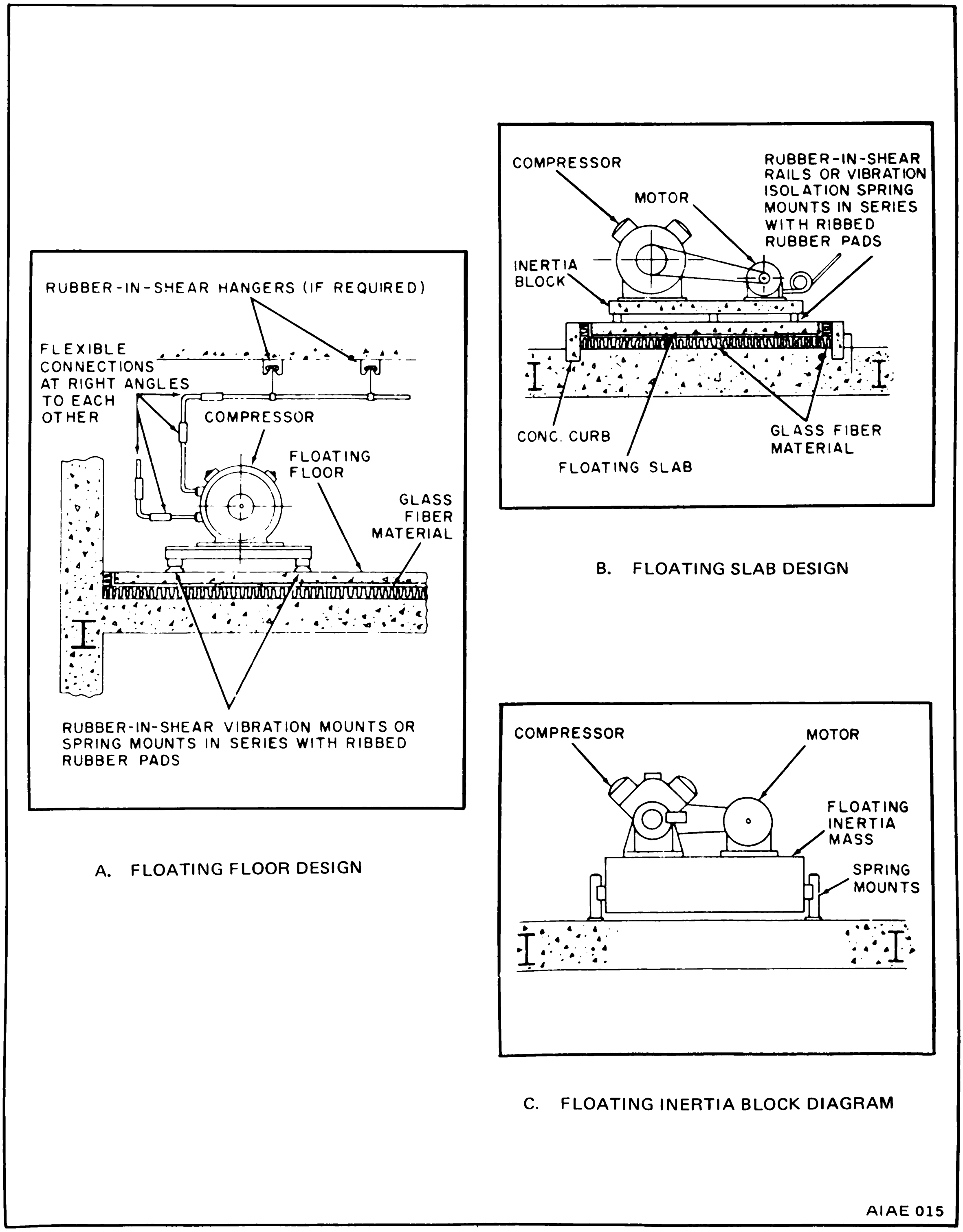


Figure 3-2. Proposed Vibration Isolation Techniques

- Increasing the distance between sources and areas to be protected. Each doubling of a distance in the open reduces noise by at least 6 dB.

- Orienting the sound source to direct maximum noise radiation away from area to be protected.

- Placing sound sources and areas to be protected on opposite sides of natural barriers (hills, woods) or artificial barriers (hangars). Barriers such as walls may be interposed for the specific purpose of blocking noise, but they must be large and close to the source to be effective.

- Enclosing sources either partially or completely to reduce noise radiation to areas to be protected.

- Confining noisy operations to those times when the annoyance to those in the general area affected will be minimal.

- Investigating the possibility of establishing flight patterns over the least populated areas of the station and surrounding countryside, and of removing the path of rapid climb away from the end of the runway into space over open country or water.

The final choice of methods to be employed depends on the amount of required noise reduction and on economic and operational factors. Required noise reduction is given by the difference, in decibels, in each octave band between noise level to be controlled and criterion level. Note that noise reduction at low frequencies is generally more difficult to obtain than at high frequencies, because typical building construction absorbs less and transmits more sound at low rather than at high frequencies.

Since acoustical noise and mechanical vibrations are intimately connected, control of noise at its source involves the use of procedures similar to those used for vibration control. Other important methods of controlling source noises, such as reduction of internal forces, balancing of moving masses, and the like, are usually impractical for the purchaser or user of equipment to apply, since they involve equipment and modification. The quietest equipment consistent with the end requirements should be selected and then the vibration isolation methods may be applied.

Control of the transmission path to reduce the energy communicated to the receiver includes the use, during the construction stages, of sound-absorbing materials, sound barriers, and other isolation methods in floors, ceilings, partitions, windows, doors, and in the air-conditioning/heating ductwork. Figures 3-3 through 3-6 and tables 3-2 and 3-3 depict methods, properties, and classifications of various materials and constructions commonly used for the attenuation of acoustical noise. The following considerations should be applied toward use of these measures:

- In practice more than 10- to 20-dB noise reduction is difficult to achieve by installing sound-absorbing materials on walls and ceilings.

- Functional sound absorbers suspended near noisy machinery may be used to advantage if sufficient wall or ceiling areas are not available.

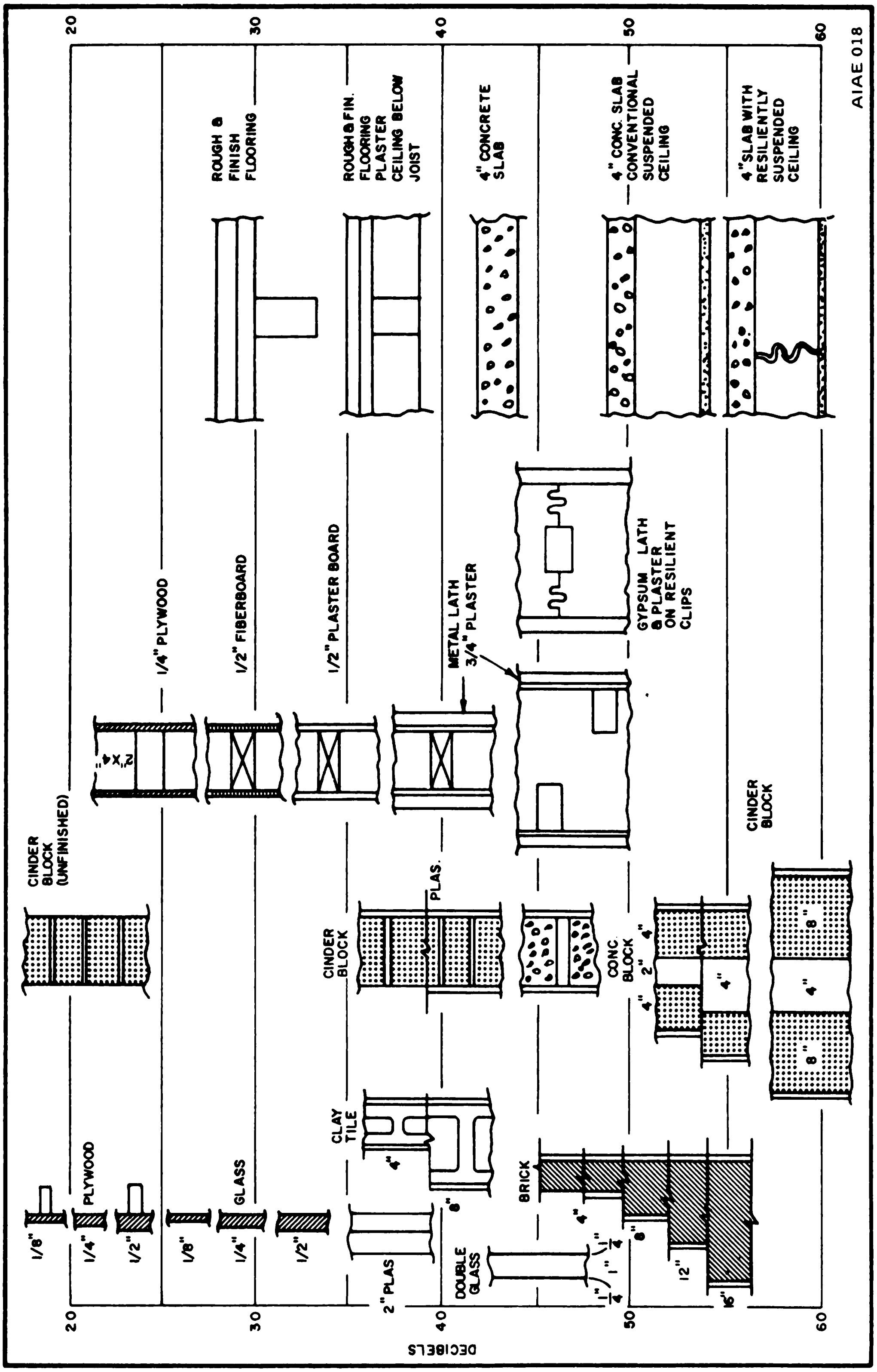


Figure 3-3. Estimated Average Sound Transmission Loss of Typical Wall and Floor Construction

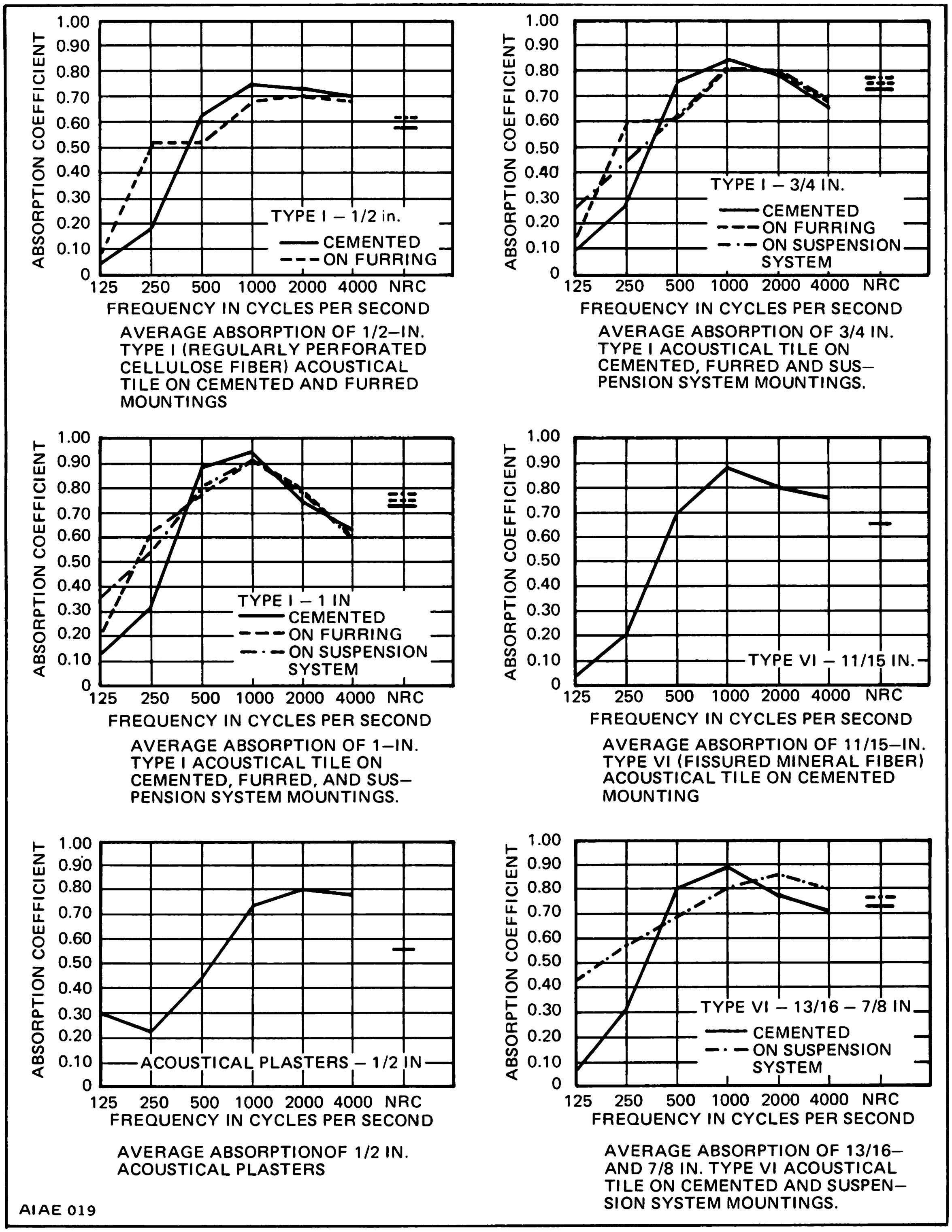


Figure 3-4. Absorption Properties of Acoustical Tiles

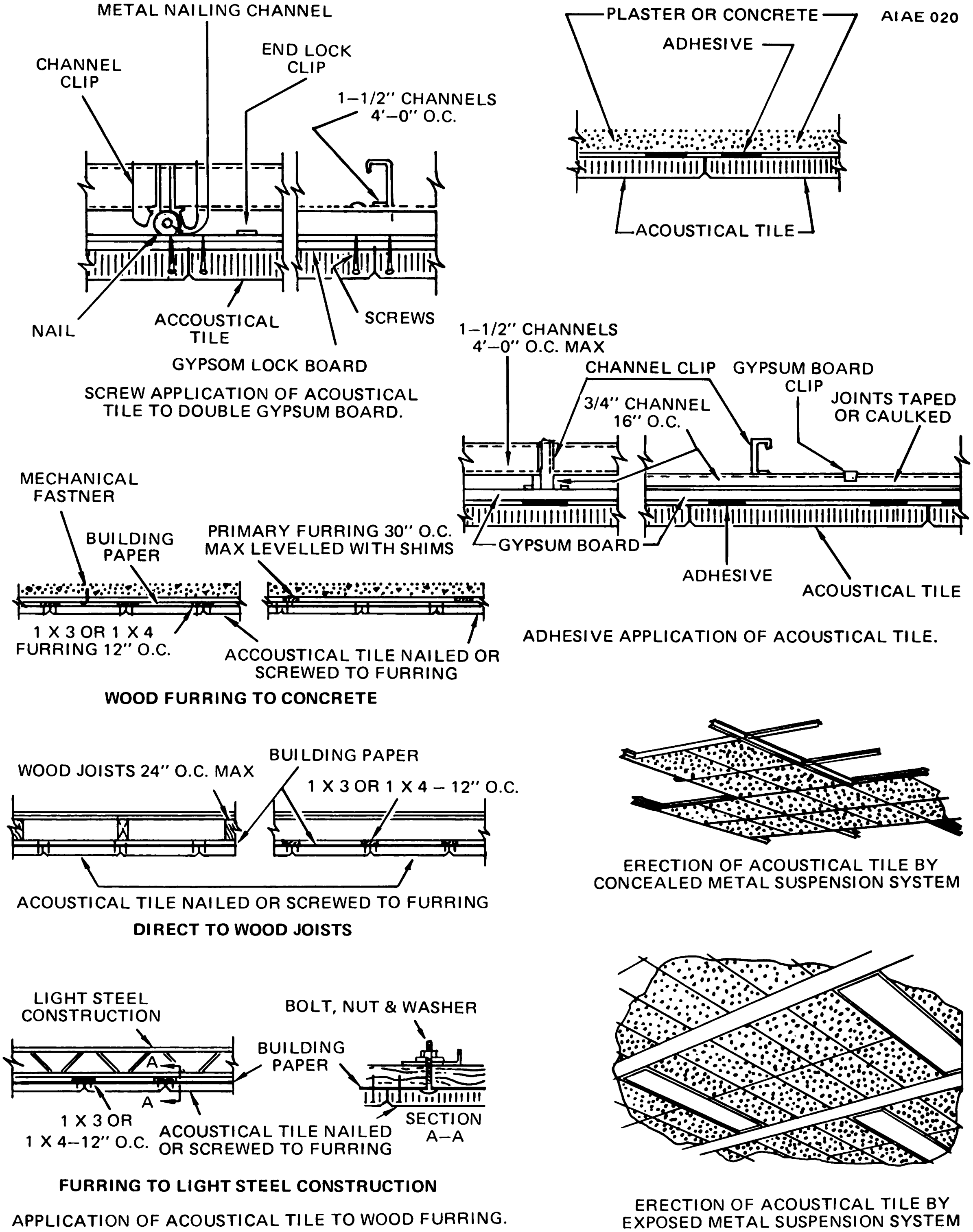


Figure 3-5. Various Applications of Acoustical Tile Ceilings

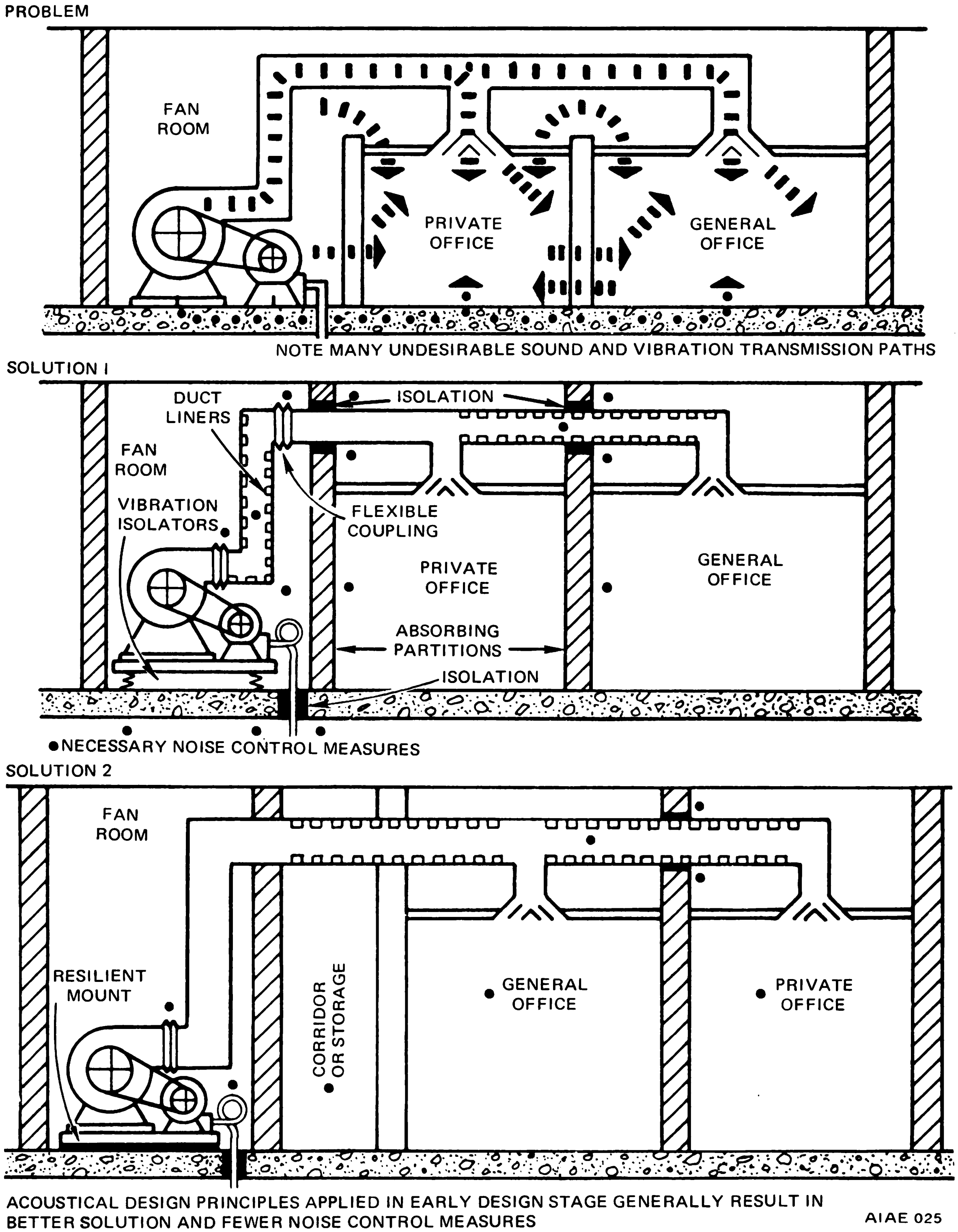


Figure 3-6. Sound Control in Ventilating System

Table 3-2. Classification of Sound Absorbing Materials (Acoustical Materials Association)

Type	Description
I	Regularly perforated cellulose fiber tile.
II	Random perforated cellulose fiber tile.
III	Slotted cellulose fiber tile.
IV	Textured, finely perforated, fissured or simulated fissured cellulose tile.
V	Membrane-faced cellulose fiber tile.
VI	Cellulose fiber lay-in panels.
VII	Perforated mineral fiber tile.
VIII	Fissured mineral fiber tile.
IX	Textured, finely perforated or smooth mineral fiber tile.
X	Membrane-faced mineral fiber tile.
XI	Mineral fiber lay-in panels.
XII	Perforated metal pans with mineral fiber pads.
XIII	Perforated metal lay-in panels with mineral fiber pads.
XIV	Mineral fiber tile rated as part of fire resistive assemblies.
XV	Perforated asbestos board panels with mineral fiber pads.
XVI	Sound absorbent duct lining.
XVII	Special acoustical panels and systems.

Table 3-3. Types of Mounting of Sound Absorbing Material (Acoustical Materials Assn.)

Type	Mounting
1....	Cemented to plaster board or concrete ceiling with 1/8 in. air space.
2....	Nailed to 1 X 3 in. wood furring 12 in. OC.
3....	Attached to metal supports applied to 1 X 3 in. wood furring.
4....	Laid directly on floor.
5....	Furred 1 in., furring 24 in. OC, 1 in mineral wool between furring.
6....	Attached to 24 ga. sheet iron supported by metal angles.
7....	Mounted on special metal supports.
8....	Furred 2 in., furring 24 in. OC, 2 in. mineral wool between furring.

Note: Mountings 1-3, and 7 are most common in building construction. Mounting 6 is typical of duct lining applications.

o Indiscriminate installation of sound-absorbing material may result in poor hearing conditions.

o Measure of effectiveness of a given material in absorbing sound is the sound absorption coefficient "a." This coefficient varies with material, thickness, type of mounting, frequency, and the angle of incidence of sound.

o To obtain a single number of effectiveness of a given material as a sound absorber, "a" is averaged arithmetically from 250 to 2000 cycles per second. This quantity is called the Noise Reduction Coefficient (NRC).

o Caution should be exercised in the selection of a material on the basis of its NRC, since low-frequency absorption is not indicated by it, but large values of low-frequency absorption are frequently required in many noise control applications.

o To prevent sound from passing from one space to another, a solid, impervious barrier is necessary.

In general, the more massive the barrier, the better the isolation (transmission loss) established. The theoretical limit of isolation is given by the so-called "mass law." The isolation provided by practical structures is generally appreciably less.

Acoustical tile and other sound-absorbing materials are light in weight and not impervious to sound; hence, they are ineffective as sound barriers. Multilayer structures with air spaces are more effective than equivalent homogenous structures. For instance, two 4-inch concrete walls with a 2-inch air space are considerably more effective than a single 8-inch thick wall.

b. Transmission Loss and Noise Reduction. The measure of effectiveness of a structure as a sound barrier is the transmission loss in decibels. Transmission loss depends on material, types of mounting, and the frequency and angle of incidence of sound.

Often in practice, noise reduction is used as a measure of effectiveness. Noise reduction is defined as the difference, in decibels, of average sound pressure levels at both sides of a structure.

Noise reduction depends on the acoustics of the two spaces separated by a barrier, in addition to the barrier properties and the frequency and angle of incidence of sound.

c. Rating of Typical Construction. As a single-number rating, the "average" transmission loss is often employed. Estimates of the average transmission loss of typical wall and floor constructions are illustrated in figure 3-3.

The use of average transmission loss in solving noise control problems is limited, as the transmission loss of typical structures is frequency dependent. Even transmission loss values measured as a function of frequency in the laboratory may be below values obtained in the field because of differences of panel sizes and mounting conditions. Values of transmission loss indicated by the weight law are almost never realized in practice. For additional criteria, see Beranek, Noise Reduction. "The Transmission and Radiation of Acoustic Waves by Solid Structures."

Sound barriers must be free of openings to be effective. Cracks, gaps, ducts, pipe chases, windows, and doors reduce the effective transmission loss of the combination. For example, openings in a barrier of 30-dB transmission loss which amount to only 1 percent of the total area reduce the effective transmission loss from the original 30 dB to 20 dB. Since doors and windows are acoustically weak links in wall construction, tight closures and gasketing (weatherstripping) are important in critical applications.

3.6 LIGHTING

3.6.1 Light Requirements

Minimum illumination intensities have been recommended by the Illumination Engineering Society (IES) in their Lighting Handbook and other publications, based on investigations by Blackwell and others in the field. Illumination levels have generally doubled each decade as a result of the increase in understanding of the visual basis for lighting requirements and the availability of lighting sources having greater efficiencies at lower operating cost.

Results of studies which have been conducted in the industrial environment, using young normal adults performing a variety of visual tasks, show that the degree of contrast with its background of the detail to be seen and the reflectance of the background determine the amount of light necessary to see the task at the normal scanning rate (with 99 percent accuracy). However, the marked changes brought about by the development of fluorescent lighting indicate that economy and efficiency have probably been the dominant factors in setting illumination standards.

It is recommended in EC-23 that a minimum of 100 foot-candles of illumination be provided at bench level from overhead fluorescent fixtures. In addition to providing the recommended quantity of illumination, other factors to be considered include the brightness ratios, control of direct and reflected glare, elimination of objectionable shadows, reflectance of room surfaces, and supplementary lighting for special applications (reading of verniers, fine scales, etc.).

The following brightness ratios are recommended between specific locations within areas of appreciable size as maximum values to achieve a comfortable brightness balance. Reductions from these values will generally be beneficial:

- 3 to 1 between task and adjacent surroundings
- 10 to 1 between task and more remote darker surfaces
- 1 to 10 between task and more remote lighter surfaces
- 20 to 1 between light sources or windows and surfaces adjacent to them

- o 40 to 1 anywhere within the normal field of view.

Further information concerning human response to, and effects on individuals of, lighting conditions is presented in a later chapter.

3.6.2 Lighting System Planning

a. Planning. Planning an interior lighting installation will normally involve providing for general lighting, which produces equal seeing conditions throughout the interior, and supplementary bench lighting which, in combination with the general lighting, provides higher illumination at a particular task. For eye comfort, the final illumination at the task should conform to the brightness ratio listed.

b. Conditions for Glare. Conditions which can result in glare should be avoided. Glare is brightness in the field of vision which causes annoyance, discomfort, eye fatigue, or interference with vision. Such discomfort and eye strain result when the eye attempts to avoid high brightness by contracting the iris. This reduces visibility and the seeing light. Glare may be reduced or avoided by observance of the following considerations and methods:

- o Bare lamps are the greatest glare offenders, followed by luminaires which are improperly shielded.

- o Reflected glare may be caused by reflections of a light source from polished or shiny surrounding surfaces; these should be avoided.

- o Room brightness may be increased without increasing source brightness by providing more luminaires of the same type.

- o Benches should be positioned so that personnel do not face windows.

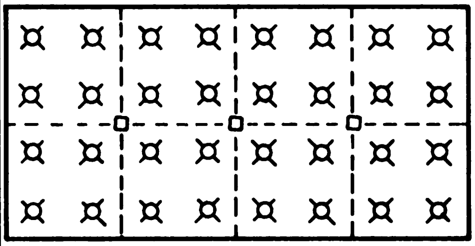
- o Local (supplementary) lighting units should be positioned to prevent direct glare.

- o Enough general illumination should be provided to keep the brightness ratio between work and surroundings from being excessive when using local lighting. Work area surroundings should be painted as recommended in a previous chapter.

- o When required to see by reflected light, glare may be reduced by using a low-brightness, large area light source.

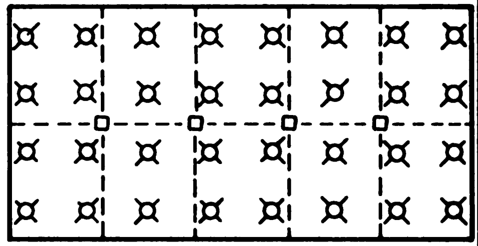
- o Bright metal trim on equipment or office machinery should be avoided.

c. Luminaires. Lighting equipment should be selected for efficiency, easy maintenance, and pleasing design, once the lamp size and number necessary to provide the required illumination level have been calculated. Fixtures are then arranged to give uniform illumination throughout the area. Typical luminaire layouts are shown in figure 3-7.



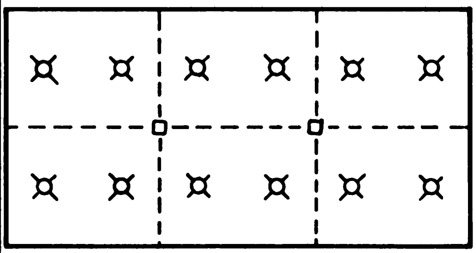
(1)
FOUR UNITS PER BAY

FOUR UNITS PER BAY IS THE MOST COMMON SYSTEM FOR THE SQUARE BAY OF USUAL DIMENSIONS.



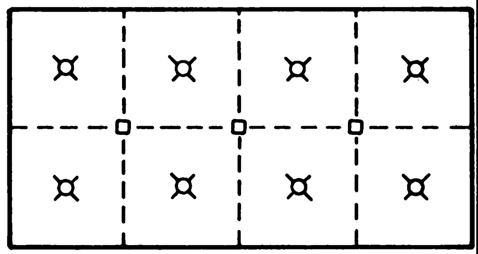
(2)
FOUR–TWO SYSTEM

THE FOUR–TWO SYSTEM IS EQUIVALENT TO THREE UNITS PER BAY AND IS AN ALTERNATE TO THE FOUR PER BAY SYSTEM.



(3)
TWO UNITS PER BAY

TWO UNITS PER BAY ARE USUALLY INSTALLED ONLY IN NARROW BAYS WHERE WIDTH IS LESS THAN TWO–THIRDS THE LENGTH.



(4)
ONE UNIT PER BAY

ONE UNIT PER BAY IS SATISFACTORY ONLY WHERE BAY SIZE IS NOT GREATER THAN MAXIMUM ALLOWABLE SPACING. THIS CONDITION IS UNUSUAL EXCEPT IN HIGH–CEILINGED ROOMS.

AIAE 026

Figure 3-7. Typical Layouts for Luminaires

Specifications for luminaire selection are given in NAVDOCKS Specification 9Y, Electrical Apparatus, Distributing Systems, and Wiring; Underwriters Laboratory publication number 57, Standard for Electrical Lighting Fixture; and the National Electrical Code.

Candle power in any direction from a lighting unit can be determined by multiplying the foot-candle on a plane perpendicular to the light rays by the square of the distance in feet from the point of measurement. Plotted on a system of polar coordinates, the curve represents the candle-power distribution in all vertical planes through a vertical axis of rotation. Each type of luminaire has its typical candle-power distribution curve, as shown in figures 3-8 and 3-9, which is useful in indicating how the light is distributed; up, down, or near-horizontal angles. These curves assist in the selection of the correct type luminaire for a given set of conditions: type of machine and visual task, position of work plane, and shape and proportions of the interior. Fixtures and lighting systems are divided into five broad classifications: direct, semidirect, general diffusing, semi-indirect, indirect.

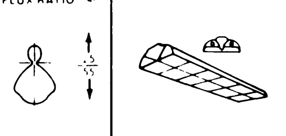
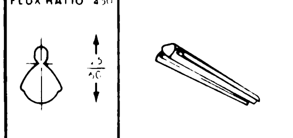
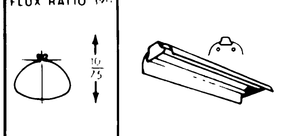
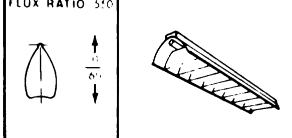
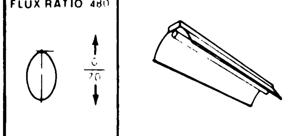
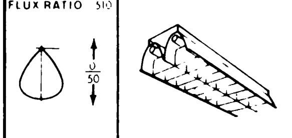
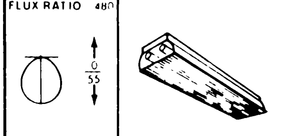
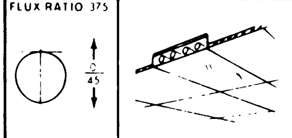
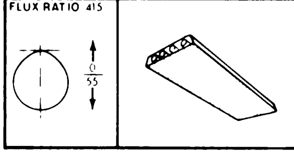
o Direct luminaires are either concentrating or distributing type. A luminaire designed to distribute 90 percent or more of its light output downward below the horizontal is classed as direct. They may be suspended, mounted on a ceiling, or recessed flush in the ceiling. Reflectors of this type are most effectively used in narrow bays and craneways when mounting the reflector at a height equal to or greater than the width of the area to be lighted. Because of their distribution of light, concentrated-beam luminaires direct much of the light to the working area without excessive loss on the walls and windows. Lighting systems with this type of light distribution are relatively much stronger in illumination on horizontal than on vertical planes. Direct luminaires of the distributing type for more widespread light distribution have many shop applications because most seeing tasks in work shops involve viewing surfaces that are nearly vertical. When distributing units are located at ordinary mounting heights of 10 to 12 feet, a satisfactory uniformity of illumination is usually obtained when they are spaced not more than the mounting height above the floor.

o A semidirect luminaire is one that distributes from 60 to 90 percent of its light output downward below the horizontal and from 10 to 40 percent of its light output upward above the horizontal. A semidirect luminaire may be suspended or mounted on a ceiling and may have the light source exposed, or concealed behind a diffusing medium of glass or plastic, or behind a louver. Although these units are essentially direct lighting in the quality of illumination produced, some added indirect light is obtained if the ceiling is light in color. The upward light contributes to comfort and good appearance by brightening a light-colored ceiling and reducing sharp contrasts between the unit and its background.

o A general diffusing luminaire distributes from 40 to 60 percent of its light output upward above the horizontal. It can be suspended or mounted on a wall, ceiling or pedestal. Its light source is concealed in a diffusing medium. One widely used unit is the glass enclosing globe for use with filament lamps. This type is simple, relatively low in cost, and produces good illumination on vertical surfaces. Where higher illumination values are desired from existing installations of enclosing globes,

FLUORESCENT LUMINAIRES

Maintenance factors (MF) for the luminaires below are suggested values, based on assumed average conditions. The designer should make adjustments for the conditions peculiar to the specific installation

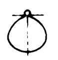
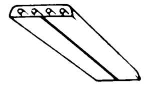
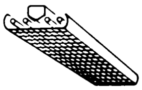
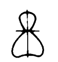
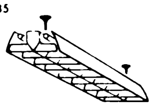
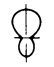
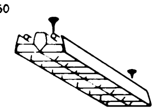
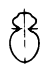
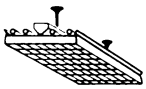
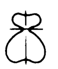
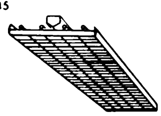
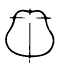
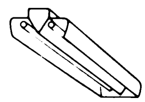
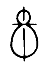
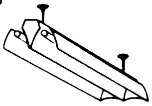
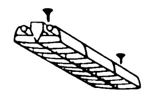
	Typical Distribution / Luminaire	Ceiling	80%			70%			50%			30%			
		Walls	50%	30%	10%	50%	30%	10%	50%	30%	10%	50%	30%	10%	
		Floor	10%			10%			10%			10%			
		Room Ratio	Coefficients of Utilization												
1	FLUX RATIO 4[illegible] 	0.6 (J)	33	28	24	32	27	24	30	26	23	29	25	22	White enamel industrial type luminaire-35° crosswise by 25° lengthwise shielding-20 35% upward light reduces brightness contrast by lighting ceiling-open top provides good ventilation improves maintenance. Suggested MF- 75
		0.8 (I)	40	35	31	39	34	30	37	32	30	34	31	28	
		1.0 (H)	46	41	37	44	40	36	42	38	35	39	36	33	
		1.25 (G)	51	46	42	50	45	41	46	43	40	43	40	38	
		1.5 (F)	55	50	46	53	49	45	50	46	43	46	44	41	
		2.0 (E)	60	56	52	58	54	51	54	51	48	50	48	46	
		2.5 (D)	63	59	56	61	57	55	57	54	52	53	50	49	
		3.0 (C)	66	62	59	63	60	57	59	56	54	54	53	51	
		4.0 (B)	69	66	63	66	63	61	61	59	57	56	55	53	
		5.0 (A)	71	68	66	68	66	64	64	61	59	58	57	55	
2	FLUX RATIO 450 	0.6 (J)	34	28	24	33	28	24	31	26	24	30	25	22	Same as No 1 but without louvers for lengthwise shielding-most comfortable when viewed crosswise to axis of lamp. Suggested MF- 78
		0.8 (I)	42	36	32	40	35	31	38	33	30	36	32	29	
		1.0 (H)	48	42	38	47	41	37	44	39	36	41	37	34	
		1.25 (G)	54	48	44	52	47	43	49	45	41	46	42	39	
		1.5 (F)	58	53	48	56	51	47	53	49	45	49	46	43	
		2.0 (E)	64	59	55	62	57	54	58	54	51	54	51	48	
		2.5 (D)	67	63	59	65	61	58	60	57	54	56	54	52	
		3.0 (C)	70	66	62	68	64	61	63	60	57	58	56	54	
		4.0 (B)	73	70	67	70	67	65	66	63	61	61	59	57	
		5.0 (A)	75	72	70	72	70	68	68	65	63	62	61	60	
3	FLUX RATIO 39[illegible] 	0.6 (J)	35	29	24	35	28	24	33	28	24	32	27	24	White enamel industrial reflector-0 10% up ward light and 13° crosswise by 0° lengthwise shielding. Suggested MF- 75
		0.8 (I)	44	37	32	43	36	32	41	35	31	40	35	31	
		1.0 (H)	50	44	39	49	43	38	47	42	38	46	41	37	
		1.25 (G)	56	50	45	56	49	45	53	48	43	51	47	43	
		1.5 (F)	61	55	50	60	54	50	57	53	49	55	51	48	
		2.0 (E)	67	62	57	66	61	56	63	59	55	60	57	54	
		2.5 (D)	71	66	62	69	65	61	65	63	59	64	61	58	
		3.0 (C)	74	69	66	72	68	65	69	65	63	66	64	61	
		4.0 (B)	77	74	71	76	72	70	73	70	68	70	68	66	
		5.0 (A)	80	77	74	78	76	73	75	73	71	72	70	68	
4	FLUX RATIO 5[illegible]0 	0.6 (J)	35	30	28	34	30	27	34	30	27	33	30	27	Single lamp parabolic aluminum troffer with baffles-low brightness, good visual comfort when viewed crosswise-efficient, neat inbuilt appearance good maintenance. Suggested MF- 75
		0.8 (I)	41	37	34	41	37	34	40	36	34	39	36	34	
		1.0 (H)	45	41	38	45	41	38	44	41	38	43	40	38	
		1.25 (G)	49	45	43	49	45	43	48	45	42	47	44	42	
		1.5 (F)	52	48	46	51	48	46	50	48	45	49	47	45	
		2.0 (E)	55	52	50	54	52	50	53	51	49	52	50	49	
		2.5 (D)	57	54	52	56	54	52	55	52	52	54	52	51	
		3.0 (C)	58	56	54	58	56	54	56	55	53	55	54	53	
		4.0 (B)	60	58	56	59	58	56	58	57	55	57	56	55	
		5.0 (A)	61	59	58	60	59	58	59	58	57	58	57	56	
5	FLUX RATIO 480 	0.6 (J)	34	31	27	36	31	27	36	31	27	35	30	27	Single lamp parabolic aluminum troffer-with 40 watt T 17 bulb, baffles not often used-very low brightness when viewed crosswise-efficient, easy maintenance. Suggested MF 78
		0.8 (I)	44	39	35	44	38	35	43	38	35	42	38	35	
		1.0 (H)	50	44	41	49	44	41	48	44	40	47	43	40	
		1.25 (G)	54	50	46	54	49	46	53	49	46	52	48	45	
		1.5 (F)	58	54	50	57	53	50	56	52	49	55	52	49	
		2.0 (E)	62	58	55	61	58	55	60	57	54	59	56	54	
		2.5 (D)	65	62	59	64	61	58	63	60	58	61	59	57	
		3.0 (C)	67	64	61	66	63	61	64	62	60	63	61	60	
		4.0 (B)	69	66	64	68	66	64	67	65	63	65	64	62	
		5.0 (A)	70	68	67	70	68	66	68	67	65	67	66	64	
6	FLUX RATIO 510 	0.6 (J)	27	24	21	27	23	21	27	23	21	26	23	21	Two lamp parabolic aluminum troffer-good utilization with low order of direct glare-best installed crosswise of principal viewing direction. Suggested MF- 75
		0.8 (I)	33	29	26	32	29	26	32	28	26	31	28	26	
		1.0 (H)	36	33	30	36	33	30	35	32	30	35	32	30	
		1.25 (G)	40	36	34	39	36	34	38	36	34	38	36	34	
		1.5 (F)	42	39	37	42	39	37	41	38	36	40	38	36	
		2.0 (E)	45	42	40	44	42	40	44	42	40	43	41	40	
		2.5 (D)	47	44	43	46	44	42	45	44	42	44	43	42	
		3.0 (C)	48	46	44	47	46	44	47	45	44	46	44	43	
		4.0 (B)	50	48	46	49	48	46	48	47	46	47	46	45	
		5.0 (A)	50	49	48	50	49	48	49	48	47	48	47	46	
7	FLUX RATIO 480 	0.6 (J)	[illegible]	[illegible]	[illegible]	28	24	21	28	24	21	28	24	21	Two lamp 12 wide troffer with light controlling glass or plastic plates or louvers-good appearance more than two lamps in this luminaire reduces efficiency, increascs brightness. Suggested MF- 70
		0.8 (I)	35	[illegible]	[illegible]	34	30	27	34	30	27	33	30	27	
		1.0 (H)	39	35	32	38	35	32	38	34	32	37	34	32	
		1.25 (G)	43	39	36	42	39	36	41	38	36	41	38	36	
		1.5 (F)	[illegible]	42	39	45	42	39	44	41	39	43	41	39	
		2.0 (E)	49	46	43	48	46	43	47	45	43	45	44	42	
		2.5 (D)	51	48	46	50	48	46	49	47	45	48	46	45	
		3.0 (C)	[illegible]	50	48	52	50	48	51	49	47	50	48	47	
		4.0 (B)	54	[illegible]	51	54	52	50	52	51	50	51	50	49	
		5.0 (A)	55	54	[illegible]	55	53	52	54	52	51	54	51	51	
8	FLUX RATIO 375 	0.6 (J)	20	[illegible]	14	20	16	13	20	16	13	19	16	13	Large area formed plastic panels-simple, contemporary in appearance. Suggested MF 70
		0.8 (I)	[illegible]	[illegible]	[illegible]	25	21	18	24	20	18	23	20	18	
		1.0 (H)	29	24	22	28	24	22	27	24	21	27	24	21	
		1.25 (G)	32	28	25	[illegible]	28	25	31	27	25	30	27	25	
		1.5 (F)	34	[illegible]	28	34	30	28	33	30	26	32	30	27	
		2.0 (E)	37	34	[illegible]	37	34	32	36	33	31	35	33	31	
		2.5 (D)	40	[illegible]	34	39	36	34	38	36	34	37	35	33	
		3.0 (C)	41	38	36	40	38	36	39	37	36	38	37	35	
		4.0 (B)	43	41	39	42	40	39	41	40	38	40	39	38	
		5.0 (A)	44	[illegible]	[illegible]	[illegible]	42	41	43	41	40	42	41	40	
9	FLUX RATIO 415 	0.6 (J)	25	21	16	25	21	18	24	21	18	24	20	18	Large area ceiling mounted or recessed louvered luminaire- various size panels-can be applied to emphasize architectural features such as bays or in appropriate size to establish scale or improve appearance. Suggested - 70
		0.8 (I)	31	[illegible]	24	31	27	24	30	26	24	30	26	24	
		1.0 (H)	[illegible]	[illegible]	28	35	31	28	34	31	28	34	30	28	
		1.25 (G)	40	[illegible]	[illegible]	39	36	33	38	35	33	38	35	32	
		1.5 (F)	43	39	36	42	39	36	41	38	36	40	38	36	
		2.0 (E)	46	43	41	45	43	40	45	42	40	44	42	40	
		2.5 (D)	49	46	43	48	46	43	47	45	43	46	44	42	
		3.0 (C)	[illegible]	48	46	50	48	46	49	47	45	48	46	45	
		4.0 (B)	53	51	49	52	50	49	51	50	48	50	49	47	
		5.0 (A)	54	51	[illegible]	54	52	51	53	51	50	52	50	49	

AIAE 027

Figure 3-8. Coefficient of Utilization and Maintenance Factors (Sheet 1 of 3)
(From: TM5-680B, Electrical Facilities Interior Electric Systems, Dept. of Army)

FLUORESCENT LUMINAIRES

Maintenance factors (MF) for the luminaires below are suggested values, based on assumed average conditions. The designer should make adjustments for the conditions peculiar to the specific installation.

