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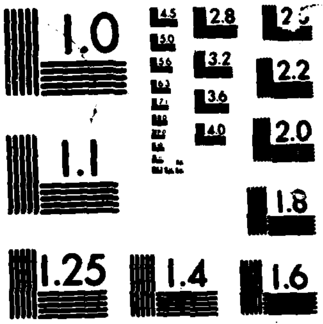

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SUGGESTIONS FOR DESIGNERS OF NAVY ELECTRONIC EQUIPMENT

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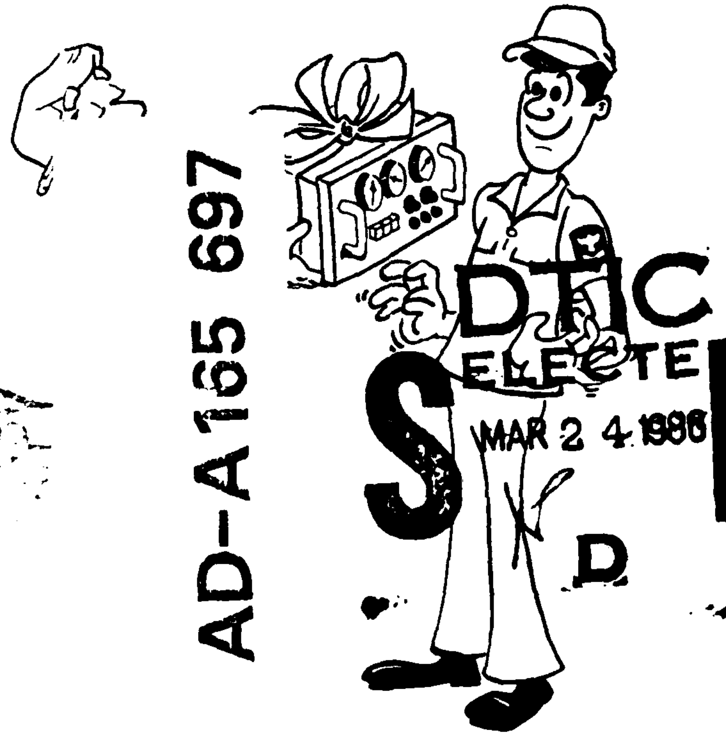
1985 Edition



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NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152-5000

It is a pleasure to make available this 1985 "Suggestions for Designers of Navy Electronic Equipment." This is the eleventh edition, a revised version of the 1975/1979 editions, which have had extensive distribution. During the last few years the Navy has witnessed an alarming escalation in support costs of operational electronic equipment. Major factors contributing to these costs are attributed to (1) the design complexity of electronic equipment; (2) the failure of equipment to operate reliably through operational mission periods; and (3) the costs of supporting equipment for mission operations. These factors relate to early design decisions. Design deficiencies or design weaknesses in equipments that are not eliminated early perpetuate themselves through production into Fleet operation.

It is the goal of this booklet to point out some of the significant design considerations that impact ultimately on Fleet operations. The designer's thoroughness sets the stage for the level of performance and service an equipment will provide to the Fleet.

Reviewed and approved by

W. A. Gaines

W.A. Gaines, CAPT, USN
Chief Staff Officer
October 1985

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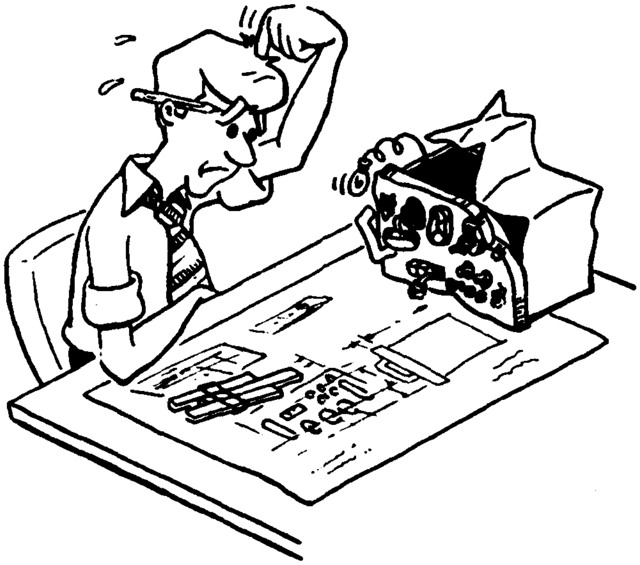
INTRODUCTION



This booklet is designed to serve as a handy checklist for engineers during the development of naval electronic equipment. The objectives are to save engineering, development, and testing time and effort, and to increase operational availability of better electronic equipment. The suggestions are intended for equipment developed for the Navy, although most of them apply to all types of military electronic equipment. This publication is not to be regarded as a substitute for military standards and specifications. Such documents can be obtained from the contracting agency concerned.

The basic specification for Navy electronic equipment is MIL-E-16400G.[1] It refers to over 130 other specifications and standards, many of which refer to additional documents. Correlation between the suggestions and MIL-E-16400 is identified by paragraph numbers in parentheses. The referenced paragraph may give additional information, authority for the suggested action, or a source of further information.

A booklet this size cannot hope to include all the volumes of engineering information and military requirements necessary for the design of naval electronic equipment. The intent is to alert the designer to possible trouble spots in his design, or to areas of conflict outside his realm of expertise or specialization. The sooner a design problem can be identified, the more easily it can be resolved.

The design philosophy for naval electronic equipment is to utilize those techniques which increase reliability, improve maintainability, and reduce costs. Low reliability means the equipment fails too often and is not available when needed. Low maintainability wastes time and money due to difficulty in repairing or maintaining the equipment. These factors can combine to produce life cycle maintenance costs of 5 to 10 times the initial purchase price. In the Electronics-X report of January, 1974, the fact that one third of the FY 74 DoD Budget for electronics ($5.4 billion) was spent for support of service operational systems attests to the lack of attention to reliability early

NOTE: Superscript numbers refer to the list of references at the back of this booklet.

in design. Thus it is more important to improve reliability and maintainability than to reduce the purchase price. However, the law of diminishing returns applies and proper trade-offs must be made. The time to reduce life cycle costs by such reliability/maintainability/purchase price trade-offs is during equipment design.

The design suggestions compiled in this guide were derived from military specifications, human engineering guides, and other basic sources. In some cases the suggestions may seem to be contradictory, considered item by item; however, this only points to the need for trade-offs. The designer must approach the design problem prepared to maximize system effectiveness — not simply to maximize reliability, or to design for the lowest cost, or the most maintainable condition. Trade-offs are the means of obtaining maximum system effectiveness.

Those suggestions that seem to be obvious are included as reminders so that previous errors which resulted in faulty equipment will not be made again. It is expected that the designer already knows most of the material in this booklet, but more designers should benefit from its use as a checklist.

Address comments on this publication to Commander, Naval Ocean Systems Center, San Diego, California 92152, attention Code 934.

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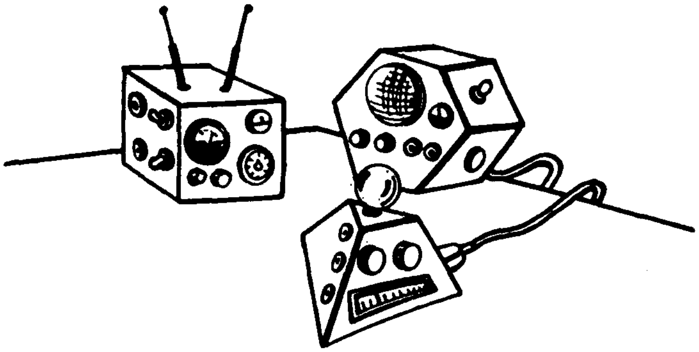
PHYSICAL CHARACTERISTICS



1. Design the equipment to meet the actual requirements; overdesign (electrical or mechanical), in itself, is undesirable.
2. Do not design circuits for greater power output or sensitivity than will be required to meet specifications. However, an adequate reserve for operation under worst case conditions must be provided.
3. Avoid excessive size and weight caused by ultra-conservative packaging and parts selection.
4. Subminiaturization (microelectronic design) should be considered during the design phase. Even if initial models will not take this form, the advantages of microelectronic circuitry (such as increased reliability due to fewer intercon-

nections and decreased size and weight) are important factors in any new design.