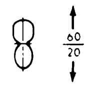
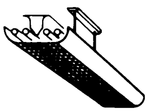
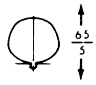
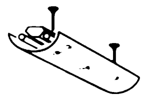
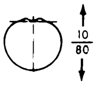
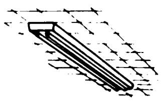
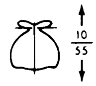
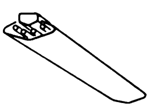
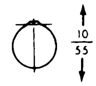
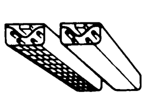
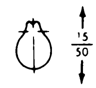
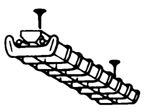
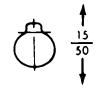
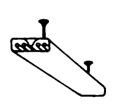
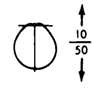
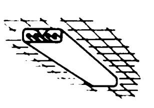
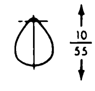
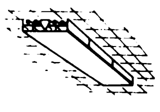
	TYPICAL DISTRIBUTION	LUMINAIRE	CEILING	80%			70%			50%			30%			
			WALLS	50%	30%	10%	50%	30%	10%	50%	30%	10%	50%	30%	10%	
			FLOOR	10%			10%			10%			10%			
			ROOM RATIO	COEFFICIENTS OF UTILIZATION												
10	FLUX RATIO 435  10 / 60		0.6 (J)	30	25	.22	30	.25	.22	.29	24	.22	.28	.24	21	Semi-direct luminaire with plastic side panels, plastic lens or louvers-often ceiling mounted-usually lowest in brightness when viewed lengthwise. Suggested MF-70
			0.8 (I)	37	32	.28	37	32	28	.35	31	28	.34	30	.27	
			1.0 (H)	43	38	34	42	37	.34	.40	36	.33	.39	35	32	
			1.25 (G)	48	43	39	.47	42	39	.45	.41	.38	.43	.40	37	
			1.5 (F)	51	47	43	50	46	43	.48	.45	.42	.46	.43	.41	
			2.0 (E)	56	52	.49	55	.51	.48	.53	.50	.47	.50	.48	.46	
			2.5 (D)	59	55	52	58	.54	52	.55	.52	.50	.53	.51	.49	
			3.0 (C)	61	58	.55	60	.57	.54	.57	55	.53	55	.53	.51	
			4.0 (B)	64	61	.59	.62	.60	58	.60	58	.56	.57	.56	.54	
			5.0 (A)	66	.64	.62	64	.62	60	.62	60	.58	59	58	.56	
11	FLUX RATIO 415  45 / 35		0.6 (J)	.25	20	.17	.24	19	16	.21	17	.15	.18	.16	.13	General diffusing fixture with plastic side panels and louvers-usual preference is for lengthwise viewing. Suggested MF-70
			0.8 (I)	.31	26	.22	.29	.24	.21	.26	.22	.19	.22	.20	.17	
			1.0 (H)	.36	32	.27	34	.30	26	.31	27	.24	.26	.24	.21	
			1.25 (G)	.41	36	.32	39	35	31	.34	31	.28	.30	.27	25	
			1.5 (F)	45	41	.36	43	.39	.34	.38	34	.31	.32	.30	27	
			2.0 (E)	.51	46	.32	48	.44	.40	.42	38	.35	.36	.33	.31	
			2.5 (D)	54	50	.46	.51	.47	.44	.44	.41	.39	38	.36	.34	
			3.0 (C)	.57	.53	.49	.53	.50	.46	.46	.43	.41	.40	38	.36	
			4.0 (B)	.60	57	.54	.55	.53	.50	.49	.46	.44	.42	.40	.38	
			5.0 (A)	62	60	57	.58	56	53	.51	49	.46	.43	.42	.40	
12	FLUX RATIO 435  35 / 45		0.6 (J)	.29	24	.20	.28	23	19	.25	.21	.18	23	.20	.17	Typical direct-indirect fixture-with opaque side panels, frequently mounted for crosswise viewing-with 40°-45° lengthwise shielding, any viewing direction usually satisfactory. Suggested MF-75
			0.8 (I)	.36	30	.26	.34	30	.26	.31	27	.24	28	.25	22	
			1.0 (H)	.41	36	.32	.40	.35	.31	.36	32	.29	.32	.29	.27	
			1.25 (G)	.46	41	37	.45	.40	36	.40	37	.34	.36	.33	.31	
			1.5 (F)	.50	46	.41	.48	44	.40	.44	.40	.37	.39	36	34	
			2.0 (E)	56	51	.47	.53	.49	.46	.48	.45	.42	.43	.40	.38	
			2.5 (D)	.59	55	.52	56	.53	.51	.51	48	.45	.45	.43	.41	
			3.0 (C)	.62	.58	55	.59	.55	.52	.53	50	.47	47	45	.43	
			4.0 (B)	.65	.62	.59	.61	59	.56	.55	.53	.51	.49	.48	.46	
			5.0 (A)	66	64	.61	.63	.61	59	.56	.55	53	.50	.49	48	
13	FLUX RATIO 450  45 / 35		0.6 (J)	27	.22	.18	.25	.21	.17	.22	19	.16	.20	.17	.14	Variation of No. 12 but with more upward light-might have slightly longer stem suspension to permit spread of upward light across ceiling. Suggested MF-75
			0.8 (I)	33	28	.24	.32	28	.23	.28	24	.21	.24	.21	.19	
			1.0 (H)	38	33	.29	36	32	.28	.32	28	25	.28	.25	.22	
			1.25 (G)	.43	38	.34	41	36	33	.36	32	.30	31	.28	26	
			1.5 (F)	.47	.42	.38	.45	40	.36	.39	36	.33	.34	.31	.29	
			2.0 (E)	52	.48	.44	50	.45	42	.43	40	.37	.37	.34	.33	
			2.5 (D)	.56	.52	.48	52	.49	.46	46	43	40	.39	.37	.35	
			3.0 (C)	.58	.55	.51	.55	.51	.48	47	45	.42	.40	.38	.37	
			4.0 (B)	.61	58	.55	57	.54	.52	49	.48	.45	.42	.41	.49	
			5.0 (A)	63	60	58	.59	56	54	.51	.49	.47	.44	.42	.41	
14	FLUX RATIO 465  35 / 35		0.6 (J)	25	20	17	24	20	17	.22	18	16	.19	16	14	Direct-indirect luminaire with opaque side panels and louvers. Suggested MF-75
			0.8 (I)	.31	26	23	30	.25	.22	26	.23	.21	.24	.21	19	
			1.0 (H)	.35	.31	28	34	30	.26	.30	27	.24	27	24	.22	
			1.25 (G)	40	36	.32	.38	34	31	.34	31	.28	30	28	26	
			1.5 (F)	43	39	36	41	37	.34	.37	34	31	32	30	28	
			2.0 (E)	.48	44	41	.45	42	39	40	38	.35	36	.33	32	
			2.5 (D)	.51	47	.44	.48	45	.42	.42	40	.38	.37	.35	.34	
			3.0 (C)	.53	.50	.47	.50	47	.44	.44	.42	.40	.39	.37	.36	
			4.0 (B)	.55	53	.50	52	50	48	.46	44	.42	.40	.39	.38	
			5.0 (A)	57	55	52	.54	51	50	47	46	44	.41	40	39	
15	FLUX RATIO 445  30 / 35		0.6 (J)	23	19	16	22	18	16	20	.17	15	.18	16	.14	Extended area suspended louvered fixture-provides "custom look" to lighting element-good maintenance. Suggested MF-75
			0.8 (I)	29	25	.21	28	24	.21	.25	22	.19	23	20	18	
			1.0 (H)	33	29	26	.32	28	25	29	26	.23	.26	.23	.21	
			1.25 (G)	37	33	30	.36	32	29	32	29	.27	.29	26	.24	
			1.5 (F)	41	37	33	39	35	32	35	32	.30	.32	29	.27	
			2.0 (E)	45	.41	38	43	40	.37	.38	36	33	.34	32	.30	
			2.5 (D)	48	44	.42	.45	42	40	40	38	.36	.36	.34	33	
			3.0 (C)	50	47	.44	.47	44	42	.42	.40	.38	.39	36	.34	
			4.0 (B)	52	50	.47	.49	47	.44	.44	42	.40	.39	.38	.36	
			5.0 (A)	.54	52	49	51	49	47	45	44	.42	.40	.39	.38	
16	FLUX RATIO 335  20 / 65		0.6 (J)	.30	24	.20	.30	24	19	28	.22	.19	.26	21	.18	Semi direct ceiling mounted fixture with luminous side panels, no cross louvers-shielding adds crosswise viewing comfort-easier to maintain than corresponding louvered fixture. Suggested MF-78
			0.8 (I)	.38	32	27	37	.31	.26	35	29	.25	.33	28	.24	
			1.0 (H)	44	38	.33	.43	37	.32	.41	35	.31	.38	.33	.29	
			1.25 (G)	.51	44	39	49	43	38	46	41	.37	.43	38	.35	
			1.5 (F)	55	49	.44	.54	48	43	50	.45	.41	.47	.42	.39	
			2.0 (E)	61	56	.51	.60	54	50	.56	.51	47	.52	48	45	
			2.5 (D)	65	60	55	.63	58	54	.59	.55	51	.55	.52	.49	
			3.0 (C)	.68	63	.59	.66	.62	.58	62	58	.55	.58	.54	.52	
			4.0 (B)	72	68	.64	.70	66	.63	.65	.62	.60	.61	58	56	
			5.0 (A)	75	72	.68	.73	69	67	.68	.65	.63	.63	.61	60	
17	FLUX RATIO 415  25 / 55		0.6 (J)	30	25	21	30	24	21	.28	.23	20	.26	.22	.19	Semi direct suspended fixture-because of reduced brightness of T 17 lamps, no louvers generally used-mounted crosswise of principal viewing direction-simple to clean and relamp. Suggested MF-78
			0.8 (I)	.38	32	28	.37	32	28	.34	30	26	.32	.28	.25	
			1.0 (H)	.44	38	34	.42	37	33	40	35	32	.37	.33	30	
			1.25 (G)	49	44	40	.48	43	.39	.44	40	.37	.41	.38	35	
			1.5 (F)	53	48	44	.52	47	.43	.48	.44	.41	.44	.41	38	
			2.0 (E)	.59	54	50	57	52	.49	.52	.49	.46	48	46	43	
			2.5 (D)	62	58	.54	.60	56	53	.55	52	.50	.51	.49	.47	
			3.0 (C)	.65	61	58	.62	59	.46	.58	.55	.52	.53	.51	.49	
			4.0 (B)	68	.64	62	.65	62	.60	60	58	.56	.56	.54	52	
			5.0 (A)	70	68	65	67	.65	63	.62	60	.58	57	56	.54	
18	FLUX RATIO 415  40 / 40		0.6 (J)	27	22	18	.26	21	17	.23	19	16	.20	18	15	Typical direct indirect fixture with luminous sides-many variations-best for lengthwise viewing-widely used for general lighting. Suggested MF-75
			0.8 (I)	.34	28	.24	.32	27	24	.29	25	.22	26	22	.20	
			1.0 (H)	.39	34	30	.37	.32	28	.33	29	26	.29	.26	.23	
			1.25 (G)	.44	39	35	.42	37	.33	.38	34	30	33	30	27	
			1.5 (F)	48	43	.39	46	.41	.37	41	37	34	36	.33	.30	
			2.0 (E)	.53	49	.45	51	46	43	.45	42	.39	39	.37	35	
			2.5 (D)	57	53	49	54	50	.47	.48	.45	.42	42	39	37	
			3.0 (C)	.60	56	.52	.56	.53	.50	.49	.47	44	.43	.41	39	
			4.0 (B)	.63	60	53	59	56	.54	.52	50	.47	.45	.44	.42	
			5.0 (A)	65	62	.59	.61	58	56	.53	52	50	47	.45	44	

AIAE 028

Figure 3-8. Coefficient of Utilization and Maintenance Factors (Sheet 2 of 3)
(From: TM5-680B, Electrical Facilities Interior Electric Systems, Dept. of Army)

FLUORESCENT LUMINAIRES

Maintenance factors (MF) for the luminaires below are suggested values, based on assumed average conditions. The designer should make adjustments for the conditions peculiar to the specific installation.

No.	Typical Distribution	Luminaire	Ceiling	80%			70%			50%			30%		
			Walls	50%	30%	10%	50%	30%	10%	50%	30%	10%	50%	30%	10%
			Floor	10%			10%			10%			10%		
			Room Ratio	Coefficients of Utilization											
19	FLUX RATIO 350  60/20		0.6	26	20	16	23	19	15	19	16	13	15	12	10
			0.8	32	27	22	29	24	20	24	20	17	18	16	13
			1.0	36	31	27	33	29	25	27	24	21	21	18	16
			1.25	41	36	32	38	33	29	31	27	24	24	21	19
			1.5 *	45	40	36	41	36	33	33	30	27	26	23	21
			2.0	50	45	43	46	42	38	37	34	31	28	26	24
			2.5	53	49	45	49	45	41	39	36	33	30	28	26
			3.0	55	52	48	51	47	44	40	38	35	31	29	28
			4.0	58	55	50	53	50	47	42	40	38	33	30	30
			5.0	59	57	54	54	52	50	43	42	40	34	32	31
20	FLUX RATIO 300  65/5		0.6	19	15	12	17	14	10	12	10	08	08	06	05
			0.8	24	20	16	21	18	14	16	13	11	10	08	07
			1.0	28	24	20	25	21	18	18	16	13	12	10	08
			1.25	32	28	24	28	24	21	21	18	16	14	12	10
			1.5 *	35	31	27	32	28	24	23	20	18	15	14	12
			2.0	40	36	32	35	32	28	26	23	21	17	16	14
			2.5	43	39	35	38	34	31	28	25	23	18	16	15
			3.0	44	41	38	39	36	33	29	27	24	19	17	16
			4.0	47	44	41	41	38	36	30	28	26	20	18	18
			5.0	48	46	43	42	40	38	31	3C	27	21	19	18
21	FLUX RATIO 300  10/80		0.6 (J)	32	25	20	32	25	20	30	24	20	29	23	19
			0.8 (I)	41	32	27	40	32	27	38	31	26	36	30	26
			1.0 (H)	48	40	34	47	39	34	44	38	32	42	36	32
			1.25 (G)	54	46	41	53	48	40	50	44	39	48	43	38
			1.5 (F)	59	52	46	58	51	45	55	49	44	52	47	43
			2.0 (E)	66	59	53	64	56	52	61	58	51	58	54	50
			2.5 (D)	70	64	58	68	62	58	65	60	56	62	58	54
			3.0 (C)	73	67	62	72	66	62	68	64	60	65	61	58
			4.0 (B)	78	73	68	70	71	67	72	69	66	70	66	64
			5.0 (A)	81	77	73	79	75	72	76	72	70	73	70	68
22	FLUX RATIO 425  10/55		0.6 (J)	28	23	20	27	23	20	26	22	20	25	21	19
			0.8 (I)	34	29	26	33	29	26	32	28	25	31	27	25
			1.0 (H)	39	34	31	38	34	30	37	33	30	35	32	29
			1.25 (G)	44	39	36	43	38	35	41	37	35	39	36	34
			1.5 (F)	47	44	39	46	41	39	44	41	37	42	39	37
			2.0 (E)	51	48	44	50	47	44	48	45	42	46	43	41
			2.5 (D)	54	50	48	53	50	47	50	48	46	48	46	43
			3.0 (C)	56	53	50	55	52	50	52	50	48	50	48	46
			4.0 (B)	58	56	54	57	55	53	54	53	51	52	51	50
			5.0 (A)	60	58	56	59	57	55	56	55	53	54	53	52
23	FLUX RATIO 370  10/55		0.6 (J)	25	20	17	25	20	17	24	20	17	23	19	16
			0.8 (I)	32	27	23	31	26	23	29	25	22	28	25	22
			1.0 (H)	37	32	28	36	31	28	34	30	27	33	29	26
			1.25 (G)	41	37	33	40	36	32	39	35	32	37	33	31
			1.5 (F)	45	40	37	44	40	36	42	38	35	40	37	34
			2.0 (E)	49	45	42	48	44	41	46	43	40	44	41	39
			2.5 (D)	52	48	45	51	48	45	48	46	43	46	44	42
			3.0 (C)	54	51	48	53	50	47	51	48	46	48	46	44
			4.0 (B)	57	54	52	56	53	51	53	51	50	51	49	48
			5.0 (A)	59	57	55	58	56	54	55	53	52	53	51	50
24	FLUX RATIO 390  15/50		0.6 (J)	25	20	17	24	20	17	23	19	17	22	18	16
			0.8 (I)	31	26	23	30	26	23	29	25	22	27	24	21
			1.0 (H)	36	31	28	35	30	27	33	29	26	31	28	25
			1.25 (G)	40	36	32	39	35	31	37	33	30	35	32	30
			1.5 (F)	44	40	36	42	38	35	40	37	34	38	35	33
			2.0 (E)	48	44	41	47	43	40	44	41	38	42	39	37
			2.5 (D)	51	47	44	50	46	44	47	44	42	44	42	40
			3.0 (C)	53	50	47	51	48	46	48	46	44	46	44	42
			4.0 (B)	56	53	51	54	52	50	51	49	47	48	46	45
			5.0 (A)	57	55	53	56	54	52	52	51	49	50	48	47
25	FLUX RATIO 335  15/50		0.6 (J)	23	18	15	23	18	15	22	17	14	20	16	14
			0.8 (I)	30	24	20	29	24	19	27	23	19	25	21	18
			1.0 (H)	34	29	25	33	28	24	31	27	24	29	26	23
			1.25 (G)	39	34	30	38	33	29	35	31	28	33	30	27
			1.5 (F)	42	38	34	41	36	33	38	35	31	36	33	30
			2.0 (E)	47	42	39	46	42	38	43	39	36	40	37	35
			2.5 (D)	50	46	42	49	45	42	45	42	39	42	40	37
			3.0 (C)	52	49	45	51	47	44	47	45	42	44	42	40
			4.0 (B)	56	52	49	54	51	48	50	48	46	47	45	43
			5.0 (A)	57	55	52	56	53	51	53	50	48	49	47	46
26	FLUX RATIO 335  10/50		0.6 (J)	22	18	14	22	17	14	21	16	14	20	16	14
			0.8 (I)	28	23	20	27	22	19	26	22	19	25	21	18
			1.0 (H)	32	28	24	32	27	23	30	26	23	28	25	22
			1.25 (G)	37	32	28	36	31	28	34	30	27	32	29	26
			1.5 (F)	40	35	32	39	34	31	37	33	30	15	32	29
			2.0 (E)	44	40	36	43	39	36	41	37	35	39	36	34
			2.5 (D)	47	43	40	46	42	39	43	40	38	41	39	36
			3.0 (C)	49	45	42	48	45	42	45	43	40	43	41	39
			4.0 (B)	52	49	46	50	48	46	48	46	44	46	44	42
			5.0 (A)	53	51	49	52	49	48	50	48	46	47	46	45
27	FLUX RATIO 395  10/55		0.6 (J)	26	22	18	26	21	18	25	21	18	24	21	18
			0.8 (I)	33	28	24	32	27	24	31	27	24	30	26	23
			1.0 (H)	38	33	29	37	31	29	35	31	28	34	30	28
			1.25 (G)	42	38	34	42	37	34	40	36	33	38	35	32
			1.5 (F)	46	41	38	45	41	37	43	39	37	41	38	36
			2.0 (E)	50	46	43	49	46	42	47	44	41	45	42	40
			2.5 (D)	53	49	46	52	48	46	49	47	44	47	45	43
			3.0 (C)	55	52	49	54	51	48	51	49	47	49	47	45
			4.0 (B)	58	55	53	56	54	52	54	52	50	52	50	49
			5.0 (A)	60	57	55	58	56	54	56	54	53	53	52	51

19 — Semi indirect luminaire–used where uniform, low brightness and soft atmosphere desired. Suggested MF- 70

20 — Luminous indirect luminaire–high quality, well diffused lighting–uniform brightness of ceiling and luminaire help minimize direct, reflected glare. Suggested MF- 65

21 — Ceiling mounted luminaire for bare lamps–not recommended for schools, offices,where soft, restrained atmosphere is desired. Suggested MF- 80

22 — Ceiling mounted fixture with prismatic glass top and bottom–useful in low ceiling interiors where upward light from fixture can be smoothly graded across ceiling. Suggested MF- 70

23 — Semi direct ceiling mounted fixture with louvered or enclosed lamps–for low-ceiling applications–suitable for schools and offices when equipped with low brightness luminous side panels–best for lengthwise viewing. Suggested MF- 70

24 — Luminous sided fixture, variation of No 18, but with less upward light. Suggested MF- 75

25 — Simply styled plastic luminaire–good appearance. Suggested MF- 70

26 — Same as No 25 but tables apply to ceiling mounted luminaire. Suggested MF- 70

27 — Semi direct ceiling mounted fixture used in stores and low ceiling interiors–suitable for school and office lighting when equipped with low brightness side panels and louvers or lens enclosure. Suggested MF- 75

AIAE 029

* Tabulated on indirect room ratio basis using ceiling height to work plane distance

Figure 3-8. Coefficient of Utilization and Maintenance Factors (Sheet 3 of 3) (From: TM5-680B, Electrical Facilities Interior Electric Systems, Dept. of Army)

TWO TYPES OF TRANSLUCENT PANEL AND LOUVER ELEMENTS (WALL TO WALL)

The efficiency of luminous or louverall elements cannot at present be measured by photometric methods commonly applied to individual fixtures. At best, output efficiency for a proposed installation can only be estimated by engineering evaluation of cavity proportions, reflections and transmission characteristics of the enclosing materials; or, photometric testing of large-scale models may provide data for specific installations. At the same time, however, efficiency and coefficients of utilization should not be the only criteria for selecting a particular design. The designer must weigh such considerations as brightness control and diffusion, pattern and texture, rigidity, ease of handling and cleaning, cost, and safety.

An important variable to be considered in the tables below is the reduction of fluorescent lamp output due to lamp operating temperatures. Wattage loading, efficiency, ballast location, heat losses, and ventilation vary considerably between installations. Consequently, the tables below include no allowance for the reduction of light output due to unfavorable temperature conditions. Such reductions may range as high as 20 per cent. At this rate, 25 percent more lamps would be required for a desired footcandle level.

Maintenance factors have been estimated as follows under poor conditions, .45 for the panel type and .55 for the louver type, and under good conditions, .65 for the panel type and .70 for the louver type.

28 VINYL

REFLECTANCE - .45
TRANSMITTANCE - .45

CAVITY	85 %			75 %		
WALLS	50 %	30 %	10 %	50 %	30 %	10 %
FLOOR	10 %			10 %		
ROOM RATIO	COEFFICIENTS OF UTILIZATION					
0.6 (J)	.21	.17	.14	.17	.14	.12
0.8 (I)	.27	.24	.21	.23	.20	.17
1.0 (H)	.32	.29	.26	.28	.24	.21
1.25 (G)	.38	.34	.31	.32	.29	.26
1.5 (F)	.42	.38	.36	.36	.32	.30
2.0 (E)	.48	.45	.41	.41	.38	.35
2.5 (D)	.52	.49	.45	.45	.42	.39
3.0 (C)	.55	.52	.49	.47	.45	.42
4.0 (B)	.59	.56	.53	.51	.49	.47
5.0 (A)	.61	.59	.57	53	.52	.50

NOTE: MODIFIED FOR VARYING CAVITY PROPORTIONS.

29 PLASTIC LOUVERS

REFLECTANCE - .19
TRANSMITTANCE - .71

CAVITY	85%			75%		
WALLS	50%	30%	10%	50%	30%	10%
FLOOR	10%			10%		
ROOM RATIO	COEFFICIENTS OF UTILIZATION					
0.6 (J)	.25	.21	.19	.22	.18	.17
0.8 (I)	.30	.25	.24	.26	.22	.21
1.0 (H)	.34	.29	.27	.30	.26	.24
1.25 (G)	.37	.33	.31	.33	.29	.28
1.5 (F)	.40	.36	.34	.36	.32	.30
2.0 (E)	.44	.39	.38	.38	.35	.34
2.5 (D)	.46	.42	.41	.41	.37	.37
3.0 (C)	.48	.44	.43	.42	.39	.38
4.0 (B)	.50	.47	.46	44	.41	.41
5.0 (A)	.51	.48	.48	.46	.43	.42

30 ACRYLIC

REFLECTANCE - .39
TRANSMITTANCE - .53

CAVITY	85 %			75 %		
WALLS	50%	30%	10%	50%	30%	10%
FLOOR	10%			10%		
ROOM RATIO	COEFFICIENTS OF UTILIZATION					
0.6 (J)	.24	21	.17	.20	.16	.13
0.8 (I)	.32	.28	.24	.27	.23	20
1.0 (H)	.37	.33	.29	.32	.28	.25
1.25 (G)	.42	.38	.34	.37	.33	.30
1.5 (F)	.46	.42	.39	.40	.36	.33
2.0 (E)	.52	.48	.45	.45	.42	.39
2.5 (D)	.56	.53	.49	.48	.46	.43
3.0 (C)	.58	.56	.52	.51	.49	.46
4.0 (B)	.62	.60	.56	.54	.52	.50
5.0 (A)	.64	.62	.60	.57	.55	.53

31 STEEL LOUVERS (WHITE)

REFLECTANCE - .75

CAVITY	85%			75%		
WALLS	50%	30%	10%	50%	30%	10%
FLOOR	10%			10 %		
ROOM RATIO	COEFFICIENTS OF UTILIZATION					
0.6 (J)	.20	.16	.16	.17	.15	.14
0.8 (I)	.23	.20	.19	.21	.18	.17
1.0 (H)	.26	.23	.22	.23	.20	.19
1.25 (G)	.28	.26	.24	.25	.23	.22
1.5 (F)	.30	.27	.26	.27	.24	23
2.0 (E)	.32	.30	.29	.29	.27	26
2.5 (D)	.34	.32	.31	.30	.28	.27
3.0 (C)	.35	.33	.32	.31	.29	.29
4.0 (B)	.37	.34	.34	.32	.31	.30
5.0 (A)	.37	.36	.35	33	.32	.31

AIAE 030

Figure 3-9. Translucent Panel and Louver Elements, Types
(From: TM5-680B, Electrical Facilities Interior Electric Systems, Dept. of Army)

the next higher wattage lamps may sometimes be installed. If the globes become uncomfortably bright, large-diameter globes should then be used.

o A semi-indirect luminaire distributes from 60 to 90 percent of its light output above the horizontal and from 10 to 40 percent of its light output below the horizontal. The light source is concealed from view below the horizontal by a diffusing medium, usually glass or plastic. Because the ceiling constitutes an important part of the lighting system, it must be white or nearly white and well maintained. Luminaires of this classification are available either completely enclosed, open top, or open bottom. The two latter types simplify maintenance.

o Indirect luminaires distribute from 90 to 100 percent of their light output upward above the horizontal. They may be suspended or mounted on the wall or a pedestal. The light source is concealed from view below the horizontal. Indirect luminaires direct practically all of their light to the ceiling and upper sidewalls and the entire ceiling becomes the light source. Shadows and reflected glare are minimized and if foot-candles are not too high, little direct glare is experienced from the ceiling brightness. With indirect lighting, luminaires and reflecting surfaces must be well maintained. Luminaire spacings tabulated in table 3-4 list the maximum spacings to be used between various units. Where continuous rows of units such as fluorescent reflectors are used, the figures apply to the spacing between rows. Individual fluorescent fixtures, because of the limited output of the small-wattage lamps, seldom follow conventional spacings. Since more units are required to produce the desired foot-candles of illumination, they must be arranged in a manner to suit the conditions.

Table 3-4. Luminaire Spacings

FIXTURE TYPE	MAXIMUM SPACING BETWEEN FIXTURES
Direct	1 x mounting height (above floor)
Semidirect	1 x mounting height (above floor)
General diffusion	1.2 x mounting height (above floor)
Semi-indirect	1.2 x ceiling height (above floor)
Indirect	1.2 x ceiling height (above floor)
Note: Spacings given for direct-type fixtures do not apply to concentrated beam luminaires. Spacing from walls should be approximately one-half the fixture spacing. For more complete information, refer to IES Handbook.	

d. Other Planning Factors. Additional considerations are:

(1) Provision for adequate wiring to handle the lighting power load.

(2) EMR suppression to minimize or eliminate potential fluorescent light-caused interference. Light loss caused by shields must be accounted for.

To minimize the effects of electrical noise generated by fluorescent lights, the following precautions should be taken.

o Power line filters should be installed in all power lines feeding the fluorescent fixtures. This precaution is necessary to prevent electromagnetic noise feedback in the lines.

o Fluorescent fixtures should be shielded to absorb electromagnetic noise radiated directly from the fluorescent light assemblies (shielding materials for this purpose are described in EC-23). After installation, specific tests should be performed throughout the laboratory in accordance with MIL-STD-462 to determine the effects of electrical interferences, if any, generated by the lights. These tests should be performed in all the major measurement areas (such as voltage, current, impedance, frequency, attenuation, etc.) by actual operation of the standards equipment. If it is determined that any measurement area is significantly affected by electromagnetic noise emanating from the fluorescent lights, or if interference levels exceed the requirements of MIL-STD-461, additional shielding or filtering or perhaps replacement of the fluorescent lights may required.

o In certain cases when fluorescent light noise interference has been minimized and additional noise reduction is required for special measurements, the laboratory should consider the use of incandescent bench-mounted lamps and have provisions for switching off the overhead fluorescent lamps in the immediate area.

o Lighting circuits should be separate from laboratory bench circuits.

(3) Use of incandescent lamps in sensitive measurements areas where electromagnetic radiation must be reduced below the levels obtained with (suppressed) fluorescent fixtures.

e. Lighting Computations. Lighting calculation methods are recommended by the IES in their handbook. For general applications, the lumen method, as outlined below, may be used. For specific cases and more accurate designs, the point-by-point method may be used. In the lumen method, the lamp lumens required to obtain the desired foot-candle level are computed from the following formulae.

Required lamp lumens =

$$\frac{\text{foot-candles x area (square feet)}}{\text{Coefficient of utilization x maintenance factor}} \qquad (3\text{-}1)$$

Number of luminaires required =

$$\frac{\text{total lumens required}}{\text{lamp lumens per luminaire}} \qquad (3\text{-}2)$$

where: The lumen is the unit of luminous flux and expresses the total amount of light emitted by a source.

The coefficient of utilization is the percentage of the source lumens that reach the working plane. A coefficient of utilization of 0.40 means that 40 percent of the emitted light contributes to the foot-candle level, while the remaining 60 percent is absorbed by walls, ceiling, and the fixture itself.

The maintenance factor is used to account for the fact that initial foot-candles, measured when lamps are new and when the fixtures are clean, are higher than the average maintained in service. The maintenance factor indicates the percentage of initial illumination to be expected under reasonable maintenance schedules of cleaning and lamp replacement.

The value of the coefficient of utilization depends upon the type of fixture, room ratio or index, reflection factor of ceiling and walls, and the maintenance factor of the fixture. Figure 3-8 gives the coefficients of utilization and suggested maintenance factors for various luminaires as a function of room ratio and reflection factor. Although luminaires may look alike, they can differ considerably in efficiency and distribution, requiring an adjustment to the coefficient.

Room ratio is that factor which is used to account for the effects of room proportion upon lighting conditions, i.e., large rooms usually light more efficiently than small ones because wall area available to absorb light is less in proportion to floor space. Similarly, high-ceiling rooms are less efficiently lighted than low-ceiling rooms with the same floor-space arrangement. Table 3-5 lists room ratios for various room sizes which may be used in figure 3-8 to determine the coefficient of utilization. The letter indices which appear with the room ratios in figure 3-8 classify room proportions into the ten classes listed in table 3-6.

The lumen method gives average values of illumination over the entire area to be lighted. It cannot be used to determine the foot-candle yield from a supplementary source. For eye comfort, such lighting should not exceed the value of the general illumination by more than a factor of ten. The correct wattage and mounting height for a supplementary source can be determined from foot-candle readings, if metering equipment is available, or from data supplied by light equipment manufacturers.

Table 3-5. Room Ratios (Sheet 1 of 3)

Based on the equation inset in the table. In this equation, H represents the distance from the light source (luminaire or ceiling) to the work plane. But, in the table below, the room ratio values are tabulated on the basis of the distance from the light source to the floor, with the work plane assumed to be 2½', above the floor.

ROOM W ft.	ROOM L ft.	Height of Light Source (Luminaire or Ceiling) above Floor (feet) (= H + 2½') The mounting height of the luminaire above the floor is used in all cases where the downward component is 40% or more of the total output. Likewise, if the downward component is less than 40%, the ceiling height is used.															
		7	8	9	10	11	12	13	15	17	19	23	27	33	43	53	63
	10	1.0	0.8	0.7	0.6	0.5											
	14	1.1	0.9	0.8	0.7	0.6	0.5										
	18	1.2	1.0	0.9	0.7	0.7	0.6	0.5									
8	24	1.3	1.1	0.9	0.8	0.7	0.6	0.6	0.5								
	30	1.4	1.2	1.0	0.8	0.7	0.7	0.6	0.5								
	40	1.5	1.2	1.0	0.9	0.8	0.7	0.6	0.5								
	50	1.5	1.3	1.1	0.9	0.8	0.7	0.7	0.6	0.5							
	10	1.1	0.9	0.8	0.7	0.6	0.5										
	14	1.3	1.1	0.9	0.8	0.7	0.6	0.6	0.5								
	18	1.4	1.2	1.0	0.9	0.8	0.7	0.6	0.5								
10	24	1.6	1.3	1.1	0.9	0.8	0.7	0.7	0.6	0.5							
	30	1.7	1.4	1.2	1.0	0.9	0.8	0.7	0.6	0.5							
	40	1.8	1.5	1.2	1.1	0.9	0.8	0.8	0.6	0.6	0.5						
	60	1.9	1.6	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5						
	12	1.3	1.1	0.9	0.8	0.7	0.6	0.6	0.5								
	16	1.5	1.2	1.1	0.9	0.8	0.7	0.7	0.5								
	20	1.7	1.4	1.2	1.0	0.9	0.8	0.7	0.6	0.5							
12	30	1.9	1.6	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5						
	50	2.1	1.8	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5					
	70	2.3	1.9	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.6	0.5					
	100	2.4	1.9	1.6	1.4	1.3	1.1	1.0	0.9	0.7	0.7	0.5					
	14	1.6	1.3	1.1	0.9	0.8	0.7	0.7	0.6	0.6	0.5						
	20	1.8	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5						
	30	2.1	1.7	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5					
14	40	2.3	1.9	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.6	0.5					
	60	2.5	2.1	1.8	1.5	1.3	1.2	1.1	0.9	0.8	0.7	0.6	0.5				
	80	2.6	2.2	1.8	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.6	0.5				
	100	2.7	2.2	1.9	1.6	1.5	1.3	1.2	1.0	0.8	0.8	0.6	0.5				
	16	1.8	1.5	1.2	1.1	0.9	0.8	0.8	0.6	0.6	0.5						
	20	2.0	1.6	1.4	1.2	1.0	0.9	0.8	0.7	0.6	0.5						
	30	2.3	1.9	1.6	1.4	1.2	1.1	1.0	0.8	0.7	0.6	0.5					
16	40	2.5	2.1	1.8	1.5	1.3	1.2	1.1	0.9	0.8	0.7	0.6	0.5				
	60	2.8	2.3	1.9	1.7	1.5	1.3	1.2	1.0	0.9	0.8	0.6	0.5				
	80	3.0	2.4	2.0	1.8	1.6	1.4	1.3	1.1	0.9	0.8	0.7	0.5				
	100	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	0.8	0.7	0.6				

$$\text{Room Ratio} = \frac{W \times L}{H\,(W + L)}$$

H = Distance from light source (luminaire or ceiling) to work plane.

Ratio for intermediate dimensions may be calculated.

Table 3-5. Room Ratios (Sheet 2 of 3)

ROOM W ft.	ROOM L ft.	Height of Light Source (Luminaire or Ceiling) above Floor (feet) (= H + 2½') The mounting height of the luminaire above the floor is used in all cases where the downward component is 40% or more of the total output. Likewise, if the downward component is less than 40%, the ceiling height is used.															
		7	8	9	10	11	12	13	15	17	19	23	27	33	43	53	63
	20	2.1	1.7	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5					
	30	2.5	2.0	1.7	1.5	1.3	1.2	1.1	0.9	0.8	0.7	0.5					
	40	2.8	2.3	1.9	1.6	1.5	1.3	1.2	1.0	0.9	0.8	0.6	0.5				
18	60	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	0.8	0.7	0.6	0.5			
	80	3.3	2.7	2.3	2.0	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.6	0.5			
	100	3.4	2.8	2.4	2.0	1.8	1.6	1.5	1.2	1.1	0.9	0.7	0.6	0.5			
	120	3.5	2.9	2.4	2.1	1.9	1.6	1.5	1.3	1.1	1.0	0.8	0.6	0.5			
	20	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.6	0.5					
	30	2.7	2.2	1.8	1.6	1.4	1.3	1.1	1.0	0.8	0.7	0.6	0.5				
	40	3.0	2.4	2.0	1.8	1.6	1.4	1.3	1.1	0.9	0.8	0.7	0.5				
20	60	3.3	2.7	2.3	2.0	1.8	1.6	1.4	1.2	1.0	0.9	0.7	0.6	0.5			
	80	3.6	2.9	2.5	2.1	1.9	1.7	1.5	1.3	1.1	1.0	0.8	0.7	0.5			
	100	3.7	3.0	2.6	2.2	2.0	1.8	1.6	1.3	1.2	1.0	0.8	0.7	0.6			
	120	3.8	3.1	2.6	2.3	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.7	0.6			
	30	3.0	2.5	2.1	1.8	1.6	1.4	1.3	1.1	0.9	0.8	0.7	0.6				
	40	3.4	2.8	2.4	2.1	1.8	1.6	1.5	1.2	1.1	0.9	0.8	0.6	0.5			
	60	3.9	3.2	2.7	2.4	2.1	1.9	1.7	1.4	1.2	1.1	0.9	0.7	0.6			
25	80	4.2	3.5	2.9	2.5	2.2	2.0	1.8	1.5	1.3	1.2	0.9	0.8	0.6	0.5		
	100	4.4	3.6	3.1	2.7	2.4	2.1	1.9	1.6	1.4	1.2	1.0	0.8	0.7	0.5		
	120	4.5	3.8	3.2	2.8	2.4	2.2	2.0	1.7	1.4	1.3	1.0	0.8	0.7	0.5		
	140	4.7	3.9	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.0	0.9	0.7	0.5		
	30	3.3	2.7	2.3	2.0	1.8	1.6	1.4	1.2	1.0	0.9	0.7	0.6	0.5			
	40	3.8	3.1	2.6	2.3	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.7	0.6			
	60	4.4	3.6	3.1	2.7	2.4	2.1	1.9	1.6	1.4	1.2	1.0	0.8	0.7	0.5		
30	80	4.8	4.0	3.4	2.9	2.6	2.3	2.1	1.7	1.5	1.3	1.1	0.9	0.7	0.5		
	100	5.1	4.2	3.6	3.1	2.7	2.4	2.2	1.8	1.6	1.4	1.1	0.9	0.8	0.6	0.5	
	120	5.3	4.4	3.7	3.2	2.8	2.5	2.3	1.9	1.7	1.5	1.2	1.0	0.8	0.6	0.5	
	140	5.5	4.5	3.8	3.3	2.9	2.6	2.3	2.0	1.7	1.5	1.2	1.0	0.8	0.6	0.5	
	40	4.2	3.4	2.9	2.5	2.2	2.0	1.8	1.5	1.3	1.1	0.9	0.8	0.6	0.5		
	60	4.9	4.0	3.4	2.9	2.6	2.3	2.1	1.8	1.5	1.3	1.1	0.9	0.7	0.6		
	80	5.4	4.4	3.7	3.2	2.9	2.6	2.3	1.9	1.7	1.5	1.2	1.0	0.8	0.6	0.5	
35	100		4.7	4.0	3.4	3.1	2.7	2.5	2.1	1.8	1.6	1.3	1.1	0.9	0.6	0.5	
	120		4.9	4.2	3.6	3.2	2.8	2.6	2.2	1.9	1.7	1.3	1.1	0.9	0.7	0.5	
	140		5.1	4.3	3.7	3.3	2.9	2.7	2.2	1.9	1.7	1.4	1.1	0.9	0.7	0.6	
	40	4.4	3.6	3.1	2.7	2.4	2.1	1.9	1.6	1.4	1.2	1.0	0.8	0.7	0.5		
	60	5.3	4.4	3.7	3.2	2.8	2.5	2.3	1.9	1.7	1.5	1.2	1.0	0.8	0.6	0.5	
	80		4.9	4.1	3.6	3.2	2.8	2.5	2.1	1.8	1.6	1.3	1.1	0.9	0.7	0.5	
40	100		5.2	4.4	3.8	3.4	3.0	2.7	2.3	2.0	1.7	1.4	1.2	0.9	0.7	0.6	0.5
	120		5.5	4.6	4.0	3.5	3.2	2.8	2.4	2.1	1.8	1.5	1.2	1.0	0.8	0.6	0.5
	140			4.8	4.1	3.7	3.3	3.0	2.5	2.1	1.9	1.5	1.3	1.0	0.8	0.6	0.5
	50		4.6	3.8	3.3	3.0	2.6	2.4	2.0	1.7	1.5	1.2	1.0	0.8	0.6	0.5	
	70		5.3	4.5	3.9	3.4	3.1	2.8	2.3	2.0	1.8	1.4	1.2	1.0	0.7	0.6	0.5
	100			5.1	4.4	3.9	3.5	3.2	2.7	2.3	2.0	1.6	1.4	1.1	0.8	0.7	0.5
50	140				4.9	4.3	3.9	3.5	2.9	2.5	2.2	1.8	1.5	1.2	0.9	0.7	0.6
	170				5.1	4.6	4.1	3.7	3.1	2.7	2.4	1.9	1.6	1.3	1.0	0.8	0.6
	200				5.3	4.7	4.2	3.8	3.2	2.8	2.4	2.0	1.6	1.3	1.0	0.8	0.6

Table 3-5. Rooms Ratios (Sheet 3 of 3)

ROOM W ft.	ROOM L ft.	7	8	9	10	11	12	13	15	17	19	23	27	33	43	53	63
		Height of Light Source (Luminaire or Ceiling) above Floor (feet) (= H + 2½′) The mounting height of the luminaire above the floor is used in all cases where the downward component is 40% or more of the total output. Likewise, if the downward component is less than 40%, the ceiling height is used.															
60	60		5.5	4.6	4.0	3.5	3.2	2.8	2.4	2.1	1.8	1.5	1.2	1.0	0.8	0.6	0.5
	80			5.3	4.6	4.0	3.6	3.3	2.7	2.4	2.1	1.7	1.4	1.1	0.9	0.7	0.5
	100				5.0	4.4	3.9	3.6	3.0	2.6	2.3	1.8	1.5	1.2	0.9	0.8	0.6
	140					5.0	4.4	4.0	3.4	2.9	2.6	2.1	1.7	1.4	1.0	0.8	0.7
	170					5.2	4.7	4.2	3.5	3.1	2.7	2.2	1.8	1.5	1.1	0.9	0.7
	200					5.5	4.9	4.4	3.7	3.2	2.8	2.3	1.9	1.5	1.2	0.9	0.7
80	80				5.3	4.7	4.2	3.8	3.2	2.8	2.4	2.0	1.6	1.3	1.0	0.8	0.6
	140						5.3	4.8	4.1	3.5	3.1	2.5	2.1	1.7	1.3	1.0	0.8
	200							5.4	4.6	3.9	3.5	2.8	2.3	1.9	1.4	1.1	0.9
100	100						5.2	4.8	4.0	3.4	3.0	2.4	2.0	1.6	1.2	1.0	0.8
	150								4.8	4.1	3.7	2.9	2.5	2.0	1.5	1.2	1.0
	200								5.3	4.6	4.1	3.3	2.7	2.2	1.7	1.3	1.1
120	120								4.8	4.1	3.7	2.9	2.5	2.0	1.5	1.2	1.0
	160								5.5	4.7	4.2	3.4	2.8	2.3	1.7	1.4	1.1
	200									5.2	4.6	3.7	3.1	2.5	1.9	1.5	1.2

Table 3-6. Classification of Room Ratios

ROOM INDEX	ROOM RATIO	RANGE OF ROOM RATIOS
J	0.6	Less than 0.7
I	0.8	0.7 - 0.9
H	1.0	0.9 - 1.12
G	1.25	1.12 - 1.38
F	1.5	1.38 - 1.75
E	2.0	1.75 - 2.25
D	2.5	2.25 - 2.75
C	3.0	2.75 - 3.50
B	4.0	3.5 - 4.5
A	5.0	4.5 up

CHAPTER 4

ELECTRICAL POWER CONSIDERATIONS

Power supply characteristics of a laboratory should be considered in reference to the measurements requirements of the laboratory, and the steps that must be taken to assure that the characteristics meet these requirements. These requirements, load, voltage regulation, distribution, etc., are discussed in this chapter.

4.1 PLANNING FACTORS

Reliable and problem-free service, suitable for electronic calibration laboratories requires a number of qualitative factors be considered during the planning stages. They should be implemented during design and layout of the interior power distribution system. The most significant of these qualitative factors to be considered are:

o To minimize interaction from other users that may result in excessive line voltage variations, transients, or conducted electromagnetic interference, the laboratory should be supplied directly from the power source, using a separate line. If a direct line is not possible, isolation transformers, voltage regulators, and power line filters should be used between the prime source and laboratory load to minimize such interactions (figures 4-1 and 4-2). Within the laboratory, regulated lines should be used for all measurements operations and separate lines used for auxiliary equipment such as office machinery, soldering irons, and heaters. The lighting system and air-conditioning system should each have individual, separate lines.

o To prevent or minimize conducted electromagnetic interference from fluorescent lamps, power line filters should be installed in all lines supplying fluorescent fixtures.

o For reasons of personnel and equipment safety, and the minimization of potential interference, an adequate grounding system should be installed within the laboratory. "Adequate" means the realization of an equipotential network which will prevent or minimize potential hazards from shock, overloads, faults, short circuits, and lightning, and which will prevent or minimize equipment interaction through radiated or conducted emissions. Details of a bonding and grounding system are given in a later chapter.

o Grounding type duplex outlets, having a 15 ampere capacity, minimum, should be installed every running foot of wall space at the rear and above bench surfaces.

o Different receptacle configurations should be used to distinguish between the various voltages and frequencies entering the laboratory to prevent accidental connection of equipment to the wrong power source. Receptacles and wall plates should conform to Federal specifications W-C-596 and W-P-455.

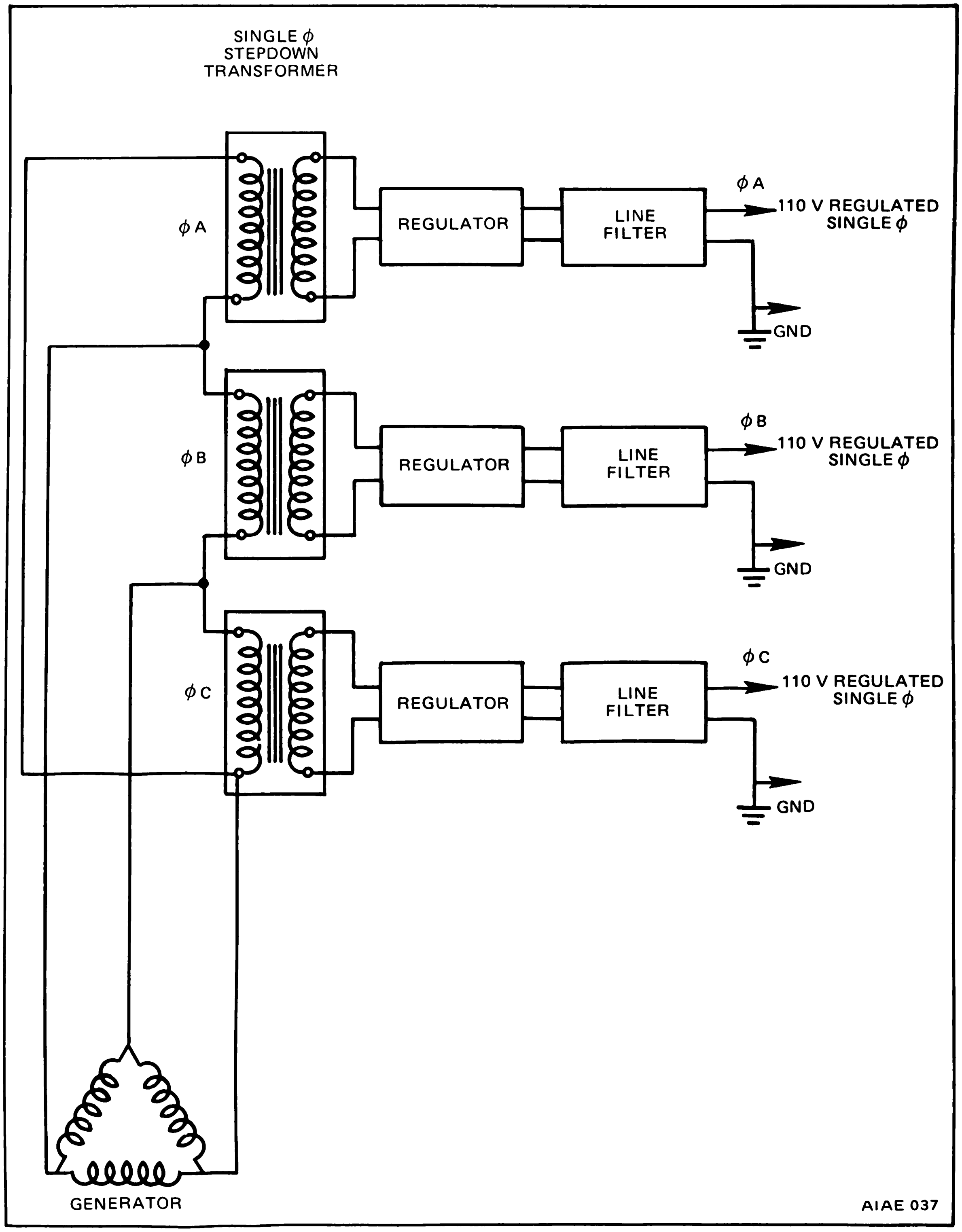


Figure 4-1. Isolation, Regulation, and Filtering of Incoming 3-Phase Primary Power Using Three Transformers

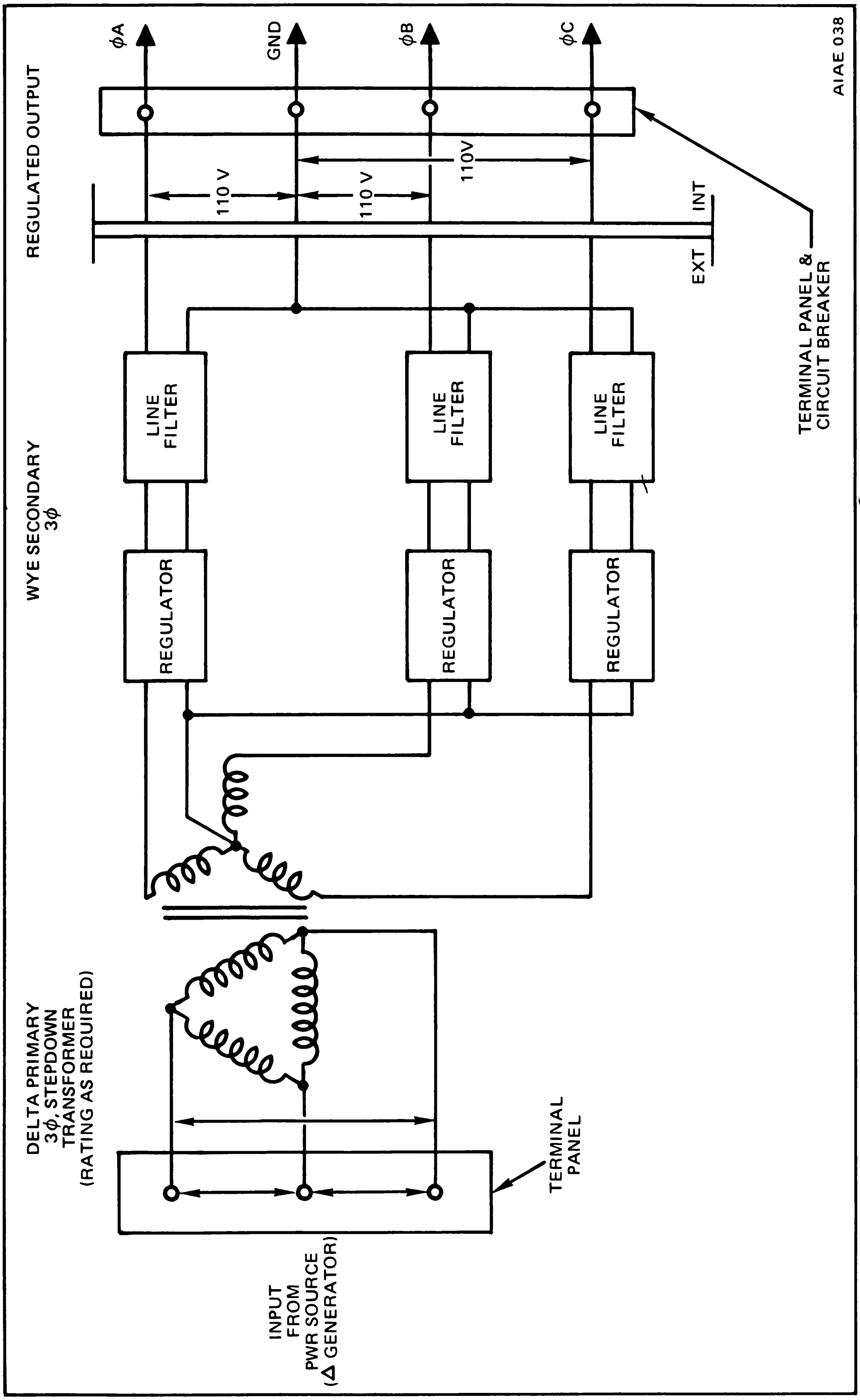


Figure 4-2. Isolation, Regulation, and Filtering of Incoming 3-Phase Primary Power Using a Delta-Wye Transformer

o Each branch or line servicing a row of benches should have an individual circuit breaker of sufficient capacity to handle the branch load. Circuit breakers should conform to Federal specification W-C-375.

o Exposed horizontal and vertical wiring runs should be avoided. Power lines of different frequencies should be installed in separate raceways and shielded.

o Transformers should be located away from all measurement areas, power lines, etc., and shielded.

o Provision should be made for emergency, standby power, as required.

4.2 POWER REQUIREMENTS

Power requirements for Naval Calibration Laboratories, as given in EC-23, are listed in table 4-1. The requirement for 60 Hz/Single Phase/115 VAC applies to all type laboratories. However, the need for other frequencies, voltages, DC distribution, or powers varies for the individual laboratory according to measurement responsibility. Thus, laboratories that calibrate certain radar test sets will require 400 Hz/Three Phase/115 VAC, while other laboratories may require 28 VDC and 400 Hz/Single Phase/115 VAC, etc. The requirement for 400 Hz/Single Phase/115 VAC power is prevalent enough to warrant the installation of a 400 Hz supply in all laboratories. Such a source can be purchased commercially or, if power requirements are not too high, constructed by the laboratory using a 400 Hz precision oscillator and power amplifier.

Table 4-1. Normal Laboratory Power Requirements

FREQUENCY	VOLTAGE	POWER OR CURRENT	NO. PHASES	DISTORTION
± 60 Hz	115 V ± 5%	40 kVA to 70 kVA	Single	5%
±400 Hz*	115 V ± 5%	5 kVA (max.)	Single	5%
± 60 Hz*	220 V ± 5%	2 kVA (min.)	Single	5%
±400 Hz*	115 V ± 5%		Three	5%
—	+28 V.D.C.* ± 2%	1 kW	—	

*Requirement varies with workload and type of calibration; measurement/installation limited to applicable measurement area.

Incoming voltage should be regulated to maintain the line voltages within the allowable tolerance of ±5 percent. Most equipments are designed to operate over this range. Equipments that are sensitive to such line tolerance variations will require additional regulations, such as provided by a bench-type regulator, or the monitoring of line voltage during their use.

Specific requirements regarding waveform distortion, transients in terms of amplitudes, rates of change, durations, etc., have not been generally standardized. This is due to their variation with load, equipment type, primary supply and distribution type, and other factors. The value of 5 percent distortion, maximum, i.e., the total RMS value of all harmonics should not exceed 5 percent of the RMS value of the fundamental (measured at no load and from line to line), is often cited in the literature. A distortion factor meter, if available, may be used to measure this parameter. Note that some meters require a "pure" (less than 1 percent harmonics) 60 Hz sinusoid for internal calibration purposes. Short time-constant, solid-state, microelectronic, and other equipments may be more susceptible to transients than fluctuations in the steady-state voltage level, thereby leading to erroneous readings or possible damage. Transients may be minimized by use of isolation, filtering, and attenuation methods. Although regulators are available which are capable of handling transients that occur in less than 1 cycle of the powerline frequency, these are limited in power capacity and are expensive.

4.3 ELECTRICAL INSTALLATIONS DESIGN AND LAYOUT

Minimum standards and specifications for electrical installations are given in the National Electrical Code, NAVFAC specification 9Y, and in the Underwriters Laboratory Standards for materials and equipment.

A systematic procedure should be employed when designing electrical circuits. If the exterior distribution system is in existence, then the voltage at the main distribution center of the building must be determined. This voltage will influence the voltage drop calculation of the interior systems. Each type of interior circuit may then be chosen based on required load and location. Wire sizes for the circuits are determined by load, wire capacity, distance, and voltage drop. Variations from National Electrical Code standards should only be taken when the field situation dictates their necessity.

4.3.1 Distribution Types

The electrical power load in any building cannot be properly circuited until the type and voltage of the central power-distribution system is known. The voltage and the number of wires from the powerlines to the buildings are normally shown or specified on the blueprints. However, a check should be made of the voltage and type of distribution at the power-service entrance to every building in which wiring is to be done. This is especially necessary when altering or adding circuits. Voltage checks are usually made with an indicating voltmeter at the service-entrance switches or at the distribution load centers. The type of distribution is determined by visual check of the number of wires entering the building (see figure 4-3).

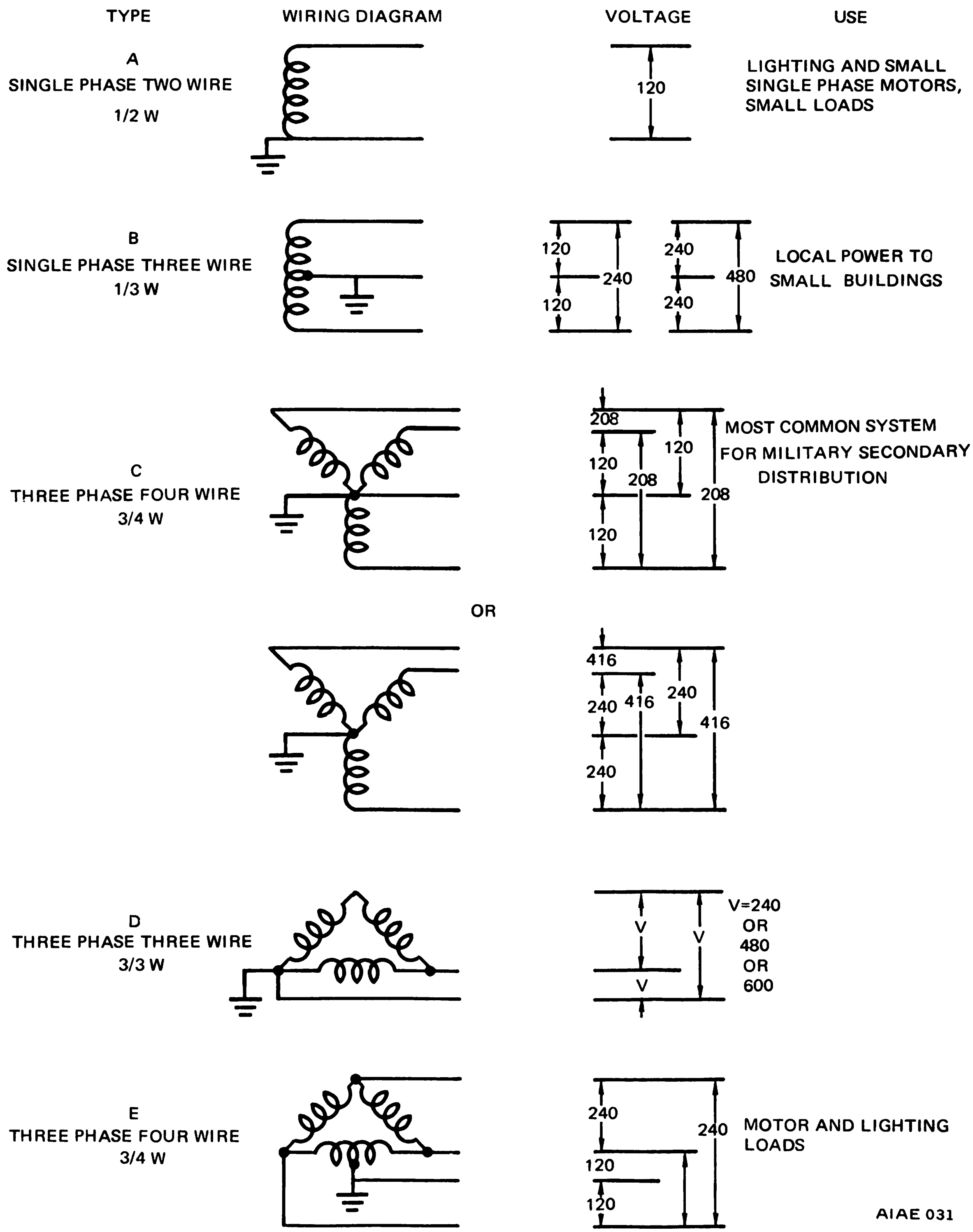


Figure 4-3. Power Distribution Types

a. If only two wires enter the building, the service is either direct current or single-phase alternating current. The voltage is determined by an indicating voltmeter.

b. When three wires enter a building from an alternating current distribution system, the service can either be single-phase, three-phase, or two ungrounded conductors and a neutral of a three-phase system (V-phase).

(1) If the service is single-phase, two of the conductors are hot and the third is ground. A voltmeter reading between the two hot conductors will be twice as great as the reading between either hot conductor and the neutral or ground conductor.

(2) If the service is three-phase, the voltage between any two of the conductors is the same. Normally one of the conductors is grounded to establish a ground reference voltage for the system.

(3) Two ungrounded conductors and a neutral, or a V-phase system is the most common service for theater of operations construction. The distribution system is described in the following paragraph. The voltage between the two hot conductors will be the $\sqrt{3}$ or 1.732 times greater than the voltage between either hot conductor and the neutral or ground.

c. Four-wire distribution denotes three-phase and neutral service. When tested, voltages between the neutral conductor and each of the three hot conductors should be the same. Voltage readings between any two of these three wires are similar and should equal the neutral to hot wire voltage multiplied by 1.732. Common operating voltages for this type service are 120 and 208 volts or 277 and 480 volts.

4.3.2 Circuit Types

The names of the circuits used in interior wiring are service, feeder, subfeeder, main, submain, and branch. Figure 4-4 shows the layout of the various circuits.

a. The service is the name given the conductors carrying electric power to a building. It may bring power to a building from the exterior secondary distribution, street main, exterior distribution feeder, local transformer, or a generator. The service terminates at the main distribution center or main fuse box of the building.

b. Feeders are circuits that supply power directly between a distribution center and a subdistribution center. The only cutout for a feeder is at the main distribution center.

c. A subfeeder is an extension of a feeder or another subfeeder through a cutout to another subdistribution center. The cutout being the subdistribution center feeding the circuit.

d. A main is a circuit to which other energy-consuming circuits are attached through automatic cutouts (fuses or circuit breakers) along its length. A main has the same size wire throughout its length and has no cutouts in series with it.

e. A submain is fed through a cutout from a main or another submain and has branch circuits or loads connected to it through cutouts. A submain has the same size wire throughout its length, but it is usually of smaller size than the main or submain feeding it.

f. A branch circuit connects one or more energy-consuming devices (loads) through one cutout to a source (distribution center, subdistribution center, main, or submain). Interior lighting circuits are usually branch circuits since many lights are connected to one circuit which is controlled by one fuse or circuit breaker.

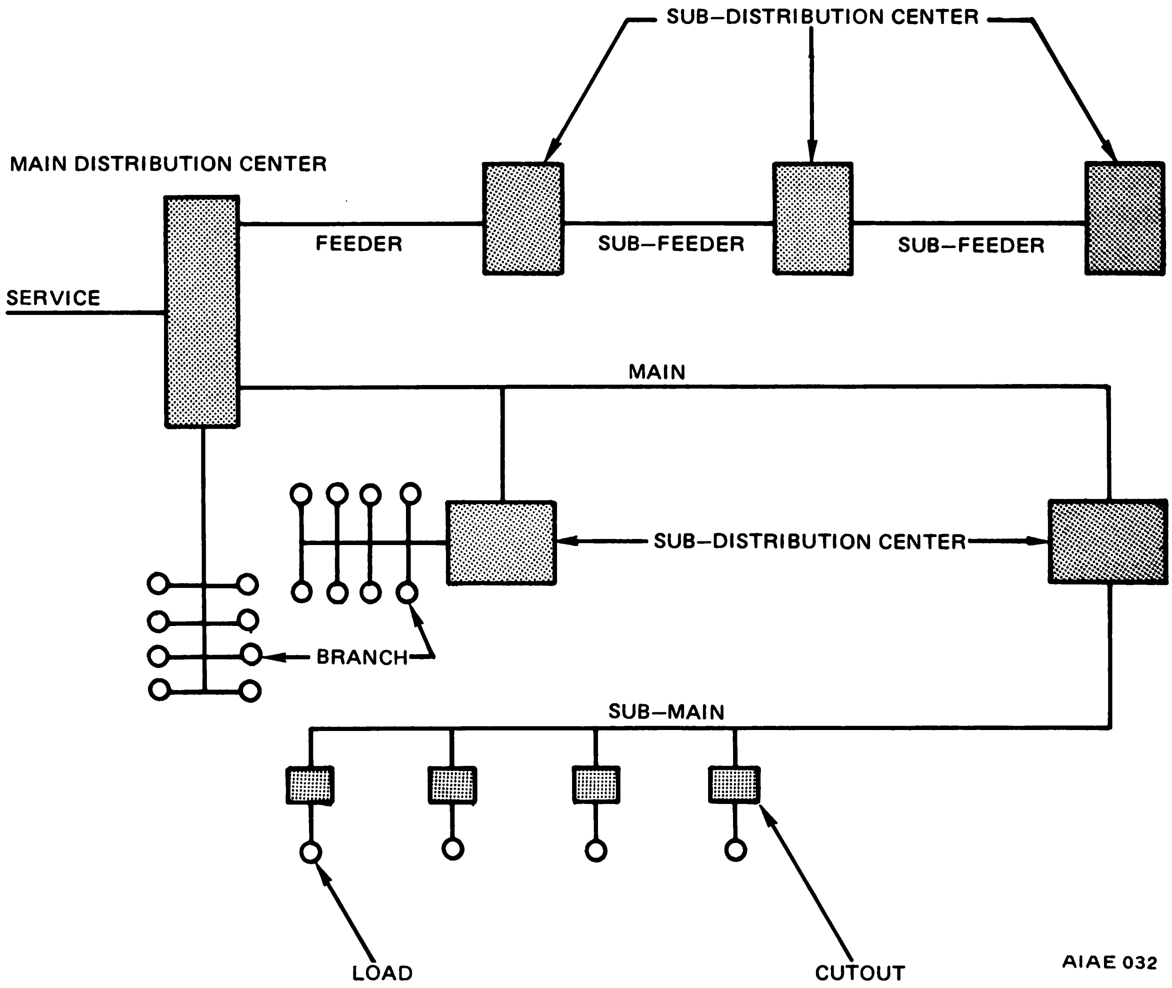


Figure 4-4. Interior Wiring Circuits

4.3.3 Load Determination

The first step in planning the circuit for any wiring installation is to determine the connected load per outlet. It is best to use volt-amperes as the method of determining electrical needs. This eliminates power factor considerations. The power needed for each outlet or load per outlet is used to find the number of circuits. It is also used to find the power needed for an entire building. The load per outlet can be obtained in several different ways.

a. The most accurate method of determining load per outlet is to obtain the stated value from the blueprints or specifications.

(1) Commonly, the lighting outlets shown on the blueprints are listed in the specifications along with their wattage ratings.

(2) If the lights used are of the incandescent type, this figure represents the total wattage of the lamp.

(3) When fluorescent type lights are specified, the wattage drain (also called load per outlet) should be increased approximately 20 percent to provide for the ballast load. For example, when the fixture is rated as a two-lamp, 40-watt unit, the actual wattage drain is 80 watts, plus approximately 16 watts for both lamp ballasts, or a total load of 96 watts.

(4) If the specifications are not available, the blueprints in many cases designate the type of equipment to be connected to specific outlets. Though the equipment ultimately used in the outlet may come from a different manufacturer, equipment standards provide the electrician with assurance that the outlets will use approximately the same wattage. If the equipment is available, the nameplate will list the wattage used or ampere drain.

b. To provide adequate wiring for systems where the blueprints or specifications do not list any special or appliance loads, the following general rules will apply:

- For heavy duty outlets or mogul size lampholders, the load per outlet should be figured at 5 amperes each.

- For all other outlets, both ceiling and wall, the wattage drain (load per outlet) should be computed at 1.5 amperes per outlet.

4.3.4 Circuiting the Load

If all the power load in a building were connected to a single pair of wires and protected by a single fuse, the entire establishment would be without power in case of a breakdown, a short circuit, or a fuse blowout. In addition, the wires would have to be large enough to handle the entire load and, therefore, would be too large in some cases to make connections to individual devices. Consequently, the outlets in a building are divided into small groups known as branch circuits. These circuits normally are rated in amperes as shown in table 4-2. This table contains a comparison of the various ampere requirements of the branch circuits with the standard circuit components. Normally the total load per circuit should not exceed 80 percent of the circuit rating.

The method of circuiting the building load varies with the size of the building and the power load.

o In a small building with little load, the circuit breakers or fuses are installed at the power-service entrance and the individual circuits are run from this location.

o For buildings of medium size with numerous wiring circuits, the fuse box should be located at the center of the building load so that all the branch runs are short, minimizing the voltage drop in the lines.

o When buildings are large or have the loads concentrated at several remote locations, the ideal circuiting would locate fuse boxes at each individual load center. It is assumed that the branch circuits would be radially installed at each of these centers to minimize the voltage drops in the runs.

Table 4-2. Branch Circuits Requirements

(Type FEP, FEPB, R, RW, RU, RUW, RH-RW, SA, T, TW, RH, RUH. RHW, RHH, THHN, THW, and THWN conductors in raceway or cable.)

CIRCUIT RATING	15 AMP.	20 AMP.	30 AMP.	40 AMP.	50 AMP.
Conductors: (Min. Size)					
Circuit Wires*	14	12	10	8	6
Taps	14	14	14	12	12
Overcurrent Protection	15 Amp.	20 Amp.	30 Amp.	40 Amp.	50 Amp.
Outlet Devices:					
Lampholders Permitted	Any Type	Any Type	Heavy Duty	Heavy Duty	Heavy Duty
Receptacle Rating	15 Max. Amp.	15 or 20 Amp.	30 Amp.	40 or 50 Amp.	50 Amp.
Maximum Load	15 Amp.	20 Amp.	30 Amp.	40 Amp.	50 Amp.

*These current capacities are for copper conductors with no correction factor for temperature.

The number of circuits required for adequate wiring can be determined by adding the connected load in watts and dividing the total by the wattage permitted on the size of branch circuit selected. This method should not include special heavy loads, such as air conditioners, requiring separate circuits. The total wattage is obtained from the sum of the loads of each individual outlet determined by one of the three methods outlined in paragraph 4.3.3. For example, if 20-ampere, 120-volt circuits are to be used, 80 percent of this rating or 16 amperes per circuit is allowed. The maximum wattage permitted on each circuit equals 16 times 120 or 1920 watts. If the total connected load is assumed to be 18,000 watts, 18,000 divided by 1920 shows that 9.375 circuits are required. Since we can only have whole circuits, ten 20-ampere circuits should be used to carry the connected load. The number of circuits determined by this method should be the basic minimum. For long-range planning in permanent installations, the best practice requires the addition of several circuits to the minimum required, or the installation of the next larger modular-size fusing panel to allow for future wiring additions. If additional circuits over the minimum required are used, the number of outlets per circuit can be reduced; therefore, the electrical installation is more efficient. This is true because the voltage drop in the system is reduced, allowing the apparatus to operate more efficiently.

Motors that are used on portable equipments are normally disconnected from the power source either by removal of the equipment plug from its receptacle or by the operation of an attached built-in switch. Some large horsepower motors, however, require a permanent power installation with special controls. Motor switches are rated in horsepower capacity. In a single motor installation, a separate circuit must be run from the fuse or circuit breaker panel to the motor, and individual fuses or circuit breakers installed. For multiple motor installations, the National Electrical Code requires that "Two or more motors may be connected to the same branch circuit, protected at not more than 20 amperes at 125 volts or less or 15 amperes at 600 volts or less, if each does not exceed 1 horsepower in rating and each does not have a full load rating in excess of 6 amperes. Two or more motors of any rating, each with individual overcurrent protection (provided integral with the motor start switches or an individual unit), may be connected on one branch circuit provided each motor controller and motor-running overcurrent device be approved for group installation and the branch circuit fusing rating be equal to the rating required for the largest motor plus an amount equal to the sum of the full load ratings of the other motors."

4.3.5 Balancing the Power Load on a Circuit

The ideal wiring system is planned so that each wiring circuit will have the same ampere drain at all times. Since this can never be achieved, the circuiting is planned to divide the connected load as evenly as possible. Thus, each individual circuit uses approximately the average power consumption for the total system. This will make for minimum service interruption. Figure 4-5 demonstrates the advantage of a balanced circuit when a three-wire single-phase, 110-220 volt distribution system is used; i.e., the current in the neutral conductor of a three-wire single-phase system will remain at zero as a result of the balanced condition.

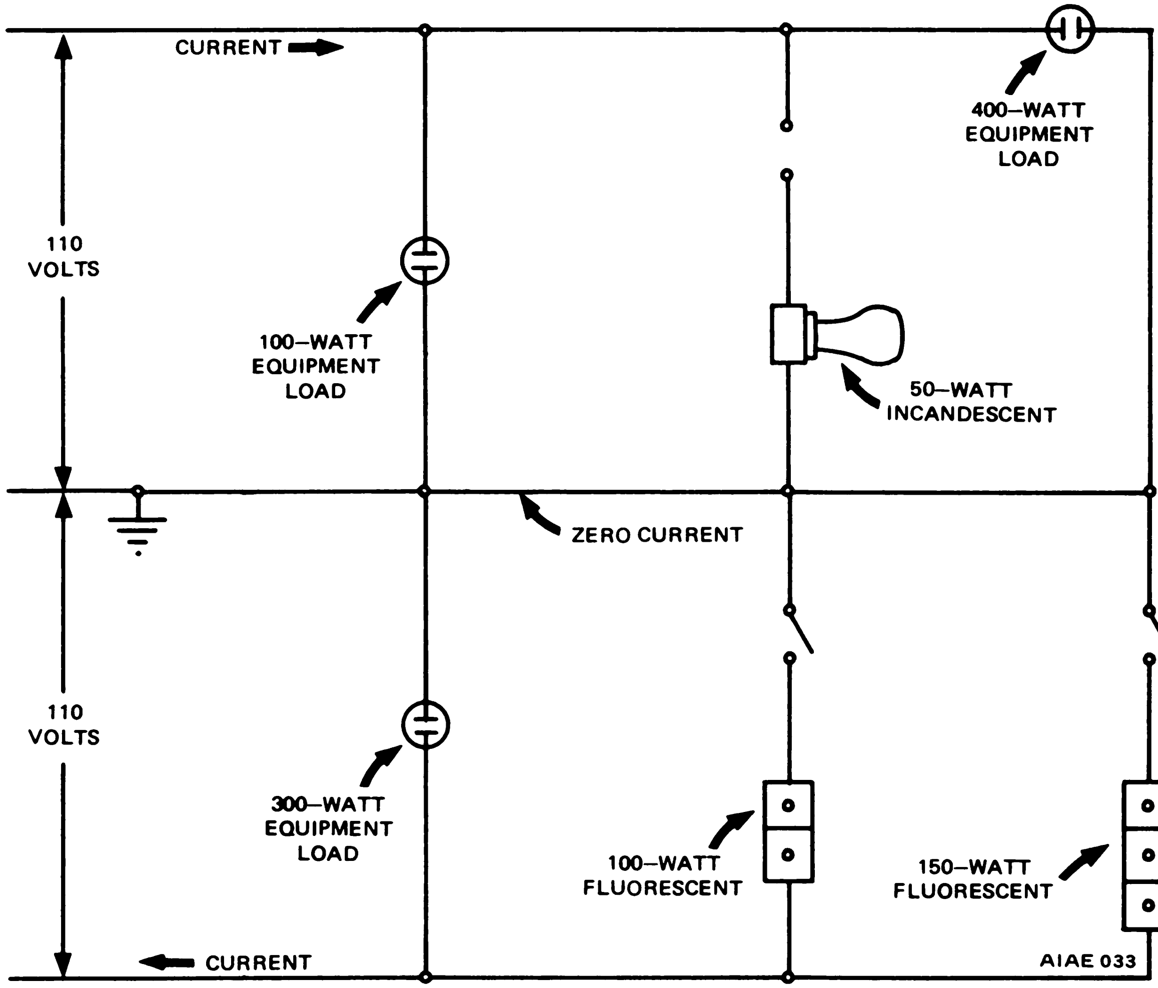


Figure 4-5. Balanced Circuit

4.3.6 Building Load

In some building installations the total possible power load may be connected at the same time. In this case the demand on the power supply, which must be kept available for these buildings, is equal to the connected load. In the majority of building installations where armed forces personnel will work, the maximum load which the system is required to service is much less than the connected load. This power load, which is set at some arbitrary figure below the possible total connected load, is called the "maximum demand" of the building.

The ratio of maximum demand to total connected load in a building expressed as a percentage is termed "demand factor." The determination of building loads can be obtained by the use of standard demand factors as shown in table 4-3. For example, if the connected load in a warehouse is 22,500 watts, using the demand factors listed

Table 4-3. Calculation of Feeder Loads by Occupancies

TYPE OF OCCUPANCY	PORTION OF LIGHTING LOAD TO WHICH DEMAND FACTOR APPLIES (wattage)	FEEDER DEMAND FACTOR
Dwellings - other than Hotels	First 3000 or less at Next 3001 to 120,000 at Remainder over 120,000 at	100% 35% 25%
Hospitals	First 50,000 or less at Remainder over 50,000 at	40% 20%
Hotels and Motels - including Apartment Houses without provision for cooking by tenants	First 20,000 or less at Next 20,001 to 100,000 at Remainder over 100,000 at	50% 40% 30%
Warehouses (Storage)	First 12,500 or less at Remainder over 12,500 at	100% 50%
All Others	Total Wattage	100%

in table 4-3 for warehouses, the actual building load can be obtained as follows: 100 percent of the first 12,500 watts equals 12,500, 50 percent of the remaining 10,000 watts equals 5,000; therefore, the total building load is 12,500 plus 5,000 watts or 17,500 watts.

The standard voltage distribution system from a generating station to individual building installation is the three- or four-wire, three-phase type. Distribution transformers on the powerline poles change the voltage to 120 or 240, and are designed to deliver three-wire single-phase service. These transformers are then connected across the distribution phase leads in a balanced arrangement. Consequently, for maximum transformer efficiency, the building loads assumed for power distribution should also be balanced, as previously illustrated in figure 4-5.

4.3.7 Wire Size

Wire sizes No. 14 and larger are classified according to their maximum allowable current-carrying capacity based on their physical behavior when subjected to the stress and temperatures of operating conditions. Fourteen-gage wire is the smallest wire size permitted in interior wiring systems.

Determination of the conductor size to be used in feeder and branch circuits is dependent on the maximum allowable current-carrying capacity and the voltage drop coincident with each wire size. The size of the conductors for branch circuits (that portion of the wiring system extending beyond the last overcurrent device protecting the circuit) should be such that the voltage drop will not exceed 3 percent to the farthest outlet for power, heating, or lighting loads. The maximum voltage drop for feeders is also 3 percent, provided that the total voltage drop for both feeder and branch circuits does not exceed 5 percent. Table 4-4, which is based on an allowable 3 percent voltage drop, lists the wire sizes required for various distances between supply and load at different amperages. This table may be used for branch circuits originating at the service entrance. This is the common house or small building circuit. A more detailed method of determining wire size is given in paragraph 4.3.9.

The minimum gage for service-wire installation is No. 8. The service-wire sizes are increased because they must not only meet the voltage-drop requirement but also be inherently strong enough to support their own weight, plus any additional loading caused by climatic conditions (ice, branches, and so on).

4.3.8 Additions to Existing Wiring

In the installation of additions to existing wiring in a building, the electrician first determines the available extra capacity of the present circuits. This can readily be obtained by ascertaining the fused capacity of the building and subtracting the present connected load. If all the outlets do not have connected loads, their average load should be used to obtain the connected load figure. When the existing circuits have available capacity for new outlets and are located near the additional outlet required, they should be extended and connected to the new outlets. Consideration must be given to the additional voltage drop created by extending the circuit. The proper wire size may then be determined.

When the existing outlets cannot handle an additional load, and a spare circuit has been provided in the local fuse or circuit breaker panel, a new circuit is installed. This is also done if the new outlet or outlets are so located that a new circuit can be installed more economically than an existing circuit extension. Moreover, the installation of a new circuit will generally decrease the voltage drop on all circuits, resulting in an increase in appliance operating efficiency. Figure 4-6 illustrates the addition of a new circuit from the spare circuit No. 4 in the circuit breaker panel.

In many wiring installations, no provisions are made for spare circuits in the fuse panel. Moreover, the location of the new circuit required is often remote from the existing fusing or circuit breaker panel. In this case, the most favorable method of providing service to the circuit is to install a new load center at a location close to the circuit outlets. This installation must not overload the incoming service and service-entrance switch. Should such an overload be indicated, the service equipment should also be changed to suit the new requirements. This sometimes can be accomplished in two-wire systems by pulling in an additional wire from the powerline. This changes the service from two-wire to three-wire at 120 to 240 volts. In these cases, the fuse or circuit breaker box should also be changed and enlarged to accommodate the increased circuit capacity. Figure 4-7 schematically illustrates the installation of an additional load center for a new circuit.

Table 4-4. Voltage Drop Table Based on 3% Drop

10—Aluminum wire
12—Copper wire

VERIFY SELECTED CONDUCTOR FOR CURRENT—CARRYING CAPACITY

	FOR 110V CIRCUIT DISTANCE TO LOAD IN FEET									
LOAD IN AMPS.	50	75	100	125	150	200	250	300	400	500
15	10 12	8 10	8 10	6 8	6 8	4 6	4 6	3 4	2 4	1 3
20	10 12	8 10	6 8	6 8	4 6	4 6	3 4	2 4	1 3	0 2
25	8 10	6 8	6 8	4 6	4 6	3 4	2 4	1 3	0 2	2/0 1
30	6 10	6 8	4 6	4 6	3 4	2 4	1 3	0 2	2/0 1	3/0 0
40	6 8	4 6	4 6	3 4	2 4	1 3	0 2	2/0 1	3/0 0	4/0 2/0
50	4 8	4 6	3 4	2 4	1 3	0 2	2/0 1	3/0 0	4/0 2/0	300 3/0
60	4 6	2 4	2 4	1 3	0 2	2/0 1	3/0 0	4/0 2/0	250 3/0	350 4/0
70	4 6	2 4	1 3	0 2	2/0 2	3/0 0	4/0 2/0	250 2/0	300 4/0	400 250
80	4 6	2 4	1 3	0 2	2/0 1	3/0 0	4/0 2/0	250 3/0	350 4/0	500 250
90	2 4	1 3	0 2	2/0 1	3/0 1	4/0 2/0	250 3/0	300 3/0	400 250	500 300
100	2 4	1 3	0 2	2/0 1	3/0 0	4/0 2/0	300 3/0	350 4/0	500 250	600 350

	FOR 220V CIRCUIT DISTANCE TO LOAD IN FEET									
LOAD IN AMPS.	100	200	300	400	500	600	700	800	900	1000
15	12 12	8 10	6 8	4 6	4 6	3 4	2 4	2 4	1 3	1 3
20	10 12	6 8	4 6	4 6	3 4	2 4	1 3	1 3	0 2	0 2
25	8 10	6 8	4 6	3 4	2 4	1 3	0 2	0 2	2/0 1	2/0 1
30	6 10	4 6	3 4	2 4	1 3	0 2	2/0 2	2/0 1	3/0 0	3/0 0
40	4 8	4 6	2 4	1 3	0 2	2/0 1	3/0 0	3/0 0	4/0 2/0	4/0 2/0
50	4 8	3 4	1 3	0 2	2/0 1	3/0 0	4/0 2/0	4/0 2/0	250 3/0	300 3/0
60	4 6	2 4	0 2	2/0 1	3/0 0	4/0 2/0	250 2/0	250 3/0	300 4/0	350 4/0
70	4 6	1 3	2/0 2	3/0 0	4/0 2/0	250 2/0	300 3/0	300 4/0	350 4/0	400 250
80	4 6	1 3	2/0 1	3/0 0	4/0 2/0	250 3/0	300 4/0	350 4/0	400 250	500 250
90	2 4	0 2	3/0 0	4/0 2/0	250 3/0	300 4/0	350 4/0	400 250	500 300	500 300
100	2 4	0 2	3/0 0	4/0 2/0	300 3/0	350 4/0	400 250	500 250	500 300	600 350

Example. A building using open wiring requires 20 amperes (at 110V) to be supplied to a load located 150 ft from the circuit breaker. From Tables A—1 and A—2 (assuming R type copper wire is used), the minimum size wire for this circuit is No. 14. From the above table, a No. 6 copper wire is required to limit the voltage drop to 3%. Therefore, a No. 6 copper wire should be used. If the wire available were aluminum, then the minimum size is No. 12, and for a maximum voltage drop of 3% a No. 4 must be used.

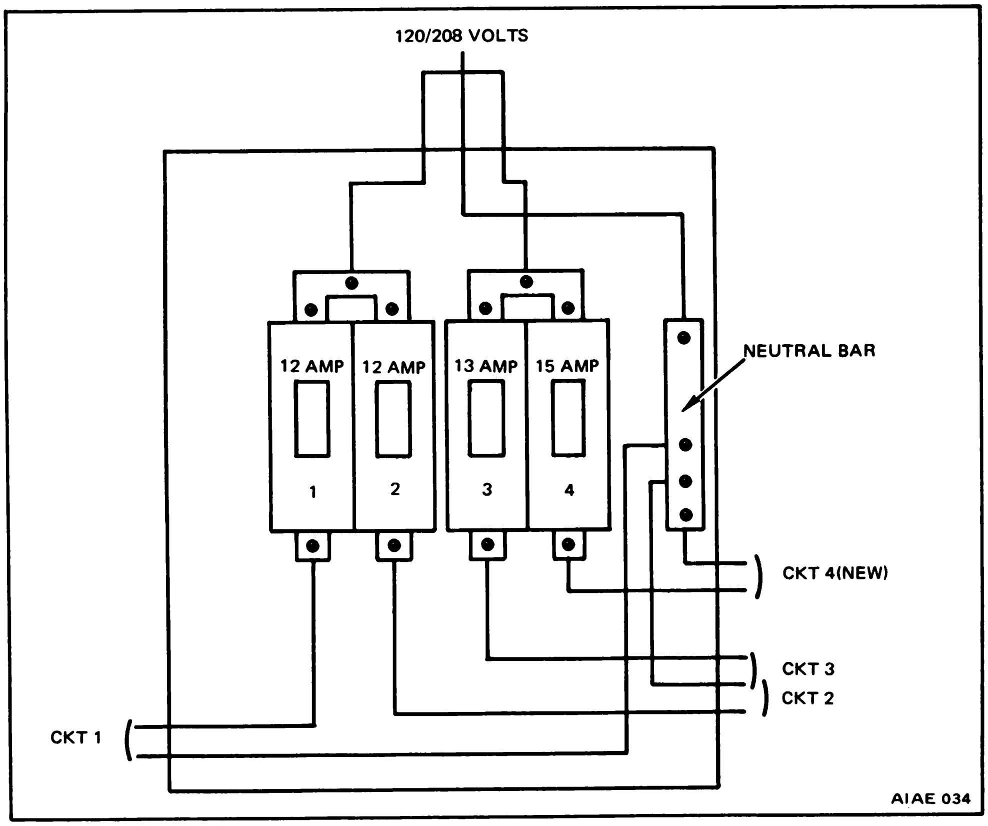


Figure 4-6. Addition of a New Circuit

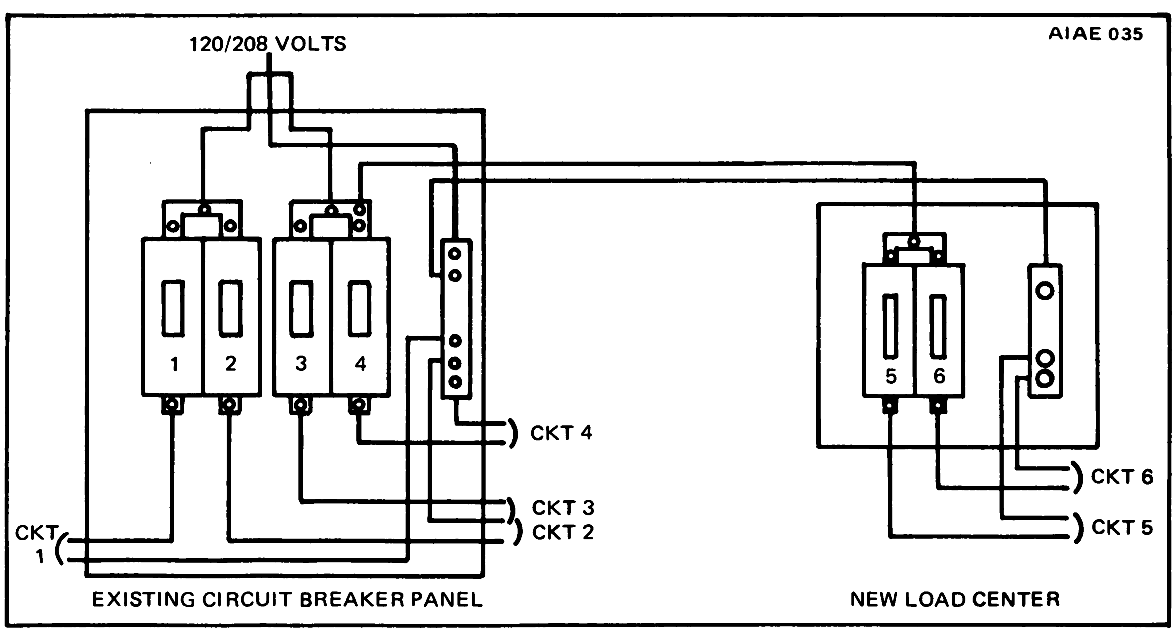


Figure 4-7. Addition of a New Load Center

4.3.9 Allowable Voltage Drop

Most equipment is designed to allow for a 10 percent total voltage drop. This means that the voltage at the equipment must be equal to or greater than 90 percent of the equipment's rated voltage and no more than 110 percent. The National Electrical Code is followed for large installations having central power plants to determine the electrical installation requirements. The National Electrical Code allows a maximum of 5 percent voltage drop from the generator to the most distant service entrance.

Therefore, inside a building another 5 percent drop may be tolerated. This normally is divided into a 3 percent drop for branch circuit and a 2 percent drop for feeders or main. The above requirements are necessary for large, city-like complexes but, under field conditions, the engineer may be able to accept larger voltage drops in a system.

The design procedures of paragraph 4.3.7 are straightforward but they do not permit flexibility in design. As an example, if a load of 20 amperes at 120 volts must be located 150 feet from the cutout, a No. 6 copper wire is required for a voltage drop of 3 percent or less. If No. 6 copper wire is not available, a larger wire could be used. This would eliminate voltage drop problems but would not be economical. It may be possible to use a smaller wire, but this must be based on an analysis of the total electrical system. The following procedure does not account for inductance, capacitance, or skin effect which may exist in alternating current circuits. This procedure, therefore, is valid for wire sizes of 4/0 and smaller for lighting circuits and No. 1 and smaller for motor circuits. As the load increases and the power factor decreases, AC design procedures from electrical engineering references must be used.

Table 4-5 gives the values of resistance for copper and aluminum wire in ohms per thousand feet. Since the first step in designing an interior wiring system is to estimate or calculate the load, the current needed in each wire is then known. The operating voltage is determined by the available power source or the equipment to be operated. Knowing the current and distance, the voltage drop for any size wire may be calculated. Since the operating voltage and allowable voltage drop are known, the system may be designed using the minimum size wires.

The benefit of this system may be shown by choosing the wire for the example above. Based on table 4-4, the 120-volt, 20-ampere load at a distance of 150 feet required a No. 6 copper wire at a minimum. Understanding the distribution system, the voltage drop from the main distribution center to any individual load within the building may be allowed to be 5 percent or 120 times 0.05 equals 6 volts. By trial and error, it will be found that the smallest size copper wire is No. 8. Table 4-5 shows that No. 8 copper wire has a resistance of 0.64 ohm per thousand feet. Two wires are needed for the circuit.