5. Subminiaturize where size and weight are major factors, but only if equipment reliability and maintainability are not decreased.
6. Design equipment to be within the following maximum size restrictions: (3.3.2.2.1)*
   a. Surface ship installation: (3.3.2.2.2)
      (1) Height: 72 inches, including mounts.
      (2) Capable of passing through a 30-inch by 30-inch hatch with round corners on 7-1/2 inch radii.
      (3) Capable of passing through a 26-inch by 45-inch door with round corners on 8-inch radii.
   b. Submarine installation: (3.3.2.2.3)
      (1) Height: 72 inches, including mounts.
      (2) Capable of passing through a 25-inch diameter tube.
      (3) Capable of passing through a 20-inch by 38-inch door with round corners on 10-inch radii.
7. Design equipment to the lightest weight consistent with sturdiness, safety, and reliability. (3.7.1)

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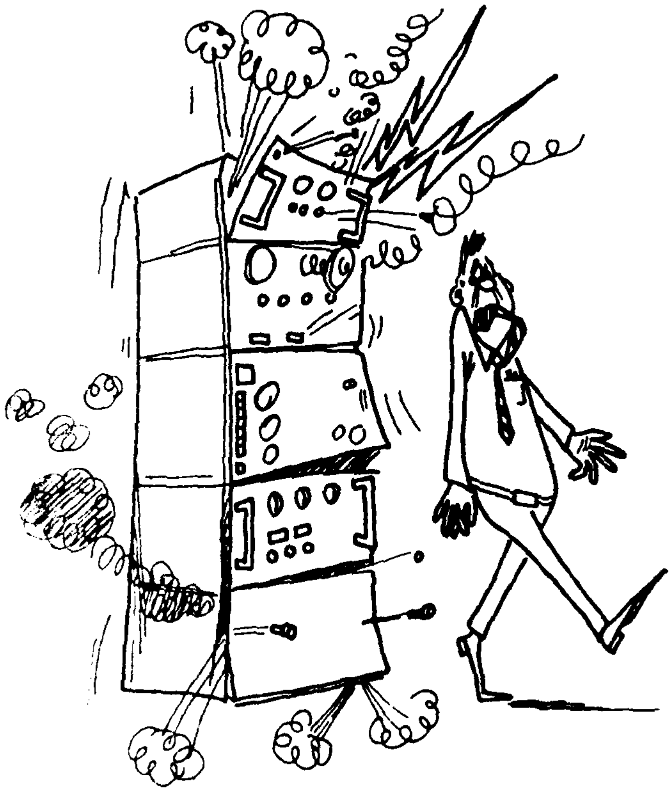
* Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

8. Keep weights of units and subassemblies down to permit lifting under realistic work conditions. Do not require one man to exceed the following limits. Reduce these limits if the task requires the equipment to be carried more than a few steps. (3.3.2.4)

Height of Lift Above Ground	Maximum Weight of Item
5 ft (152 cm)	35 lb (16 kg)
4 ft (122 cm)	50 lb (23 kg)
3 ft (91 cm)	65 lb (29 kg)
2 ft (61 cm)	80 lb (36 kg)
1 ft (30 cm)	85 lb (39 kg)

9. Provide handles for units weighing more than 10 lbs or which are difficult to grasp, remove, or hold.
10. Provide suitably labeled lifting eyes on equipment weighing more than 150 pounds. (3.7.2.7)
11. Additional general design information can be found in references 2 and 3 at the back of this booklet. For aircraft equipment, see MIL-E-5400.[4]

RELIABILITY



In analyzing the many factors affecting the operational reliability of an electronic system it is obvious that "design" is the most significant. All other considerations can, at best, optimize or preserve that inherent reliability which is designed and manufactured into the system. From this we must conclude that the designer has the critical role of incorporating this inherent reliability through sound basic engineering.

RELIABILITY PROGRAM

Reliability is the probability that an item will perform its intended function for a specified interval within a stated operational environment. The designer should establish a reliability program during the earliest phase of a development. Detailed reliability program requirements are provided in MIL-STD-785.[5] (3.3.3)

A reliability program consists of those plans and tasks scheduled in a manner to provide control over all factors affecting the reliability of equipment during conceptual design and feasibility demonstration, development, preproduction and production to insure that the quantitative reliability requirements of the equipment are met. Reliability tasks germane to a reliability program are program planning, design guides, mathematical modeling, allocation, prediction, failure modes and effects analysis, parts program, trade-off studies, contractor control, documentation and data control plans, design reviews, developmental test planning and testing, and failure analysis during testing. The majority of these tasks are performed during concept design and developmental stages of a program before a preproduction design is formulated.

The most important of the above tasks are:

- Allocation
- Prediction
- Failure Modes and Effects Analysis
- Test Planning and Testing
- Failure Analysis During Testing
- Design Reviews

ALLOCATION (3.3.3.1)

Allocation is the apportionment of equipment reliability from an individual equipment specification to lower limits within the equipment. This is accomplished by allocating numerical reliability goals to each assembly and subassembly down to each nonrepairable part. When combined with the mathematical model, the allocated goals should yield an equipment reliability not less than that required in the individual equipment specification. A reliability group usually performs this task and the results provide the designer with his numerical reliability requirement.

PREDICTION (3.3.3.2)

Prediction is the determination of equipment reliability from the reliability characteristics of its components. Reliability predictions, performed early in the design phase, are used as a basis for determining the adequacy of the equipment configurations in meeting the allocated design goals. Prediction makes it possible to determine the weak links in the equipment and to determine the necessary changes, costs, and improvements.

Subtasks of prediction are

a. Reliability logic block diagram (which shows the relationships between equipment operation/failure and constituent equipment or component operation/failure) and
b. Math model of the logic block diagram in equation form. MIL-STD-756[6] shows how to construct the logic block diagram and to make predictions. MIL-HDBK-217[7] is a basic source of component data.

FAILURE MODES AND EFFECTS ANALYSIS (FMEA) (3.3.3.3)

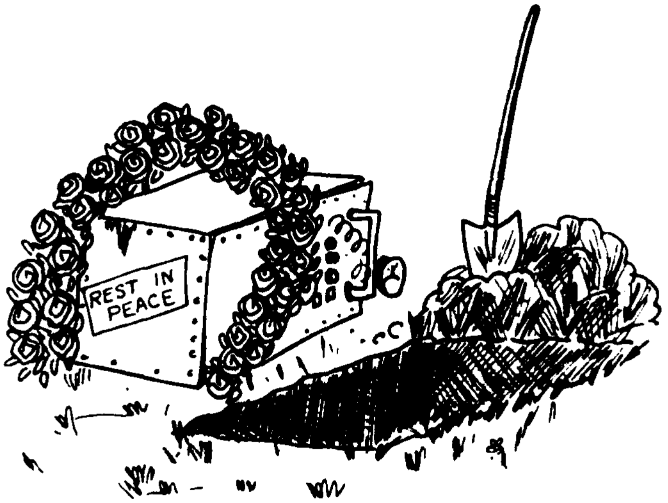
FMEA determines the effects on hardware (circuit) outputs when constituent parts fail in different modes. Typical part failure modes are fail open, fail closed, and parameter drift. Examples are given in the *Reliability Design Handbook*.[8] This task points out to the designer the effects of each item failure on his design and the manner in which the failure occurs. Failures which might appear to be simple could be critical to system operation. The designer now can soften or remove the impact of the failure by changing the design. The FMEA results combined with the prediction task will provide information to the designer on the reliability worthiness of his design and the weak links in the reliability chain. From this information he can make more reasonable decisions as to the need for design changes and, if needed, the types or areas of change that will yield a significant improvement in reliability. FMEA is used as a tool for design improvements to eliminate or reduce item criticality by providing redundancy, alternate modes of operation or increased personnel and material safety. Procedures for performing the FMEA are in MIL-STD-1629.[9]

TEST PLANNING AND TESTING

The proof of achieved reliability and, conversely, the uncovering of deficient areas of design, lie in the testing of the item. The designer should gather appropriate data for reliability purposes during the development and testing stages. Measures such as accept/reject criteria, the definition of a failure, and instrumentation and data requirements should be established. The designer should also supply information indicating the types of tests needed, test equipment required for each test, acceptable limits of operation, and type of test report required. Testing should be performed at the environmental stresses listed in the individual equipment specification. This data and information allow the test and evaluation group to develop a reliability test plan as described in MIL-STD-781.[10]

FAILURE ANALYSIS DURING TESTING

This task determines the following: (1) estimation of the reliability of hardware from test data; (2) if the equipment is to be accepted or rejected; and (3) causes of failure and weaknesses in design. (See MIL-STD-781.) The results of this task provide the basic data for the design analysis and redesign of equipment. It provides the feedback loop to designers so they can effect a design change that eliminates the uncovered deficiencies.



DESIGN REVIEWS

Formal and informal design reviews provide the necessary interaction between the designers, the sponsors and the users. These reviews provide an insight into the designer's ideas and allow an appraisal of his approach, progress, and problems. The designer gains a more precise understanding concerning the requirements and problems and whether his design approach will fulfill the reliability needs of the user. Formal design reviews usually consist of a Preliminary Design Review, held during the preliminary design of the equipment, the Critical Design Review, usually held 30 days prior to formal design release, and the Final Design Review.

Information and guidance that will help to design more reliable equipment can be found in references 8 and 11 through 20 at the back of this booklet.

DESIGN SUGGESTIONS

1. Design for reliability first, maximum performance second.
2. Verify that reliability program tasks (allocation, prediction, failure modes and effects analyses, et al.) being conducted in support of the circuit/assembly design effort fulfill all contractual reliability program requirements.
3. When performing a predicted reliability value for the circuit, use part failure rates

that reflect only those part failure modes whose occurrence will induce an out-of-specified tolerance output from the circuit.

4. Minimize use of moving parts.
5. Use fail-safe features. Minimize the possibility of any faulty part causing an unsafe condition, a series of other parts to fail, or complete equipment failure.
6. Use parts whose dominant failure mode has a minimum effect on the output of the circuit.
7. Make circuits and mechanical designs as simple as practicable.
8. Keep the number and complexity of individual stages to an absolute minimum.
9. Keep the number and variety of components (electrical and mechanical) to an absolute minimum.
10. Utilize common parts where possible. Insure complete interchangeability of all like removable assemblies and parts. (3.4.7)*
11. Use adequate derating factors for temperature effects (especially with semiconductors, capacitors, and resistors) to insure reliability under worst-case conditions.
12. Compensate in equipment design for known limitations of parts.

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*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

13. Choose relays and switches with the proper contacts considering peak current to be interrupted, lowest current to be conducted, and a maximum acceptable contact resistance.
14. Use tolerances which allow for use and wear throughout equipment lifetime (electrical and mechanical parts). (3.4.5)
15. Eliminate critical circuits by allowing large tolerance margins in circuit operation. (3.4.5)
16. Check circuit function with random selection of tubes, transistors, or integrated circuits. Determine if shifts in characteristics or normal aging of other components is likely to affect operation seriously during the desired equipment life. (3.4.5) (3.4.7)
17. Do not push state-of-the-art technology if readily available, proven reliable, common-use technology will do the job. Because it is the latest creation does not make it the best, and the newest devices do not have reliability "track records." Significant advantages in cost, size, weight, speed, etc. may justify the use of state-of-the-art technology, but only if there is a definite advantage needed to meet a requirement.
18. Minimize use of parts known to have high failure rates, such as connectors, relays, and electron tubes.

19. Do not employ active elements if a function can be performed entirely by passive elements unless designing microcircuits.
20. Prevent possible open circuits in variable resistors by connecting the wiper to one end whenever that end would otherwise be left unconnected.
21. Be certain that resistor wattage rating is still adequate when adjusted toward minimum resistance.
22. Use a single connector pin of adequate current rating rather than dividing the current between several pins of lower rating.
23. Minimize power supply demands and internal temperature rise in equipment by using the lowest feasible values of current and voltage. This keeps power losses to a minimum. Avoid the use of high-loss circuit configuration. Do not sacrifice stability or performance.
24. Design shore station equipment to operate properly over a range of 90 to 110% of nominal power-line voltage and 95 to 105% of nominal power-line frequency. Other ranges apply for shipboard and aircraft power sources. (3.5.1)
25. Regulate heater current for electron tubes to reduce initial surges and lower failure rate.
26. Avoid circuits that require a high degree of voltage regulation.

27. Do not connect dial lamps in series. (3.7.8.4)
28. Where an observation is critical, illuminate from two or more sources in parallel. (3.7.8.2)
29. Critically screen manufacturer's electrical parameter values, as these values quite frequently are unrealistic and optimistic. It is recommended that integrated circuits be tested to determine typical values.
30. Do not load integrated circuit outputs to more than 70% of manufacturer's maximum fanout rating.
31. Do not exceed the manufacturer's recommended power supply voltage. Maximum ratings should never be used.
32. Combine internal wiring into a cable and hold together by means of lacing tape or permanently mounted cable ducts. The cable should be clamped to the chassis at frequent intervals to prevent conductor breakage or insulation removal during vibration. This does not apply to backplanes or to wiring which requires isolation because of electromagnetic interference. (3.4.8.9) (3.5.7.1)
33. Protect wires and cables running through holes in metal partitions or across sharp metal edges from mechanical damage by the use of grommets or other suitable means. (3.5.7.2)

34. Route cables to protect them from damage during movement or from moving parts. Such damage includes cutting, chafing, crushing, pinching, flexing, stretching, and bending sharply. (3.5.8.2)
35. Do not route electrical cables below fluid lines.
36. Do not use edge-board connectors. Two-piece connectors are more reliable.
37. Be sure that certain failure modes do not negate the use of redundant equipment.
38. Use is often made of redundancy when complex equipment is intended for long periods of operation. The presence of redundant elements in an equipment implies the existence of more than one way to do a task; therefore, the failure of a redundant element will not ordinarily result in failure of the equipment. The advantages are obvious, but redundancy introduces problems of additional cost, size, weight, and complexity (more components to fail). The presence of redundant elements does not necessarily imply complete functional redundancy.

MAINTAINABILITY

Maintainability design is an important part of Navy electronic equipment. With its expected long deployment life span, it must have a high level of maintainability not only to reduce equipment downtime, but also to help reduce the life cycle cost of maintenance and logistic support. Specifically, maintainability design is that part of equipment design which contributes to the rapidity, ease, and economy of maintenance and repair. The main purpose is to provide features and functions which will simplify or expedite the maintenance tasks which must be performed to keep an equipment in its specified operating condition, or to restore it to that condition, in the environment where the equipment will be used. As a prerequisite to ensure optimum maintainability of Navy electronic equipment, it is important that the designer be aware of both the established shipboard maintenance procedures and the physical conditions under which maintenance is to be performed. Similarly, the designer should also be aware of the qualifications and limitations of the technicians who will maintain the equipment, and take care to keep the maintenance methods and test procedures within the capabilities of the available maintenance personnel.

It is clear that maintainability must be considered early in equipment design. MIL-STD-470[21] contains the basic requirements and guidelines for a maintainability program. (3.3.4) A maintainability analysis is performed in accordance with MIL-STD-470.[21] Techniques for the maintainability prediction are found in MIL-HDBK-472.[22]

(3.3.4.2) Maintainability design reviews are held at appropriate stages of the equipment development. Maintainability status reports are required at specified intervals. MIL-STD-471[23] gives the procedures, test methods, and requirements for verification of the specified maintainability requirement.

Even if the design is not required to supply information for, or participate in, the maintainability program, he should be aware that such events are taking place and may interact with his design. Maintainability design books are included in references 24 through 27 at the back of this booklet.

GENERAL

1. Design equipment for maintenance under worst case conditions: inexperienced personnel working under personal stress in a difficult environment.
2. Provide for the making of crucial adjustments in emergency situations without need for complex associated equipment.
3. Where feasible, all maintenance tasks should be easily and rapidly accomplishable by one man.
4. Use throw-away modules where it is cost effective. Provide means for an easy Go/No-Go check. (3.3.2.3)*

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*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

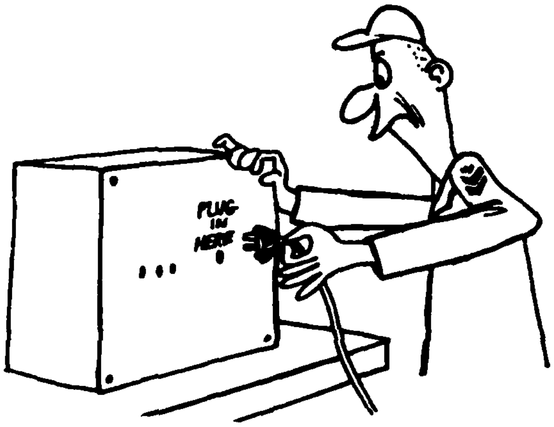
5. Eliminate dirty, awkward, and tedious job elements.
6. Use air filters and RFI screens that are easily accessible from outside the equipment for inspection, cleaning, and replacement. (3.4.8.14) (3.8.1.4)
7. Design equipment and use components which require little or no preventive maintenance.
8. Identify parameters or conditions which should be monitored or checked through preventive maintenance actions.
9. Whenever possible, eliminate the need for maintenance adjustment by use of stable parts and circuit designs. Never use adjustable parts when part values need not change during the life of the equipment.
10. Provide time totalizing meters to indicate elapsed time for both standby and operating conditions. Do not use the electrochemical type. (3.7.8.14)
11. Limit the need for long and complex maintenance manuals and procedures.
12. Provide rotating assemblies with means for hand rotation, and indicate normal direction of rotation.
13. Insure that all moving parts operate smoothly and quietly. Keep backlash and torque-lash to a minimum.

14. Design moving mechanical components for use without replenishment of lubricant where practicable.
15. When lubrication is required, moving parts should not require disassembly.

TESTABILITY

16. All equipment must be tested during its manufacture, installation, and, extensively, throughout its useful life. Therefore, efforts expended to improve ease of testing and calibration at all levels will result in a reduction in system life cycle cost.
17. The design of modular systems greatly facilitates test and repair and is encouraged; however, these modules or building blocks must be easily tested within the system and by themselves, preferably without the use of special equipment.
18. Built-in-test (BIT) should be used for both fault detection and isolation,[28] and should normally be limited to no more than 15% increase in equipment complexity.
19. Fault indicators, both visual and audible, are desirable and must themselves be easily tested.
20. Provide test and control points for checking signals from, or inputting to, essential voltages and/or waveforms.