Table 4-5. Wire Characteristics

SIZE AWG OR MCM	NO. WIRES	DIAMETER		RESISTANCE Ohms per 1,000 feet	
		Inches	Millimeters	Copper	Aluminum
14	solid	.0641	1.63	2.57	4.22
12	solid	.0808	2.05	1.62	2.66
10	solid	.102	2.59	1.02	1.67
8	solid	.129	3.27	0.640	1.05
6	7	.184	4.67	0.410	0.674
4	7	.232	5.89	0.260	0.424
3	7	.260	6.60	0.205	0.336
2	7	.292	7.41	0.162	0.266
1	19	.332	8.42	0.129	0.211
0	19	.373	9.46	0.102	0.168
2/0	19	.418	10.6	0.0811	0.133
3/0	19	.470	11.9	0.0642	0.105
4/0	19	.528	13.3	0.0509	0.0836
250	37	.575	14.6	0.0431	0.0780
300	37	.630	16.0	0.0360	0.0590
350	37	.681	17.3	0.0308	0.0505
400	37	.728	18.5	0.0270	0.0442
500	37	.814	20.6	0.0216	0.0354
600	61	.893	22.7	0.0180	0.0295
700	61	.964	24.5	0.0154	0.0253
150	61	.998	25.4	0.0144	0.0236

Thus:

voltage drop = load in amps x resistance of wire

$$= \frac{20(2)\ (.64)\ (150)}{1,000}$$

= 3.84 volts

Since this is less than a 5 percent drop it is acceptable.

4.3.10 Minimizing Voltage Drops

One method of reducing low voltage problems caused by nonavailability of proper wire sizes is to increase the power supplied to the system by increasing the voltage output of the generator. In other words, the increase in generator output may be used to compensate for the voltage drop between the generator and the nearest service entrance or building. The voltage at any building should not exceed the rated value. As an example, the building nearest to the generator site must be identified. The maximum voltage at this point is to be the circuit's rated voltage. The voltage drop of the wire between the generator and this point is the value that the generator output voltage may be increased (figure 4-8). For building A, the voltage drop that may now be allowed for interior wiring would be 10 percent since the rated voltage of 220 volts appears at the service entrance. The wire needed in the example problem of paragraph 4.3.7 may, if located in building A, be a No. 14. Thus, if the supply of wire is limited in variety of sizes, this method may permit the supply of power or a location previously unattainable. Buildings further from the generator would have different design limits. The allowable voltage drops would depend on the voltage drop along the supply line. Since the first voltage drop (line A B) has been compensated for, the voltage at all buildings will be higher. This will permit greater allowable drops for building interiors and, therefore, smaller wire sizes to be used.

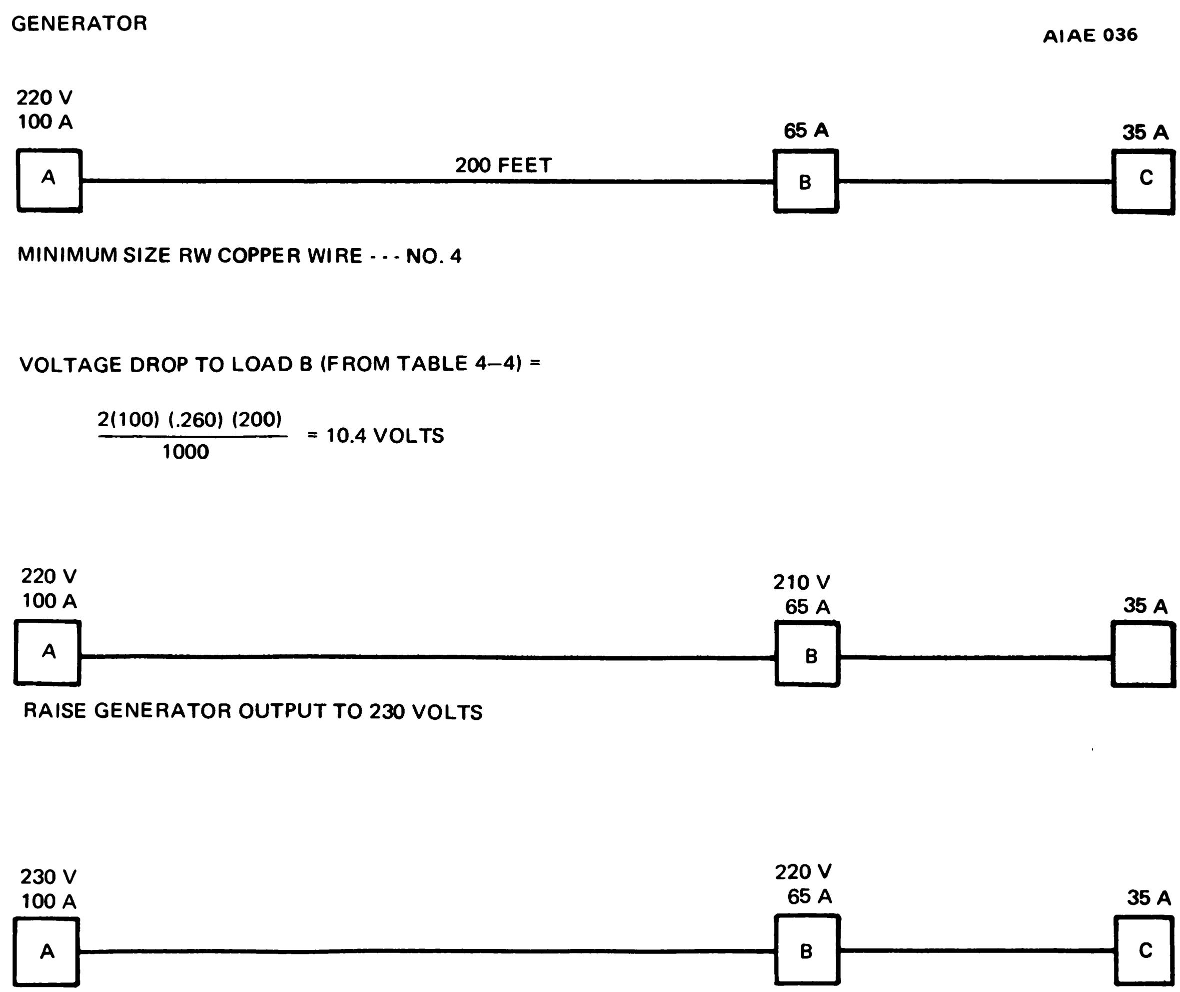


Figure 4-8. Minimizing Voltage Drops

CHAPTER 5

ADDITIONAL LABORATORY REQUIREMENTS

Special requirements and/or conditions do not permit the routine equipment measurement, testing, and calibration to be performed in the laboratory facility described in the previous chapters. To fulfill these particular needs, additional facilities and special equipment are required. The additional laboratory facilities may be either shielded enclosures or clean rooms, or both. Special equipment consists of selected antennas with optimum characteristics for reception of time and frequency standards transmitted from the U.S. Naval Observatory.

5.1 SHIELDED ENCLOSURES

In Chapter 2 it was stated that the expense of constructing a screen or shielded room must be justified on a per case basis since experience has demonstrated that a large percentage of existing shielded rooms were not necessary or were overdesigned in many cases.

Where tests demonstrate the presence of electromagnetic radiation (EMR), from either external or internal sources, of such levels as to cause objectional interference with measurements, or where an area of containment is needed to perform calibration on interference producing equipment, some type of shielded enclosure may be employed. Whenever possible, use should be made of small, benchtop type enclosures since these are more economical than the larger shielded rooms and, frequently, are more effective in achieving the desired attenuation.

5.1.1 Selection of Enclosure Type

Selection factors for shielded enclosures include:

- o The types and levels of electromagnetic fields present in the vicinity of the intended enclosure location; i.e., Electric (E) field, Magnetic (H) field, or both.
- o The frequency range of the unwanted EMR.
- o The attenuation required over the range of frequencies encountered.
- o Structural requirements, if any.
- o Enclosure size and configuration; e.g., door position, ceiling height, etc.

MIL-E-8881A specifies minimum construction and performance requirements for three basic enclosure types. See table 5-1 and figure 5-1. The enclosures should be designed to provide minimum attenuation levels, as categorized by the various classes listed in table 5-2. Attenuation is the figure of merit used to designate the shielding effectiveness of an enclosure and is defined as the ratio, in dB, of the received powers on opposite sides of a shield when the shield is illuminated by electromagnetic radiation. The attenuation should be measured, using the methods of MIL-STD-285, with the enclosure completely assembled, powerline filters and coaxial connectors installed, and with power fed into the enclosure.

Table 5-1. Basic Shielded Enclosure Types

TYPE	NUMBER OF SHIELDS	SHIELDING MATERIAL
Ia	Single Shield	Screen Mesh or Perforated Metal
Ib	Single Shield	Solid Metal
IIa	Double Shield, Cell Type	Screen Mesh or Perforated Metal
IIb	Double Shield, Cell Type	Solid Metal
IIIa	Double Shield, Isolated	Screen Mesh or Perforated Metal
IIIb	Double Shield, Isolated	Solid Metal

Table 5-2. Minimum Attenuation Design Criteria for Shielded Enclosures

TYPE OF ELECTROMAGNETIC FIELD	CLASS AND dB OF ATTENUATION*				
	A	B	C	D	E
Magnetic (100 kHz to 30 MHz)	30	40	70	76	82
Electric (100 kHz to 30 MHz)	110	120	140	190	220
Plane Waves (30 MHz to 1,000 MHz)	60	70	100	220	240
Microwaves (1,000 to 10,000 MHz)	35	50	100	240	250

*Nominal attenuation varies from 70 to 130 dB because of deviations in the nominal separation distance between the two shields.

NOTES

1) Attenuations greater than 250 dB are not listed as they represent the reduction down to 1 microvolt per meter (minimum discernible signal) from 3,160 kilovolts per meter (breakdown of free space).

2) The types of electromagnetic fields and frequency ranges considered are those that predominate in the vicinity of the enclosure at relatively high levels.

3) The attenuations listed for each class take into consideration the deleterious effect on shielding effectiveness of the enclosure introduced by the impedance at the seams between adjacent panels.

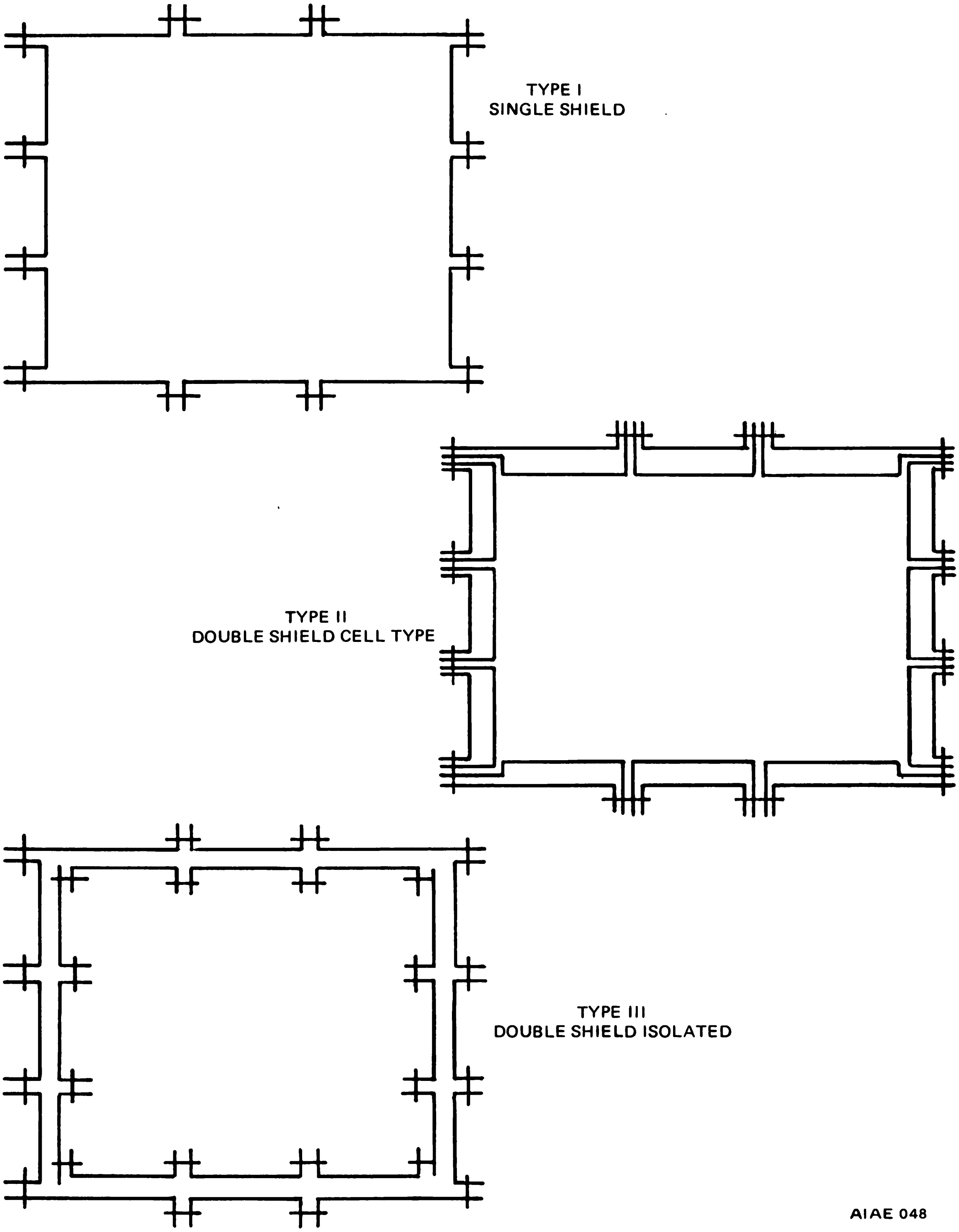


Figure 5-1. Basic Construction of Three Shielded Enclosure Types

Attenuation should not be confused with insertion loss which is the ratio of received powers before and after insertion of shielding material between a source and receiver of electromagnetic energy.

Selection of attenuation class depends on the type and magnitude of the undesired signals present at the enclosure location. Table 5-3 is given for guidance in the selection process. For general applications, the attenuation provided by class C is considered adequate.

Table 5-3. Guide for Selecting Required Attenuation Class

SOURCE OF SIGNAL TO BE SUPPRESSED	CLASS OF ATTENUATION*
Electrical Machinery, light, power	A
Ignition, arc-welding, diathermy, induction heating, X-ray	B
Low power transmitters and radars (up to 100 watts)	C
Medium power transmitters and radars (100 watts to 100 kilowatts)	D
High power transmitters and radars (100 kilowatts to 10 megawatts)	E

*See table 5-4 for class distinction.

NOTE: Since signals from AM, FM, TV stations, and high tension powerlines are remotely generated from enclosures, any class of attenuation listed will give adequate suppression.

5.1.2 Basic Design Criteria

The design of an enclosure, either permanent or portable, usually centers around the type and thickness of material that will provide the required shielding effectiveness. Exceptions to this are those instances where structural requirements predominate in the selection of material thickness and type.

Where magnetic field shielding is required, thicker ferrous materials are usually employed. For high E-field shielding, thin, solid metal sheet is recommended, made of copper, steel, or aluminum. Materials which may be used for low and moderate E-field levels include copper and bronze screening, foils, wire mesh, and metal impregnated cloth, sprayed-on coatings, and honeycomb materials.

MIL-E-8881A lists various materials (see table 5-4) which may be used to meet the attenuation classes of table 5-3. However, any material for which equivalent effectiveness can be demonstrated may be used.

Table 5-4. Shielded Room Materials

CLASS	ENCLOSURE TYPE	MATERIAL DESCRIPTION
A	Ia	Commercial Bronze Window Screening with 18 by 14 mesh.
B	Ia	a) 22 mesh copper screening, 15 mils minimum thickness, with a woof of hard-drawn and a warp of soft-annealed wire or, b) perforated copper sheets, 15 mils thick, minimum. Perforations to be evenly distributed, with distance between the periphery of adjacent perforations not less than 15 mils. Circular holes to have a maximum diameter of 37 mils. Square holes shall have a maximum side of 32 mils.
C	IIa or IIIa or	a) *Two sheets of screening material as specified in (a) above, or b) *Two sheets of perforated metal as specified in (b) above.
	Ib	Solid copper sheet of 18 mils thickness, minimum.
D	Ib	Solid copper sheet of 25 mils minimum thickness.
E	IIb or IIIb	*Two sheets of solid copper, each of 10 mils minimum thickness.
*Distance between shields shall be sufficient to meet specified performance.		

Other design factors which must be considered include seam design, and structural and environmental requirements, if any. The latter must be considered when an enclosure is subject to climatic conditions such as wind, moisture, and extreme temperature changes. However, this situation is rare. Careful seam design is extremely important in achieving and maintaining shielding integrity, especially in portable enclosures or those incorporating interchangeable panels. Doors and other openings and penetrations, such as for filters, connectors, and honeycomb air vents, may be considered as seams; they are potentially the weakest points of the enclosure from a leakage or high-impedance viewpoint.

o The total seam length should be minimized to reduce potential leakage and to reduce construction time.

o Seams should be located away from edges and other points of maximum stress.

o Butting-type seams should meet in the same plane since sealing in two or three planes is difficult.

o Use of shielding gaskets in seams of portable enclosures is not recommended, especially where magnetic field or E-field shielding above 200 MHz is required. However, use of gaskets may become feasible in cases where seam length is small and only moderate levels are encountered.

o Access doors should be hinged and provided with two sets of serrated phosphor-bronze contact fingers (fingerstock) arranged around the periphery at right angles to form a seal. The optimum arrangement consists of one set acting as a wiper which is compressed when the door is closed. To assure sufficient pressure, a three-point wedge-type locking system should be used which can be operated from both sides of the enclosure. Both the door and jamb should be braced sufficiently to avoid sag.

o Bolts that fasten adjacent panels together should have a maximum center-to-center distance of 16 inches. Inside bolting is preferred. If possible, avoid passing bolts through the shield, since they may act as radiators at certain frequencies.

Specific recommendations for clamping pressure depend on seam structural requirements, desired shielding effectiveness, and enclosure materials. However, pressure should be evenly distributed and bolts tightened as much as possible without damage to the screw threads or other parts. Loose bolts on a cell type room can result in attenuation losses on the order of 25 to 30 dB.

The width of seam lips should be 1 inch, minimum, for single-shielded enclosures, 2 inches, minimum (total), for double-shielded enclosures, and at least 1 inch for each lip of the double-shielded, isolated type enclosure.

Wood frame type structures (such as those using a plywood core panel faced on each side with the shielding material) should be avoided since the wooden core can absorb moisture which induces warping and, consequently, loosening of the joints. Also, it is difficult to achieve and maintain high pressure on a bolted, wood-frame structure.

Information concerning prefabricated shielded enclosures can be found in MIL-E-4957(ASG).

5.1.3 Powerline Filters

Powerline filters must be considered an integral part of an enclosure since penetration by unfiltered lines or wires will adversely affect the attenuation characteristics of the enclosure, no matter how well designed. As a minimum, one 28 volt DC/100 ampere, two 115 volt/60 Hz/50 ampere, and three 115 volt/400 Hz/three-phase/40 ampere filters should be supplied. These should conform to MIL-F-15733 which specifies general requirements for current-carrying filters (AC and DC) used primarily for reduction of interference. Selection of filter attenuation characteristics to complement the enclosure design or application is not a simple task. The degree of filter attenuation is only roughly related to the attenuation of the room. The usual solution is to initially provide filters with an attenuation capability somewhat less than that of the enclosure, and then add filters in series, if later required, to provide the additional attenuation. MIL-F-8881A specifies that powerline filters should have a minimum insertion loss of 100 dB from 100 kHz to 20,000 MHz, as measured in accordance with MIL-STD-220 (from 100 kHz to 1,000 MHz).

Both mechanical design and mounting method are important factors in obtaining desired filter performance. Filter input and output sections should be isolated by design and/or use of a shield to provide a minimum of 100 dB decoupling between input and output. A panel, known as the filter and connector panel, is used to mount the filter to the enclosure wall. All neutrals are tied together and connected to a common grounding stud on the panel. Where screening is used as the shielding material, the panel is reinforced by a solid copper plate soldered to the mesh over its entire periphery. Filters are commonly mounted on the outside of the enclosure, with the filtered line passing into the enclosure through threaded pipe nipples.

5.1.4 Connectors

Coaxial connectors, as required, are mounted to the aforementioned panel by means of special coaxial fittings, similar to the threaded pipes used to bring the powerlines into the enclosure. If high-level signals are known to exist, double-shielded coaxial cables should be used for these connections.

As a minimum, MIL-E-8881A specifies that two type N assemblies, as per MIL-C-71, with receptacles equivalent to type UG-29B/U, one twin coaxial plug equivalent to type UG-493/U, and two type HN assemblies, as per MIL-C-3643, with receptacles equivalent to type IPC11050, be provided.

5.1.5 Air-Conditioning and Ventilation

Room enclosures of all types, but especially the solid-wall enclosures, require some means of forced ventilation. If the room is to contain substantial amounts of equipment and/or personnel, air-conditioning will be necessary.

Moving air must be provided without affecting shielding effectiveness. This is usually accomplished by providing intake and exhaust openings consisting of metal grills which incorporate the waveguide-beyond-cutoff principle in their construction. The idea is to provide a large number of small-diameter "tubes" arranged in a parallel configuration, with each tube bonded to its neighbors to preclude leakage from cracks or seams.

The tube length should be at least three times the diameter to obtain attenuations of the order of 80 dB. The size and placement of these vents depend on individual room requirements; however, MIL-E-8881A specifies a minimum area of 1 square foot, and an attentuation of 100 dB below 20,000 MHz.

5.1.6 Lighting

Although suppression of fluorescent-light generated signals is available in the form of special shielding and line filtering, the amount of suppression attainable is usually not sufficient to enable use of fluorescent lighting in shielded rooms. For this reason, incandescent lighting is usually provided for enclosures, in the form of overhead general lighting, plus supplementary bench lighting, as required to achieve the recommended foot-candle levels. See Chapter 3 for details of room lighting.

5.2 ANTENNAS FOR RECEPTION OF TIME AND FREQUENCY STANDARDS TRANSMISSIONS

5.2.1 Frequency and Time Broadcasts

The U.S. Naval Observatory, as the agency which determines time for the United States, provides transmissions of precise time and frequency signals for use in correction and maintenance of time and frequency standards at Navy facilities. These broadcasts are made in the very low frequency (VLF) band (3-30 kHz) because of the inherent stability of the phase characteristics of VLF transmissions over thousands of miles. The predictable time delay plus the stability of the VLF signal contribute to the increased measurement accuracy.

Prior to the inception of VLF broadcasts, Navy Laboratories used the high frequency (HF) broadcasts provided by the National Bureau of Standards (NBS) for calibration of time and frequency standards. The limited accuracy of HF transmissions (as received beyond ground wave distance), caused by ionospheric instabilities and other propagation effects, coupled with the increasing need for higher accuracies, has motivated the shift to the VLF band.

At present, seven Navy LF stations (see table 5-5) are phase stabilized and transmitting precise signals.

In addition, the NBS operates a VLF station (WWVL) which transmits on 20 kHz, the international assigned VLF standard frequency, and a low frequency (LF) station (WWVB) operating at 60 kHz.

Since frequencies and radiated powers, as well as transmission formats, are subject to periodic change, it is advisable to obtain the latest schedules and announcements of both the Naval Observatory and the NBS to keep abreast of this information.

5.2.2 Antennas

Because of the long wavelengths associated with VLF transmission, the use of antennas whose dimensions are a fraction of the received wavelength (e.g., $1/4\lambda$, $1/2\lambda$) are not practical. For example, at 18 kHz, a quarter-wavelength antenna would have a maximum dimension of approximately 12,500 feet. Fortunately, antenna efficiency in the VLF-LF band can be very low without affecting the signal-to-noise ratio. For a receiver having a noise figure of 1.0 dB, receiving antenna efficiency may be as low as -120 to -140 dB. Thus, the most commonly used antenna types are the simple vertical whip, the rotary loop, and the long wire antenna. Traveling wave antennas, such as the Beverage type, are occasionally used to obtain noise discrimination. Loop antennas may also be used to obtain some noise discrimination from sources on bearings different from that of the desired signal. Also, the loop can be electrostatically shielded to provide some degree of additional immunity.

Table 5-5. VLF Radio Stations

STATION	LOCATION	FREQUENCY (kHz)	NORMAL RADIATED POWER (kW)
NAA	Cutler, Maine	17.80	2000
NBA	Balboa, Canal Zone	24.00	1000
NLK/NPG	Jim Creek, Wash.	18.60	1000
NPM	Lualualei, Hawaii	23.40	1000
NSS	Annapolis, Md.	21.40	85
NWC	Harold E. Holt North West Cape, Australia	22.30	2000
NDT	Yosami, Japan	17.40	500
WWVL (N. B. S)	Fort Collins, Colorado	20.00 or 20.50	

Selection of the optimum antenna characteristics depends on receiver geographic location; i.e., strength of received field, "noise" levels caused by worldwide lightning discharges, etc. Many papers and reports, published by the NBS, the CCIR, and various individuals and groups, may be found in the literature dealing with VLF propagation phenomena and atmospheric noise predictions, and offering various models which may be used to calculate the received signal strength. A summary of the most popular (empirical) formulas for calculating field strength is given in table 5-6. The results of these equations are compared in figures 5-2 and 5-3. Figure 5-4 presents a nomogram for the Espenschied formula, the use of which is restricted to daylight, overseas propagation paths with distances greater than about 2000 kilometers.

Table 5-6. VLF Field Strength Equations

FIELD STRENGTH, E(v/m):	FORMULA
$\frac{0.300\sqrt{P}}{d} \sqrt{\frac{d/a}{\sin(d/a)}} \exp\left\{\frac{-0.0016d}{\lambda^{0.5}}\right\}$	Austin-Cohen
$\frac{0.300\sqrt{P}}{d} \sqrt{\frac{d/a}{\sin(d/a)}} \exp\left\{\frac{-0.0014d}{\lambda^{0.6}}\right\}$	Modified Austin-Cohen
$\frac{0.300\sqrt{P}}{d} \sqrt{\frac{d/a}{\sin(d/a)}} \exp\left\{\frac{-0.005d}{\lambda^{1.25}}\right\}$	Espenschied, et al
$\frac{0.300\sqrt{P}}{d} (0.4) \exp\left\{-1.151\alpha d \times 10^{-4}\right\}$	Wait
$231 \frac{P}{\sin(d/a)} \exp\left[-d/a(0.1 f_{kHz})^{k}\right]$	Pierce

where
- P = radiated power in kilowatts
- d = distance in kilometers
- a = earth radius in kilometers (6380 km)
- λ = wavelength in kilometers
- α = attenuation factor in dB per 1000 km
- f_{kHz} = frequency in kilohertz

Typical antenna installations are elucidated in EC-7, Frequency Standards and Measurements, and EC-17, Installation and Operation Instructions for Very Low Frequency (VLF) Phase Tracking Systems. These are summarized in the following subparagraphs.

a. Long Wire Antenna

(1) Length: 100 to 500 feet

(2) Orientation: in line with transmitting antenna

(3) Height: at convenience

(4) Tuning system recommended to improve reception

(5) Transmission line: No. 10 AWG stranded or single conductor copperweld.

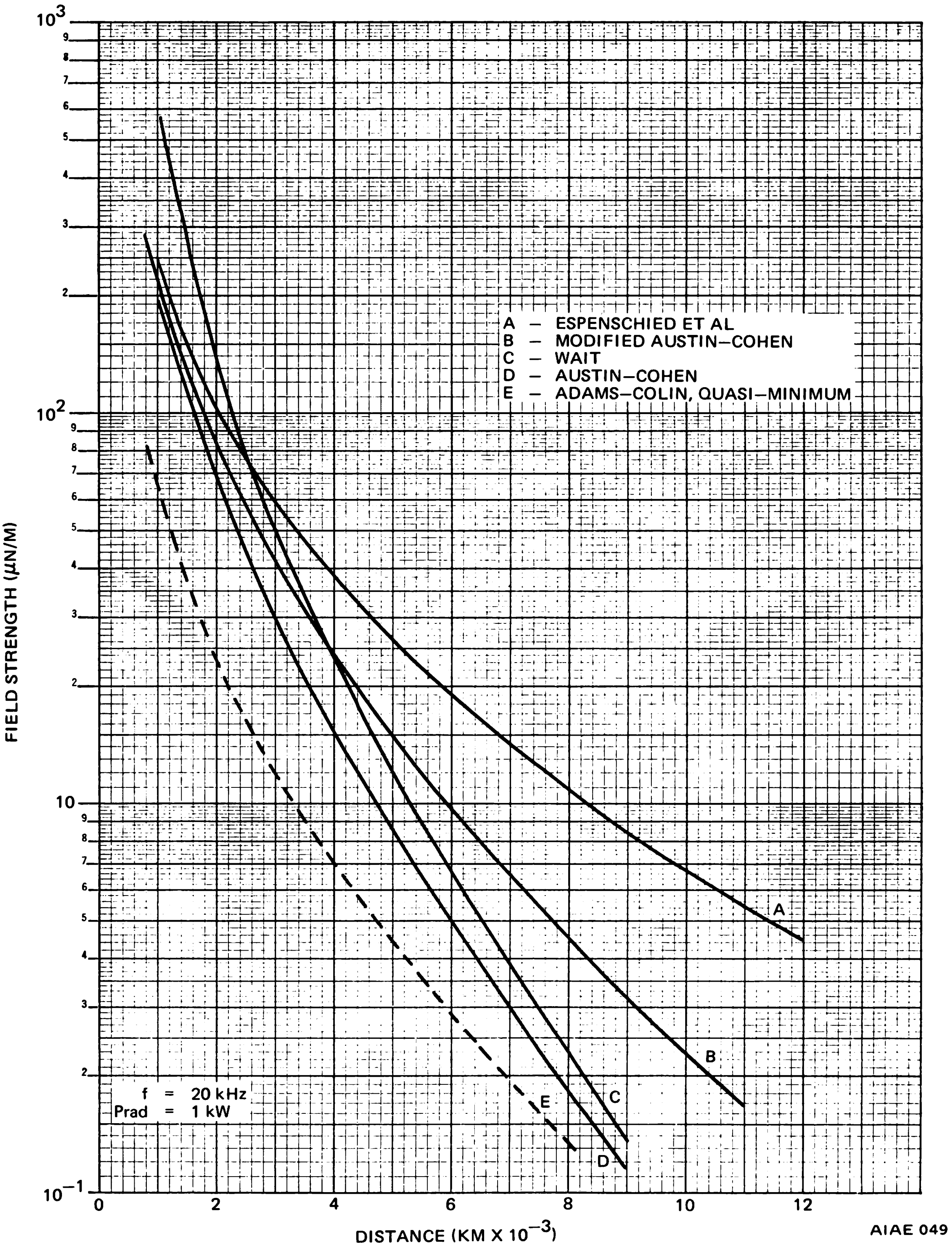


Figure 5-2. Estimated Daylight Field Strength vs Distance for Over-Sea Paths

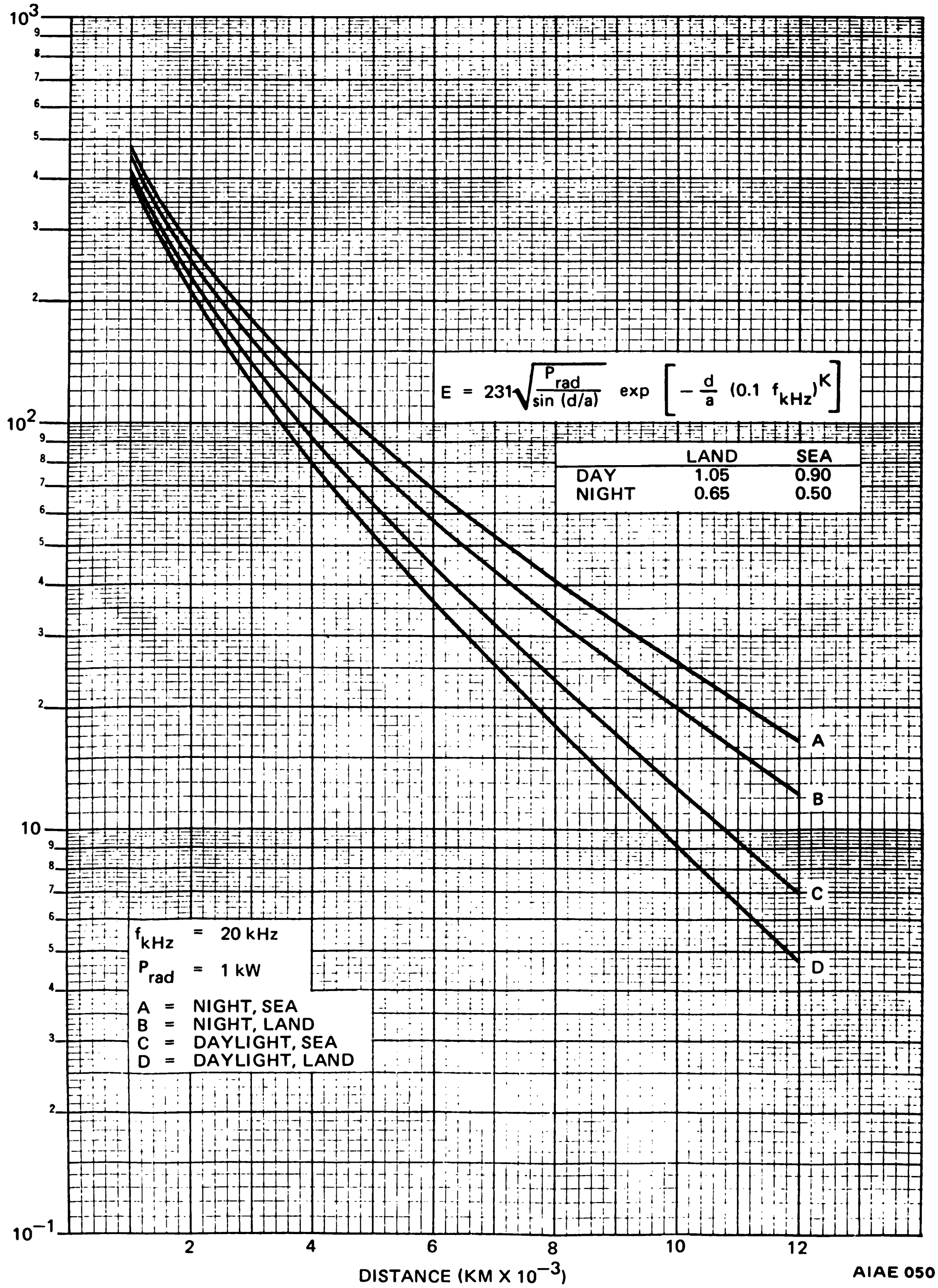


Figure 5-3. Estimated Field Strength vs Distance Based on Pierce's Formula

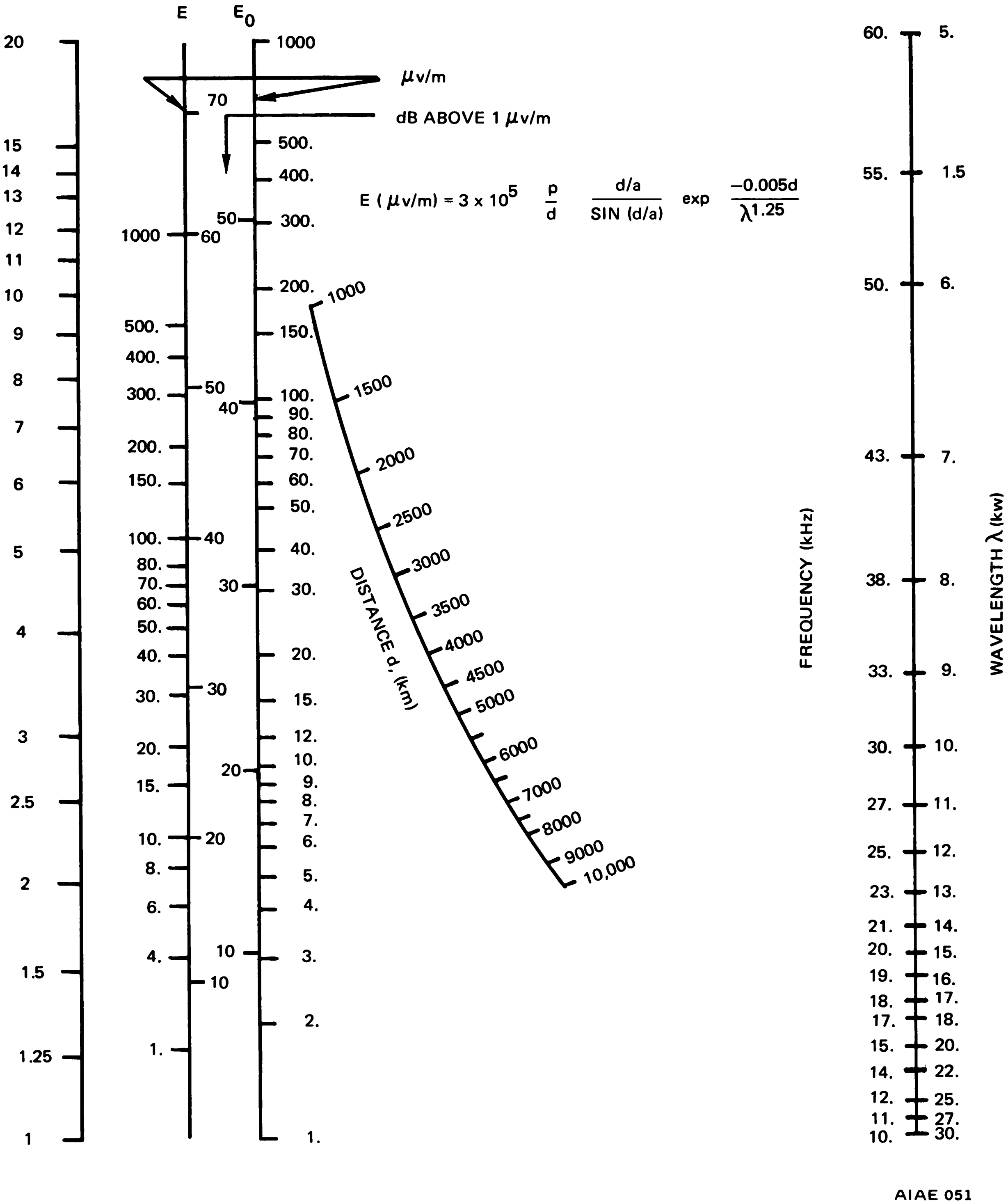


Figure 5-4. Estimated Field Strength Based on Espenshield Et Al Equations

b. Vertical Whip Antenna

(1) Length: 20 feet

(2) Orientation: vertical

(3) Height: as high as possible

(4) Transmission line: 50 G-58/U

c. Loop Antenna

(1) Area: 65" by 65" square

(2) Turns: 40 turns, No. 20 AWG

(3) Terminating resistance: 50

(4) Shielding: loop enclosed within aluminum tubing

(5) Transmission line: RG 58/U

(6) Orientation: loop plane aligned in line with transmitter antenna

d. All Antenna Types

(1) Locate antennas a maximum of 100 feet from the receiver

(2) Site antennas away from all potential radiators, such as powerlines, and away from other antennas

(3) Where available, antenna AT 252/SR or antenna group AN/SRA-17 (XN-1) may be used.

5.2.3 Omega

Omega is a VLF worldwide radio navigation system which, ultimately, will consist of eight strategically located transmitting stations. The navigational accuracy of Omega is dependent on rigid frequency control derived from four cesium beam standards (per station). Because of this feature, the Naval Observatory has cited Omega as an accredited source of standard frequency. Operations stations, frequencies, and schedules for Omega may be obtained in the Time Service Announcements of the Naval Observatory. However, it is recommended that use of these frequencies be limited to emergencies until all eight stations are completed and operating on a permanent basis.

5.3 CLEAN ROOMS

Ordinarily, electronic calibration laboratories do not have the need for clean room capabilities. However, unique applications may arise requiring highly specialized and controlled measurements to be performed. The ideal solution is to perform these measurements within the controlled environment of a clean room.

Detailed data and information pertaining to the installation, operation, and maintenance of a clean room may be found in Federal Specification Fed. Std. No. 209, "CLEAN ROOM AND WORK STATION REQUIREMENTS, CONTROLLED ENVIRONMENT."

5.4 PACKING AND SHIPPING

Packaging is necessary to protect equipment from shock and vibration encountered during transit, and to fulfill special requirements such as waterproofing, maintenance of a constant temperature, etc.

In shipyards, Naval Stations, and other facilities where equipments are mainly "hand-carried," special calibration vans equipped with vibration isolation shelves are recommended for use to transport equipment between the user and the laboratory (figures 5-5, 5-6 and 5-7). Vans which are not presently equipped with isolation mounts may be modified in accordance with installation drawings: "Modification Kit Assembly for Calibration Van"; drawing number F-4-1074 (3 sheets); July 19, 1965; U.S. Naval Air Station, Overhaul and Repair Department, Norfolk, Virginia.