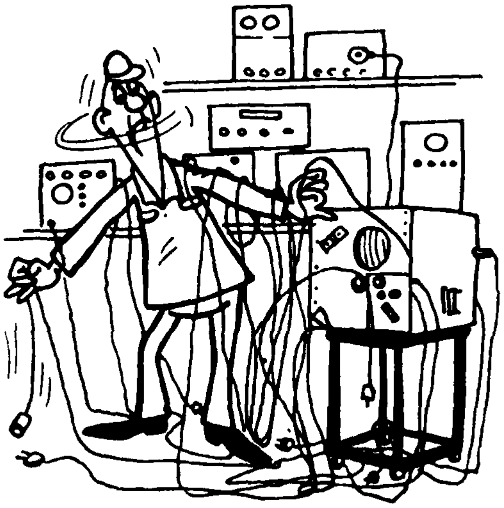
21. Design test points and test connector to allow accidental shorting of pins both to ground and to each other without circuit damage.



22. Whenever possible, minimize the need for in-field adjustments of the equipment. Modules and subassemblies must be replaceable without requiring system realignment.
23. Design for rapid and positive adjustment and calibration. Adjustments should be accessible and easily identified.
24. In general, always
    a. Provide methods of interrupting feedback loops.
    b. Try to prevent "Domino" failures.
    c. Allow for external initialization.
    d. Allow internal clocks to be easily disabled.

   - e. Break up long counter chains.
   - f. Design BIT circuitry to allow failsafe operation in case of BIT failure.
   - g. Allow for reasonable capacitive loads for both input/output lines and test points.

25. Provide built-in-test equipment (BITE) whenever:
   - a. Frequent observations are necessary while prime equipment is in actual operation (e.g., panel meters and monitor scope).
   - b. Portable test equipment cannot readily or effectively provide necessary information (e.g., test antenna and rf sampling probes).



c. Testing requires disassembly of an equipment or transmission line (e.g., directional couplers, slotted lines, and waveguide switches for dummy loads).
d. Measurements endangering life must be made.
e. A significant reduction in mean-time-to-repair will result.

26. Built-in monitoring devices/BITE should be easily removable for calibration and repair. (3.6.1.1)
27. Provide, in an easily accessible location, any special tools and/or test cards and cables.
28. Use a defeatable keying system in subassemblies to minimize special adapters but be sure it cannot be accidentally bypassed.

LABELING

29. Lubricant type and frequency of lubrication should be on a label at or near lubrication points. (3.4.9.12)
30. Clearly mark points which MUST be removed at specified intervals for maintenance or replacement. Indicate the interval in calendar or operating time.
31. Mount maintenance instructions and calibration charts on the equipment in full view for maintenance. Design them to last the equipment life. Instructions should be simple, complete and readable.

32. Locate part reference designations adjacent to each part. Markings should be legible and permanent.

33. Select multi-contact connectors that are keyed, polarized, or configured to prevent improper connections, positioning, or mating. (3.4.8.10.7)
34. Design removable parts so they can be installed only in the proper position by means of keying, color coding, size, or shape. (3.6.6)
35. Provide guide pins if required for alignment of modules or high density connectors.
36. Aligning or keying pins on connectors should project beyond the electrical pins.

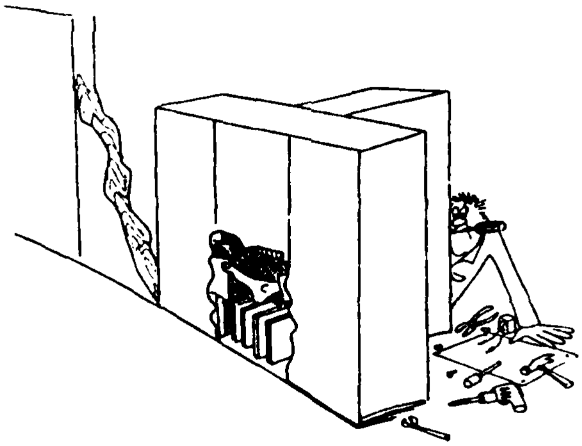
37. Proper orientation of components within a case should be obvious through either design or appropriate labels. All similar sockets and polarized components should have the same physical orientation.
38. Labels on plastic or metal should be stamped, etched, engraved, silk screened, or stenciled and covered with clear lacquer. Do not use paper labels or decals. (3.9.4)
39. The method of opening and closing should be obvious from construction of cover or instructions attached to the outside.
40. Mark, index, or meter all controls so that the control position can be readily identified.
41. Place fixed guide marks on equipment if the pre-setting of controls is required for standard maintenance operations.
42. Index mechanical assemblies subject to maintenance disassembly to insure proper relative position of parts on reassembly.
43. Route cables to be easily accessible for inspection and repair, and secure them with easily operated cable clamps.

44. Wires and cables should be coded, labeled, and easily identifiable throughout their length.

45. Color code chassis wiring in accordance with MIL-STD-681.[29] Noninsulated leads should be color coded by means of colored lacquer spots near the terminals (3.4.8.36) (3.9.4.4)
46. Mark transmission line terminals with the characteristic impedance of the line.

ACCESSIBILITY

47. Avoid need for access to the rear and sides of equipment. Normal shipboard installations make such access difficult.
48. Provide access to parts and leave sufficient hand room for testing, removal and replacement.
49. Provide sufficient spacing between connectors so they may be grasped easily for connecting and disconnecting. (3.6)

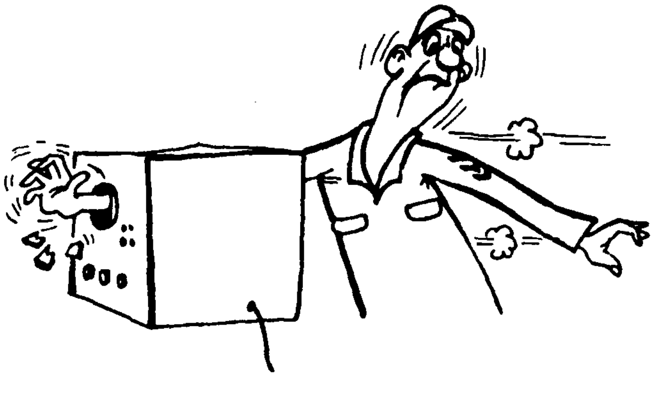


50. Design equipment so that components with a high probability of failure are the most easily accessible. (3.6)
51. Use plug-in techniques for easy and rapid replacement of assemblies with spares. (3.3.2.3)
52. Minimize the number of inputs and outputs for each replaceable unit.

53. Avoid stacking of parts. Replaceable units should be mounted to the chassis rather than to each other.
54. Units and components should not be blocked by other large or difficult to remove units, components, or structural members. (3.5.8.1)
55. Prevent the possibility of excessive torque or pressure being applied to cases, modules, or connectors during installation.
56. Consider self-locking plugs with a safety catch rather than plugs requiring safety wire.

57. Use care in mounting miniature parts. Their smallness often influences the designer to mount them in ways which make maintenance difficult. (3.5.8.1)
58. For physical access, the following should be used in this order of preference, consistent with possible performance degradation: (3.6)
    - Opening with no cover.
    - Sliding or hinged door if moisture or foreign materials are a problem.
    - Quick-opening cover plate if a door will not meet stress or sealing requirements.
59. Provide doors and hinged covers with slip hinges, braces, locks, stays, or stops to hold them open. (3.6.6.1)
60. Design all chassis to be completely removable from the enclosure without extensive disassembly.
61. Mount frequently removed, large assemblies on drawer slides. (3.6.6)
62. Choose drawer slides which are adequate for the load. There should be no sagging, binding, or swaying motion with the chassis in the opened position. Automatically operated locks with a quick disconnect feature should hold the chassis open in the maintenance position. If flexible cables are employed, cable handling should be automatic. (3.6.6)

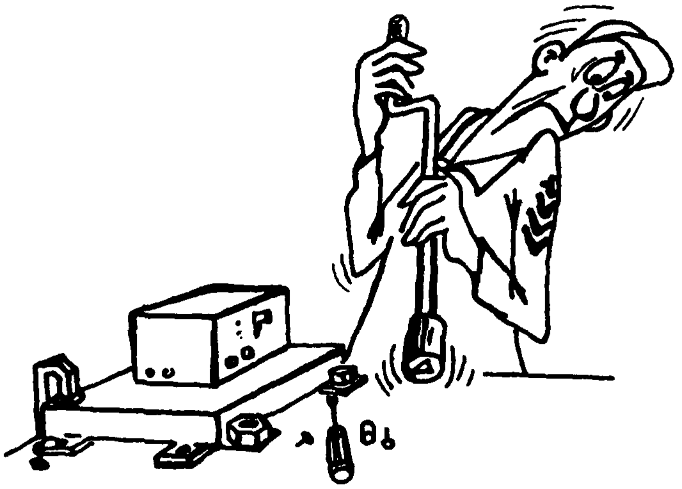
63. Slides which pivot and lock the drawer in a vertical plane allow easy access to the top or bottom of drawer-mounted equipment while still installed in a rack. (3.11.10.1)
64. Provide flexible cables (preferred to "patch cords") that are long enough to permit drawer slides to be fully extended without breaking electrical connections.
65. Provide handles or bales for removing units of chassis from enclosures.
66. Design the equipment so that parts will not be susceptible to damage during servicing and maintenance. Provide guards to protect exposed delicate parts from damage. Bales or other suitable means should be provided to protect parts when the chassis is removed and inverted for servicing. (3.6.7)
67. Provide chassis mounted rests or stands for large or heavy components while they are being removed or installed. (3.6)



68. Design equipment to permit thorough visual inspection of all parts so that obvious failures (such as damaged parts, burned resistors, or broken wires) can be located quickly. For visual access, the following should be used in the following order of preference, consistent with possible performance degradation: (3.6)

- Opening with no cover.
- Transparent plastic window if dirt, moisture, or foreign materials are a problem.
- Break-resistant glass if physical wear or contact with solvent will cause optical deterioration of plastic.
- Quick-opening metal cover if glass will not meet stress or other requirements.

69. Where practicable, provide for maintenance without the use of tools.
70. Limit the number and variety of tools, accessories, and support equipment.
71. Minimize the need for special tools. Where required, they should be mounted securely in a convenient place in the equipment. (3.6.3)
72. Insure that assemblies and units can be replaced with nothing more than common hand tools.



73. Lighted switches and panel lights should have front replaceable lamps. Use lock-type lamp holders. Minimize the number of lamp types.
74. Localize circuit parts and subsystems to the maximum extent consistent with good electrical and mechanical design.

75. Provide slack in flexible conductors to allow for at least two replacements of the attached parts.

76. When soldering leads and wires to terminals, wrap lead of wire around terminal no less than half or more than a full turn to prevent movement during soldering. Leave no extension on wires soldered to terminals. (3.5.7.3.1)

77. Never mount more than three wires on one terminal or wrap-post. (3.4.8.31)

78. Position connectors and associated labels in full view. All connector pins should be clearly identified.

79. When using connectors with solder terminals, the terminals should be long enough and far enough apart to prevent damage to neighboring terminals, wiring insulation, or surrounding connector material.

80. Mount terminal strips and test points so as to be accessible when the equipment is opened for maintenance without the removal of cable entrance plates or cables. (3.7.2.8.3)

OVERLOAD PROTECTION

81. Protect equipment with fuses, etc., to prevent damage from unexpected operating conditions, such as current overload, excessive heating, or internal faults. (3.5.2)

82. Make overload protective devices such as fuses and circuit breakers readily available (from the front panel if possible). No special tools should be required unless needed for safety. (3.6)
83. Provide overload indicators on major components even if overloaded circuits must sometimes be kept in operation.
84. Provide a positive indication on the front panel that a fuse or circuit breaker has opened a circuit. Labels should be provided on fuse panels to indicate the rating of each fuse and the area of major equipment served by the fuse or circuit breaker. (3.5.2.1)
85. Provide holders for spare fuses in a convenient location, and mark "SPARE" adjacent to each spare holder in letters at least 3/64 inch high. (3.4.8.17) (3.5.2)
86. Provide one spare fuse for each type used, and at least 10% of the total number. (3.8)
87. Select circuit breakers capable of being manually operated to the ON and OFF positions. (3.4.8.8)
88. Use trip-free circuit breakers unless the application requires emergency overriding of the trip mechanism (nontrip-free). (3.4.8.8)

ENVIRONMENTAL CONDITIONS

"THE TROUBLE WITH SNEDLY IS THAT HE GETS TOO INVOLVED WITH HIS WORK."

The military environment is recognized as a constant challenge to designers. Successful Navy electronic equipment depends on consideration of platform requirements from the early planning stages, and designing to survive the required environmental conditions.

DESIGN SUGGESTIONS

1. Apply all parts with proper concern for environment. Allow for change in values of part characteristics with time, temperature, and humidity.
2. When not requiring a complete military environmental specification, a "tailored specification" for equipment should be employed using applicable sections from military specifications but softening the specification in areas where full military specification is not required.
3. Design for MIL-E-16400[1] extreme environmental requirements (may be modified by equipment specifications): (3.3.5)*
    a. -62 to +71°C (non-operating).
    b. -54 to +65°C (operating) or other ranges as defined by the equipment specification.
    c. 95% relative humidity.
    d. Equipment should withstand the grade A, type A, class I shock test of MIL-S-901.[30]
    e. Equipment should withstand the type I vibration test of MIL-STD-167.[31]
    f. Equipment exposed to weather is expected to withstand winds of 100 knots and to operate in winds of 75 knots.

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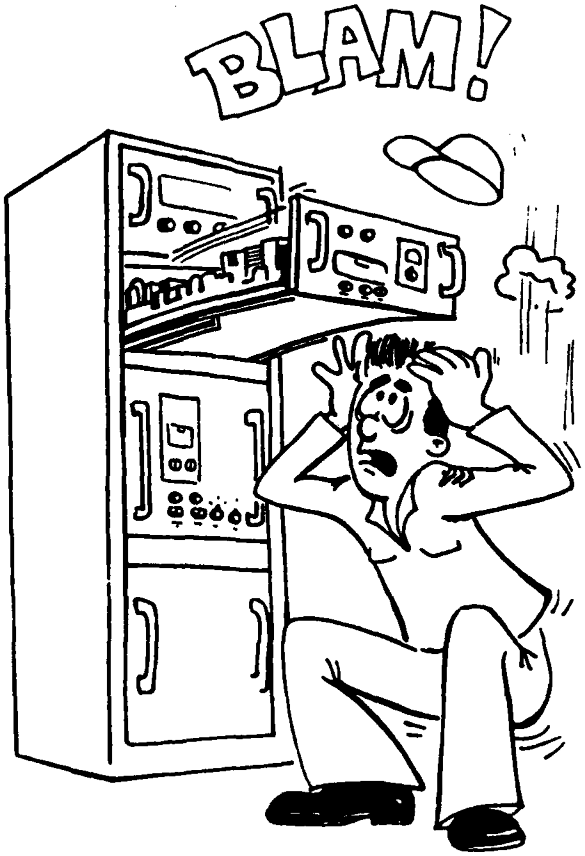
*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

g. Equipment exposed to weather should withstand salt spray.
h. Use watertight enclosures for equipment exposed to weather. (3.7.2.1)
i. Use dripproof enclosures (even if tilted 45 degrees) for equipment to be installed inside ship spaces. (3.7.2.1) (3.8.1.3)

4. Protect external connectors from damage or contamination from dirt, water, etc., by means of attached plug or socket covers.
5. Clamp or otherwise secure electronic parts (having a diameter of 1/2 inch or more, or whose weight exceeds 1/4 ounce per lead) to the chassis or board to prevent lead breakage from fatigue under vibration. (3.5.8)
6. Use stranded wire rather than solid conductor where flexure in vibration may cause breakage.
7. Secure stranded copper wire that has been soldered to a terminal so that vibration does not cause the conductor to flex near the area where the individual strands have been soldered together.
8. Do not join leads without a support at their junction.
9. Use alignment pins or similar devices of sufficient strength to bear shock and vibration loads between chassis assemblies and enclosures. Never depend on electrical connectors and chassis slide assemblies to bear such loads.

10. Drawers or removable chassis should have at least two guide pins on both front and rear surfaces. Mating parts should fit such that they do not hammer during vibration.
11. Provide adequate locking devices on doors and drawers to prevent them from opening during shock or vibration.



12. Insure that mechanical design provides adequate mounting and support for all component parts, using a minimum of structural material.
13. Avoid cantilever mounting of parts.
14. Locate heavy parts as close to load-bearing structures and as low as practicable. For tall equipment requiring a stabilizer mount or bracket at top of the equipment, mount heavy parts as close to the rear equipment wall as practicable.
15. Determine grouping and location of parts on a chassis by good mechanical design practices to withstand the rigors of shock and vibration in use.
16. Equipment enclosures should not resonate in vibration below 50 Hz. (3.7.2.3)
17. Improve the rigidity of large, flat sheet metal items with creases, bends, or stiffeners. (3.7.2.4)
18. Modules and printed wiring boards should have a higher natural frequency than their mounting structure (preferably above 60 Hz). This can be accomplished by the use of small boards or stiffeners.
19. Use shock or vibration mounts only if absolutely necessary. If their use is permitted, they must meet certain specifications. They are treated as nonstandard parts and approval is required. (3.7.4)

20. Shock or vibration mounts should be easy to replace. Provide adequate clearance to allow freedom of travel. Avoid cascading systems of such mounts. Include attached cables in analysis for shock or vibration mounts.
21. Guard against relay contacts opening during shock or vibration.
22. Do not allow the possibility of electrical instabilities during vibration caused by loose mechanical parts.
23. Avoid use of friction or pressure contacts where possible. Where used, they should be designed to prevent erratic operation under service conditions. (3.5.7.3.2)

ELECTRO-OPTICS

Although the field of electro-optics is relatively new to military systems, it has become increasingly apparent that no other technology will see such an increase in application throughout the 1980's.

PHYSICAL SHOCK

Electro-optic systems generally contain certain fragile components which, even when ruggedized to the most feasible limits, are susceptible to damage if they encounter the maximum shock and vibration scenarios typical of most naval platforms. Therefore, it is advisable that extreme care be taken when choosing fixture designs and locations for such equipment, if such choices are possible within the operational requirements.