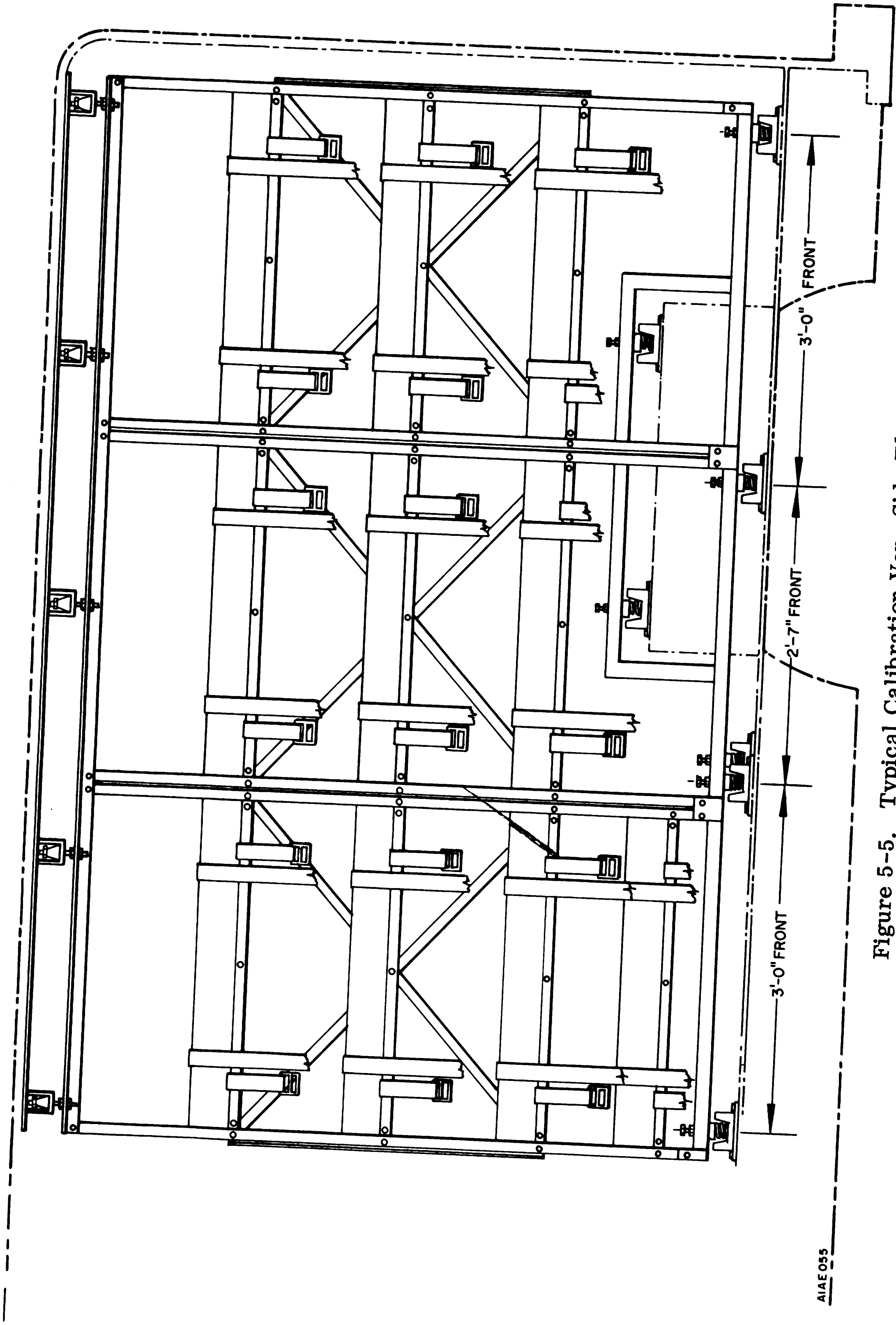


Figure 5-5. Typical Calibration Van, Side Elevation

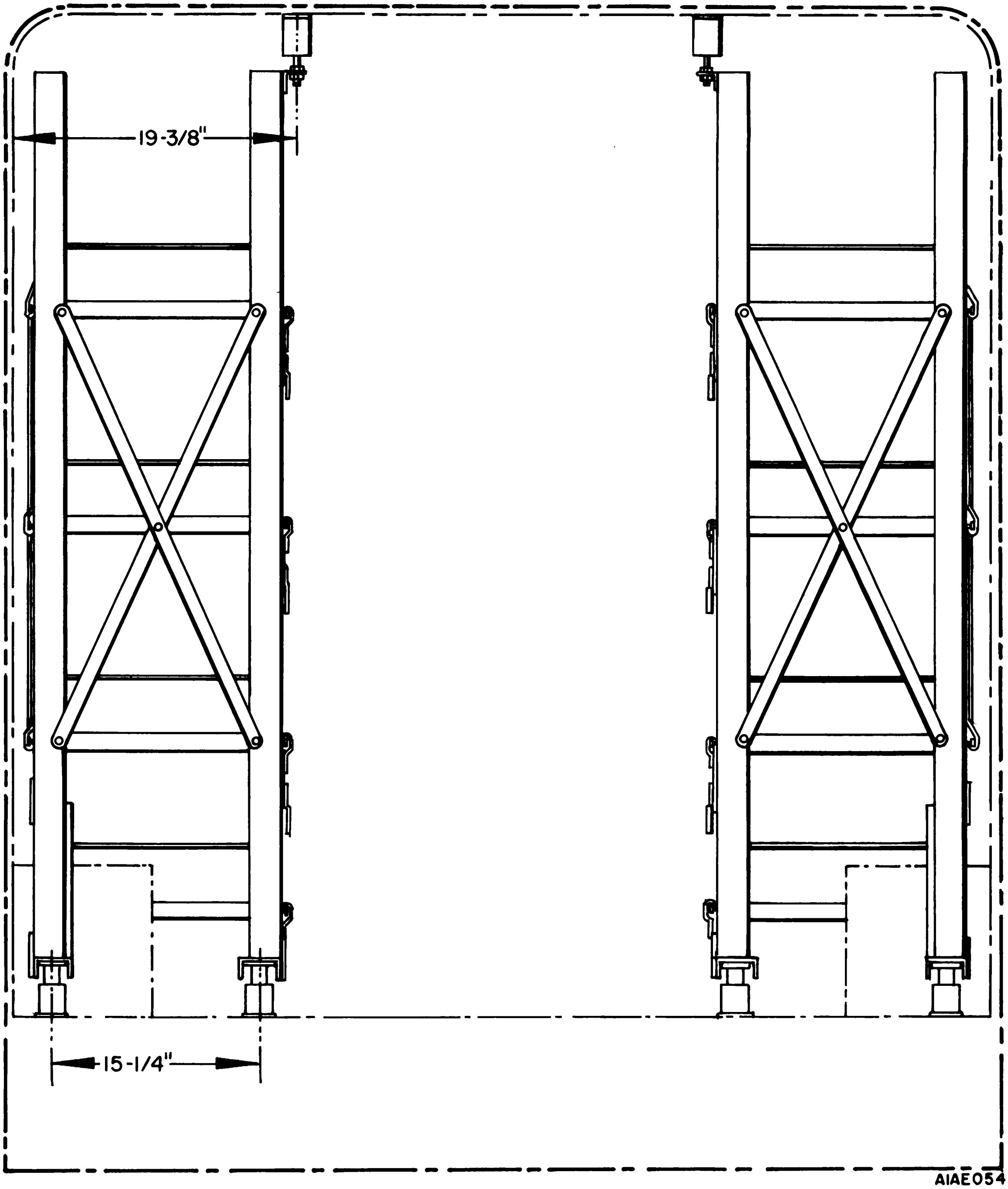


Figure 5-6. Typical Calibration Van, End Elevation

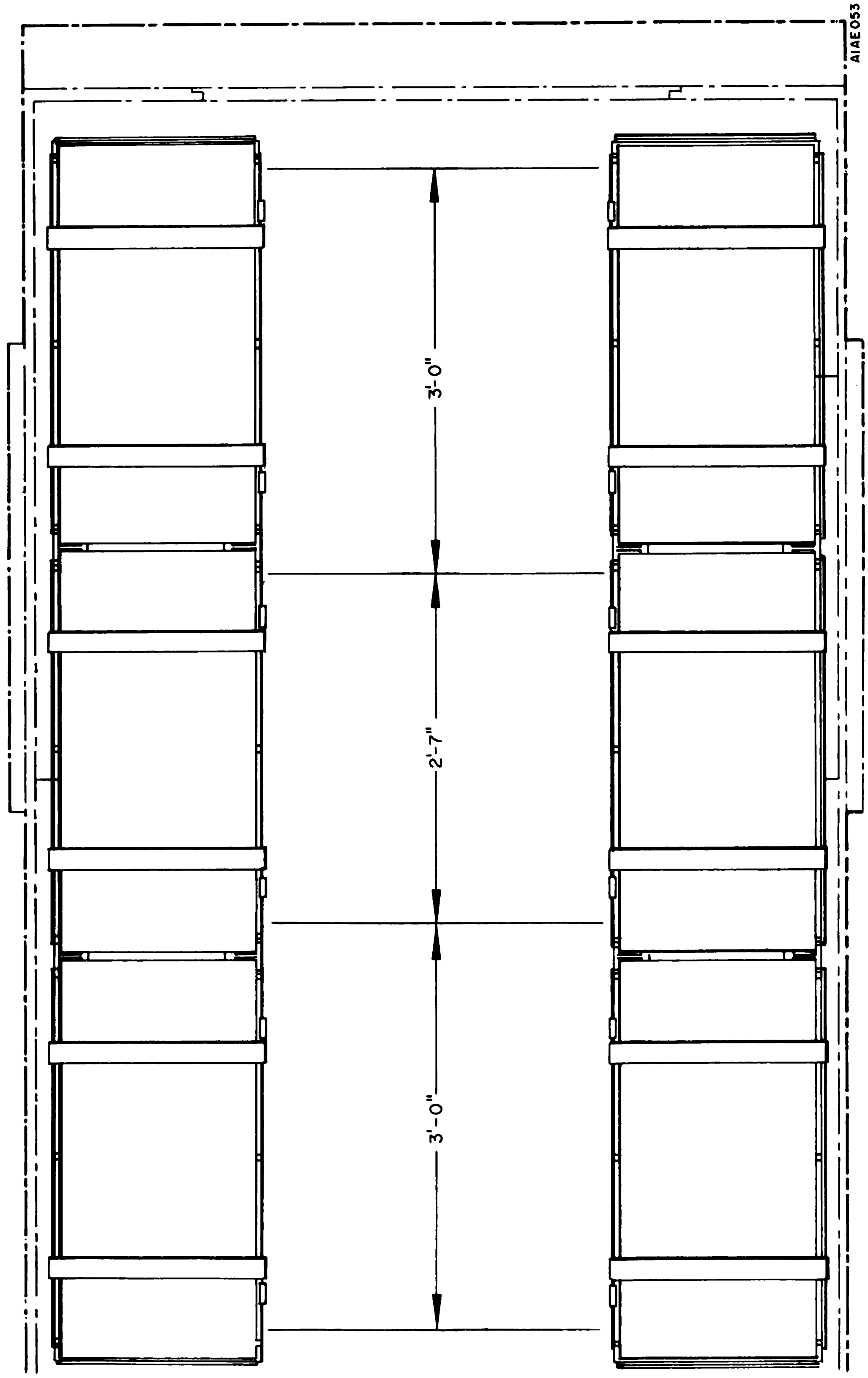


Figure 5-7. Typical Calibration Van, Plan View

CHAPTER 6

ELECTROMAGNETIC COMPATIBILITY CONSIDERATIONS

Electromagnetic compatibility is the ability of communications-electronics (C-E) equipment, subsystems, and systems to operate in their intended operational environments without suffering or causing unacceptable degradation because of unintentional electromagnetic radiation or response. It does not involve a separate branch of engineering, but directs attention to improvement of electrical and electronic engineering knowledge and techniques to include all aspects of electromagnetic effects.

In general, three major goals are to be achieved in the quest for compatibility:

o Minimization of emissions which may affect other equipment or internal elements within a system.

o Minimization of susceptibility to emissions, either internally or externally originated.

o Elimination of potential hazards to both personnel and material.

In order to achieve these goals within a specific project, controls must be applied at each of the major functional activities connected with the project. For example, the following controls should be applied during the construction and equipment installation stages of a new calibration laboratory:

o Use established siting criteria, if available, for location and orientation of equipments during installation.

o Provide rules for equipment mounting and interfacing, including cable runs.

o Provide rules for grounding, bonding, and shielding of both power service and distribution systems and electrical/electronic equipments.

o Use manuals, ICP's, etc., which fully describe the proper methods and procedures for setting up, checking, adjusting, aligning, calibrating, and operating the equipment.

o Inspect and approve installation to assure that undesired emission, susceptibility, and hazard modes are not introduced.

NAVELEX 0101,106, Electromagnetic Compatibility and Electromagnetic Radiation Hazards, provides engineering material which may be used to implement the listed controls. Additional information on bonding and grounding techniques is included in this chapter.

6.1 GROUNDING

Grounding systems are effected at C-E facilities to provide protection from shock, lightning, and fault currents, and to minimize EMI and other equipment interactions. This is accomplished by establishing a low-impedance network, for both DC and VF potentials, which limits inadvertent voltages appearing on metallic structures to safe levels, and which facilitates operation of overcurrent devices. The "network" usually consists of all metallic objects within a facility, including structural steel, reinforcing steel, flashing, downspouts, ventilators, pipes, cable trays, enclosures, cabinets, and raceways. The continuous structure(s) so created are connected to a buried electrode or other earthing network to establish the low resistance to solid earth ground. This is illustrated in figure 6-1. In general, all power distribution systems and electrical/electronic equipment should be grounded. This requirement is in addition to the measurement grounding system discussed in paragraph 2.7.2.d.(1).

6.1.1 Power Distribution Systems and Electrical Apparatus

Utility power systems are grounded to earth primarily for safety. Each generating station, substation, primary and secondary distribution system, and terminal building connection is earth grounded. This provides a safe path in case of line trouble for power fault currents through the earth back to the generator. The trouble might be a break in the feeder line or high-voltage transmission line caused by a storm, or flying debris, or an equipment short circuit. In any case, ground current will flow and, if the ground connections are kept at a low impedance, the hazardous voltages caused by the ground currents will be kept to a minimum. Starting with the utility power systems, low-impedance ground connections will also insure a minimum of EMR generation and transmission. When a faulty noisy equipment operating somewhere in the distribution system is generating electromagnetic interference, the low-impedance ground path will drain off the spurious energy and prevent it from reaching other users of the power system. As a general rule, the low-impedance ground path or ground plane is one and the same with the generator return, or is connected directly to the generator reference plane.

Grounding should be in accordance with the provisions of the National Electrical Code and the National Electrical Safety Code except that grounds and grounding systems should have a resistance to solid earth ground not exceeding the values given in table 6-1.

The National Electrical Code (NEC) requires that before entering the user building, the neutral must be earth grounded. Within the building and within the equipment, the primary power ground is left floating.

Any secondary AC power that is derived, but separated from the primary AC power, has its own ground system with the ground returned to the secondary power source. At the power source, the secondary power ground system is then grounded to the system ground plane.

Where practicable, electrically continuous, metallic, buried water piping may be used for the grounding electrodes. If this is not possible, an electrode system may be established using the criteria outlined in NAVFAC Specification 9Y.

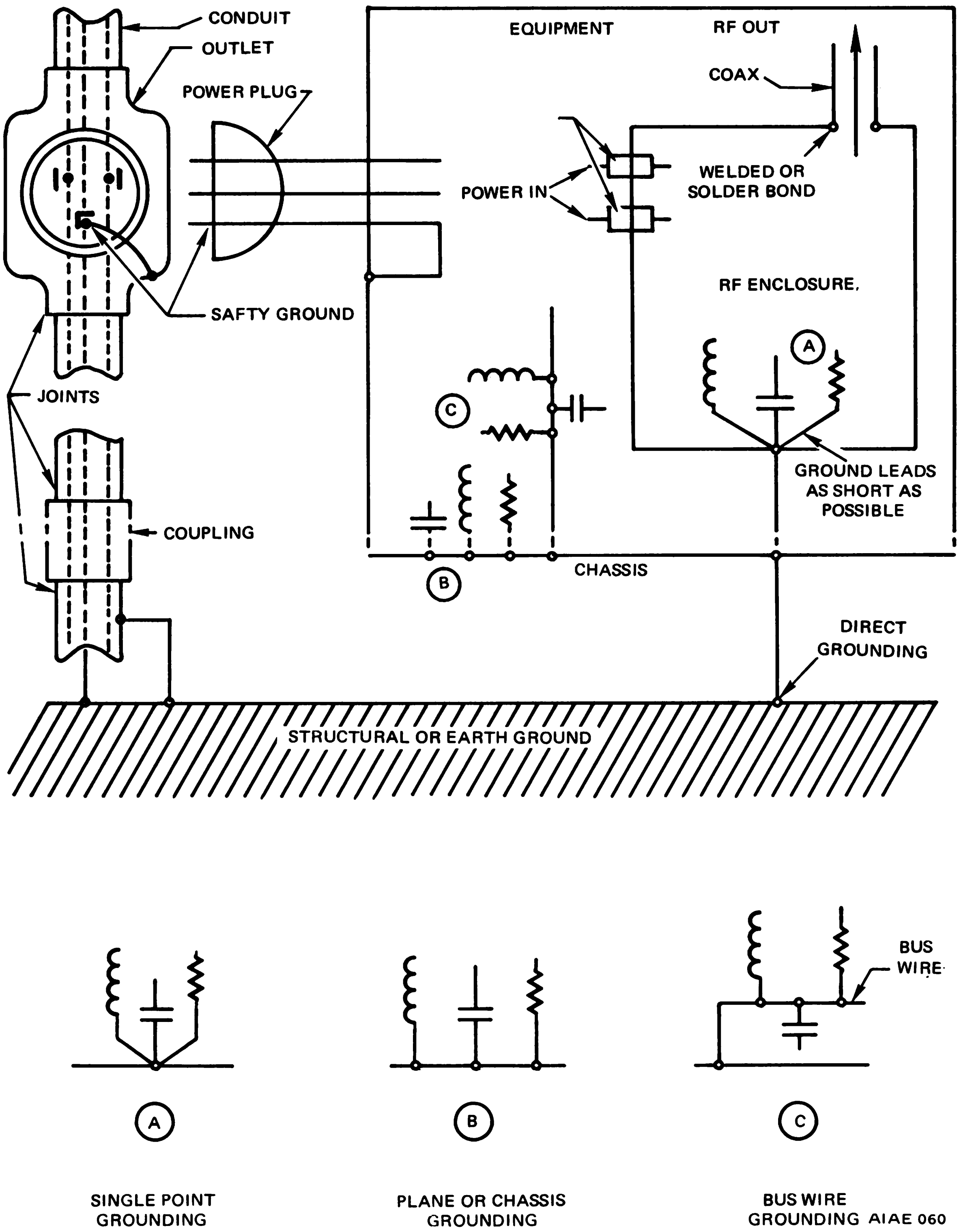


Figure 6-1. Typical Grounding Connections

Table 6-1. Maximum Grounding Resistances of Electrical Apparatus and Power Distribution Systems

SYSTEM	GROUNDING RESISTANCE (Ω)
Metal enclosures of electrical and electrically operated equipment and cable sheaths of connecting cables	3
Grounding systems to which portable electrical utilization equipment or appliances are connected	3
Secondary distribution systems (neutral), non-current carrying metal parts associated with distribution systems, and enclosures of electrical equipment not normally within reach of other than authorized and qualified personnel	10
Individual transformer and lightning arrester grounds on a distribution system	10
Equipment not covered above	10

6.1.2 C-E Facilities and Equipments

Grounding and bonding requirements for C-E facilities and equipments are listed in table 6-2. To accomplish interference suppression through an effective grounding system, all electrical and structural components must be maintained at the same reference potential. This is generally accomplished by setting up separate grounding systems for the structural and the various electrical parts of a system and combining these separate grounds only at one common reference point or plane. The object is to prevent any electromagnetic interference generated by one unit of the system from being transferred through a common ground impedance to the other units. If potential differences are not allowed to exist, interference currents cannot flow and spurious signals can neither be radiated nor conducted to the susceptible parts of the system. Obviously, the larger the system, the less this ideal can be achieved. No conductor has zero impedance; hence, zero potential difference can only be approached, never completely achieved.

6.1.3 Earth Networks

Design and installation details for earthing electrodes and grid networks are given in NAVELEX 0101,106. Generally, the resistance of a grounding network is a function of many parameters, including configuration, electrode size, depth of burial earth characteristics, and other factors.

6.2 BONDING

Bonding may be defined as the process of physically connecting two metallic surfaces to provide a low-impedance path for VF current.

Table 6-2. Grounding and Bonding Requirements for C-E Facilities/Equipments

FACILITY BUILDING	BONDING	GROUNDING
Radio transmitter	All metal objects in the building shall be electrically bonded and grounded, including such objects as structural steel, reinforcing steel, flashing, downspounts, gutters, cable trays, pipes, and ventilators. Reinforcing steel shall be bonded together at a maximum spacing of 8 ft. on centers. Isolated items of metal not exceeding 2 ft. in any direction need not be bonded.	Provide grounds for equipment, building, and electronic systems. Standard practice provides a wire mat imbedded in the grade slab, extended to the exterior of the building and welded to a cable run around the periphery of the building. The mat shall consist of No. 6 AWG copper-encased steel wire fabricated as a 1-ft-square mesh with all crossings welded. The peripheral cable shall be of 2/0 bare copper and grounded by exothermic welding to 3/4 in. x 10 ft. copper-clad ground rods, 20 ft. on centers. The mat shall have a minimum resistance of 5 ohms to ground.
Radio receiver	Same as radio transmitter buildings.	Ground all bonded metal structural members to a wire mat imbedded in the concrete grade slab and extended to the periphery of the building. The mat shall consist of No. 6 AWG copper-encased steel wire fabricated as a 1-ft-square mesh with all crossings welded. Electronic equipment must have an independent ground system that can be used to ground the building if connection to the building is below grade and if a separate ground from building to common point is installed. A separate building ground conductor and an electronic ground system conductor shall be run to common ground and have a maximum of 3 ohms resistance to ground.
Communication centers and terminal equipment		Connect electrical ground to a moderate buried ground system in locations where ground conductivity is poor. Otherwise, a sufficient ground can be made to the water piping system. Provide grounding for control of compromising emanations according to the appropriate specifications.

The surfaces may be joined by welding, brazing, or soldering, called a direct bond, or by other means, in which case the junction is called an indirect bond (e.g., a jumper or strap). Adequate bonds reduce interference by preventing both the development of electrical potentials between metal structures, and non-linear currents which can produce intermodulation products.

For convenience, the DC resistance, rather than the AC impedance, of a bond is often employed as an indication of low-frequency bonding effectiveness. At high frequencies, however, bond effectiveness is best determined by means of impedance measurements because bond capacitance and inductance become significant and may result in relatively high RF bond impedances, despite low DC resistance readings. In practice, DC resistance measurements are utilized to detect grossly defective bonds, and to determine quickly, by comparison with manufacturer's test data, whether or not bonds on existing equipment have deteriorated in the field. The DC resistance of an adequate bond should be between 0.00025 and 0.0025 ohm. In addition to impairing shielding effectiveness, high-impedance bonding jumpers may re-radiate RF energy. Resonant frequencies of a bonded circuit can be determined by a "Grid-dip Meter," and will roughly indicate the quality of the bond.

In designing and establishing bonding criteria for specific applications, it is necessary to consider a variety of factors, such as interference frequency spectrum and maximum allowable bonding impedances for frequencies within a specific range. Of importance are such physical characteristics as size, strength, fatigue resistance, corrosion resistance, resistivity, and temperature coefficients. It is the designer's responsibility to provide bonds that will not deteriorate appreciably even when equipment is subjected to adverse environmental conditions. Bonds may be affected by electrolytic action between the metals used and their surroundings. An excellent bond at time of fabrication may actually become a serious interference source shortly afterwards if proper precautions have not been taken.

Bonding jumpers should preferably be flat, thin, and short solid straps to provide large surface areas for low RF impedance (RF currents flow along conductor surfaces). The measured RF impedance of a typical flat bond strap at frequencies up to 30 MHz increases almost linearly with frequency. Such impedance is due almost entirely to the self-inductance of the strap. The capacitance between the bonded members is in parallel with the inductance of the bond strap, and the bond strap has the characteristics of a parallel capacitance-inductance circuit operating far below its resonant frequency. At the frequency of self-resonance, the RF impedance of such a parallel capacitance-inductance circuit is very high compared to its DC resistance, and effectiveness of the bond strap is nil.

Bonding requirements for C-E facilities are listed in table 6-2. Detailed bonding methods for equipments and structures may be found in NAVELEX 0101, 106, MIL-B-5087 and MIL-STD-1310A.

CHAPTER 7

HUMAN FACTORS ENGINEERING

Human factors engineering (HFE) may be defined as the summation of available knowledge which defines the nature and limits of human capabilities as they relate to the operation, maintenance, or control of systems or equipment. In turn, these may be applied during engineering design to achieve optimum compatibility between equipment/facilities and human performance application of HFE design criteria to facility design is intended to ensure safe, reliable, and effective operation, with a minimum of manpower skill requirements. This is accomplished by providing a work environment which fosters effective procedures, work patterns, and personnel safety, and which minimizes discomfort, distraction, and other factors which can degrade human performance.

Some HFE factors which should be considered in facility design are accessibility, environment, safety, and maintainability. These, and other factors, are discussed in the following paragraphs.

7.1 ACCESSIBILITY

Accessibility refers to the provision for adequate space for man, his equipment, and his required movement for performing operating and maintenance duties under both normal and emergency conditions. The size and shape of space/equipment arrangements are determined by personnel, equipment, and task requirements. The gross dimensions of required equipment, together with the clearance necessary for its operation and maintenance, will determine specific space requirements.

In order to be as universally accessible as possible, configurations and sizes should be designed to accommodate at least 90 percent of Naval personnel. The middle 90 percent of Naval population is usually selected; i.e., those personnel whose body dimensions fall between the 5th and 95th percentiles. Many studies have been performed to determine the range of human body dimensions in various working positions (standing, sitting, kneeling, etc.), not only for static positions, but to determine dynamic measurements; i.e., the dimensions of the workspace or work envelope needed by men as they perform their work.

The results of such studies are listed in table 7-1 and illustrated in figure 7-1, and may be used for guidance in the design of workspaces for seated and standing operations. Note that allowances for clearance are necessary when using the tables.

7.1.1 Work Stations

In general, work stations are designed for efficiency, rather than the saving of space. They should be designed for seated or sit-stand operations, except where a large percentage of personnel duties (80% or greater) require mobility.

Table 7-1. Suggested Accessibility Body Dimensions

(a) Seated Body Dimensions

KEY TO FIGURE 7-1(a)	DIMENSION	5TH PERCENTILE (INCHES)	MEAN (INCHES)	95TH PERCENTILE (INCHES)
N	Seated Height	35.8	35.9	30.0
O	Eye Height	29.4	31.5	33.5
P	Shoulder Height	21.3	23.3	25.1
Q	Elbow-Rest Height	7.4	9.1	10.8
R	Thigh-Clearance Height	4.8	5.6	6.5
S	Knee Height	20.1	21.7	23.3
T	Buttock-Knee Length	21.9	23.6	25.4
U	Popliteal Height	15.7	17.0	18.2
V	Forearm-Hand Length	17.6	18.9	20.2
W	Buttock-Leg Length	39.4	42.7	46.1
X	Buttock-to-Inside-Knee	17.7	18.9	20.2
Y	Elbow-to-Elbow Breadth	15.2	17.3	19.8
Z	Hip Breadth	12.7	14.0	15.4
AA	Shoulder Breadth	16.5	17.9	19.4
BB	Span	65.9	70.8	75.6

(b) Standing Body Dimensions

KEY TO Figure 7-1(b)	DIMENSION	5TH PERCENTILE (INCHES)	MEAN (INCHES)	95TH PERCENTILE (INCHES)
A	Vertical Reach	77.0	83.6	90.3
B	Stature	65.2	69.1	73.1
C	Eye Height	60.8	64.7	68.6
D	Shoulder Height	52.8	56.5	60.2
E	Elbow Height	40.6	43.5	46.4
F	Wrist Height	31.0	33.5	36.1
G	Knuckle Height	27.7	30.0	32.4
H	Kneecap Height	18.4	20.2	21.9
I	Ankle Height	4.9	5.6	6.8
J	Chest Depth	8.0	9.1	10.4
K	Buttock Depth	7.6	8.8	10.2
L	Functional Reach	29.7	32.3	35.0
M	Depth of Reach	23.0	--	--

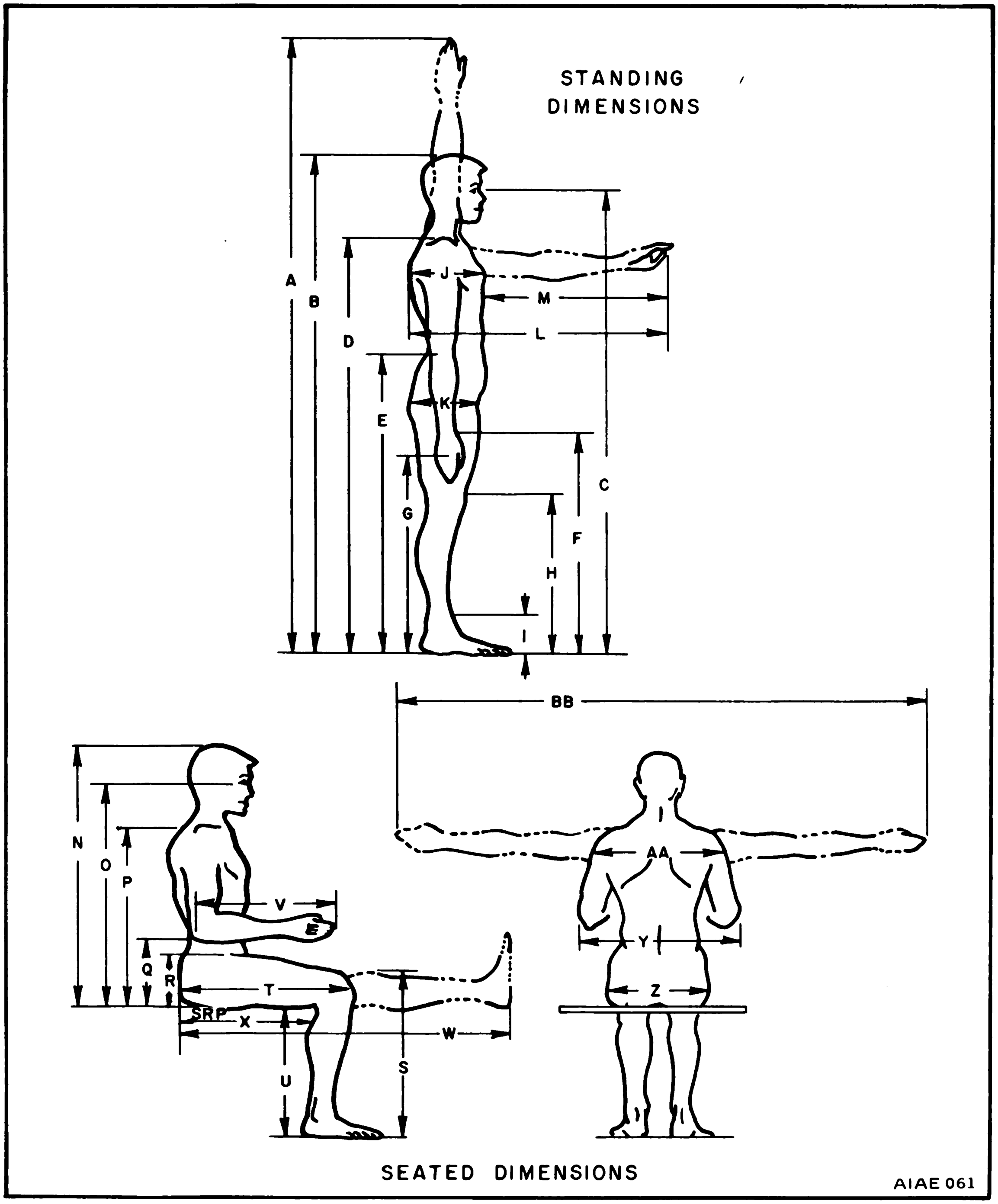


Figure 7-1. Body Dimensions, Typical

Clearances should be provided at all the front and sides of equipment consoles, racks, and filing cabinets. At least 4 to 5 feet of free floor space is usually required in front of consoles. At least 42 inches of clear, three-dimensional space in front of drawers, as measured from drawers in the extended position are:

- o 18 inches on each side where maintenance is performed in place.
- o 18 inches on each side for removable drawers weighing over 45 pounds.
- o 18 inches on one side, 4 inches on the other side for removable drawers weighing less than 45 pounds.

7.1.2 Aisles and Corridors

Aisles and corridors should be designed to minimize travel distances from those areas having the anticipated heaviest flow of traffic. In addition, the following general criteria are considered desirable goals:

- o Aisles and corridors should be straight especially when used for passage of equipment.
- o Intersections should be at 90 degree angles.
- o Visibility across corners should be provided - mirrors may be used at blind corners.
- o Aisles and corridors should be free of obstructions such as columns, refuse containers, water coolers, fire extinguishers, etc. If necessary, these may be recessed in a wall.

Table 7-2 lists minimum and recommended widths for aisles. The clearance height for aisles and corridors should not be less than 76 inches.

Table 7-2. Aisle and Corridor Widths

NORMAL TRAFFIC	MINIMUM WIDTH	RECOMMENDED WIDTH
Feeder Aisles	30"	36"
Main Aisles	50"	60"
One Person (no passing)	30"	36"
Two Persons (passing)	50"	60"
Three Persons Abreast	66"	72"
Mobile Equipment Plus Personnel (two-way traffic)	Twice the maximum width of the equipment plus 30".	

7.1.3 Doorways

The maximum anticipated equipment size requiring access, including benches and furniture, will dictate the size of doors and other openings. Doors providing access from corridors to rooms should be hung to open into the room, except where safety or system requirements dictate otherwise. However, exterior doors should open to the outside. Sills, saddles, and other projections should be avoided.

If swinging doors are provided, they should have visual access to the other side with the doors in a closed position.

7.1.4 Lighting

Criteria for laboratory lighting was given in a previous chapter. Human factors enter into lighting design because of the subjective nature of man's response to illumination. People do not react to levels of illumination as defined by foot-candles. The reaction is to the brightness of the light source or luminaire and the ratio of this brightness to the brightness of other surfaces in a space. A uniform level of illumination with low brightness ratios can be tolerated much more easily than a higher brightness level of illumination with high brightness ratio contrasts as is typical with incandescent, small luminous area, suspended luminaires. When the eye perceives a source of brightness it is not a discreet small area, but rather the brightness of the entire emitting surface or average luminaire brightness. Because of the shielding angle of the brows, when the subject is looking directly ahead, the luminaire will not come into view until it is sufficiently distant to be viewed at an angle of approximately 40 degrees from the horizontal. This means that discomfort caused by direct glare in small rooms should be lower than that in larger rooms since glare is largely a function of luminaire average brightness.

As a general rule, a lighting installation will be more comfortable with a greater number of low average surface brightness luminaires in the critical viewing angles than a smaller number of higher average surface brightness luminaires in the same viewing angles, all other things being equal. Photometry of the light energy distribution of the luminaire provides the raw data from which efficiency, brightness, and direct glare effects can be calculated.

Another factor concerns the effects of age and subnormal vision. As a base of departure, most illuminating engineering studies use young, normal adults. However, present data indicate that, for older people, the visual performance curve is shifted upward, similar to the effect of disability glare. In other words, there is increased scattering of light rays within the eye, similar to the effect of fog, which causes a veiling brightness to overlay the image the eye is trying to see, and decrease its contrast. With reduced contrast more light is needed to make the detail visible as quickly and accurately as it is to the young adult.

7.1.5 Acoustical Noise

Similarly to man's response to illumination, his response to sound depends on many subjective factors, as well as the pressure levels and frequency content of the noise. Much has been written during the past several decades on both the objective and subjective observations of acoustic noise and the effect of noise on humans. With increased knowledge, there is now concern about exposure to high sound levels that may be injurious to people. Although no harmful effects of a lasting nature occur from distracting noises at the sound levels of common experience, these noises can be psychologically harmful without the subject being aware of the effect. Such considerations must be kept in mind in the design of laboratories.

Because there is so little information in the literature on noise level surveys in specialized laboratory areas, the best criterion that can be advanced is the noise levels commonly tolerated for private offices. It is reasonable to expect that the operations in a standards laboratory should be carried out in an environment that is as conducive to concentration and freedom from distracting noises as one would find in an executive office with quiet surroundings.

There is a considerable amount of information available on office environments in the literature. Because of more refined methods of measurement, there has been a trend in recent years to recommend even lower noise levels. In the earlier years of measurement and evaluation, the noise tolerance usually specified for a private office was that it should be no greater than 50 dB as measured on a sound level meter. Such a measurement must be obtained in accordance with the American Standard for Sound Level Meters with a reference level of 0.0002μ bar (or 0.0002 dynes/cm^2).

Within the last decade or so, the acceptable noise level for private offices has been lowered to 40-45 dB, as measured on a sound level meter using the A, or 40 dB weighting network. More recently, extensive investigations have indicated that the problem of noise measurement is considerably more complex than it was 30 years ago. In consequence, new measurement techniques have been developed with more complex methods of evaluation. There is greater assurance that objective measurements made today correlate more closely with the subjective elements. The most extensive investigations have been made by Beranek, Stevens, and Kryter. Peterson and Gross have consolidated this information into a handbook. On the basis of these general findings, it is recommended that noise can be considered as a continuous background and that it can be measured at a reference level of 0.0002μ bar, with a level no greater than 35 on the Noise Criteria (NC) curve from 20 to 9600 cps. The size of the room, degree of sound absorption, the noise produced by laboratory equipment, and the number of people in the area will be the determining factors for sound levels under working conditions. The sound level can be high, on occasion, due to normal work activity and noise from laboratory and office equipment. Attainment of a low sound level will come mainly from a relatively low noise level of the general environment and, to some degree, can be partially achieved by sound-insulated walls, floors, and ceilings. The use of sound-absorption materials on interior surfaces is recommended to obtain more pleasant surroundings by reducing reverberation effects and the harsh effects of highly reflecting surfaces. It is very important to choose material that does not flake for use as a sound absorber in the laboratory area; otherwise, there is the continuous presence of dust particles.

7.2 SAFETY

As a part of system facility and facility equipment design, safety factors should be given major consideration.

7.2.1 Warning Labels

Conspicuous warning placards should be mounted adjacent to hazardous or potentially hazardous equipment, such as high voltage equipment, very hot equipment, and equipment that may be automatically or remotely started.

7.2.2 Electrical Receptacles

All receptacles, with the exception of 120-volt general-purpose convenience outlets, should be marked with their amperage, voltage, phase, and frequency characteristics.

7.2.3 General Workspace Hazards

a. Warning Devices. A hazard alerting device shall be provided to warn personnel of impending danger of existing hazards (e.g., fire, the presence of combustible or asphyxiating gas, radiation, etc.).

b. Emergency Exits. Emergency doors and exits shall be constructed so that they are readily accessible, unobstructed, and quick-opening. The door or hatch shall be designed so that it can be opened by a single motion of the hand or foot. Where barrier (e.g., fire doors) are designed for automatic operation, the design shall also provide for manually operated, quick-acting, personnel exit.

7.2.4 Electrical Hazards

a. General. Guards, grounding, interlocks, rubber mats, and warning placards shall be provided to minimize the possibility of exposing personnel to dangerous voltages. Equipment shall be designed to preclude accidental contact with voltages in excess of 24 volts. Shields or interlocks should be provided where more than 70 volts may be encountered.

b. Plugs and Receptacles. Plugs and receptacles shall be designed to preclude improper mating. Wiring shall be routed through plugs and connectors so that removal of a plug or connector will not expose "hot" leads. Equipment shall be designed so that receptacles will be "hot" and plugs "cold" when disconnected. Plugs which have a self-locking safety catch shall be provided rather than plugs which must be safety-wired.

c. Interlocks. Exposure to voltages in excess of 500 volts shall be prevented when equipment cases and seals are removed for maintenance and repairs. Access doors or covers shall be equipped with interlocks which remove all potentials in excess of 150 volts.

d. Capacitors. Capacitors and other parts which retain heat or electrical potential after the equipment is turned off shall be located where technicians are not likely to touch them while changing commonly malfunctioning parts, such as tubes.

e. Grounding. General grounding requirements are:

- General Requirements. Equipment shall be designed so that all external parts, with the exception of antenna and transmission line terminals, will be at ground potential. Antenna and transmission line terminals shall be at ground potential, except for energy to be radiated.

- Portable Tolls and Equipment. Convenience outlets and plugs for use with portable tools and equipment shall have approved provisions for automatically grounding the tools and equipment when the plug is mated with the receptacle.

CHAPTER 8

FLEET ELECTRONIC CALIBRATION LABORATORIES

In order to provide the Fleet with a greater flexibility in obtaining equipment calibration services and ensure adherence to the prescribed calibration intervals, Fleet Electronic Calibration Laboratories (FECL) have been established on Navy Tenders and Repair Ships and at selected shore bases. The basic laboratory facility shipboard design and configuration has been standardized to satisfy the environmental conditions and space allocations and to facilitate the planner/designer task. For shorebased FECLs, the same criteria and standards discussed in the previous chapters for the establishment of a new Calibration Laboratory apply.

8.1 GENERAL REQUIREMENTS

For shipboard FECLs, more stringent design considerations must be exercised by the planner/designer to meet the environmental conditions and limited allowable space. New criteria and standards must now be applied by the planner/designer when initially equipping the laboratory and for any subsequent laboratory additions or expansions.

8.2 FECL CALIBRATION STANDARDS EQUIPMENT REQUIREMENTS

The calibration standards required to implement an FECL are presented in Appendix B.

8.3 SHIPBOARD FACILITY CONFIGURATION

In order to provide the space required to support this function it is recommended that a minimum of 960 square feet of space be allocated for the FECL. The general configuration of the FECL should be as shown in MEC Drawing ML-114 (figure 8-1). It is also recommended that the FECL be located adjacent to the Electronic Repair Shop to improve working relationships and to expedite any major repairs that may be required.

Specific criteria and standards that apply to the basic laboratory furniture and work benches are discussed in the following paragraphs.

8.3.1 Workbenches

Workbenches should conform to BUSHIPS Electronic Workbench, Modular (wooden) Drawing No. 805-2280492 (latest revision) except that the two 27.7 VDC Outlets depicted on the Electrical Distribution Box and Terminal Board Assembly of this drawing should be changed to two 117 VAC, 60 cycle outlets.

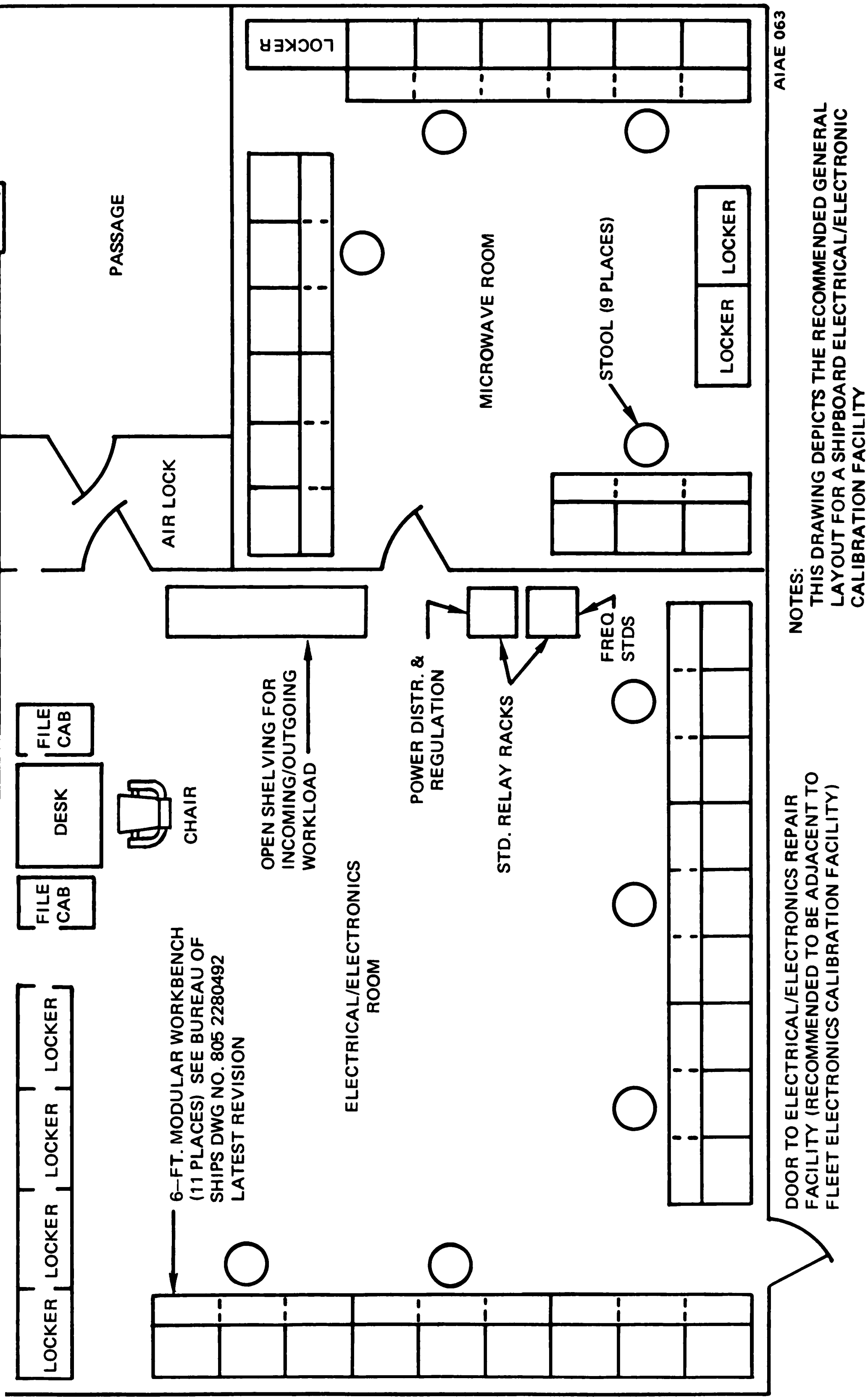


Figure 8-1. Recommended FECL Layout

Although the drawing does not indicate it, the workbenches and shelves should be equipped with channel and lock bars for an adequate equipment tie-down system when the ship is underway. These channel and lock bars should be designed for easy installation, and removal and storage when not in use.

A 1/4" x 3/4" copper ground bar should be provided along the rear of workbenches and connected at only one end by a flexible conductor (such as SR-1-9 cable) to the laboratory grounding system.

8.3.2 Flooring

Requirements of paragraph 2.8.3.a apply. The use of vinyl tiles is not recommended as dielectric breakdown can occur as the space between the tiles becomes contaminated with various debris.

8.3.3 Stowage

a. Provisions should be made for stowage of tools, accessories, and a limited supply of commonly required vacuum tubes, transistors, fuses, resistors, etc.

b. A filing cabinet is required to stow copies of all calibration certificates, calibration procedures, calibration checklists, reporting forms, labels, tags, operational and maintenance manuals, and other instruction material.

8.3.4 Separate Repair/Maintenance Area

The nature of work performed in calibration laboratories requires that this work be physically separated from groups doing general repair work. Soldering, drilling, cleaning instruments and equipments with air, etc., are not environmentally conducive to good calibration laboratory operations.

8.4 LIGHTING

It is recommended that 100 foot-candles, minimum, of incident illumination intensity be provided at bench level from overhead fluorescent fixtures. The requirements of paragraph 3.6 apply.

8.5 POWER REQUIREMENTS

- 110/115V AC 60 Hz power should be provided from a standard Type II power source such as are found aboard FBM tenders.

- 110/115V AC 400 Hz power should be provided from a standard Type III power source such as are found aboard FBM tenders.

- A power source providing 208/115V (± 1%)/three phase/400 (± 1%) Hz, 1 KVA (minimum) power is required.

Specifications of the standard Types II and III power are given in table 8-1.

Circuit breakers should be installed within the laboratory in all powerlines.

Laboratory power should be provided directly from the source so that line fluctuations emanating from the Missile Crane and other ship's users will be minimized.

A separate generator is required for exclusive power utilization in crane operation, machine shop, and carpenter shop for powered shop tools. The heavy power requirements in these areas cause extreme line voltage excursions beyond an economical means of providing adequate and required voltage regulation.

To minimize problems arising from noise being generated outside the laboratory or excessive line fluctuations, the following precautions should be taken:

- o Input power (60 Hz) to the laboratory should be conducted directly from the power source, and should be coupled through a three-phase, 15 KVA (approximate rating) transformer as per either figure 4-1 or figure 4-2.

- o Voltage regulators should be installed at the secondary of the stepdown transformer in each phase to ground for all bench 60 Hz wiring for every 6 KVA required to minimize line voltage fluctuations.

- o Powerline filters, as specified on figure 4-1 or figure 4-2, should be installed in the phase A, phase B, and phase C lines following the voltage regulators to minimize conduction of noise generated by motors, engines, defective fluorescent fixtures, etc., into each laboratory.

Single-phase 60 Hz and 400 Hz wiring is required on all benches throughout the laboratory with at least 15 amperes of each frequency available to each bench; 12 KVA maximum 60 Hz and 5 KVA 400 Hz power is required for normal laboratory operation. Provision should also be made for 208/115 volt/three phase/400 Hz (1 KVA) availability at two outlets within the laboratory for support of SUBROC requirements, when required.

Laboratory wiring circuits should utilize all three phases of the transformer secondary. This will prevent an unbalanced condition between phases.

Circuit breakers should be installed in the FECL work area rated at 30 amperes. Blown fuses have become a problem during peak workload calibration.

Navy type 31A duplex receptacles or heavy duty Wiremold 3000 series (or equivalent) with an adequate number of receptacles (equivalent of one every three running feet of bench space for 400 Hz and one every running foot for 60 Hz) should be provided for the 60 and 400 Hz power lines. Receptacles should be identified and color coded to distinguish between 60 and 400 Hz. All receptacles are to be installed at the rear of each bench and above the bench surface.

Table 8-1. Power Specifications for Tenders and Repair Ships

SPECIFICATION	TYPE II	TYPE III
Nominal Utilization Voltage	440 or 115	440 or 115
Nominal Frequency (Hertz)	60 or 400	400
Steady State Voltage		
(1) Steady State Voltage Limits		
(a) Average line to line voltage for three phase	± 1%	± 1/2%
(b) Line to line voltage for single phase of a three phase system	± 3%	± 1-1/2%
(2) Maximum unbalance between phases	2%	1%
(3) Modulation Amplitude (Steady state limits)	2%	1%
Transient Voltage		
(1) Transient Voltage Limits	± 16%	± 5%
(2) Recovery Time	0.25 Seconds at 400 Hertz 0.75 Seconds at 60 Hertz	0.25 Seconds
Steady State Frequency Limits	± 5%	± 1/2%
Transient Frequency		
(1) Transient Frequency Limits	± 3%*	± 1%
(2) Recovery Time	2 Seconds	0.25 Seconds
Waveform		
(1) Total Harmonic Content	6%	3%
(2) Maximum Single Harmonic	4%	2%

*With frequency transient of 3 percent only 1 percent shall be outside the steady state frequency tolerance band.

8.6 ENVIRONMENTAL CONTROL

Requirements given in Chapter 3 apply.

8.7 SPECIAL REQUIREMENTS

8.7.1 RF Shielding

All door openings from external areas into the Electronic Calibration Laboratory operating spaces (Electrical and Electronic) should be bonded to assure an electrical ground when the door is closed.

Vents, exhausts, and other openings into all operating spaces should be covered by a screening properly bonded, metal to metal, with 1/16 inch squares of phosphor bronze mesh or 1/4 inch aluminum honeycomb mesh screen to prevent radio frequency leakage.

In special cases where internally or externally generated signals produce objectionable interference within the laboratory, the use of small shielded enclosures may also be required.