While the Navy has had much experience with the emplacement of visible optic systems, delicate electro-optic systems present an even greater challenge to the engineer. The actual optic train of an electro-optic system may be composed of germanium or other exotic materials such as zinc selenide, or zinc sulphide. Such materials are required for the bandwidth transmissivity in the 3-5 and 8-14 micron regions (infrared). Low Light Level Television (LLLTV) also poses special problems as the LLLTV camera tubes are highly delicate and unless mounted with extreme care are subject to damage from physical shock.

Aboard the ship, the system should be placed as far as possible from gun mounts, steam catapults, or quick acting doors or ramps which may be a source of shock or vibration. This criterion is not trivial for if the location of the system is forced into a suspect area, then accelerometer and other instrumentation tests are highly advisable before emplacement, lest the system be rendered inoperative by the environment even prior to use.

THERMAL SHOCK

In addition to being generally structurally weaker than ordinary materials, the elements of an electro-optic system also pose the problem of an acute sensitivity to thermal shock, or thermal differentials across the materials.

When in the limiting case, actual destruction of the material (such as germanium or zinc selenide) may ensue. But even prior to that point, image degradation may take place rendering the system operationally useless. In some cases, as with germanium, the transmissivity practically ceases when the material reaches about 90°C. This is a definite limiting factor for high-speed aircraft or missile applications.

To illustrate the complexity of the problem, one manufacturer recently discovered that in order to compensate for expected thermal variations, the germanium lens elements in the system had to be movable over a one-half inch travel distance. The design of this automatic thermal compensation and lens system cost approximately $100,000.

ELECTRICAL AND ELECTRONIC NOISE

Fiber-optic transmissions of light do not cause electromagnetic emanations. Fiber-optic cables can also be made smaller and lighter than ordinary wire cables. Unfortunately, the optic fibers are susceptible to breakage which reduces transmissivity. Connectors are also a source of low transmissivity.

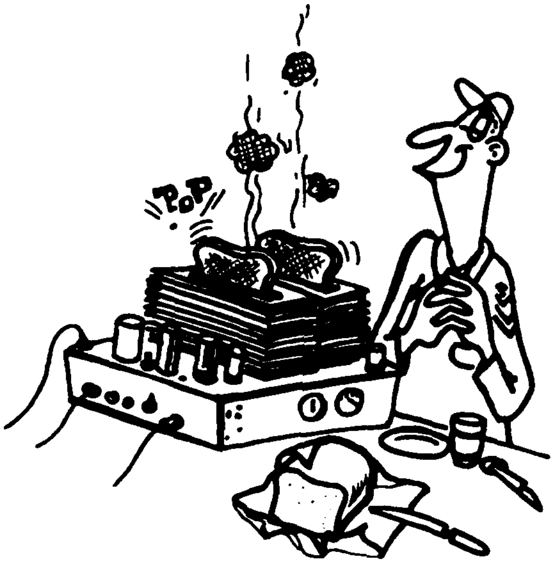
While the problems of physical or thermal shock provide no specific hazard regarding fiber-optic systems design, there are special electrical or electronic noise problems associated with fiber-optic systems. These problems can become difficult if not dealt with from the inception of system design.

An often used technique to take advantage of the increased bandwidth capacity is the multiplexing of several "wire" channels into a single fiber-optic channel. The multiplexing electronics and the electro-optic transmitter are thus operating at much higher data rates than the previous parallel electrical channels. This higher speed operation means higher frequency electrical signal components and possibly a more significant filtering requirement for the electronics. Higher frequency or higher data rate outputs will also evolve without multiplexing and may also require more filtering. Attention should be paid to the fiber-optic connectors to assure the proper waveguide filter action of the cable ferrule and bulkhead connector in equipment to keep such equipment shielded (so radio frequency interference cannot enter through the fiber-optic "opening" in the equipment case).

SUMMARY

Other than the preceding points, the design practices necessary to provide a reliable electro-optic system are very much the same as those given in the other sections of this booklet.

THERMAL DESIGN



High temperatures and temperature cycling are causes of deterioration for most electronic parts which leads to degraded performance or failure of electronic equipment. Inadequate cooling is thus a major cause of poor reliability. Parts should be chosen to withstand expected temperatures and must be kept within their thermal ratings. Cooling systems should be designed to control the temperatures and reduce temperature cycling of parts under all intended thermal environments. The *Reliability Design Handbook for Thermal Applications*[32] is an excellent guide for thermal design.

GENERAL

1. Select the simplest and most efficient cooling method that will remove 80% of the total heat generated. (3.8.1)*
2. The choice of cooling means for an equipment depends on the total heat load to be dissipated, operating environment, part temperature sensitivity, equipment reliability requirement, size, weight, power, and others. (3.8)
3. Limit heat dissipation by choosing efficient parts (semiconductor devices instead of electron tubes, for example) and circuits (class B or C operation instead of class A).
4. Use parts which have a greater thermal operating range than worst-case conditions, and minimum temperature sensitivity.
5. Keep the thermal environment as nearly constant as practicable to reduce the thermal stresses caused by temperature cycling and thermal shock.
6. Always assume the equipment will be mounted adjacent to other equipments which are hotter than the ambient air temperature.

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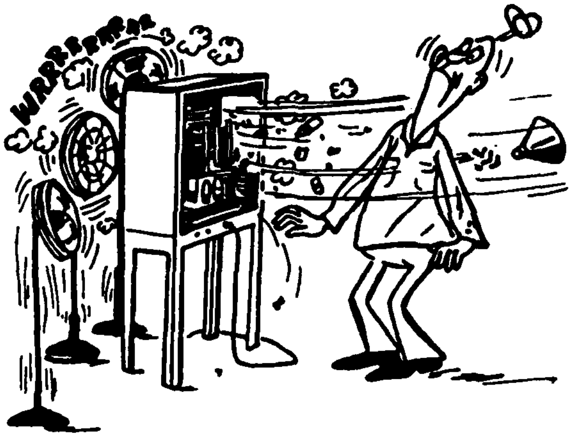
*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

NATURAL COOLING

7. Use simple cooling techniques based on conduction, radiation, and free convection to the maximum extent possible. Use the ambient as the thermal sink rather than require external cooling provisions. (3.8)
8. Ensure that heat flow paths are as short as possible, have large cross-sectional areas, and are made of material having high thermal conductivity. (3.8.2)
9. Consider heat pipes for applications requiring high thermal conductance. Properly applied, a heat pipe can be hundreds of times as efficient in transferring heat as a solid copper conductor.
10. Be certain that inclination of the heat pipe will not degrade its performance beyond acceptable levels.
11. Use a metal case or chassis for conducting heat. (3.8.2)
12. Make sure all joints conduct heat well and are close fitting to provide a maximum metal-to-metal contact. Where necessary, a thin layer of silicon grease is recommended for improving thermal conductivity.
13. Mount parts which dissipate more than one watt on metal chassis or provide them with heat paths leading to a heat sink. (3.4.8.37)

14. Orient and mount parts to achieve maximum convection.
15. Place temperature-sensitive components below heat sources, or isolate them. (3.8.2)
16. Position parts in the equipment with due regard to the heat radiated by surrounding parts so that the temperatures of individual parts and circuits do not exceed maximum operating temperatures. Avoid hot spots.
17. Provide polished and unpainted heat shields for heat-sensitive components located close to a heat source.
18. Make sure that heat sources have high emissivity and, if embedded, are provided with metal heat conductors to some means of cooling.
19. Glass-epoxy circuit boards are poor heat sinks. Do not rely entirely on natural cooling.
20. Consider metal-core printed wiring boards for applications involving more heat than can be dissipated by glass-epoxy printed wiring boards.
21. Use physical isolation and thermal insulation where appropriate (3.8.2)

FORCED AIR COOLING



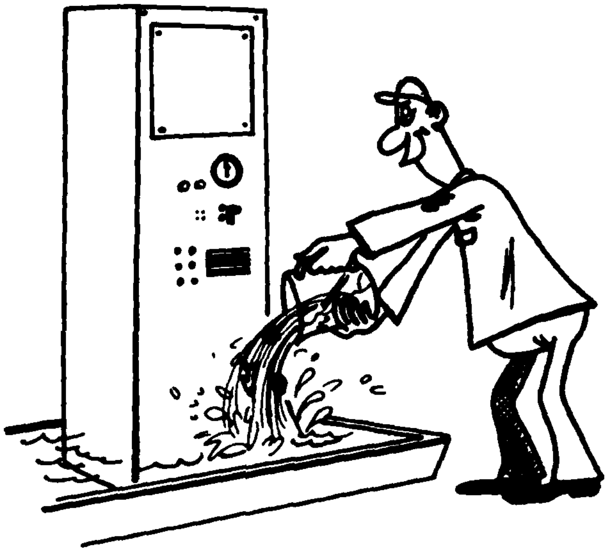
22. Provide adequate ventilation. If necessary, add blowers to keep parts within safe operating temperatures. Ventilation openings must meet appropriate dripproofing requirements, electromagnetic interference specifications, and the ducting requirement for hazardous atmospheres. (3.8) (3.8.1.3)
23. Base the design of forced-air cooling systems on the amount of heat to be dissipated, the quantity of air to be delivered at the pressure drop of the enclosed *equipment, the volume of the* equipment, the attainment of safe operating temperature at the heat sources, and the minimization of cooling power; i.e., the energy requirement for moving the air through the cooling system. (3.4.8.3) (3.8)
24. Design so the blower motor is cooled.

25. Filter external air used to cool internal components. Large amounts of contaminants can otherwise be deposited on sensitive circuitry causing performance degradation or corrosion (which is accelerated by high humidity). Contaminants can also restrict air flow and thermally insulate the hot components in need of cooling air. (See Maintainability No. 6.)
26. Design so that forced convection is in a direction to aid the natural convection.
27. Cool hot parts by parallel air flow paths.
28. Avoid reuse of cooling air. If secondhand air or series-flow air must be used, the sequence of air passage over cooled parts must be carefully planned. Cool temperature-sensitive parts or parts with low maximum permissible operating temperatures first. Insure that the coolant has sufficient thermal capacity to maintain required temperature for all parts. (3.8.2)
29. Design forced air systems to create a positive pressure within the enclosure.
30. Provide an integral cooling system to preclude damage in equipment containing heat critical parts which might otherwise be damaged by excessive heat when a chassis is withdrawn for maintenance. (3.8.1.5)
31. The inlet and outlet air temperature differential should not exceed 14°C. (3.8.1.1)
32. Insure that intakes and exhausts are far apart.

33. Do not locate ventilation or air exhaust openings on enclosure top or front panel without specific approval. (3.8)
34. Minimize air-flow noise and vibrations including blowers interacting with equipment cases. (3.4.8.3)
35. Use fans, blowers, and pumps driven by brushless ac motors if possible, or properly shielded dc motors. (3.8)
36. Be certain that retractable writing surfaces and drawers do not block the flow of cooling air.
37. Include in air-flow calculations, area reduction caused by wiring in the air ducts.

LIQUID COOLING

38. Liquid or vaporization cooling may be permitted for equipment designed to operate in a high ambient temperature or with high heat densities where natural or forced air cooling methods are unsuitable. (3.8)
39. If liquid cooling must be used, water is the preferred liquid coolant. (3.8.1.2)
40. Design so that the coolant can expand freely and the enclosure can withstand the maximum vapor pressure of the coolant.
41. Be sure that the piping is adequate and equipment is hermetically sealed. Prevent air locks.
42. Provide adequate drains and filter plugs.



43. Design equipment so drains are at low points and bleeder valves are at high points of the system.
44. Use a check valve at each disconnection.
45. Insure that the coolant does not boil below maximum temperature and, if necessary, provide a temperature control device. Insure that coolant does not freeze above minimum temperature. Either condition may cause bursting.
46. Avoid condensation of moisture in equipment.
47. In designing the cooling assembly, consider the aspects of maintenance and repair. Select exchangers, coolant, and piping as a system. Coolant must be noncorrosive to exchangers and piping.

VAPORIZATION COOLING (Liquid Cooling Factors Apply Here Also.)

48. Be sure that sufficient coolant is provided.
49. If required, install a make-up reservoir.
50. Provide pressure control and pressure relief valves.
51. Conduct environmental tests on refrigeration systems.

ELECTRON TUBES AND SHIELDS

52. Space unshielded tubes at least 1-1/2 diameters apart.
53. Avoid overheating tube anodes.
54. Use tube shields on all miniature and subminiature tubes. The shields should fit tightly, be nonmagnetic, and use nonprecious metals. (3.4.8.28) (3.4.8.28.1)
55. To reduce thermal radiation from tubes to heat-sensitive components, choose shields that are highly emissive (blackened) internally, polished externally, and thermally conductive to the chassis.
56. Avoid mounting heat-conducting shields on a plastic chassis.

SEMICONDUCTORS

57. Remember that semiconductor devices are usually very heat sensitive. Thus, their thermal designs are critical.
58. Allow for the complementary heating of densely packed microcircuits.
59. Provide power transistors and power rectifiers with connections of low thermal resistance to well-cooled, heat-conducting chassis, or large, vertical fins. Be certain that electrical insulation does not produce unsound thermal designs.
60. Ceramic integrated circuits have better thermal characteristics than plastic ICs.
61. Hybrid microcircuits must have a thermal analysis performed prior to fabrication.

THERMAL TESTING

62. Provide temperature, pressure, or flowrate indicators for monitoring the performance of the forced-air or liquid cooling system. Locate the sensing elements at appropriate locations to detect abnormal conditions and operate automatic alarms and protective devices. (3.8.4) (3.8.4.1)
63. Protect against equipment damage in case of cooling failure by means of automatic shut down, except for power to cooling fans or pumps. Provide a manual override switch (battle short). (3.8.4.2)

64. Test the thermal design at maximum specified ambient temperature with the equipment fully assembled and operating in its hottest mode. Measure all critical temperatures. Include thermally sensitive parts, components expected to be hot, and those dissipating 1% or more of the equipment power. Never assume that a design will be satisfactory over the range of temperatures required of military equipment on the basis of tests performed at room temperatures on a development bench. (3.8.5)
65. Use thermocouples, thermistors, infrared photography, or temperature-sensitive materials to investigate thermally critical applications. Do not permit test devices to affect the accuracy of their own measurements by heat sinking, blocking normal air flow, or leaving open an access which would normally be closed. (3.8.5.2)
66. Verify air flow in equipment by measuring and mapping with smoke.

MATERIALS, PROCESSES, AND PARTS

The designer must bear in mind the ever growing life cycle costs of equipment. Unnecessary complications in design lead to higher cost and less reliability. The simplest design is not always mandatory, of course, but uncluttered thinking is vital. The designer must be conscious of and willing to use preferred reliable parts and circuits where possible (although he should not be restricted to them) in his initial breadboards. He should not be forced to use preferred reliable parts where other parts will give better performance for the particular circuit that he needs. However, the part that the normal research and development man uses is often the part closest to him and therefore the supply of parts that he has readily available should be preferred reliable parts. This is considered most important from the standpoint of economy and eventual reliability because there is always a natural great reluctance to change a circuit once it has been designed. Quite often the use of inferior parts may be so extensive that the change to preferred standard parts will require expensive redesign. Once a "breadboard" is accepted, its weaknesses are magnified in subsequent evaluations, tests, production engineering, manufacture, installation, maintenance, support, and logistics problems.

USE OF STANDARD PARTS

It is sometimes a tedious procedure to locate suitable standard parts. However, the time spent finding standard parts is usually more than compensated for by the time and money saved in procuring and documenting the part. In equipment which must eventually be logistically supported, a further savings in time and effort will be realized in the preparation of provisioning documentation, and overall savings to the Navy will be realized in the logistic support costs for each equipment. Even those standard parts which are apparently more expensive than other parts will prove to be cheaper when the long term costs are considered.

A few of the advantages of standard parts are listed below:

- Simplified procurement documentation (no need for sole source documentation, acceptable source documents, etc.).
- No need for the approval required for nonstandard parts. (3.4.3)
- No need for source control drawings and specifications.
- No need for multiple source solicitations.
- Availability of specification data including tolerances and performance over the environmental range, derating parameters, etc.
- Availability of reliability data.

Other advantages are accrued by standard parts for which a logistic system is already established.

PROCEDURE FOR FINDING STANDARD PARTS (3.4.1)

a. Go to the *Military Standard for Electronic Equipment Parts, Selected Standards (MIL-STD-242).*[33] This document cites reference documents and (usually) a list of preferred parts, values, etc. The referenced documents include military drawings, specifications, and other "selection and use" standards. If a specific part suitable for the design requirements is not listed, go to the reference document(s) for additional information.


TRASH

b. "Selection and Use" standards constitute more detailed preferred parts lists than MIL-STD-242[33] and likewise list specific parts and reference documents. "Selection and Use" standards exist for the following parts:

capacitors	MIL-STD-198
resistors	MIL-STD-199
electron tubes	MIL-STD-200
crystals and crystal holders	MIL-STD-683
dry batteries	MIL-STD-688
semiconductors	MIL-STD-701
synchros	MIL-STD-710
switches	MIL-STD-1132
terminals, terminal boards, etc.	MIL-STD-1277
meters, electrical	MIL-STD-1279
transformers, coils, and inductors	MIL-STD-1286
waveguide coupling assemblies	MIL-STD-1327
directional couplers	MIL-STD-1328
switches, rf coaxial	MIL-STD-1329
relays	MIL-STD-1346
knobs	MIL-STD-1348
attenuators	MIL-STD-1352
connectors	MIL-STD-1353
waveguide, rigid	MIL-STD-1358
fuses and fuse holders	MIL-STD-1360

lamps and lampholders	MIL-STD-1368
filters and networks, electrical	MIL-STD-1395
resolvers	MIL-STD-1451
microcircuits	MIL-STD-1562

c. If the design requirement still isn't satisfied, go to the individual military specifications.

d. From the specification or standard, obtain the military part numbers for the desired parts. The part numbers can be quickly referenced through the federal supply system. Also helpful are the Qualified Products Lists (QPLs) associated with many component specifications; they can lead the designer to manufacturers and are useful in reducing procurement lead time.