8.7.2 Antennas

An antenna system for reception of standard frequency and time signals is recommended for exclusive use by the Fleet Electronic Calibration Laboratory. It is suggested that a ship antenna be utilized for this purpose. The antenna should be installed as far as possible from communications antennas. To prevent impedance mismatch and transmission line attenuation, it is desirable that unbroken lengths of shielded coaxial cable extend from the antenna to an all weather BNC feedthrough at the watertight bulkhead, and from the feedthrough to the receiving equipment.

Very low frequency (VLF) phase tracking systems may be installed in either shipboard laboratories (FECL) or in shore laboratories. The criteria to follow are outlined in general in NAVSHIPS 900,000.101 and EC-17.

To provide a guide to the equipment allocation table 8-2 will be helpful. Table 8-2 is not to be considered authoritative for issuance of equipment, but should serve only as a quick reference to the various system requirements at different installations (see figure 8-2).

Instructions concerning installation of a VLF Antenna are provided below:

a. The Antenna. The Tracor 599-825 whip antenna supplied may be installed provided the whip itself is removed each time the vessel is underway (see EC-17 for technical discussion). The base section may be modified to accept the connectors required to conform to the standard installation practices for armored coaxial cable.

Table 8-2. Allocation of VLF Equipment for FECL (Sheet 1 of 2)

EQUIPMENT	REMARKS
Antenna. Whip, Vertical 20' Steel, Tracor 599-825.	Whip must be removed while ship is underway.
Antenna. Whip, Vertical, Stationary. Navy Type 66046 or 66047, 35' overall in 7' sections.	Use Tracor 599-816 Coupler at base of antenna, modified as necessary.
Antenna. Loop, Rotary, Tracor 599-601B-3.	
Antenna. Long wire, with Coupler (Tracor 599-816).	
Transmission Line. 50 ohm RG-58/U.	
Transmission Line. Armored RG-227/U.	
Transmission Line. Single conductor copperweld, stranded #10 AWG.	
Receiver. VLF Phase Tracking, Tracor 599-J. 1. External Recorder. 2. Doppler Compensation Removed.	

Table 8-2. Allocation of VLF Equipment for FECL (Sheet 2 of 2)

EQUIPMENT	REMARKS
Frequency Difference Meter. Tracor 527A.	The AN/URM-115 Frequency Deviation Meter may be used instead, if on board.
Linear Phase Detector. Sulzer Model LPD.	
Recorder. Texas Instruments PRR-1M-A16-A-FR.	1 each with 599-J.
Panel. Recorder, Texas Instruments Type P-1.	
Panel. Recorder, Texas Instruments Type P-2.	
Recorder. Rustrak Model 156/88 w/8 RPM Motor Gear Trains #1/4 and #15 included.	
Oscillator. Standard Frequency. AN/URQ-9, AN/URQ-10.	
Frequency Comparison System. MET D-147 (4 channel).	May be required for very heavy workloads.
OMEGA Gating Unit. Tracor 533-S.	Optional. (As directed by MEC).

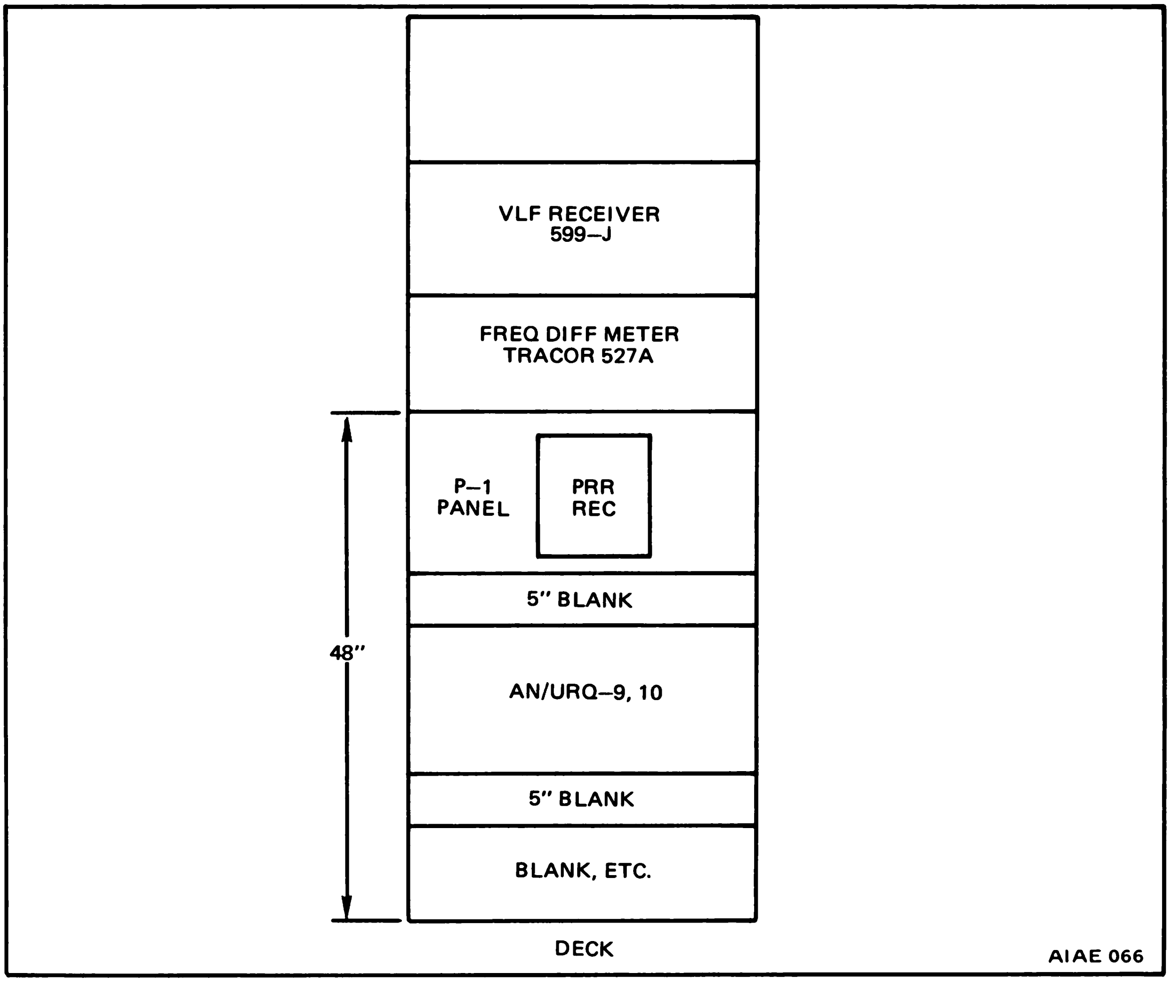
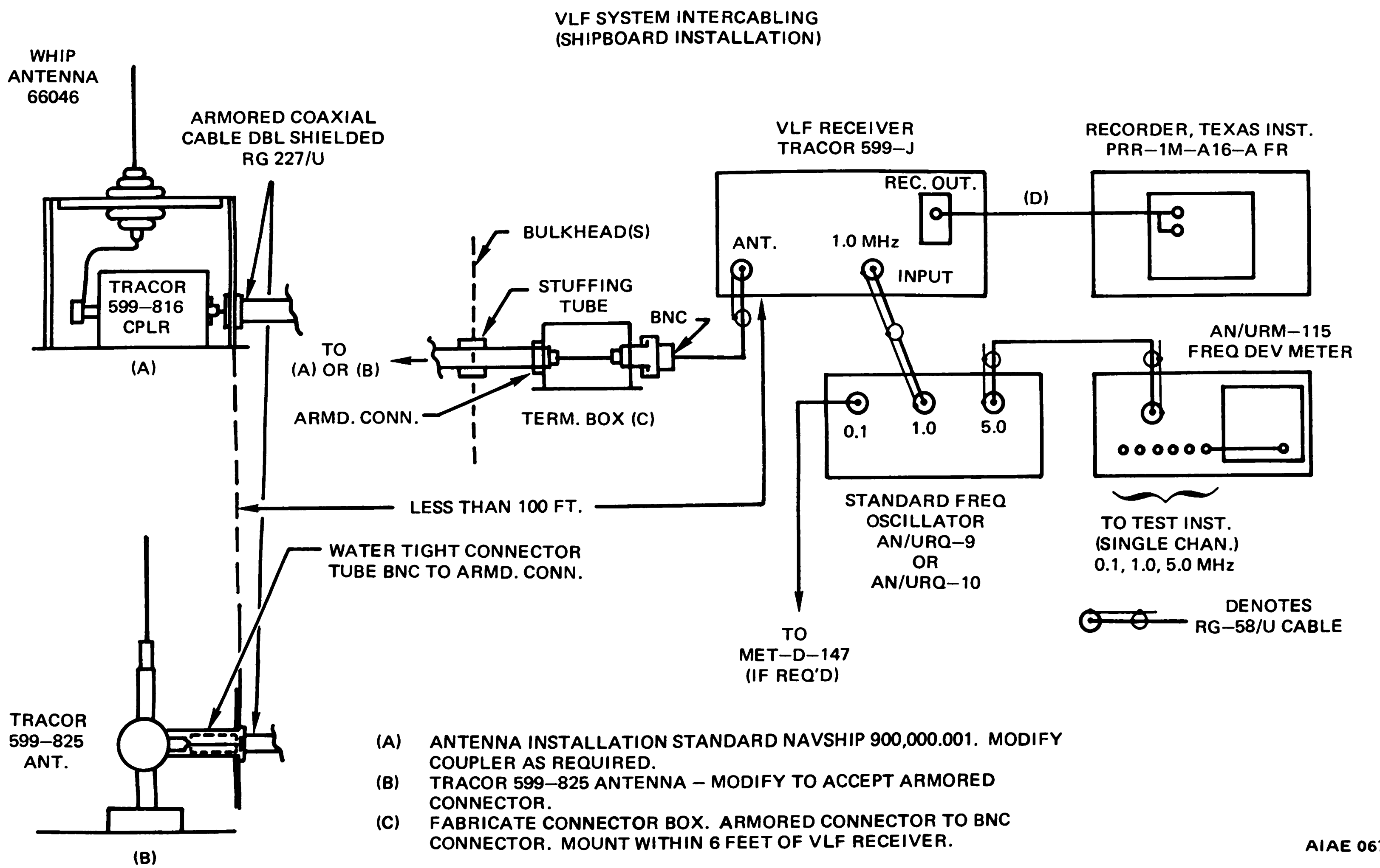


Figure 8-2. FECL VLF Equipment Arrangement

Where a permanent antenna installation is necessary or desirable, the standard whip specified in NAVSHIPS 900,000.101 is recommended. (This is the Navy Type 66046 or 66047.) The Tracor 599-816 Coupler should be used, as shown in figure 8-3, with the NT-66046 or NT-66047 antennas.

b. The Transmission Line. Any 50 ohm ±2 ohm armored coaxial cable may be used; however, the RG-277/U appears to best meet the requirements of the system. The overall length must be less than 100 feet from the antenna base to the receiver input. The criteria to follow for installation of armored coaxial cable are outlined in NAVSHIPS 900,000.101.

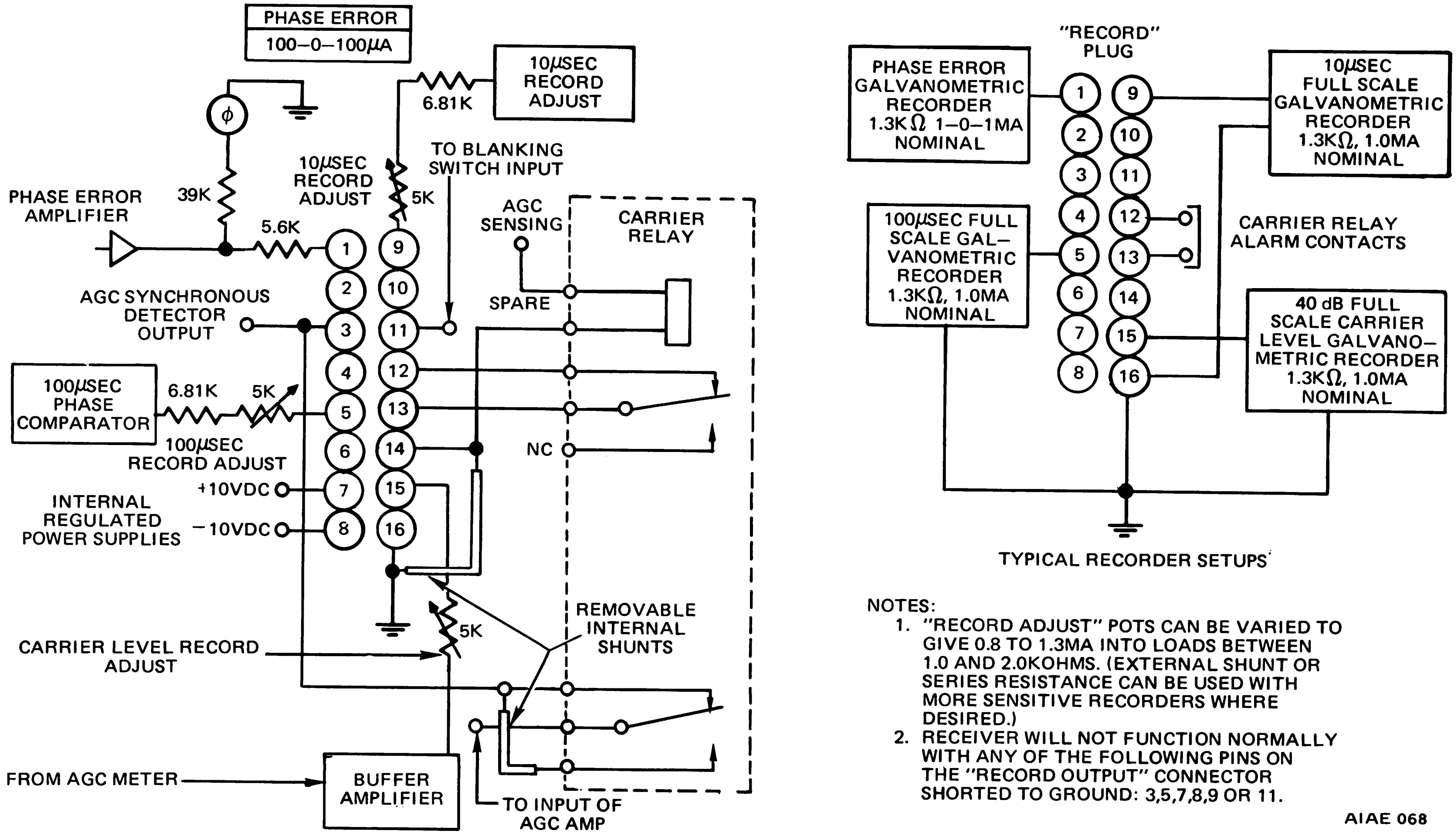
c. The Receiver. The Tracor 599-J VLF Phase Tracking Receiver requires installation in a 19-inch standard relay rack 22 inches or more deep. Interconnections and cable specifications are shown in figure 8-4.



(A) ANTENNA INSTALLATION STANDARD NAVSHIP 900,000.001. MODIFY COUPLER AS REQUIRED.
(B) TRACOR 599–825 ANTENNA – MODIFY TO ACCEPT ARMORED CONNECTOR.
(C) FABRICATE CONNECTOR BOX. ARMORED CONNECTOR TO BNC CONNECTOR. MOUNT WITHIN 6 FEET OF VLF RECEIVER.

Figure 8-3. Shipboard Installation of VLF System Intercabling

TRACOR 599–J VLF RECEIVER



NOTES:
1. "RECORD ADJUST" POTS CAN BE VARIED TO GIVE 0.8 TO 1.3MA INTO LOADS BETWEEN 1.0 AND 2.0KOHMS. (EXTERNAL SHUNT OR SERIES RESISTANCE CAN BE USED WITH MORE SENSITIVE RECORDERS WHERE DESIRED.)
2. RECEIVER WILL NOT FUNCTION NORMALLY WITH ANY OF THE FOLLOWING PINS ON THE "RECORD OUTPUT" CONNECTOR SHORTED TO GROUND: 3,5,7,8,9 OR 11.

Figure 8-4. "Record Output" Connection Diagram

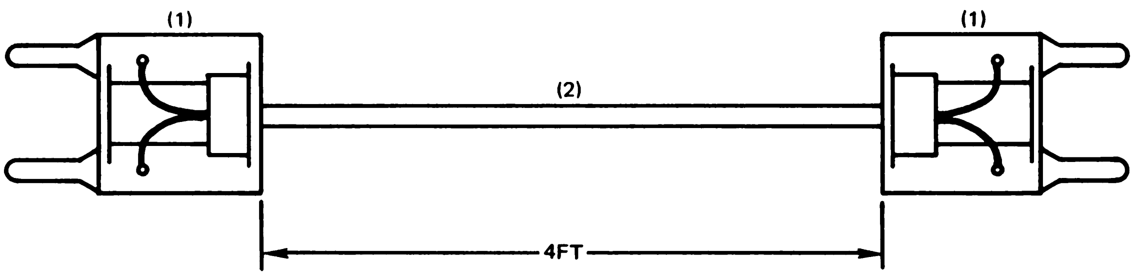
d. The Recorder. The Texas Instruments PRR-1M-A16-A-FR Recorder is supplied with a P-1 type panel for mounting in a standard 19-inch relay rack. Connect the recorder to the VLF receiver using the 100 microsecond pair of the record output cable specified in figures 8-5 and 8-6. Instructions in the recorder manual should be followed when loading the recorder with ink and paper.

e. The Oscillator. For shipboard installations, the existing AN/URQ-9 or AN/URQ-10 Oscillators are adequate. They are to be rack mounted as shown in figure 8-2. Follow the installation instructions outlined in the appropriate manual.

f. The Comparator. Tracor 527A Frequency Difference Meter or AN/URM-115 is used for shipboard installation. Follow the installation instructions contained in the manual and connect the Comparator as shown in figure 8-4.

8.7.3 Safety

Housekeeping, safety, and first aid instructions should be posted in a conspicuous location throughout the laboratory area. Danger and respiration signs are to be in accordance with MIL-P-15024B type F.



(1) PLUG, MALE, 2 PRONG BANANA PLUG, 3/4 INCH CENTER TO CENTER POMONA ELECTRONICS CO. MDP OR EQUAL
(2) TWO CONDUCTOR NO. 18 AWG 16/30 PLASTIC COVERED ALPHA NO. 1897 OR EQUAL

AIAE 070

Figure 8-5. Cable Frequency, Difference Meter to Recorder

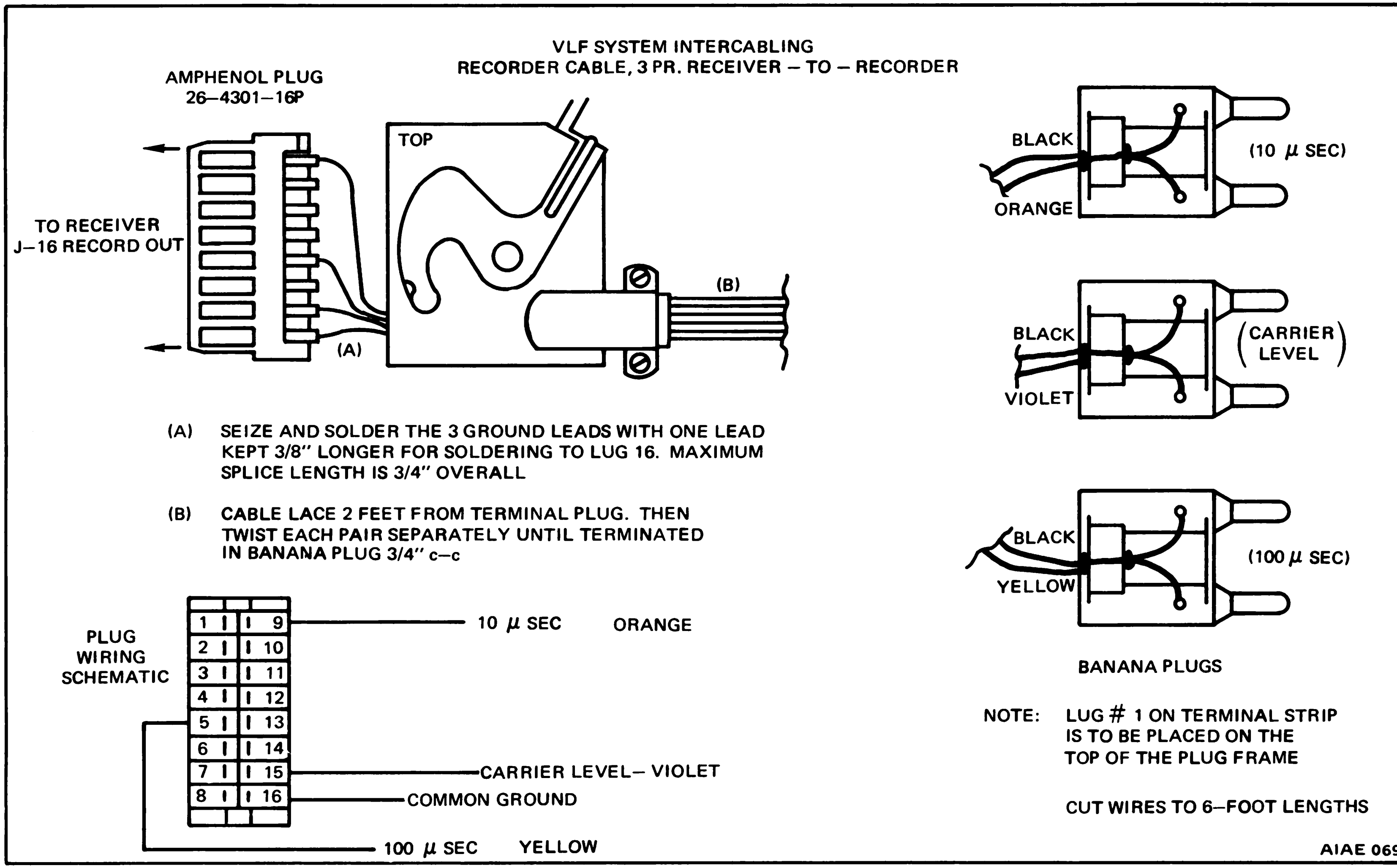


Figure 8-6. VLF System Recorder Cable

CHAPTER 9

FIELD QUALIFICATION REQUIREMENTS

NAVMAT Letter 0413:ERJ of 6 March 1972 changed the name of the Qualification Segment to Field Calibration Segment.

The Field Calibration (Qualification) Segment of the Navy Calibration Program was established to extend calibration support capability to selected ships and shore activities to ensure the accuracy and reliability of test and measuring equipment and permit users to calibrate certain items of their own low accuracy-high volume test equipment.*

Establishment of a complete Field Calibration Activity (FCA) consists of suitable working spaces, Qualification Package(s), trained personnel, and necessary support documentation (METRL, ICPs, METBULL Qualification Supplement). ICPs are provided as MRCs (Maintenance Requirements Cards) and as NAVAIR 17-20 VQ Series procedures. FCAs are identified by a three-letter identification code assigned by MEC.

Assistance in determining suitable working spaces and Qualification Packages; scheduling training, if required; obtaining support documentation; and assignment of a three-letter code should be requested from the local NAVELEX Field Calibration Technical Representative (FCTR) identified in enclosure (11) of NAVELEX INST. 9690.3.

Field Calibrations (Qualifications) are considered valid when performed by Field Calibration Activities on test equipment for which adequate Qualification Standards and Qualification Procedures have been authorized and provided and personnel have been trained. However, these Qualification Standards must be calibrated periodically by a Navy Calibration Laboratory or Standards Laboratory in order for Qualification to be valid. Qualification should be limited to those test and measuring equipments for which Qualification Procedures have been provided.

9.1 TYPES OF FIELD CALIBRATION (QUALIFICATION) ACTIVITIES

The Field Calibration (Qualification) Segment is divided into phases as follows:

- Phase A-1 - Electrical/Electronic measuring devices, such as VOMs, VTVMs, multimeters, etc. (Not including frequency response testing.)

- Phase A-2 - Same as A-1 except includes capability for response testing.

*The Metrology Engineering Center (MEC), Pomona, publishes a Quarterly Supplement Metrology Bulletin which provides latest information and updates the list of test equipment covered by the Qualification Segment.

o Phase B-2 - Pressure indicating instruments and pressure switches.

o Phase B-3 - Piston-type pressure gages.

o Phase C-1 - Oscilloscopes only.

o Phase C-2 - Electronic test and measuring equipments, such as signal generators, frequency counters, oscilloscopes, etc.

o Phase D-1 - Torque wrenches and tools.

o Phase D-2 - Cable Tensiometers.

o Phase E, F, etc. - These phases tentatively reserved for other test and measuring equipment and will be implemented as requirements dictate.

NAVELEX is presently implementing Phases A-1, A-2, and C-2. Each phase is provided as a Qualification Package; i.e., a group of standards and accessories required to perform the calibration. The Phase A-1 Qualification Package consists of a Meter Calibrator, Abbey Electronics MC-10C, or Fluke 760A, and an Autotransformer, GR W10MT3A or GR W8MT3-VM (see figures 9-1 and 9-2). Phase A-2 consists of Phase A-1 Standards and Test Oscillator HP S01-652A. The current Phase C-2 Qualification Package appears in table 9-1 (see figures 9-3, 9-4, 9-5 and 9-6).

Standards and accessories designated for exclusive use as Qualification Standards are marked with a Qualification Standards Equipment Label prior to distribution to a designated FCA. Qualification Standards can be considered true Standards because of the careful and restricted manner in which they are handled; the controlled environmental conditions under which they must be used and stowed; and the special shipping arrangements that must be made in transporting equipments to and from a higher level Calibration Laboratory for periodic calibration. Qualification Standards are submitted to a NCL or a FECL at intervals specified in the METRL.

The Qualification equipment should not be used for purposes other than Qualification. Qualification Standards should be identified and custody maintained in a manner to assure that they are used only for calibration of test and measuring equipment. The Qualification equipment should be made available for calibration of test equipment from all departments of the ship or shore activity.

The Qualification Packages do not include equipment to be used for trouble-shooting and repair. Therefore, the test equipment should be placed in operable condition before submitting for Qualification.

Qualification Packages should be kept in one location on a ship or at a shore activity. Collocation with other ship or shore functions is permissible, providing interference between the two distinct functions does not result and that all other FCA requirements are met.

Table 9-1. Phase C-2 Qualification Package

STANDARDS	MANUFACTURER	DESCRIPTION
C92-400H	H-P	EVM
HQ-180A (with modification M-44) (HQ-145A with modification M-23 alt.)	Hammarlund	Receiver
*MET D-114A		Oscp Adaptor
*MET D-114B		Oscp Adaptor
*MET D-133		RF Detector
*MET D-150		Vert. Amp. Input Fixt.
*MET KQ-1		Accessory Kit
*MET KQ-2		Accessory Kit
MV-828A or MV-928A	Millivac	RF EVM
T10AR10,000	Helipot	Var. Resistor
1A1	Tek	Dual-Trace Preamp.
2901 (Tek 184 alt.) (Fairchild 781A alt.)	Tek	Time-Mark Gen.
132A-8	E-H Labs	Pulse Gen.
270-3	Simpson	VOM
332A	H-P	Distortion Analyzer
355C Opt 001	H-P	Attenuator
355D Opt 001	H-P	Attenuator
H05-415E (H-P 415D alt.)	H-P	Stdg Wave Ind
432A (H-P 431 alt.) (PRD 686 alt.)		Power Meter
478A (PRD N6284 alt.)	H-P	Thermistor Mount
5245L	H-P	Counter
5253B	H-P	Freq. Converter
5254C (H-P 5254A alt.)	H-P	Freq. Converter
547 (Tek 545B alt.)	Tek	Oscp
KQ-1	*MET	Accessory Kit
KQ-2	*MET	Accessory Kit

*MET - Metrology Engineering Center design and procurement.

NOTE: This Package is modernized as required and as conditions warrant.

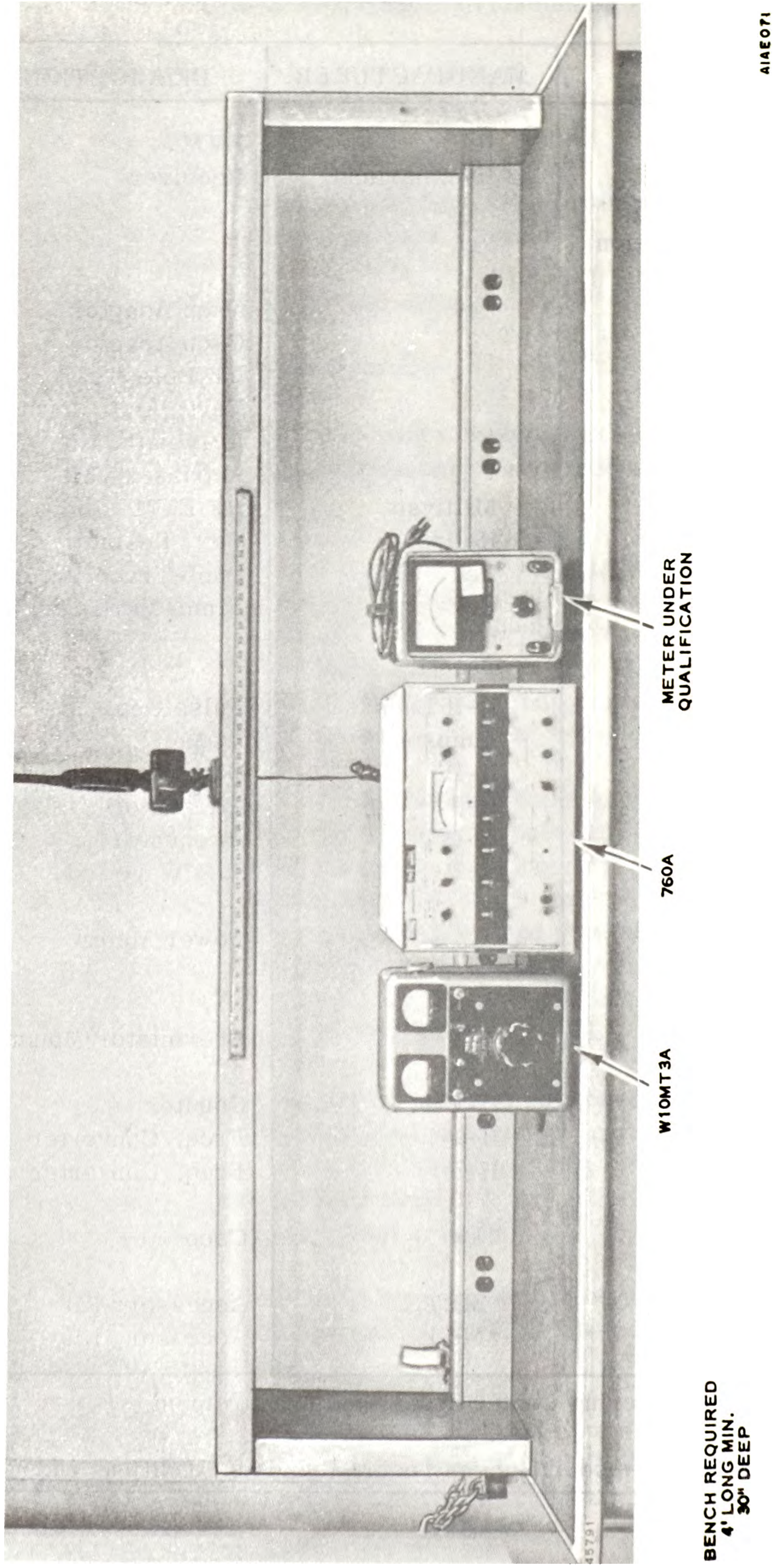


Figure 9-1. Phase A-1 Qualification Package with Fluke 760A Meter Calibrator

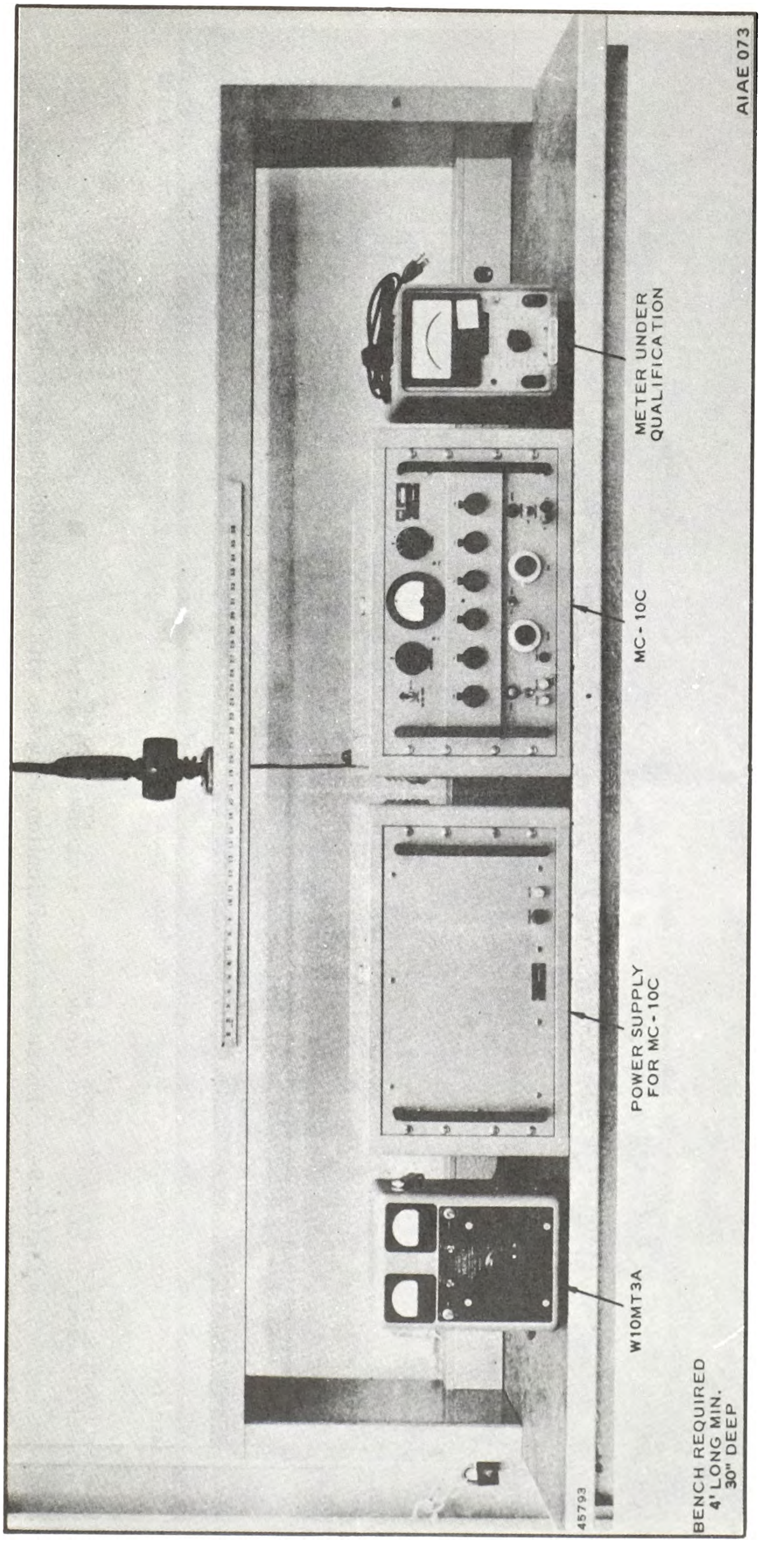


Figure 9-2. Phase A-1 Qualification Package with Abbey MC-10 Meter Calibrator

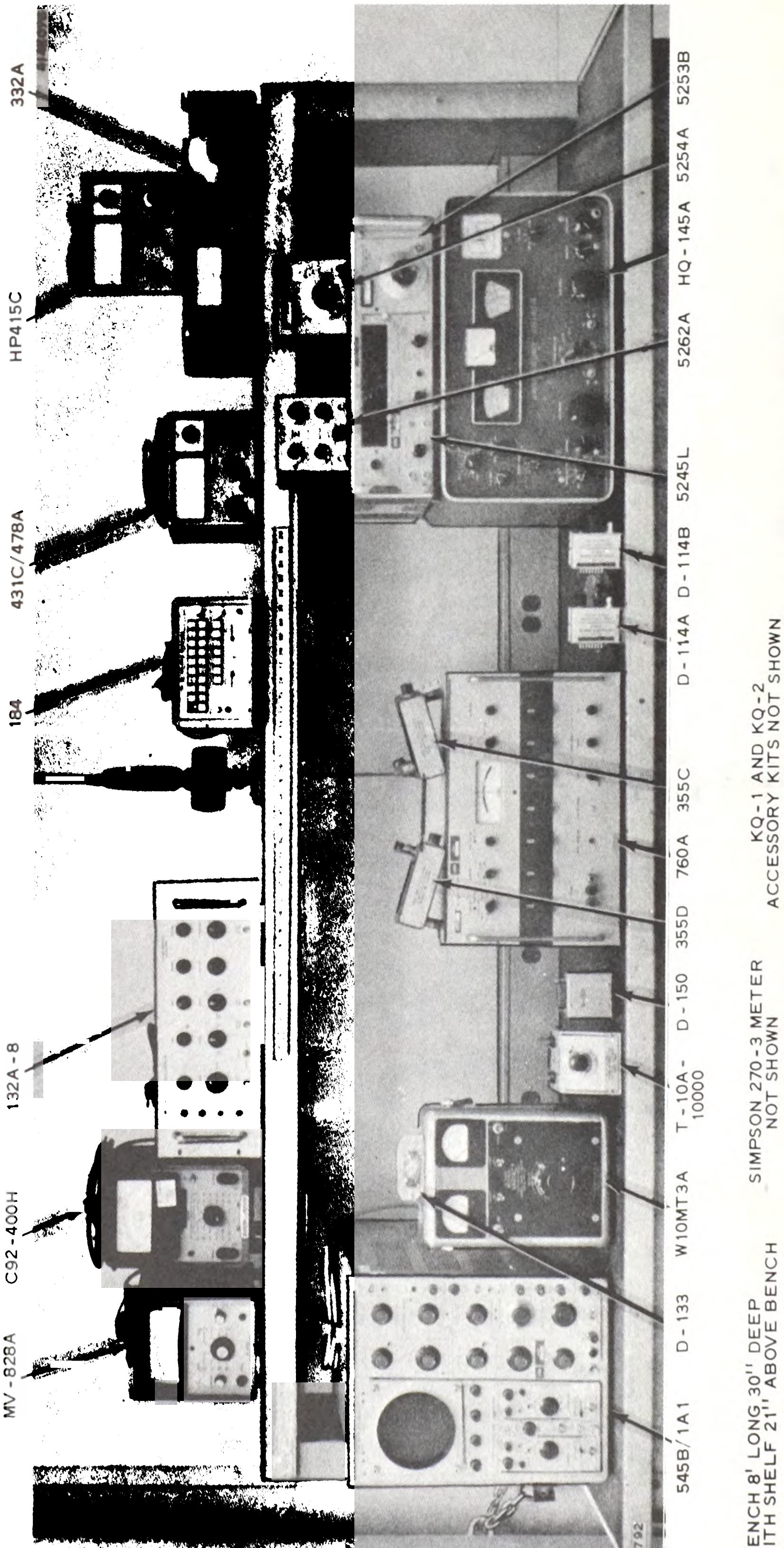


Figure 9-3. Phase C-2 Qualification Package with Fluke 760A Meter Calibrator

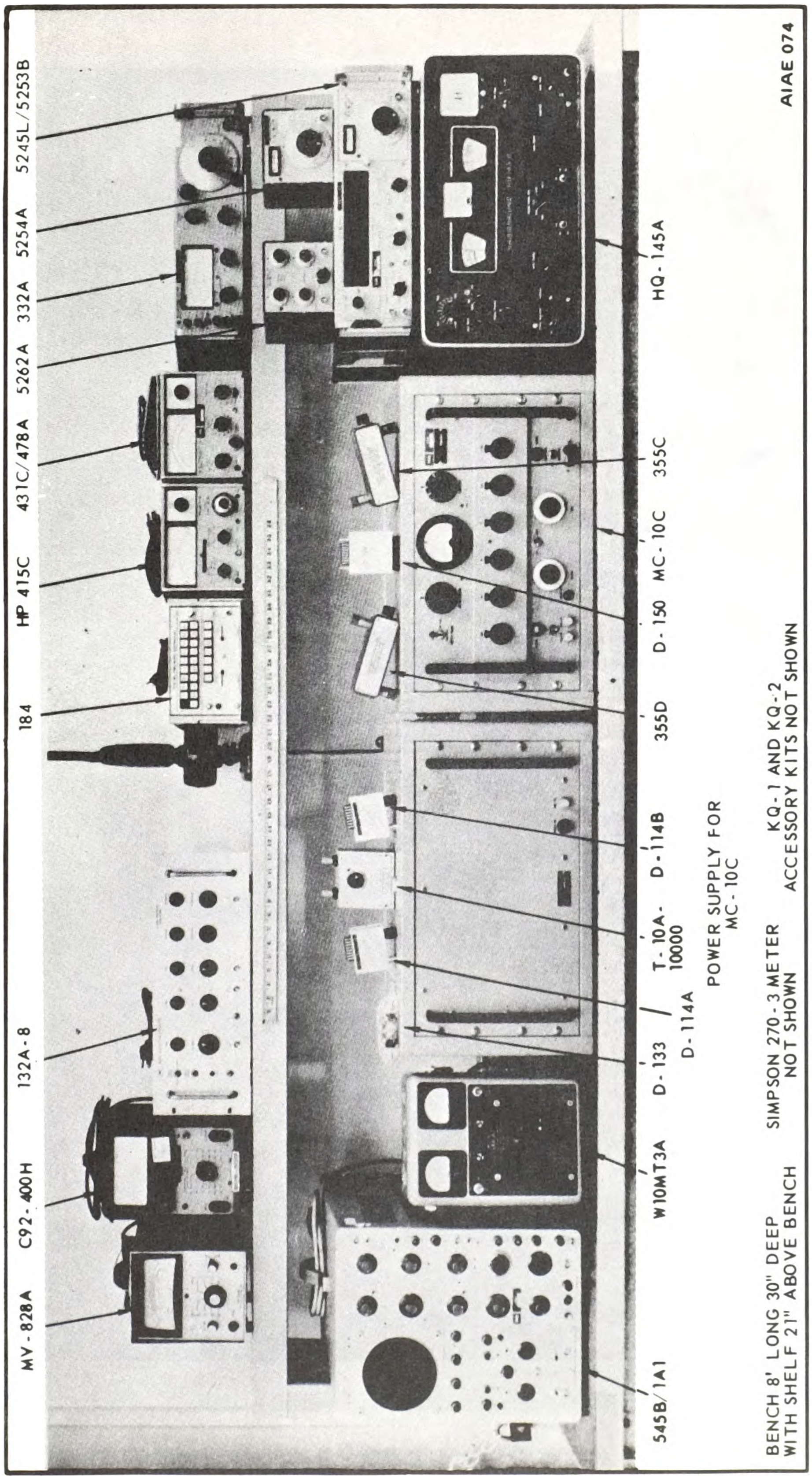


Figure 9-4. Phase C Qualification Package with Abbey MC10 Meter Calibrator

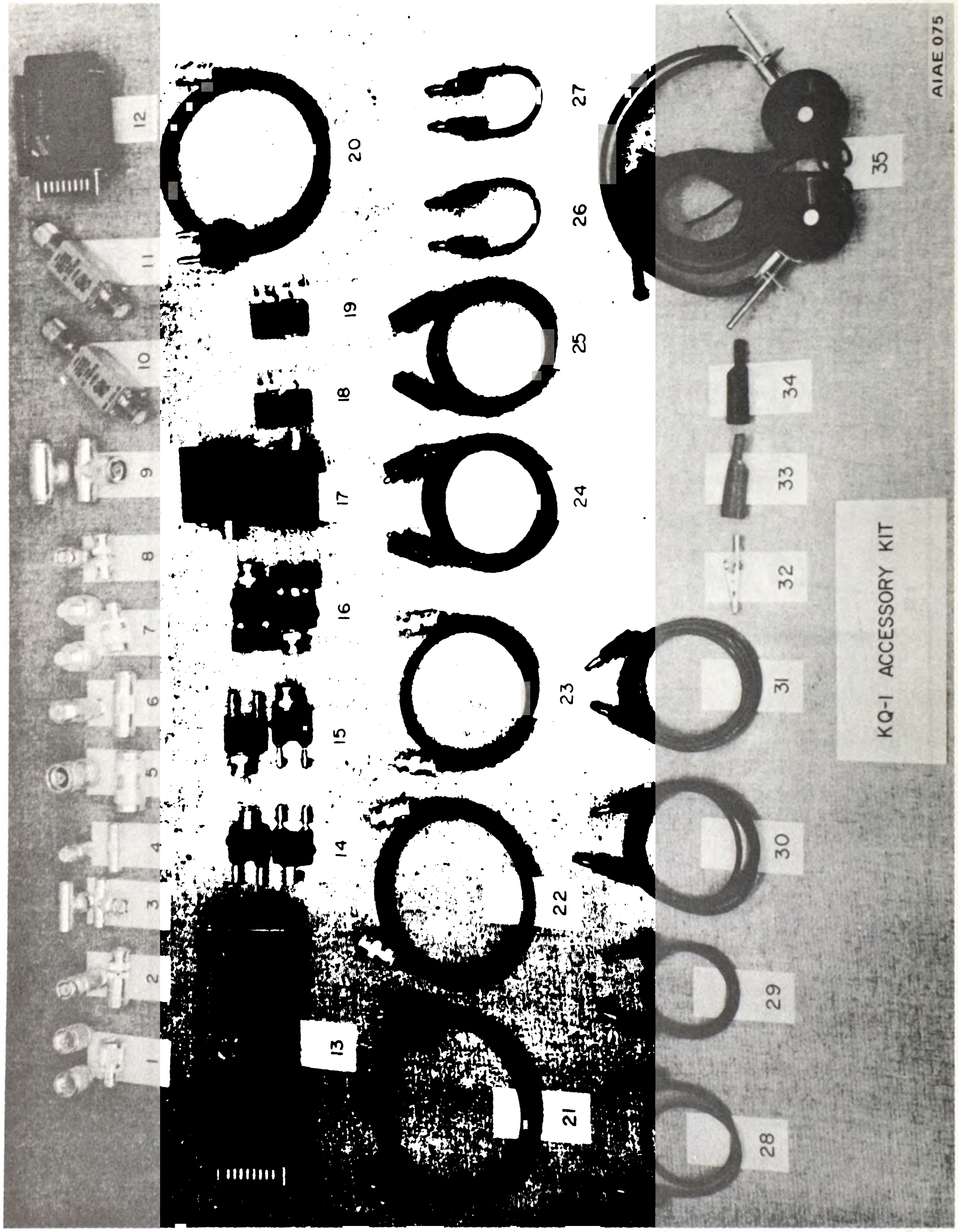


Figure 9-5. KQ-1 Accessory Kit

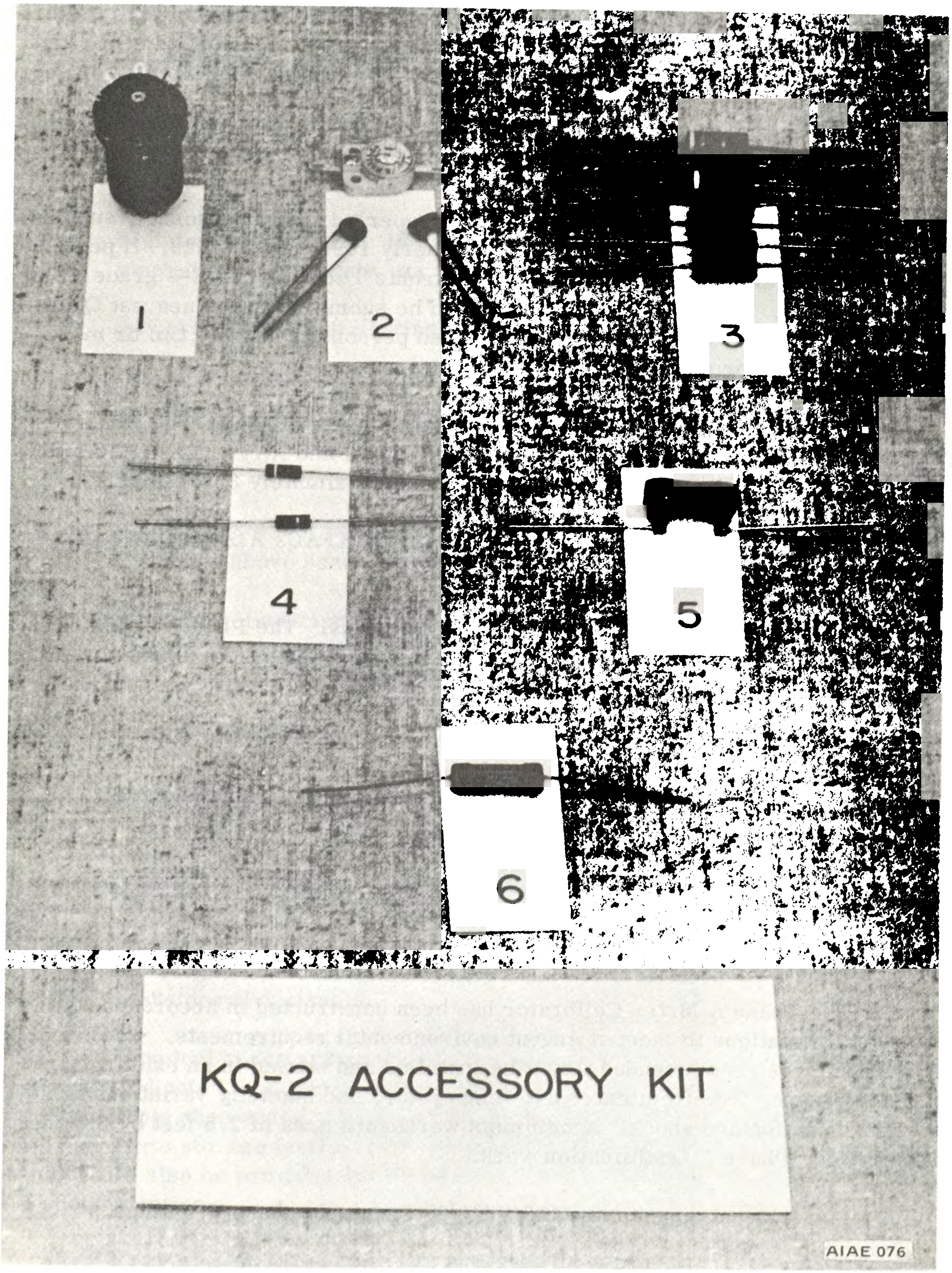


Figure 9-6. KQ-2 Accessory Kit

Ships and shore activities that have been provided with Qualification Packages are expected to support their own test equipment within the limitations of the Qualification Standards. These test equipments should only be sent to a Tender or Shore Calibration Laboratory when the Qualification does not cover required measurement ranges, in emergency situations, or when repair is beyond the capability of the ship or shore activity.

9.2 PERSONNEL REQUIREMENTS

Field Calibration should be performed only by properly trained personnel, such as, Navy Enlisted Men's Code (NEC) ET-1598 (formerly 1591) or AT-6622. If personnel in these classifications are not available, Electronic Technicians, E-4 grade or higher, should be trained. Requests for training should be submitted to the nearest Qualification Training Site. At least one properly trained person (preferably two or more) should be on board for performing Field Calibrations.

- Phase A Training Sites have been established at all Naval Shipyards (except PTSMH), NAVSHIPREPFAC YOKO, SUBIC, and GUAM and NAVELEXACT CARIB and NAVELEXSOWEST DIV. This training requires approximately 3 working days.

- Phase C Training Sites are: NAVAIREWORKFACs ALAMEDA, NORTH ISLAND, NORFOLK, PENSACOLA, and NAD OAHU.

- Phase C training takes approximately 4 weeks. The Phase A training is a prerequisite for the Phase C Qualification training. Requests for Phase C training should be submitted to the nearest METCAL GROUP.

9.3 OTHER PROGRAM DETAILS

Other details of the FCA (Qualification) Segment, such as qualification procedures and labels and tags, are found in NAVELEX INST 9690.3, enclosure (5).

9.4 MINIMUM ENVIRONMENTAL, POWER, AND SPACE REQUIREMENTS

9.4.1 Phase A

a. The Phase A Meter Calibrator has been constructed in accordance with military specifications to meet stringent environmental requirements. However, for best results, it is recommended that it be installed and stowed in an existing air-conditioned space, free from excessive temperature and humidity variations and excessive vibration and shock. A minimum workbench area of 2.5 feet by 6.0 feet is required for Phase A Qualification work.

b. Power requirements are 115 VAC/60 Hz/single phase/5.0 amps.

9.4.2 Phase C

a. Environmental Requirements:

Temperature: 65 to 90° F (continuous), ideally 75° ± 5° F

Humidity: Less than 60% relative

Atmosphere: Non-corrosive and free from salt

Lighting: Overhead, 80 to 100 foot-candles or existing lighting supplemented by bench lights, as required.

b. Power: Excluding lighting, heating, and air conditioning:

115 VAC ± 5 VAC/20 amps/single phase/60 Hz; less than 5% distortion; ± 5% line regulation. At least 25 receptacles are required.

c. Space:

Bench: 2.5 feet by 8 feet minimum. Should have a 12-inch wide shelf 21 inches above bench.

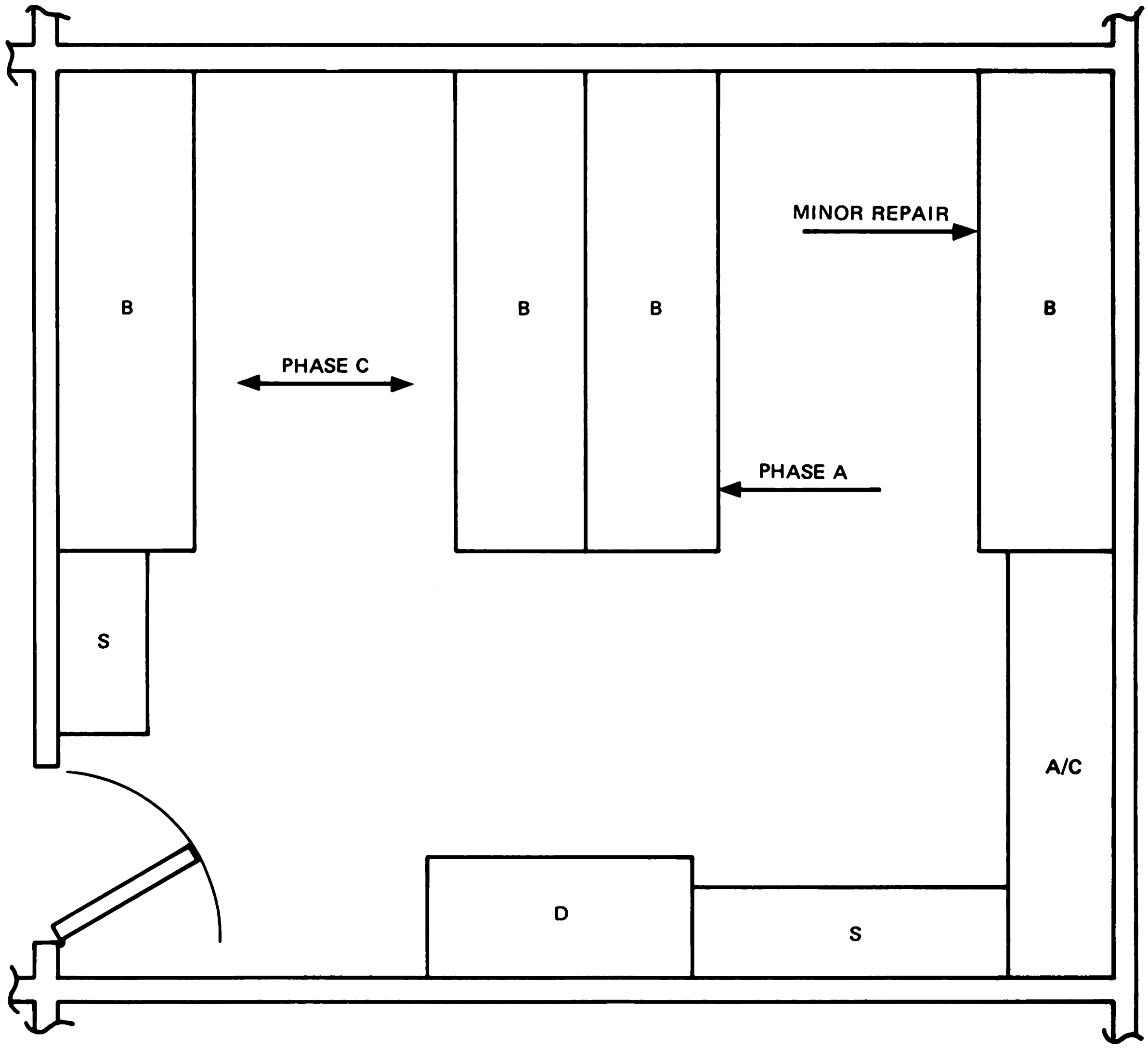
Stowage: Sufficient space to stow the Qualification Standards when not required in a particular setup and sufficient space to stow all Qualification Standards when not in use.

9.5 FIELD CALIBRATION (QUALIFICATION) ACTIVITY LAYOUTS

9.5.1 Shorebased

a. Section 9.4 establishes the minimum requirements for application of the Phase A and C Qualification Packages. Somewhat more extensive facilities are recommended for shorebased Field Calibration Activities as reasonable space is usually available. A typical facility arrangement is shown as figure 9-7. The space shown is considered adequate for Phase A-C operation. Smaller spaces may be adequate but are not considered desirable.

b. A typical space arrangement for Phase A only operation is not shown. As previously indicated, the Phase A package can be operated on a single workbench within available shop space. As the Phase A package contains only two basic components, separate storage facilities or other space considerations are not required. Space should also be provided for the stowage of associated technical and administrative documentation.



NOTES:
B – CALIBRATION BENCH – 8 PER FIG. 2–6

S – SHELVING

D – DESK OR TABLE FOR ADMINISTRATION ADMINISTRATIVE

A/C – SPACE FOR AIR CONDITIONING EQUIPMENT AS REQUIRED

AIAE 077

Figure 9-7. Phase A-C Field Calibration Activity, Shorebased, Typical Layout

9.5.2 Shipboard

a. The operation of a Phase A and C Field Calibration Activity onboard ship poses special problems because of limited available space. Figure 9-8 shows two possible configurations. The smaller arrangement is considered minimal for successful operation. The larger space would represent the ideal situation. Neither space need be a separate compartment if adjacent operations will not interfere with maintaining minimal environmental conditions. Air-conditioning equipment is not shown; however, there is enough space for installation in the larger configuration. The smaller space could be cooled, if necessary, by ducting from adjacent air-conditioned areas.

b. A Phase A only configuration is not shown for reasons discussed above. Technical and administrative documentation requirements also apply.

9.6 FIELD CALIBRATION (QUALIFICATION) ACTIVITY REQUIREMENTS CRITERIA

9.6.1 Criteria

The following criteria should be used to determine if establishment of a Field Calibration Activity is required and is economically feasible:

a. Determine the quantity of test equipment on board which can be calibrated by the desired Qualification Package. (The test equipment eligible for calibration by the respective Qualification Package is listed in the MEC Metrology Bulletin Qualification Supplement.)

b. Then apply the following formula:

(1) $C_M = Q \bullet N \bullet C \bullet C_H$

(2) $C_M = (\text{Qty of TE}) \left(\frac{\text{Cal.}}{\text{Yr.}}\right) \left(\frac{\text{Hrs.}}{\text{Cal.}}\right) \left(\frac{\text{Cost of Cal.}}{\text{Hour}}\right)$

(3) $C_T = \sum_{M=1}^{M} C_M$

where:

C_M = Calibration cost of each model of eligible Test Equipment (TE)

M = Number of models of TE

Q = Quantity of TE (same model)

N = Number of calibrations/individual TE/year (based on calibration interval in METRL)

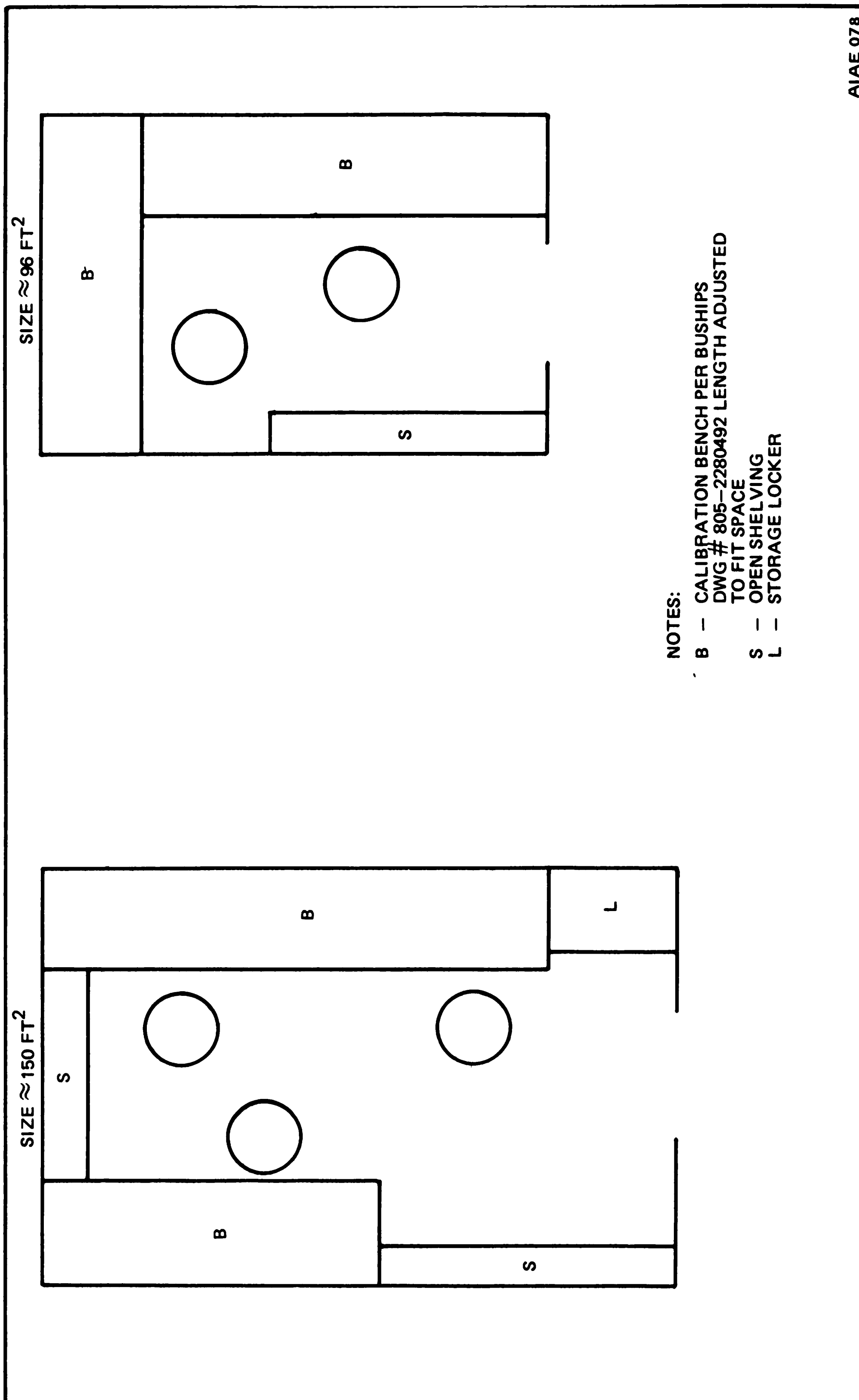


Figure 9-8. Phase A-C Field Calibration Activity, Shipboard, Typical Layout

H = Hours required to perform calibration

C_H = Calibration cost/hour (average cost = $12.00-$15.00/hr.)

C_T = Total cost of calibrating all models of test equipment on board which can be calibrated by the respective Qualification Package. This approximates the savings that may accrue to an activity as the result of becoming an FCA.

c. The cost of acquiring and owning a Qualification Package is indicated below:

Qualification Package	Acquisition Cost (Est.)	Cost of Calibration/Year (Approx.)
Phase A-1	$ 2,800	$150
Phase A-2	$ 3,600	$250
Phase C-2	$13,000	$750*

*13 Qualification Standards require higher level calibration.

d. To justify the establishment of an FCA, the savings accruing to an activity should amortize the cost of a Qualification Package in less than 2 years.

9.6.2 Fleet Requests

Requests from the Fleet for the establishment of an FCA should be addressed to NAVELEXHDQTRS via chain of command, and NAVELEX FCTR. (See NAVELEX INST. 9690.3 enclosure (11).)

9.6.3 Shore Requests

Requests from shore activities, under the technical cognizance of NAVELEX, for an FCA should be addressed to their respective HDQTRS Command, via NAVELEX FCTR, and NAVELEXHDQTRS.

9.6.4 Request Data

All pertinent information and data as noted in above paragraph 9.6.1 should be included with each request for an FCA.

APPENDIX A

CAPABILITIES OF CALIBRATION LABORATORIES

This appendix contains the Measurement Capabilities of NAVELEX Calibration laboratories and Fleet Electronics Calibration Laboratories.

- o The listed capabilities represent those typically available or planned for NAVELEX shorebased calibration laboratories and Fleet Electronic Calibration Laboratories.

- o Where a given capability is limited to only certain types of facilities, appropriate annotations are made in the remarks column.

- o Estimated uncertainties reflect accuracies attainable by the overall measurement system for which the standards or key system components are listed. Use of the equipment listed in the "Available Substitute Column" does not necessarily provide the same performance as the equipment listed in the "Standard/Key System Components" column.

- o The terms "active" and "passive" in the "Measurement Parameter" column refer to the measurement system/standard utilized and are defined as follows:

  - o Active - An active system/standard is one that internally generates a specific output or provides the required stimulus to the test equipment calibrated or to an external device, e.g., signal generator, power supply, etc. Standards such as standard resistors, standard reflections, standard capacitors, etc., are also listed as "active." Although these devices are not strictly "active" in the above sense, they can be considered as generators of known quantities of a given parameter for application to the test equipment being calibrated or to an external device.

  - o Passive - A passive system/standard is one that measures a specific input or produces a given condition when acted upon by an external stimulus, e.g., voltmeter, impedance bridge, frequency counter, etc.

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Direct Voltage (Active)	0-1111V	DC	±0.003%	Fluke 332B Voltage Calibrator	Fluke 332A	
Direct Voltage (Active) (Passive)	0-1100V	DC	±0.0015% to ±0.002%	Fluke 332A/B, 720A, 721A, 750A, 845A with ±10 ppm Voltage Ref.		NCL & FBM Tenders only
Direct Voltage (Active)	1mV-1000V	DC	±(0.05% + 25μV)	Fluke 760A Meter Calibrator	Abbey MC10C	MC10C no longer procurable
Direct Voltage (Passive)	±15mV to ±1500V	DC	±2% F.S.	HP 410C EVM		
Direct Voltage (Active)	±0-300V	DC	±0.15% to 0.25%	Ballantine 421B Mcter Calibrator	HP 738	
Direct Voltage (Passive)	1mV-1100V	DC	±0.0025% to 0.005% of input	Fluke 895A Differential Voltmeter		NCL's and FBM Tenders only
Direct Voltage (Passive)	0-1100V	DC	±0.01%	Fluke 883B		
Direct Voltage (Passive)	1mV-1000V F.S.	DC	±2%	Fluke 845AB		
Direct Voltage (Passive)	1mV-1500V	DC	±0.02% to ±0.05%	L&N 7553-5 K3 Pot. w/Eppley 100 Std. Cell and L&N 7593 Volt Box		L&N 7553-5 no longer procurable
Direct Voltage (Active)	0.01-1000V	DC	±0.2%	HP 6920B Meter Calibrator		Selected NCL and FBM only for on-site work
Direct Current (Active)	0.001-10A	DC	±(0.1% + 0.01μA)	Fluke 760A Meter Calibrator	Abbey MC10C	
Direct Current (Active)	0-50A	DC	-	Kepco 8-50 Power Supply		
Direct Current (Passive)	1μA-300A	DC	±0.02% to ±0.06%	L&N 7553-5 K3 Pot. w/L&N 4360, 4361, 4363 Current Shunts		L&N 7553-5 no longer procurable

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Direct Current (Active)	1μA-5A	DC	±0.2%	HP 6920B Meter Calibrator		Selected NCL and FBM only for on-site work
Alternating Voltage (Active)	0.001-511.110V	50, 60, 400, 800, 1000, 4800 Hz	±0.05% to ±.075% of setting	Rotec 146AG5 AC Voltage Standard	Rotec 146A	Rotec 146A no longer procurable
Alternating Voltage (Active)	0.1mV-1200V	10 Hz-110 kHz	±0.02% to ±0.2% of setting	HP 745A/745A AC Calibrator and High Voltage Amplifier	Optimation AC2021/PA2021 Weston-Rotec 146A, CVO-100, CVO-110, HVA-120	No longer procurable (Weston Rotec)
Alternating Voltage (Active)	0.001-1000V	60 Hz, 400 Hz	±(0.25% + 25μV) of setting	Fluke 760A Meter Calibrator	Abbey MC10C	MC10C no longer procurable
Alternating Voltage (Active)	0.01-1000V	60 Hz	±0.4% + 1 digit	HP 6920B Meter Calibrator		Selected NCL and FBM only for on-site work
Alternating Voltage (Active)	Freq. response to 3V into 50 Ohms 0-1000V (ABS)	10 Hz-10 MHz (Freq. Response) 400 Hz, 1000 Hz (ABS)	0.25%-1.75% (Freq. Response) 0.3% ABS	HP S01-652A Oscillator with Ballantine 421B Meter Calibrator	HP 738, 739 & 200 SR	
Alternating Voltage (Passive)	0.001V-1000V	5 Hz-100 kHz	0.1% to 1% of input	Fluke 883AB Differential Voltmeter	Fluke 803, 887AB	
Alternating Voltage (Passive)	0.001-300V	5 Hz-4 MHz	±1% F.S. to ±5% F.S.	HP C92-400H VTVM	HP 400H, HP 400L	
Alternating Voltage (Passive)	0.5-300V	20 Hz-700 MHz	±3% F.S. to ±10% F.S.	HP 410C EVM	HP 410B	
Alternating Voltage (RMS) (Passive)	0.01-1100V	2 Hz-1 MHz	±0.05% to ±3%	Fluke 931B RMS Differential Voltmeter		
Alternating Voltage (Passive)	0.001-3V	100 kHz-400 MHz	±3% to ±10%	Millivac MV928A RF Voltmeter	MV 828A	
Alternating Voltage (Passive) (Freq. Response)	0.25V-10V	15 Hz-30 MHz	0.05% to 0.5%	MET D8 Coax. Thermal Voltmeter		

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Alternating Voltage (Active) (Freq. Response)	1μV–0.1V	DC - 500 MHz	1% - 5% (Freq. Resp)	MET D-39 Micropotentiometer		
Alternating Voltage (Passive)	0.25-1000V	5 Hz-1 MHz	±0.007% to ±0.2% (Transfer Acc)	Fluke 540B Thermal Transfer Standard	Holt Model 6,6A	
Alternating Voltage (Passive)	0-1200V	20 Hz-30 MHz	±0.003% to 1% (Transfer Acc)	Holt 11 Transfer Std		Reference only
Alternating Current (Active)	2.5-100A	30 Hz-10 kHz	-	Altec 1570BN Amplifier		
Alternating Current (Active)	1μA-10A	60 and 400 Hz	±(0.25% + 0.025μA)	Fluke 760A Meter Calibrator	Abbey MC10C	
Alternating Current (Passive)	2.5 mA-20A	5 Hz-100 kHz	±0.03% (Transfer)	Fluke 540B Thermal Transfer Std with A40 Current Shunts	Holt Model 6,6A with HCS-1 Current Shunts	
Alternating Current (Active)	1μA-5A	60 Hz	±0.4% + 1 digit	HP 6920B Meter Calibrator		Selected NCL and FBM only for on-site work
Resistance (Passive) (Bridges)	0.1 mΩ-120 MΩ	-	50 ppm (Nom) (±0.005%)	ESI 242B Resistance Meas. System	ESI 242C, L&N 4232B	
Resistance (Passive) (Bridges)	0.1 mΩ-12 MΩ	-	±0.1% + 1 div.	ESI 250DE Impedance Bridge		
Resistance (Passive) (Bridges)	0.0001-110.1Ω	-	±0.05% ± V	L&N 4287 Kelvin Bridge	L&N 4285 Kelvin Bridge	
Resistance (Active) (Resistance Decades)	0-1,111,110 ohms (1-ohm step)	-	±(0.02% + 2mΩ)	GR 1433B Decade Resistor	GR 1432B, ESI DB62, GR 1432P	
Resistance (Active) (Resistance Decades)	0-11,111.1 ohms (0.01 step)	-	±(0.02% + 2mΩ)	GR 1433W Decade Resistor	GR 1432W, ESI DB62, GR 1432N	
Resistance (Active)	1,10,100,1000,10K, 100K ohms	-	±0.002%	ESI Type SR-1 Series Standard Resistors	L&N 4000 Series	

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Resistance (Active)	10KΩ	-	±0.0005% (Nom.)	ESI SR 104 Resistance Standard		NCL only obtain from Type I NSL
Resistance (Active)	1KΩ/step, 10Ω/step	-	+0.005% (Nom.)	ESI SR1010, SR 1010/LTC Resistance Transfer Standards		NCL only obtain from Type I NSL
Resistance (Active)	1Ω-10^9Ω	-	±0.5% 1Ω to 300KΩ ±2% above 300KΩ	MET D-140 Ohmmeter Calibrator		
Resistance (Active)	10MΩ (1M steps)	-	±0.01%	Angstrohm RC 106P Resis. Trans. Std.	Gen. Res 105T	
Resistance (Active)	100 MΩ, 10M steps	-	±0.02%	Angstrohm RC107P Resis. Trans. Std.	Gen. Res 106T Shallcross 980	
Ratio, AC (Active)	0.0001 to 1.1111	50 Hz-10 kHz	±0.001% (50-3000 Hz)	Gertsch RT60 Ratio Transformer	Gertsch RT5	
Ratio, AC (Active)	0.0000001 to 1.1111110	50 Hz-10 kHz	±0.0001% (50-1000 Hz)	Gertsch 1011R Ratio Transformer		
Ratio, DC (Active)	Input 1100V-1V Output 1100V-0.1V	DC	±0.0005% of output (NOM)	Fluke 750A Reference Divider		NCL and FBM only
Ratio, DC (Active)	0-1.0	DC	±0.1 ppm (linearity)	Fluke 720A Kelvin Varley Divider		NCL and FBM only
Ratio, DC (Active)	3-1500V	DC	±.02%	L&N 7593 Volt Box	L&N 7592S	
Ratio, DC (Active)	0-1.000000	DC	±0.2-1 ppm (linearity)	ESI RV722 Kelvin Varley Divider		
Inductance (Passive) (Bridges)	0.1μH-1200H	1000 Hz	±0.2% + 1 div. + 1.2%/Q	ESI 250DE Impedance Bridge	ESI 250DA, ZM-11 Series	
Capacitance (Passive) (Bridges)	0.1pf-1.1μf 0.00002 to 0.56 Dissipation Factor	30 Hz-300 kHz	±0.1% ±2%	GR 716C Capacitance Bridge		

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Capacitance (Passive) (Bridges)	0-1200μf 0-1.05 Dissipation Factor	1 kHz	±0.2% ±1%	ESI 250DE Impedance Bridge		
Capacitance (Active)	100pf-1.11μf	1 kHz	±0.05% ± 0.05 pf	GR 1423A Decade Capacitor	GR1423AM	
Capacitance (Active)	50-1100pf	1 kHz	±0.1%	GR 1422MD Precision Capacitor	GR722MD	
Frequency (Passive)	-	0-50 MHz	±1 Hz, 0-1 MHz	HP 5245L Counter	HP 524, AN/USM207	
Frequency (Passive)	-	50 MHz-512 MHz	±1 Hz/MHz, 1 MHz-18 GHz	HP 5245L w/HP5253B Converter		
Frequency (Passive)	-	150 MHz-3 GHz		HP 5245L w/5254C Converter		
Frequency (Passive)	-	3-12.4 GHz		HP 5245L w/5255A Converter		NCL only
Frequency (Passive)	-	50 MHz-18 GHz		HP 5245L w/5257A Transfer osc plug-in	HP 2590B HP 540B	
Frequency (Passive-Active)	VLF	100 kHz, 1 MHz, 5 MHz	$\pm 5 \times 10^{-11}$	TRACOR 599J VLF Receiver		
				TRACOR 527A Freq. Diff. Meter	AN/URM-115 FR 140/URM	
				AN/URQ-9/10 Std. Oscillator	GR 1115C	
				Texas Inst. PRR1M16FR Recorder		
				TRACOR 599-825 VLF Antenna		
				Freq. Comparison System	MET D-147	Selected NCL only

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Frequency (Passive)	-	0.96-4.2 GHz	±0.17%	HP 536A Coax. Freq. Meter	FXR N410A	
Frequency (Passive)	-	3.7-12.4 GHz	±0.17%	HP 537A Coax. Freq. Meter	FXR N414A	
Frequency (Passive)	-	3.95-5.85 GHz	±0.065%	HP G532A W/G Freq. Meter		NCLs only
Frequency (Passive)	-	5.3-8.2 GHz	±0.065%	HP J532A W/G Freq. Meter		NCLs only
Frequency (Passive)	-	7.05-10 GHz	±0.0.75%	HP H532A W/G Freq. Meter		
Frequency (Passive)	-	8.20-12.4 GHz	±0.08%	HP X532A W/G Freq. Meter		
Frequency (Passive)	-	12.4-18.0 GHz	±0.10%	HP P532A W/G Freq. Meter		NCLs only
Frequency (CW) (Active)	3.16V into 50Ω	10 Hz-10 MHz	±2% to ±3% (Freq.)	HP S01-652A Test Oscillator		
Frequency (CW) (Active)	10V 600 ohms	5 Hz-600 kHz	±2% (Freq.)	HP 200CD Test Oscillator		
Frequency (CW) (Active)	3V 50 ohms	50 kHz-65 MHz	±1% (Freq.)	HP H19-606B HF Signal Generator	HP H19-606A	
Frequency (CW) (Active)	100-300 mW	50-500 MHz	±1% (Freq.)	GR 1363 VHF Oscillator	GR 1215C, 1215B, 1209BL, 1209CL	
Frequency (CW) (Active)	1V, 50 ohms	10-480 MHz	±0.5% (Freq.)	HP H03-608E Signal	HP 608C, HP 608D	
Frequency (CW) (Active)	25-200 mW	10-500 MHz	±2% (Freq.)	HP 3200B VHF Oscillator		
Frequency (CW) (Active)	50W	10-50 MHz	±1% (Freq.)	Microdot 445 Power Oscillator w/MOD 184 plug-in		
Frequency (CW) (Active)	50W	50-200 MHz	±1% (Freq.)	Microdot 445 Power Oscillator w/MOD 185 plug-in		

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Frequency (CW) (Active)	50W	200-500 MHz	±1% (Freq.)	Microdot 445 Power Oscillator w/MOD 186 plug-in	Microdot 408B, Sierra 470A-500	
Frequency (CW) (Active)	50W	500-1000 MHz	±1% (Freq.)	Microdot 445 Power Oscillator w/MOD 187 plug-in		
Frequency (CW) (Active)	0 to -127 dBm	450-1230 MHz	±1% (Freq.)	HP 612A Sig Gen		
Frequency (CW) (Active)	100-200 mW (Nom)	450-1050 MHz	±1% (Freq.)	GR 1361A VHF Oscillator	GR 1361A	
Frequency (CW) (Active)	+10 dBm to -127 dBm	0.8-2.4 GHz	±0.5% (Freq.)	HP H16-8614A Sig Gen	HP 8614A, HP 614A	
Frequency (CW) (Active)	25-50 mW (Nom)	0.95-2.4 GHz	±0.5% (Freq.)	Polarad 1205 Sig Source	GR 1218, FXR L772	
Frequency (CW) (Active)	+10 dBm to -127 dBm	1.8-4.5 GHz	±0.5% (Freq.)	HP 8616A Sig Gen	HP 616	
Frequency (CW) (Active)	25-50 mW (Nom)	1.95-4.2 GHz	±0.5% (Freq.)	Polarad 1206 Sig Source	GR 1360	
Frequency (CW) (Active)	25-50 mW (Nom)	3.8-8.2 GHz	±0.5% (Freq.)	Polarad 1207 Sig Source	Sperry 2K43	
Frequency (CW) (Active)	0 to -127 dBm	3.8-7.6 GHz	±1.0% (Freq.)	HP 618C Sig Generator	HP 618B Varian X-26F, X-26B	
Frequency (CW) (Active)	25-50 mW (Nom)	6.95-11.0 GHz	±0.5% (Freq.)	Polarad 1208 Sig Source	FXR X772A	
Frequency (CW) (Active)	100-200 mW (Nom)	8.2-12.4 GHz	-	Varian X13 Klystron		NCL only
Frequency (CW) (Active)	100-200 mW (Nom)	7.5-11.0 GHz	-	Varian X13B Klystron		NCL only
Frequency (CW) (Active)	100-200 mW (Nom)	12.4-18.0 GHz	-	Varian X12 Klystron		NCL only

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Frequency (Pulsed, Squarewave and Miscellaneous Sig Generators/Sources)	0-30V P-P (Open Circuit)	0.0005 Hz-5 MHz	1% (Freq.)	HP 3310 (Function Generator)	HP 202A	
Frequency (Pulsed, Squarewave and Miscellaneous Sig. Generators/Sources)	0.1μs-5s Markers 0.5V (min.)		10 MHz ±10 ppm 3ppm stability	Tektronix 2901 Time Mark Generator	Tektronix 184, 180	
Frequency (Pulsed, Squarewave and Miscellaneous Sig. Generators/Sources)	50V 50Ω	5 Hz-3.5 MHz	10ns RT	E-H 132A8 Pulse Generator	HP211A	
Frequency (Pulsed, Squarewave and Miscellaneous Sig. Generators/Sources)	5V 50Ω 30V 600Ω	1 Hz-10 MHz	<5ns R.T. 5V 50Ω <70ns R.T. 30V 600Ω	HP 211B Squarewave Generator	HP 211A	
Frequency (Pulsed, Squarewave and Miscellaneous Sig. Generators/Sources)	175mV 50Ω	2μs (pulse width) >100 kHz prf	<100ps R.T.	HP 213B Pulse Generator		
Time Interval (Passive)	1μs-10^8s	-	±1 Count ± counter time base accuracy	HP 5245L s/5262A		
Phase (Passive)	0-360°	50 Hz-50 kHz	±0.1 degree	Dranetz 305C Digital Phase Meter	MAXON 901/1010	MAXON 901, no longer procurable NCL & FBM only
Phase (Passive-Active)	0-360°	30 Hz-10 kHz	±0.2° to .06° (depending on range & freq.)	DYTRONICS 311/RT1/717 Phase Angle Standard		FBM Ref Labs
Phase (Passive-Active)	0-360°	4 Hz-500 kHz	±0.03°, 4 kHz-30 kHz ± F/10^3 where F = freq in kHz	DYTRONICS 312		Ref Labs Only
Phase (Active)	0-360°	20 Hz-10 kHz 10 Hz-20 kHz	±1% ±3%	ACTON 709A Phase Shifter		NCL and FBM only
Distortion, Signal, and Spectrum Analysis	0.1-100% (F.S.)	5 Hz-600 kHz	±3% to ±12% (depending on range)	HP 332A Distortion Analyzer	HP330B	

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Distortion Signal and Spectrum Analysis		20 Hz-50 kHz	±5% (amplitude) + (1% + 5Hz) Freq.	HP 302A Wave Analyzer		
Distortion Signal and Spectrum Analysis	-140 dBm max	1 kHz-110 MHz	±0. 8 dB amplitude ±10 Hz Frequency	HP 141T w/8552B, 8553B Spectrum Analyzer		Selected NCLs only
Waveshape (Oscilloscopes)	-	DC - 500 kHz	-	HP 130C Oscilloscope		
Waveshape (Oscilloscopes)	-	DC - 50 MHz	-	Tektronix 547 Oscilloscope w/1A1, W, and 1S1 plug-ins	TEK 545A/B, AN/USM-140 HP 150A and associated plug-ins	NCLs and FBM only for 1S1 and with plug-ins
Waveshape, Reflection Coefficient (Oscilloscopes)	Reflection Coeff. greater than 0. 001	Risetime less than 150 ps	±3% (attenuator) ±5% (distance scale)	HP 140A Oscilloscope w/1415A TDR Plug-in		NCLs only
VSWR (Active)	1. 2 VSWR	3. 95-5. 85	±0. 01 VSWR	Maury G320D Std Mismatch	FXR H510D	NCLs only
VSWR (Active)	1. 2 VSWR	5. 85-8. 20	±0. 01 VSWR	Maury C320D Std Mismatch	FXR C510D	NCLs only
VSWR (Active)	1. 2 VSWR	7. 05-10. 0	±0. 01 VSWR	Maury H320D Std Mismatch	FXR W510D Narda 411-10	
VSWR (Active)	1. 2 VSWR	8. 2-12. 4	±0. 01 VSWR	Maury X320D Std Mismatch	FXR X510D HP X916C	
VSWR (Active)	1. 2 VSWR	12. 4-18. 0 GHz	±0. 01 VSWR	Maury P320D Std Mismatch	FXR Y510D Narda 409-10	NCLs only
VSWR (Passive) Coaxial	1. 01-2. 0 (VSWR)*	1 MHz-1200 MHz	±0. 005 to ±0. 078 (VSWR)	ANZAC RB-3 (MOD) with HP 8405A Vector Voltmeter or HP 415E	HP 415C, 415D	*VSWR from 2. 0 to 10. 0 at reduced accuracy
VSWR (Passive) Coaxial	1. 01-2. 0 (VSWR)*	20 MHz-1 GHz	±0. 05 to ±0. 08 (VSWR)	PRD 219 Standing Wave Detector w/HP 415E	HP 415, 415D	*VSWR from 2. 0 to 10. 0 at reduced accuracy
VSWR (Passive) Coaxial	1. 01-2. 0 (VSWR)*	500 MHz-4 GHz	±0. 05 to ±0. 08 (VSWR)	HP 805C Slotted Line w/HP 415E	HP 415C HP 415D	*VSWR from 2. 0 to 10. 0 at reduced accuracy
VSWR (Passive) Coaxial	1. 01-2. 0 (VSWR)*	1. 2-18. 0 GHz	±0. 03 VSWR to ±0. 06 (1-10 GHz) ±0. 04 to 0. 07 (VSWR) 10. 0-18. 0 GHz)	Alford 3050 Slotted Line w/HP 415E	HP 806B	HP 806B no longer procurable

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
VSWR (Passive) Waveguide	1.01-2.0 VSWR*	3.95-18.0 GHz	±0.02 to ±0.04	HP 810B Series Slotted Section w/HP 415E	HP415C, 415D	FECL 7.05-10 GHz, 8.2-12.4 GHz only. *VSWR from 2.0-10.0 at reduced accuracy
Attenuation (Active) Coaxial	10 dB Step	30 MHz	±.009 dB	NBS SA-1		For VM-3 cal obtain from Type I NSL (NCL only)
Attenuation (Active) Coaxial	12 dB, 1 dB Steps	DC - 1 GHz	±0.1 dB at 1 kHz ±0.25 dB 0-500 MHz ±0.35 dB 0-1 GHz	HP 355C, OPT 001		
Attenuation (Active) Coaxial	120 dB, 10 dB Steps	DC - 1 GHz	±0.2 dB 0-80 dB at 30 MHz ±1.5-3.0 dB, 0-1 GHz	HP 355D, OPT 001		
Attenuation (Active) Coaxial	3-6-10-20 dB	DC - 18 GHz	*±0.01 dB + 0.05% at 30 MHz ±0.1 dB to ±0.2 dB 100 MHz-9 GHz	Weinschel AS-6 Precision Attenuator Set	HP H43-11582A Weinschel AS-1, AS-4	*Type I or II NSL Cal
Attenuation (Active) Waveguide	0-50 dB	2.6-18.0 GHz*	±2% or 0.1 dB ±0.05 dB or 0.5%**	HP 382 Series Precision Variable Attenuators		*7.05-10 GHz, 8.2-12.4 GHz only for FECL **Type I NSL Cal.
Attenuation (Passive) Coaxial	0-100 dB	0.5 MHz-500 MHz	±0.2 dB to ±1.5 dB	HP 355C/D VHF Attenuator w/Hammarlund HQ180A, Comm. Electr. 907/FE25-3 Receivers	HQ 145A, HR060 Receivers	
Attenuation (Passive) Coaxial	0-50 dB	0.2-10 GHz	±0.1 dB/10 dB or ±0.1 dB	HPH05-415E SWR Meter w/ Associated Bolometer mount and accessories	HP 415D, 415E Weinschel BA-5 or CF-1, BA-1 and IN-1	Audio Substitution method
Attenuation (Passive) Waveguide	0-100 dB	2.6-18.0 GHz	±0.1 dB to ±0.8 dB	Weinschel VM-3 with associated mixers and accessories	Narda 61A1A, 61A1B	Parallel IF substitution method
Attenuation (Passive) Signal Source Attenuators (Coaxial)	-20 to -40 dBm -50 to -80 dBm -90 to -100 dBm	30 MHz-10 GHz	±0.2 dB ±0.3 dB ±0.4 dB	Weinschel VM-3 with associated mixers and accessories	Narda 61A1A, 61A1B	Parallel IF Substitution

MEASUREMENT PARAMETER	RANGE	FREQUENCY	ESTIMATED UNCERTAINTY	STANDARD/KEY SYSTEM COMPONENTS	AVAILABLE SUBSTITUTES	REMARKS
Attenuation (Passive) Signal Source Attenuator (Waveguide)	-20 to -40 dBm -50 to -80 dBm -90 to -100 dBm	2.6-18.0 GHz	±0.2 dB ±0.3 dB ±0.4 dB	Weinschel VM-3 with associated mixers and accessories	Narda 61A1A, 61A1B	Parallel IF Substitution
RF-Microwave Power (Passive)	10μW-10mW	10 MHz-10 GHz Coaxial	±4% to ±12%	HP 432A w/478A Power Meter & Therm. Mount	HP 431C	
RF-Microwave Power (Passive)	10μW-10mW	2.6-18.0 GHz	±4% to ±12%	HP 432A w/486 Series Thermistor Mount	HP 431C	FECLs 7.0-10 GHz & 8.0-12.4 GHz only
RF-Microwave Power (Passive)	10mW-10W	0-12.4 GHz	±2% to ±11%	HP 434 Calorimetric Power Meter		
RF Power (Passive) (RF Wattmeter Cal)	0-50W 0-150W 0-1000W	30-500 MHz 60 Hz + RF 15-500 MHz	±5%	Microdot 445 w/184, 185, or 186 plug-in, Narda 3000 series Directional Coupler & HP 431C/432 Power Meter w/478A Thermistor Mount		
RF Power (Passive)	0-50W	144-470 MHz	±5%	Sierra 164B w/180A470 Plug-in		
Microwave Power (Active) (Test Set Power Input Cal)	1mW-1W	8.2-12.4 GHz	2-2.5%	*MET-D-63A (Bolometer Coupler Unit) w/HP431C/432A		*Cal by Type I NSL
Microwave Power, Coaxial (Bolometer Mount Cal)	1mW or 10mW	10 MHz-10 GHz	±4% (Cal Factor)	*HP 478A Coax. Therm. Mt. w/HP431C/432A		*Cal by Type I NSL
Microwave Power, Waveguide (Bolometer Mount Cal)	1mW or 10mW	2.6-18.0 GHz	±2.5% (Cal Factor)	*HP 486A Series Therm. Mt. w/HP 431C/432A		*Cal by Type I NSL
Power (Pulsed) (Active)	To 5 kW	920-1250 MHz	±0.5% (Freq)	Narda 18500-21042 Pulsed Source		
Power (Peak Pulsed) (Passive)	10-200mW 100mW 100W-5 kW	50-2000 MHz 920-1250 MHz 920-1250 MHz	±1.5 dB ±0.3 dB ±0.6 dB	HP 8900B Peak Power Meter with Narda 18500-21042 Pulsed Power Source and Narda 2936 Variable Directional Coupler		
Power (Peak Pulsed) (Passive)	10-100mW 100mW-10 kW	100 MHz-4 GHz 100 MHz-11 GHz 100 MHz-4 GHz 100 MHz-11 GHz	±0.25 dB ±0.6 dB ±0.45 dB ±0.80 dB	Pacific Meas. PMI 1018 Peak Power Meter w/Narda 18500-21042 Pulsed Power Source and Directional Coupler		NCLs only

APPENDIX B

FECL EQUIPMENT REQUIREMENTS

This appendix contains the Minimum Equipment Requirement List (MERL) of Fleet Electronic Calibration Laboratories (FECL).

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
1		AN/URQ-10		AN/URQ-9			Frequency Standard	2	2	2	2	NAVSHIPS Controlled item.
2	ALFORD	3050	CAQI CAQI CAQI	805C Opt C-11 K18-805()w/ 806B			Coaxial Slotted Line 0.5 - 4 GHz	1	1	1	1	
3	ANZ	HFK417	ANZ	HFK20RW			Balanced Mixer 10 - 1000 MHz	1	1	1	1	
4	ANZ	RB3 MOD					VSWR Detector	1	1	1	1	
			CBES	219								
			CBES	330LL			Calibrated Susceptance	1	1	1	1	
			CBES	3302			Calibrated Susceptance	1	1	1	1	
5					CAG CAG	716CM, 716CSM1 740B	Capacitance Bridge	*	*	*	*	*Allowed if on board. No known requirement. Replaced by item 194.
6			CAG	874MRL	CAG	874MR	Rectifier Mixer	*	*	*	*	*Allowed if on board.
7	CAG	1201C			CAG	1201B	Regulated Power Supply	-	-	-	1	FBM Tenders only.
8	CAG	1203B					Power Supply 50 ma	1	1	1	1	
9	CAG	1216A					30 MHz IF Amplifier	1	1	1	1	
10	CAG	1217C	CAG	1217B			Pulse Generator 0.1μs - 1 sec	1	1	1	1	
11	CAG	1232-AS2	CAG	1232A	CAG CAG	1212A w/ 1212P2	Null Detector	1	1	0	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
12	CAG	1264B(*)	CAG CAG	1264A w/ 1264PL(**)			Power Supply Modulator w/Adapter	1	1	1	1	*Required with 1361A & 1363 **Required with 1264A
13	CAG	1361A	CAQI	612A			Unit Oscillator 450 - 1050 MHz w/Power Supply	1	1	1	1	
14	CAG	1363	CAG	1215B or C & 1209 BL or CL	CBSH CBSH CBSH	MS-12 w/ MS-13 w/ MO-3	Unit Oscillator 56 - 500MHz w/Power Supply	1	1	1	1	Added for all tenders
15	CAG	1422MD	CAG	722MD	CAG CAG	722D 1422D	Precision Capacitor	1	1	1	1	
16	CAG	1423AM	CAG	1423A	CAG CLN CAG	1401A,1419K 1091 1409F,L,T,Y	Decade Capacitor 100PF - 1.µF	1	1	1	1	
17	CAG	1433B	CAG	1432B,1432P	CAG CSM	1432M 817B	Decade Resistor 1M ohms	1	1	1	1	
18	CAG	1433W	CAG CAG	1432W 1432N	CAG CSM	1432T 817	Decade Resistor 10K ohms	1	1	1	1	
19	CAG	1450TB					Decade Attenuator	1	1	1	1	
20	CAG	1455A	CAG	1454A			Voltage Divider	1	1	1	1	
21	CAG	1552B					Sound Level Calibrator	1	1	1	1	
22	CAG	1559B	CAG	1559A			Microphone Reciprocity Calibrator	-	-	-	1	FBM only
23	CAG	1571AL	CAG CAG	1570/ALS-15 1570/ALS-15P1			Voltage Regulator Control Unit	1 1	1 1	1 1	1 1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
24	CAG	W10MT3A	CAG CABU	W5MT3A UC-1M			Autotransformer	4	4	4	3	
25	CAG	2995-9139					Transducer Insert Adapter	1	1	1	1	
26	CAQI	130C	CAQI	130B			Oscilloscope 300 KHz	1	1	1	1	
27	CAQI	141T					Analyzer, Spectrum Display Section	1	1	1	1	Not procured
28	CAQI	200CD	CDBX	401H	CBSH CBSH CAG	MS-14 w/ MO-3 1214M	Oscillator, 5 Hz - 600 KHz w/Power Supply	2	2	2	2	
			CAQI	C01-200SR	CAQI	200SR		*	*	*	*	*Required w/CAQI 739AR only.
29	CAQI	213B					Pulse Generator	1	1	1	1	
30					CAQI	H281A	W/G to Coax Adapter 7.05 - 10 GHz	-	-	-	-	There are no known requirements for these items, however some FECFs may desire retention.
31					CAQI	G281A	W/G to Coax Adapter 3.95 - 5.85 GHz	-	-	-	-	
32					CAQI	J281A	W/G to Coax Adapter 5.30 - 8.20 GHz	-	-	-	-	
33					CAQI	S281A	W/G to Coax Adapter 2.60 - 2.95 GHz	-	-	-	-	
34	CAQI	X281A					W/G to Coax Adapter 8.2 - 12.4 GHz	4	4	4	4	
35	CAQI	HX292B					W/G to W/G Adapter 7 - 10 GHz	2	2	2	2	
36	CAQI	302A					Wave Analyzer	1	1	1	1	
37	CAQI	3310A	CAQI	202A			L. G. Generator 0.008 - 1200 Hz	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
38	CAQI	332A	CAQI	H01-330D	CAQI	330B	Distortion Analyzer	1	1	1	1	
39	CAQI	355C Opt 001	CAQI	335C	CAQI	355A	Coaxial Attenuator 0 - 12 db	1	1	1	1	
40	CAQI	355D Opt 001	CAQI	355D	CAQI	355B	Coaxial Attenuator 0 - 120 db	1	1	1	1	
41	CAQI	360A					Filter, Low Pass 700 MHz	1	1	1	1	
42	CAQI	360B					Filter, Low Pass 1200 MHz	1	1	1	1	
43	CAQI	360C					Filter, Low Pass 2200 MHz	1	1	1	1	
44	CAQI	360D					Filter, Low Pass 4100 MHz	1	1	1	1	
45	CAQI	X372D					W/G Attenuator 0 - 20 db	-	-	-	1	FBM only
46					CAQI CCUJ	H382A W164A	W/G Attenuator 0 - 50 db	-	-	-	-	No known requirements for WR 112 W/G Size
47	CAQI	X382A	CCUJ	X164A			W/G Attenuator 0 - 50 db	2	2	2	2	
48	CAQI	C92-400H	CAQI CAQI	400H 400L(*)	CAQI	400D	VTVM 1 mv - 300 VAC	3	3	3	4	*Logarithmic scale allowed if on board. -
49	CAQI	410C w/	CAQI	410B w/			VTVM 15 mv - 300 VAC/ DC	2	2	2	2	
49a	CAQI	11036A					Probe	2	2	2	2	
49b	CAQI	11042A	CAQI	455A			Coax "T" Connector	2	2	2	2	
49c	CAQI	11045A	CAQI	459A			DC Voltage Divider	2	2	2	2	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
50	CAQI	412A	CCFV	MV-77B-1			VTVM 1 mv - 1000 VDC	1	1	1	1	
51	CAQI	H05-415E	CAQI	415D & E	CAQI	415B & C	VSWR Meter	2	2	2	2	
					CBSH	CF-1	AF Attenuator	*	*	*	*	*CF-1, BA-1C, IN-1
					CBSH	BA-1C	Audio Level Indicator	*	*	*	*	Required if CAQI
					CBSH	IN-1	Bolometer Preamplifier	*	*	*	*	415D or E not on board.
52	CAQI	423A	CAQI	420A	CBES	613M	Crystal Detector 10 Hz - 12.4 GHz	1	1	1	1	
53	CAQI	432A	CAQI	431C	CAQI	431A & B	Microwave Power Meter	3	3	3	3	
					CAQI	430C						
					CBVT	P-3						
54	CAQI	434A			CAQI	434	Calorimetric Power Meter	1	1	1	1	
55	CAQI	440A					Coaxial Detector Mount w.6 - 12.4 GHz	2	2	2	2	
56	CAQI	447B	CAQI	444A			Untuned Probe 2.6 - 18 GHz	2	2	2	2	
57	CAQI	478A			CAQI	477B	Thermistor Mount	3	3	3	4	*w/CBTV P-3 only.
					CBTV	TM-1(*)						
					CAQI	H486A	Thermistor Mount	-	-	-	-	No known requirements for WR 112 W/G size.
					CBES	647						
					CCPC	541						
					CADY	5628						
58	CAQI	X486A	CCPC	540			Thermistor Mount	2	2	2	2	
59					CAQI	H532A	W/G Frequency Meter 7.0 - 10.0 GHz	-	-	-	-	No known requirements for WR 112 W/G size.
					CCUJ	W410B						
60	CAQI	X532B	CCUJ	X410B			W/G Frequency Meter 8.2 - 12.4 GHz	1	1	1	1	

Item	Preferred		Acceptable		Limited/Obsolete		Description	Quantity				Remarks
	Mfr	Model	Mfr	Model	Mfr	Model		AD	AR	AS	FBM AS	
61	CAQI	536A	CCUJ	N410A			Coaxial Frequency Meter 1 - 4 GHz	1	1	1	1	
62	CAQI	537A	CCUJ	N414A			Coaxial Frequency Meter 4 - 11 GHz	1	1	1	1	
63	CAQI	H19-606B	CAQI CAQI	H19-606A 606A	CBSH CBSH	MS-15 w/ MO-3	Signal Generator w/ Power Supply	1	1	1	1	
64	CAQI	H03-608E	CAQI CAQI	H01-608C 608C	CAQI	608D	Signal Generator 10 - 480 MHz	1	1	1	1	
65	CAQI	S01-652A	CAQI CAQI CAQI	615A or B 650A H01-739AR	CAQI	739AR	Test Oscillator 10 Hz - 10 MHz (Freq Response Test Set)	1	1	1	1	
					CAQI CAQI CCPC	716B 716A 438	Klystron Power Supply	*	*	*	*	*Allowed if on board.
66					CAQI CCUJ	H752C W610C	W/G Directional Coupler	-	-	-	-	No known requirements for WR 112 W/G size.
67					CAQI CCUJ	H752D W610D	W/G Directional Coupler	-	-	-	-	No known requirements
68	CAQI	X752C	CCUJ CCPC	X610C 45X1-10			W/G Directional Coupler	1	1	1	1	
69	CAQI	X752D	CCUJ	X610D			W/G Directional Coupler	1	1	1	1	
70	CAQI	809C	CAQI	809B			Carriage Probe	1	1	1	1	
71	CAQI	X810B					W/G Slotted Line 8.2 - 12.4 GHz	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
72					CAQI	H810B	W/G Slotted Line 7.05 - 10.0 GHz	-	-	-	-	No known requirements for WR 112 W/G size.
73					CAQI CCPC CCUJ	H914A 381 W502A	Moving Load 7.05 - 10.1 MHz	-	-	-	-	No known requirements for WR 112 W/G size
74	CAQI	X914B	CCUJ	X502A & B			Moving Load 8.2 - 12.4 GHz	2	2	2	2	
75	CAQI	X930A					Shorting Switch 8.2 - 12.4 GHz	1	1	1	1	
76	CAQI	11004A	CAQI	AC-60B			Line Matching Transformer	2	2	2	2	
77	CAQI	11507A					Output Termination	-	-	-	1	FBM only
78	CAQI	11592A					Service Kit	1	1	1	1	Not procured. Required with CAQI 141T Analyzer System.
79			CAQI CAQI	1117B w/ 10476A 1116A			Testmobile (w/Wheel Locks)	*	*	*	*	*Allowed if on board
80	CAQI	5245L	CAQI CBPM	5243L 6146	CAQI	524()	Frequency Counter	2	2	2	2	
81	CAQI	5253B	CAQI CBPM	5253A 607	CAQI	525A,B or C	Frequency Converter 50 - 500 MHz	2	2	2	2	
82	CAQI	5254C	CAQI CAQI	5254B 5254A			Frequency Converter 500 - 3000 MHz	2	2	2	2	
83	CAQI	5257A	CAQI	540B	CAQI CAQI	540A w/ X934	Transfer Oscillator w/ Harmonic Mixer	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
84	CAQI	5261A			CAQI	526A	Video Amplifier	1	1	1	2	
85	CAQI	5267A	CAQI	5262A	CAQI	526B	Time Interval Unit	1	1	1	2	
86	CAQI	6111A					Power Supply	-	-	-	2	FBM only
87	CAQI	8402B			CAQI	8402A	Power Meter Calibrator	1	1	1	1	
88	CAQI	8405A					Vector Voltmeter	1	1	1	1	Not procured.
89	CAQI	8477A					Power Meter Calibrator	1	1	1	1	Not procured. Required for calib of CAQI 432A Power Meter.
90 91	CAQI CAQI	8552B 8553B					IF Section RF Section	1 1	1 1	1 1	1 1	Not procured. Required with CAQI 141T Analyzer
92	CAUY	T10AR100					Variable Resistor 100 ohms	1	1	1	1	
93	CAUY	T10AR1000					Variable Resistor 1000 ohms	1	1	1	1	
94	CAUY	T10AR5000					Variable Resistor 5000 ohms	1	1	1	1	
95	CAXE	QR-36-15A	CAXE CAXE	DCR-40-20 QRC-40-15			Power Supply	-	-	-	2	FBM only
96	CAXE	DCR-150-10A					Power Supply	1	1	1	-	
97	CAXE	ACR 1000S	CAXE	1000S			Voltage Regulator	2	2	2	2	
98	CBES	159B	CCPC	47X2	CAQI CCUJ CCUJ	X375A X151A X155A	W/G Attenuator 8.2 - 12.4 GHz	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
99	CBFB	421B	CAQI	738BR	CAQI	738AR	H.V. AC/DC Precision Calibrator	1	1	1	1	
100	CBSH	AS-6	CBSH CAQI	AS-1, AS-4 E43-11582A			Coaxial Attenuator Set DC-18 GHz	1	1	1	2	
			CAQI CBSH CBSH CBSH CBSH	H43-8491B3 50-3 210-3 2-3 530A-3			Coaxial Attenuator 3 db	*	*	*	*	*CBSH AS-1 includes 1 ea per set of CBSH 50 and 210 series: CBSH AS-4 includes 1 ea per set of CBSH 50 and 530A series: CBSH AS-6 includes 1 ea per set of CBSH 2 series: CAQI E43-11582A includes 1 ea per set of CAQI H43-8491B series.
			CAQI CBSH CBSH CBSH CBSH	H43-8491B6 50-6 210-6 2-6 530A-6			Coaxial Attenuator 6 db	*	*	*	*	
			CAQI CBSH CBSH CBSH CBSH	H43-8491B10 50-10 210-10 2-10 530A-10			Coaxial Attenuator 10 db	*	*	*	*	
			CAQI CBSH CBSH CBSH CBSH	H43-8491B20 50-20 210-20 2-20 530A-20			Coaxial Attenuator 2Q db	*	*	*	*	
101	CBSH	2-30	CAQI	H44-8491A30	CBSH	50-30	Coaxial Attenuator 30 db	1	1	1	1	
102	CBSH	2-40	CAQI	H44-8491A40	CBSH	50-40	Coaxial Attenuator 40 db	1	1	1	1	
103	CBSH	2-50	CAQI	H44-8491A50	CBSH	50-50	Coaxial Attenuator 50 db	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
104	CBSH	DS-109	CDAC	1873S	CCUT	S100	Double Stub Tuner	2	2	2	2	
105	CBSH	DS-109LL			CCUT	S200	Double Stub Tuner	1	1	1	2	
106	CBSH	MB-1					Measurement Bench	1	1	1	1	
107	CBSH	F1403N	CCPC CCPC	370NF 371NF	CBSH	535FN	Coaxial Termination DC-10 GHz	2	2	2	2	
108	CBSH	M1403N	CCPC CCPC	370NM 371NM	CCPC CBSH	372NM 535MN	Coaxial Termination DC-10 GHz	2	2	2	2	
109	CBSH	905					Coaxial Attenuator 10 db	1	1	1	1	
110	CBSH	926	CAQI	476A	CBES	627A	Bolometer Mount	1	1	1	1	
111	CBSH	936N					Noise Suppressor 10 MHz - 12.4 GHz	1	1	1	1	
112	CBSH	936X					Noise Suppressor 8.2 - 12.4 GHz	1	1	1	1	
113	CBTV	84					Plug-in Adapter	-	-	-	1	
114	CBTV	1A1	CBTV	C MX-2930E MX-2962 AM-3567/USM AM3568	CAQI CAQI CBTV CBTV CBTV	151B 152B CA D I	Dual Trace Plug-in	2	2	2	2	
115			CBTV CBTV	500-53B 202-2			Scopemobile Cart	*	*	*	3	*Allowed if on board

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
116	CBTV	547	CBTV	545A or B AN/USM-140D	CAQI	150A	Oscilloscope 30 MHz	2	2	2	2	
117	CBTV	2901	CBTV CFJ	184 781A	CBTV CFJ	180A 0-1293/U	Time Mark Generator	1	1	1	1	
118	CBTV	011-0051-00					Input RC Standardizer	-	-	-	1	FBM only
119	CBTV	013-0007-00	CBTV	013-007			Deflection Plate Adapter for CBTV 530/540 Series	1	1	1	1	
120	CBTV	067-0502-01					Amplitude Calibrator and Comparator	1	1	1	1	Not procured
121	CBTV	067-0521-01					Calibration Fixture for CBTV 530, 540 & 550 Series	1	1	1	1	Not procured
122			CBTV CBTV	TU-5 015-0043-00			Pulser Package	-	-	-	1	FBM only. Replaced by HEA 213B, Item 29
123	CBTV	Quote #0010					Deflection Plate Adapter for CBTV 545B and 547	1	1	1	2	
124	CBTV	C-12R					Oscilloscope Camera	-	-	1	1	AS's only
125	CBTV	616-0226-00					Oscilloscope Camera Adapter	-	-	1	1	AS's only
126	CBUW	160B-150FN			CBUW	160-100FN	Coaxial Termination 100 Watts	1	1	1	1	
127	CBUW	164B-FMN	CBUW	164FMN			Bi Directional Power Meter	1	1	1	1	
128	CBUW	181A-1000	CBUW	181-1000			Power Monitor 460 - 1000 MHz	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
129	CBVT	1205	CAQI	8614A	CAG CBSH CBSH	1218A or B MS-8 w/ MO-3 (**)	Signal Source 900 - 2000 MHz w/Power Supply	1	1	1	1	CAG 1218B or A allowed if on board
130	CBVT	1206	CAQI	8616A	CAG CAG CBVT CBVT	1360AM 1360A or B SSS-B w/ KX-B (*)	Signal Source 1.7 - 4.1 GHz w/Power Supply	1	1	1	1	CAG 1360A or B allowed if on board **1 ea CBSH MO-3 required with CBSH
131	CBVT	1207	CCUJ	C772A	CBVT CBVT	SSM-A w/ KX-B (*)	Signal Source 3.8 - 8.2 GHz w/Power Supply	1	1	1	1	(Weinschel MS Signal Sources series only) *CBVT KX-B required
132	CBVT	1208	CCUJ	X772A	CBVT CBVT	SSX-A w/ KX-B (*)	Signal Source 7.0 - 11 GHz w/Power Supply	1	1	1	1	with CBVT (Polarad SSM, SSS & SSX Signal Sources series only.)
133	CBYI	MA7501DNM	CGZ	2N180MC 2N180M10			Coaxial Switch	1	1	1	2	
134	CCAM	UX			CCAM	U-88	Polyranger	1	1	1	1	
135	CCAP	1011R					Ratio Transformer	-	-	-	2	FBM only
136	CCAP	RT60	CCAP	RT-5			Ratio Transformer	1	1	1	2	
137	CCAP	ST-100A	CAG	578BS-5	CCAP	797	Transformer, Isolation	1	1	1	1	
138	CCDH	311/RT1/717			CCTQ CBLH CBLH	709A 1010 901	Phase Meter	-	-	-	1	FBM only
139	CCFO	KS8-50M			RIA	D-12	Power Supply	*	*	*	1	*Allowed if on board.
140	CCFB	DCA-10			CCAR	MI-200AB	Power Amplifier 10 Watts, 200W	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
141	CCFV	MV-928A	CCVO CCFV	91DA MV-828A			RF Voltmeter 300 μv - 300v	1	1	1	1	
142			CCGJ	2733	CCGJ	2730	Potentiometer	1	1	1	1	Use items 172 or 175.
143	CCHC	569-20	CCPC	1011	CCUJ CAQI	W612D H750D	W/G Directional Coupler	-	-	-	-	No known requirement for WR 112 W/G size.
144	CCHC	615	CCPC	34X1	CAQI	X485B	W/G Detector Mount 8.2 - 12.4 GHz	1	1	1	1	
145	CCHC	678H	CCUJ	X641A			W/G Switch 8.2 - 12.4 GHz	1	1	1	1	
146	CCHC	683	CAQI CDAC CBES	X870A X353 303A			Slide Screw Tuner	2	2	2	2	
147	CCMY	445					Power Oscillator	1	1	-	1	Not yet provided. It is anticipated that the preferred equipments will be provided by future procurement action.
148	CCMY	185					Plug-in Head 50 - 200 MHz	1	1	-	1	
149	CCMY	186			CCMY CBUW	408() 470A500	Plug-in Head 200 - 500 MHz	1	1	-	1	
150	CCMY	187					Plug-in Head 500 - 100 MHz	1	1	-	1	
151	CCMY	1933					Carrying Case	1	1	-	1	
152					CAQI CCPC	H485B 34H1	W/G Detector Mount	-	-	-	-	No known requirement. This item has not been supplied to non-FBM FECFs.

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
153					CBES CCUJ CCUJ CAQI CCPC	185B W151A W155A H375A 47H2	Attenuator Set, Level 0-40 db, 7.05-10.0 GHz	-	-	-	-	No known requirement for WR 112 W/G Size
154	CCPC	792			CBSH	953-10	Coaxial Attenuator 20 db, 10 db	1	1	1	1	
155	CCPC	61A1B	CBSH CBSH	VM-3 VM-3S	CCPS CCPS	61A1A 61A1	Microwave Receiver	1	1	1	1	
156	CCPC	2936					Variable Coaxial Attenuator	1	1	1	1	
157	CCPC	3000-10					Directional Coupler 225-460 MHz	2	2	2	2	
158	CCPC	3000-20					Directional Coupler 225 - 460 MHz	1	1	1	2	
159	CCPC	3001-10					Directional Coupler 460 - 950 MHz	1	1	1	2	
160	CCPC	3001-20					Directional Coupler 460 - 950 MHz	-	-	-	2	FBM only
161	CCPC	3002-10					Directional Coupler 950 - 200 MHz	2	2	2	2	
162	CCPC	3002-20					Directional Coupler 950 - 2000 MHz	1	1	1	2	
163	CCPC	3003-10					Directional Coupler 2 - 4 GHz	2	2	2	2	
164	CCPC	3003-20					Directional Coupler 2 - 4 GHz	1	1	1	2	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
165	CCPC	3004-10					Directional Coupler 4 - 10 GHz	2	2	2	2	
166	CCPC	3004-20					Directional Coupler 4 - 10 GHz	1	1	1	2	
167	CCPC	18500-21042					Peak Power Source	1	1	1	1	
168	CCRS	2543ND	CCRS	2543BF			Balanced Mixer 4 - 8 GHz	1	1	1	1	
169	CCRS	2553Q					Balanced Mixer 8 - 12 GHz	1	1	1	1	
170			CCUH	301C	CCUH CCAM	406 THACH-PC	Power Supply 1.02 - 1012 VDC	*	*	*	1	*Allowed if on board
171	CCUH	332B	CCUH	332A	*CCTY *CCTY	302 301C	Direct Voltage Standard	1	1	1	1	*Allowed if on board
172	CCUH	540B	CAOR	1605A	CAOR CCUF	1605 6	AC/DC Transfer Standard	1	1	1	1	
173	CCUH	A40			CCUF	HCS-1	Shunt Kit	1	1	1	1	
174	CCUH	760A	CDBT	MC-10C	CCZQ CAOR CCRA	MC-5400A 33 SV-194	Meter Calibrator	1	1	1	1 * *	*Allowed if on board
175	CCUH	845AB			CLN	9834	Null Detector	1	1	1	1	
176	CCUH	883AB			CCUH	803 Series	Differential Volt- meter 0 - 500 VAC/DC	1	1	1	1	1 ea 803 in addition to the 883AB allowed if on board.
177	CCUJ	B200A	CCPC	229B			Tuner Probe 1 - 12.4 GHz	1	1	1	2	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
178	CCUJ	LA-50N	CCUJ	FL-5001			Filter, Low Pass 500 MHz	1	1	1	1	
179	CCUJ	LA-70N	CCUJ	FL-7001			Filter, Low Pass 700 MHz	1	1	1	1	
180	CCUU	100					Unsaturated Standard Cell	3	3	3	3	
181	CCUV	500					Milliammeter 1μa - 1ADC	1	1	1	1	
182	CCVA	TLC44-7EE	CBUW	184-44			Filter, Low Pass 44 MHz	1	1	1	1	
183	CCVA	TLC76-7EE	CBUW	184-76			Filter, Low Pass 76 MHz	1	1	1	1	
184	CCVA	TLC135-7EE	CBUW	184-135	CCUJ	LA02N	Filter, Low Pass 135 MHz	1	1	1	1	
185	CCVA	TLC230-7EE	CBUW	184-230	CCUJ CCUJ	LA03N FL201	Filter, Low Pass 230 MHz	1	1	1	1	
186	CCVA	TLC400-7EE	CBUW	184-400	CCUJ CCUJ	LA04N FL401	Filter, Low Pass 400 MHz	1	1	1	1	
187	CCYC	2215D	CCYC	2215C			Accelerometer	-	-	-	2	FBM only
188	CCYM	SR-1	CLN	4020B			Resistor 1 ohm	2	2	2	2	
189	CCYM	SR-1	CLN	4025B			Resistor 10 ohms	1	1	1	1	
190	CCYM	SR-1	CLN	4030B			Resistor 100 ohms	1	1	1	1	
191	CCYM	SR-1	CLN	4035B			Resistor 1K ohms	1	1	1	1	
192	CCYM	SR-1	CLN	4040B			Resistor 10K ohms	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
193	CCYM	SR-1	CLN	4045R			Resistor 100K ohms	-	-	-	1	FBM only
194	CCYM CCYM	250DE w/ 1325	CCYM CCYM	250DA 291B	CAG CAG	1632A 650A ZM-11 series	Impedance Bridge w/ Power Supply	1	1	1	1	
195	CCYM	RV-722	CDAE	DV-4107			Voltage Divider	1	1	1	1	
196	CCYM	242B	CLN CLN CLN	4232A10 4232A1 4232B	CSM	6350	Resistance Measuring System	1	1	1	1	
197	CCZP	146AG5	CCZP	146A	CCUF	AVS-321	AC Voltage Standard	1	1	1	1	
198	CCZP	601					Multiplier	-	-	-	1	FBM only. Required w/146AG5 only.
199	CCZT	FE-25-3	CCZT CDAW	FE-25-2 FC-201	CCZT	FE-25-1	Frequency Converter	-	-	-	1	FBM only.
200	CDAC	A-007					Connector Gage Type N	1	1	1	1	
201	CDAC	X101-6	CCUJ	X634A	OMEGA	1540-7	W/G Section 6"	2	2	2	2	
202					CDAC CCUJ Microwave Components	H125-4 W623B H126	Waveguide Bend 90° E-Plane	-	-	-	-	No known requirement for WR 112 W/G size.
203	CDAC	X125-4	CCUJ Microwave Components	X623B X-126			W/G Bend 90° E-Plane	2	2	2	2	
204					CDAC CCUJ Microwave Components	H135-4 W624B H136	W/G Bend 90° H-Plane	-	-	-	-	No known requirement for WR 112 W/G size.

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
205	CDAC	X135-4	CCUJ Microwave Components	X624B X-136			W/G Bend 90° H-Plane	2	2	2	2	
206	CDAC	X145	CCUJ Microwave Components	X625A X146-5			W/G 90° Twist	1	1	1	1	
207					CDAC CCUJ Microwave Components	H150 W620A W351	W/G Series Tee 7.05 - 10.0 GHz	-	-	-	-	No known requirement for WR 112 W/G size
208	CDAC	X150	CCUJ Microwave Components	X620A X351			W/G Series Tee 8.20 - 12.4 GHz	2	2	2	2	
209					CDAC CCUJ Microwave Components	H151 W621A H351	Shunt Tee, W/G E-Plane	-	-	-	-	No known requirement for WR 112 W/G size.
210	CDAC	X151	CCUJ Microwave Components	X621A X-352			Shunt Tee, W/G H-Plane	2	2	2	2	
211					CDAC CCUJ CCUJ	H301A W501C W501B	W/G Termination 7.05 - 10.0 GHz	-	-	-	-	No known requirements for WR 112 W/G size.
212	CDAC	X301A	CCUJ	X501C	CBNN	X501B	W/G Termination 8.2 - 12.4 GHz	1	1	1	1	
213					CDAC CBNN CCPC CCPC	H320D W510A,E 411-20 411-10	Reflection Standard 7.05 - 10.0 GHz	-	-	-	-	No known requirement for WR 112 W/G Size

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
214	CDAC	X320D	CCUJ CAQI CCPC	X510D X916C 410-10	CBNN CAQI CCPC	X510A,E X916B,D & E 410-20	Reflection Standard 8.2 - 12.4 GHz	1	1	1	1	
					CDAC	M-3	Broad Band Mixer	*	*	*	*	*Allowed if on board. Recommended for deletion.
215	CDAF	2-3414-30	CDAY	5444	CCVW	AU-10	Coaxial Attenuator 30 - 60 db	1	1	1	1	
216	CDAU	S11PS			CS CS	D44S15 D44S5	Coaxial Isolator 2 - 4 GHz	2	2	2	2	
217	CDAU	C20PS			CS CS	D44C15 D44C5	Coaxial Isolator 4-8 GHz	2	2	2	2	
218	CDAU	L20PS			CS MPI CS	D44L15 L1100 D44L5	Coaxial Isolator 1 - 2 GHz	3	3	3	3	
219	CDAU	CX20PS			CS CS	D44X15 D44X5	Coaxial Isolator 7 - 11 GHz	2	2	2	2	
220	CDAU	X110L1A	CDAU CBES MPI	X110LI 1203 X1300	CS	D41X5	W/G Isolator 8.2 - 12.4 GHz	2	2	2	2	
221	CDAW	SR-201	CCZT	901A			Receiver 30 - 300 MHz	1	1	1	1	
222	CDAX	RC-106P	CDAE	105T			Resistance Transfer Standard	1	1	1	1	
223	CDAX	RC-107P	CDAE	106T	CSM	980	Resistance Transfer Standard	1	1	1	1	
224	CDAY	Set A	RIA	D-8			Thermal Voltmeter Set	1	1	1	1	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
225	CDAY	5985	RIA	D-22			Coaxial Voltage Divider	1	1	1	1	
226	CHC	HQ-180A w/MOD M-44	CHC CNA	HQ-145A HRO-60R		AN/URR-36A R-390A/URR	Receiver 0.5 - 30 MHz	1	1	1	1	
						AN/BRR-3 AN/SRR-11 RBA ()	Receiver 14 KHZ - 600 KHz					Recommended for deletion
227	CLN	2430C					Galvanometer	*	*	*	*	*Allowed if on board.
228	CLN	3294					Pinch Switch	1	1	1	1	
229	CLN	3702					Tapping Key	1	1	1	1	
230	CLN	4287	CLN	4285			Kelvin Bridge 0.0001 - 26.6 ohms	1	1	1	1	
231	CLN	4360	CCGJ	1163			Current Shunt	-	-	-	1	FBM only
232	CLN	4361	CCGJ	1166			Current Shunt	-	-	-	1	FBM only
233	CLN	4363	CCGJ	1168			Current Shunt	-	-	-	1	FBM only
234	CLN	4385					Variable Shunt	1	1	1	1	
235					CLN CLN	7553-5 7553	Potentiometer K-3	-	-	-	*	*Allowed if on board for FBM tenders only. A more accurate std (Item 171) CCUH 332A has been provided to all FECFs. No known requirements remain for the CLN 7553-5 in non-FBM FECFs.
236					CLN CLN CLN	7593 7592S 7592	Volt Box Divider	-	-	-	*	

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
237	CLX	1569AN	RIA	D-3			Voltage Amplifier 10 - 1000 Volt RMS	1	1	1	1	
238	CLX	1570BN	RIA	D-7			Current Amplifier 2.5 - 100 Amperes	1	1	1	1	
239	CMC	240C					Power Resistor	1	1	1	1	
240	CSV	269AF	CSV	269			Multimeter AC/DC	1	1	1	2	
241	CSV	260		AN/PSM-4			AC/DC Multimeter	2	2	2	2	
242	CTB	F4069TH w/ 8244					Thermohumidigraph w/Chart Paper (100/box)	1	1	1	1	
243	CTI	21740G					Thermometer	3	3	3	3	
244	CV	CVO-100					Constant Voltage Oscillator	-	-	-	1	FBM only
245	CV	CVO-110					Divider Plug-in w/CVO-100	-	-	-	1	FBM only
246	CV	HVA-120					Amplifier High Voltage	-	-	-	1	FBM only
247	CV	341 (1910001)					Voltmeter 150/300/ 750 VAC/DC	1	1	1	1	
248	CV	370 (2903003)					Ammeter 2.5/5.0 AC/DC	1	1	1	1	
249	CV	432 (9901018)					Wattmeter, DC 0 - 150W	-	-	-	1	FBM only
250	CV	622 (1962004)					Voltmeter 1000 ohm/volt	1	1	1	1	

Item	Preferred		Acceptable		Limited/Obsolete		Description	Quantity				Remarks
	Mfr	Model	Mfr	Model	Mfr	Model		AD	AR	AS	FBM AS	
251	CV	931 (2901008)					Ammeter 0 - 5A/DC	-	-	-	1	FBM only
252	CV	432 (9901030)					Wattmeter 0-150-300W	-	-	-	1	FBM only
253	CV	432 (9901008)					Wattmeter 0-1.5-3KW	-	-	-	1	FBM only
254					CWT	FA181/W-F129	Manometer 1000 - 6000 ft.	1	1	-	-	AD and AR only
255	CYK	230A					Power Amplifier	-	-	-	1	FBM only.
256	CYK	8900B	CYK	8900A			Peak Power Calibrator	1	1	1	1	
257					RIA	D-5	Battery Pack	-	-	-	1	FBM only
258					RIA	D-39	Micropotentiometer Set	*	*	*	1	*Allowed if on board.
259	RIA	D-101					Standard Weights	1	1	1	1	
260	RIA	D-114A					Oscilloscope Adapter	1	1	1	1	
261	RIA	D-114B					Oscilloscope Adapter	1	1	1	1	
262	RIA	D-116					100 mh Inductor	1	1	1	1	
263	RIA	D-129					Calibrator	1	1	-	-	AD and AR only
264	RIA	D-130					Standard Cell Lag Box	4	4	4	4	
265	RIA	D-140					Ohmmeter Calibrator	1	1	1	1	
266	RIA	D-150					Oscilloscope Adapter	1	1	1	1	
267	RIA	D-152					Input Test Adapter	-	-	-	1	FBM only
268	RIA	D-153					Input Test Adapter	-	-	-	1	FBM only

Item	Preferred Mfr	Preferred Model	Acceptable Mfr	Acceptable Model	Limited/Obsolete Mfr	Limited/Obsolete Model	Description	Quantity AD	Quantity AR	Quantity AS	Quantity FBM AS	Remarks
269	RIA	D-158					Post Amplifier Test Fixture for USM-117	1	1	1	1	
270	RIA	D-166					Phase Test Fixture	-	-	-	1	FBM only
271					RIA	D-13	Low Pass Filter	-	-	-	-	No known requirements
272	AERTECH	MX2003	CCRS	2523BQ			Balanced Mixer 1 - 2 GHz	1	1	1	1	
273	AERTECH	MX4003	CCRS	2533BP			Balanced Mixer 2 - 4 GHz	1	1	1	1	
274	EH Research Labs	EH-132A8	CAQI CAQI	211A 212	CBTV	105	Pulse Generator	1	1	1	1	
275	TEXTRAN	533S					Omega Commutator	-	-	-	1	FBM only
276	TOPAZ	70412			CDAF	P6161	Isolation Transformer	4	4	4	4	
277	TRACOR	527A	TRACOR	527 AN/URM-115 FR-140/URM			Frequency Deviation Meter	1	1	1	1	
278	TRACOR	599J	TEXTRAN	599G	CAQI	K17999B	VLF Receiver	1	1	1	1	
279	TRACOR	599-825	TEXTRAN	599-805			VLF Antenna	1	1	1	1	
280	CAVK	PRR1M16FR					VLF Recorder	2	2	2	1	1 ea required if AN/URM-115 is on board.

APPENDIX C

REFERENCES

1. BUSHIPINST 9690.12A, Fleet Electrical and Electronic Test Equipment Calibration Program; guidance concerning.

2. CCL-1, Calibration Capability Listing for Fleet Electronic Calibration Facilities and NAVELEX Calibration Facilities.

3. Design Manual, Research, Development, and Test Facilities, NAVFAC DM-31, Naval Facilities Engineering Command, March 1968.

4. DOD Directive 4155.18, Improved Management of Metrology and Calibration.

5. EIA/EMC Bulletin No. 3, Designer's Guide on EMC - Testing and Measurement Techniques for Electronic Equipment.

6. Engineering Circular EC-7, Frequency Standards and Measurements.

7. Engineering Circular EC-17, Installation and Operation Instructions for Very Low Frequency (VLF) Phase Tracking Systems, Metrology Engineering Center, Pomona, California.

8. Engineering Circular EC-19, Recommended Facility Requirements for Tender Fleet Electronic Calibration Laboratories, Metrology Engineering Center, Pomona, California.

9. Engineering Circular EC-20, Recommended Facility Requirements for Tender Fleet Mechanical Calibration Laboratories, Metrology Engineering Center, Pomona, California.

10. Engineering Circular EC-23, Recommended Facility Requirements for Navy Calibration Laboratories, Metrology Engineering Center, Pomona, California.

11. Fed. Spec. W-C-375A, Circuit Breaker, Molded Case, Branch-circuit and Service.

12. Fed. Spec. W-C-596A, Connector, Plug, Electrical, Connector, Receptacle, Electrical.

13. Fed. Spec. W-P-455A, Plate, Wall Electrical.

14. Fed. Standard 595A, Color.

FED-STD-209, Clean Room and Work Station Requirements, Controlled Environment.

Fed. Test Methods Std. No. 501, Floor Coverings, Resilient, Nontextile: Sampling and Testing.

Lighting Protection Code 1968, National Fire Protection Association, Boston, Massachusetts.

MEC Drawing ML-114, Fleet Electronics Calibration Facility.

MEC SK 116, Advanced Base Functional Component E31 Metrology Laboratory Component.

MERL, Minimum Equipment Requirements for FECLs.

MIL-B-5087B, Bonding, Electrical, and Lighting Protection for Aerospace Systems.

MIL-C-71B, Connectors, Coaxial, Radio Frequency, Series N and Associated Fittings.

MIL-C-3643A, Connector, Coaxial, Radio Frequency, Series Hn, and Associated Fittings, General Spec. for.

MIL-E-4957 (ASG), Enclosure, Electromagnetic Shielding, Demountable, Prefabricated, for Electronics Test Purposes.

MIL-E-8881A, Enclosure, Electromagnetic Shielding, Demountable, Prefabricated, General Spec. for.

MIL-F-15733, Filter, Radio Interference.

MIL-H-24148, Human Engineering Requirements for BUSHIPS Systems and Equipments.

MIL-H-27894A, Human Engineering Requirements for Aerospace Systems and Equipments.

MIL-P-15024D, Plate, Tags and Bands for Identification of Equipment.

MIL-STD-108D, Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment.

MIL-STD-220A, Method of Insertion-Loss Measurement.

MIL-STD-285, Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method of.

33. MIL-STD-461, Electromagnetic Interference Characteristics, Requirements for Equipment.

34. MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of.

35. MIL-STD-1310B, Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Compatibility and Safety.

36. NAVAIR 17-35MTL-1, NAVELEX, 0967-133-2010, Metrology Requirements List.

37. NAVDOCKS DM-1, Architecture.

38. NAVDOCKS DM-3, Mechanical Engineering.

39. NAVELEX 0101,106, Electromagnetic Compatibility and Radiation Hazards, Naval Electronic Systems Command, Washington, D.C.

40. NAVELEXINST 9690.3, Electronic Test Equipment Calibration Program.

41. NAVFAC Spec. 9Y, Electrical Apparatus, Distributing Systems and Wiring.

42. NAVMAT ltr MAT 0413: AMH, Subj: Establishment of Manager for Navy Metrology and Calibration Program.

43. NAVMAT ltr MAT 0413: ERJ of 6 Mar 1972, Subj: Qualification Segment of the Navy Calibration Program; Information Concerning.

44. NAVMAT P5100, Safety Precautions for Shore Activities, Department of the Navy.

45. NAVMATINST 4355.66, Department of the Navy Metrology and Calibration (METCAL) Program; Servicing Labels and Tags.

46. NAVMATINST 4355.67, Department of the Navy Metrology and Calibration (METCAL) Program.

47. NAVMATINST 4355.68, Department of the Navy Metrology and Calibration Program: Terminology and Related Definitions.

48. NAVORDINST 4855.14, Naval Ordnance Systems Command Calibration Program.

49. NAVSHIPS 0967-000-0110, Electronics Installation Maintenance Book.

50. NCE-1, Navy Calibration Equipment List.

51. OPNAVINST 4790.2, The Naval Aviation Maintenance Program (NAME).

52. OPNAVINST 5450.176, Mission and Functions of Chief of Naval Material.

53. Recommended Environments for Standards Laboratories, A. D. Isaacs, et al, Instrument Society of America, Transactions Vol. 3, No. 4, October 1964.

54. SECNAVINST 4355.11B, Department of Navy Metrology and Calibration Programs.

55. The Thermal and Visual Aspects of Lighting, Heating and Cooling Systems, Annual Meeting June 1968, American Society of Heating, Refrigerating and Air-Conditioning Eng's., New York, New York.

56. Underwriters Laboratory Publication No. 57, Standards for Electrical Lighting Fixtures.

GLOSSARY

Calibration. Calibration is the process by which Standards, Calibration and Qualification Facilities compare a standard or measuring equipment or instrument with a standard of higher accuracy in order to ensure that the former is within specified limits throughout its entire range. The calibration process involves the use of approved instrument calibration procedures and may include any adjustments or incidental repair necessary to bring the standard or instrument being calibrated within specified limits.

Calibration Interval or Period. The maximum length of time between calibration services during which each test equipment is expected to maintain reliable measurement capability under reasonable handling.

Calibration Procedure. A document which outlines the steps and operations to be followed by Standards, Calibration and Qualification Facility personnel in the performance of an instrument calibration.

Calibration Schedule. A documented schedule distributed by cognizant scheduling activities listing test equipments that each participating activity will submit to a designated calibration point for processing.

Field Calibration Activity. Those ship and shore activities which have been authorized to perform qualification functions and have been provided with Qualification Packages. Qualification standards are submitted to NCFs or FECFs for calibration.

Fleet Electronic Calibration Laboratories (FECL). FECLs are on board tenders and repair ships and at selected shore activities to provide calibration services for the Fleet electrical and electronic test and measuring equipment. Metrology standards from these are submitted to higher echelon laboratories for calibration.

Incidental Repair. Those repairs found necessary during calibration of an operable equipment to bring it within its specified tolerances, including the replacement of parts which have changed value sufficiently to prevent calibration but do not otherwise render the equipment inoperative. This repair work is normally performed in the Calibration Facilities incidental to the calibration of test equipment or standards.

Metrology. The science of measurement.

Metrology/Calibration Standard. A laboratory type device which is used to maintain continuity of value in the units of measurement embodied by periodic comparison with higher echelon or National Standards. It may be used to calibrate a standard of lesser accuracy or it may be used to calibrate the test equipment directly.

Metrology Requirements List (METRL) (NAVAIR 17-35MTL-1 NAVELEX 0967-133-2010). A NAVAIR publication that provides test equipment information regarding model number or nomenclature, FSN description or manufacturers' code, calibration procedures, and approved calibration intervals. Data contained therein is authorized for the NAVELEX Calibration Program.

National Bureau of Standards (NBS). This is the chartered agency of the Federal Government having custody of the Nation's basic physical standards (National Standards). It will provide the common reference for all measurements (except for precise time and time interval) made within the scope of this program and will calibrate the Department of the Navy metrology standards maintained by the Navy Type I Standards Laboratory.

Navy Calibration Laboratories (NCL). These shorebased laboratories obtain metrology standards calibration services from higher echelon laboratories. The capabilities of these laboratories vary and the mission is twofold; (1) maintain standards of measurement within the activity; and (2) calibrate and repair metrology standards and calibrate and accomplish incidental repair on Fleet and shore activity test and measuring equipment.

Navy Standards Laboratories - Type I. These laboratories maintain the highest metrology standards within the Department of the Navy Metrology and Calibration Program. They maintain and disseminate the most accurate units of measurement within the program, except for precise time and time interval. They will obtain calibration services from the NSD/U. S. Naval Observatory and will calibrate standards and associated measuring equipment received from Type II Navy Standards Laboratories.

Navy Standards Laboratories - Type II. These laboratories provide the second highest calibration services, within the extent of existing capabilities, to assigned geographical areas within the Navy. They will obtain metrology standards services from the cognizant Type I Navy Standards Laboratory, except for precise time and time interval which they receive from the U. S. Navy Observatory, and will calibrate metrology standards and associated measuring equipment received from lower echelon laboratories.

Operable Equipment. An equipment which, from its most recent performance history and a current cursory electrical and physical examination, displays an indication of satisfactory performance for all of its functions.

Qualification. Is the term given to the calibration process performed by authorized Navy activities other than FECFs, NCFs or Standards Facilities. These calibrations are considered valid when accomplished by personnel trained to use the specified qualification standards and qualification procedures. For all intents and purposes, qualification performs the same functions as calibration except that it is accomplished at a specified activity other than a Calibration Facility or Standards Facility and by specially trained personnel utilizing authorized standards and equipment. Although restricted in range and scope, qualification is subject to the same close control as calibration in order that overall quality and accuracy of the test and measuring equipments qualified can be maintained.

Repair: Defined as the repair and/or replacement of malfunctioning parts of a measuring instrument (or standards) to the degree required to restore the instrument (or standard) to an operating condition as defined under operable equipment.

Special Purpose Test Equipment (SPTE). That test equipment which is part of or is used for test, repair, and maintenance of a specific system or subsystem. SPTE equipment has application to one or a very limited number of NAVELEX and NAVSHIPS electronic or electrical systems.

Special Support Equipment (SSE). That equipment which is used for test, repair, and maintenance of a specific system or subsystem. This equipment has application to one or a very limited number of NAVAIR and NAVORD weapons or aircraft systems.

Test and Measuring Equipment. Measuring tools and test equipment required specifically for research, development, test, evaluation, production quality assurance, maintenance and operation of any equipment, major assembly or components used therein—the normal intended function of which is to measure, or to provide a known reference for comparison with, or verification of, performance characteristics.

U. S. Navy Observatory. The single Department of Defense component responsible for Precise Time and Time Interval (PTTI), and covers all PTTI activities connected with the Department of the Navy.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 469-002