NONSTANDARD PARTS

If a suitable standard part is not available, the use of parts already in the national stock system is still desirable. QPLs associated with the specification closest to the requirement can be helpful in locating manufacturers' part numbers which are in the stock system. Whenever a nonstandard part is used, it is worth checking to find out if it is already available through the supply system.

Help in finding such parts and thus avoiding the procedure for obtaining approval of nonstandard parts can be found in MIL-STD-965.[34] Included is a list of part types and telephone numbers for obtaining fast, informal information. A formal, written procedure is also available.

MATERIALS

1. Do not use the following materials without specific approval: (3.4.10 — unless otherwise noted)
    a. Asbestos (3.4.9.6)*
    b. Cast iron (3.4.9.6)
    c. Cellulose, acetate
    d. Cellulose, nitrate
    e. Cellulose, regenerate
    f. Cork
    g. Ebonite (hard vulcanized rubber) (3.4.9.6)
    h. Felts, hair or wool
    i. Fiber asbestos electrical insulation
    j. Glass (3.4.9.9)
    k. Graphite base lubricants (3.4.9.12)
    l. Jute
    m. Leather
    n. Linen
    o. Magnesium or magnesium alloy
    p. Mercury (3.4.10.1)
    q. Organic fiberboard
    r. Paper and cardboard
    s. Plastic (using cotton linen or wood flour as a filler)

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*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

    - t. Porcelain (3.4.9.6)
    - u. Radioactive materials (3.4.10.1)
    - v. Silicone lubricant compounds (3.4.9.12)
    - w. Wood
    - x. Zinc casting (3.4.11.1)

2. Do not use toxic or hydroscopic materials or materials which will support combustion or fungus. (3.3.5.6) (3.4.9.5) (3.4.9.7)
3. Avoid materials which swell, decompose, or otherwise change properties in the presence of high humidity. If in doubt, test the material.
4. Do not use acid or corrosive soldering fluxes or pastes. Rosin is the only noncorrosive flux. (3.5.7.3.1)
5. Do not use dissimilar metals in contact, especially where corrosion can be expected. (3.4.9.13.2)
6. Where dissimilar metals must be assembled intimately, interpose a material compatible with each metal. (3.4.9.13.2.1)
7. Use corrosion-resisting metals and alloys, or give them a corrosion-resisting treatment or coating. (3.4.9.13)
8. Minimize the use of iron, steel or other magnetic materials except where required for electromagnetic or strength reasons. Corrosion-resisting alloys are preferred to plated or painted ferrous alloys. (3.4.9.13.3) (3.7.6.1)

9. The use of conformal coatings to seal integrated circuits is encouraged, since leads are generally Kovar and rust rapidly. Consideration must be given to use of coatings which will facilitate repair if this is part of the maintenance philosophy.
10. Rigid epoxy encapsulation can cause damaging stresses on delicate parts such as glass diodes. It is prohibited to use hard epoxies to hold replaceable parts. (3.6.6)
11. Be cautious about potting components likely to become hot. Some flexible epoxies tend to soften mechanically and have high-frequency electrical losses at high temperatures. Some potting materials are not flame resistant, or they crack or otherwise degrade at high temperatures.
12. Insure that the coefficient of thermal expansion, oven heat or heat from an exothermal (self-heating) curing reaction, and chemical properties of the potting compound are compatible with the protected part. (3.4.9.3)

PROCESSES

13. Equipment can be built without production planning. However, it is more economical if production aspects are considered as a part of the design phase.
14. Do not anodize the contact surfaces of aluminum gear teeth. (3.4.11.2)

15. Do not use cadmium plating inside any equipment or on the following parts when contained in an enclosure: (3.4.11.2)
    - Parts in grease or oil chambers
    - Lock washers
    - Threaded parts
16. Ultrasonic cleaning may damage certain parts, particularly transistors, and should generally be avoided. (3.4.11.4) (3.5.7.3.1)
17. Do not use multilayer printed wiring boards unless two-sided printed wiring boards cannot handle the circuit complexity or density.
18. Plated-through holes are preferred to eyelets. (3.4.8.37)
19. The use of solder is preferred for mounting of integrated circuits to boards. In general, sockets should not be used because of their unreliability (corrosion, or loosening in shock or vibration). The use of welding is not recommended since repairs often damage circuit board conductors and create quality control problems.
20. The use of wire-wrap in accordance with MIL-STD-1130[35] provides acceptable backplane wiring but requires approval (requirement 69 of MIL-STD-454).[36] Solder terminations with sufficient quality control generally result in acceptable wir-

ing. Any other termination should be subjucted to critical screening through environmental evaluation, as well as maintenance tests prior to selection and usage. Consider any required training of production, assembly, and inspection personnel depending on the type of wiring selected. (3.4.11.4)

21. Give consideration to the methods of preparation for delivery (packaging and packing) as specified in MIL-E-17555.[37]

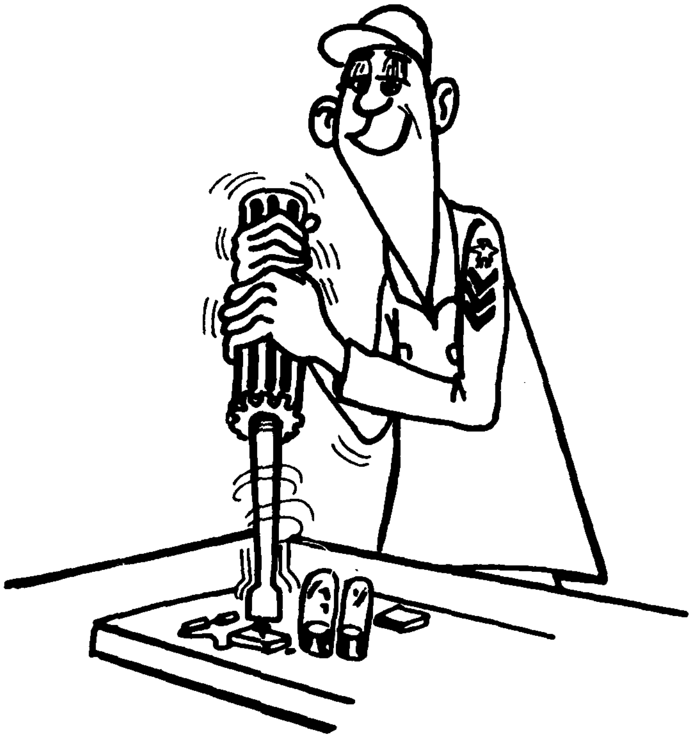
PARTS

22. Do not use the following parts unless required by specification:
    a. Batteries (3.4.8.1)
    b. Banana Plugs (3.4.8.10.8)
    c. Sleeve-type bearings (3.4.8.2.1)
    d. Convenience power receptacles (3.6.5)
23. Avoid parts available from only one source.
24. Functionally equivalent integrated circuits from different manufacturers are not always directly interchangeable (will not necessarily give identical performance). Identical pin assignments and specifications can be deceptive. Test any second-source parts in the circuit rather than assume interchangeability. (3.4.7)

25. Where feasible, select semiconductor devices in the following order of precedence:
    - Large Scale Integration (LSI)
    - Hybrid Integrated Circuits
    - Discrete Integrated Circuits
    - Discrete Semiconductors
26. CMOS (Complementary-Symmetry Metal-Oxide Semiconductor) circuits currently provide the best (lowest) power-to-performance ratio of all semiconductor technologies.
27. Electrolytic capacitors are restricted to power filter applications and only where other military conditions are met. (3.4.8.7.1)
28. Refer to MIL-E-16400[1] for selection criteria for any type of capacitor. (3.4.8.7)
29. Provide 10% spare terminals (at least two) on terminal boards and strips. (3.4.8.31.1)
30. Provide a minimum of 2 unused contacts on the periphery of external connectors with a total of up to 25 contacts; 4 spares for up to 100; 6 spares for totals over 100 contacts. (3.4.8.10.5)
31. Do not use relays for switching currents in excess of 10 amperes. (3.4.8.23)
32. Relays should be of the sealed type.
33. Use hermetically sealed parts in preference to equivalent non-hermetically sealed parts.

34. Secure glass windows to panels with clips, snap rings, or other positive means. Do not use cement alone. (3.7.8.12)
35. Secure all electron tubes, large fuses, and other plug-in items by easily released, positive holding clamps. Large electron tubes require support for the envelope. A clamp at the base is seldom successful. (3.4.8.28)

FASTENERS



36. Use hand-operated fasteners if possible.
37. Use captive fasteners where there is danger of parts being dropped into assemblies. (3.4.8.13)
38. Use quick opening captive fasteners for equipment which must be serviced frequently; however, do not use 1/4-turn fasteners for structural applications. (3.4.8.13)
39. Use a minimum number of large screws where quick opening fasteners do not meet stress, pressurization, shielding, or safety requirements. Limit to 4 screws if practicable.
40. Minimize the number of turns required for mounting bolts, consistent with mounting requirements.
41. Insure that covers or shields, through which mounting screws must pass for attachment to the chassis, have large enough holes for passage of the screw without perfect alignment.
42. Screws, nuts, bolts, and studs should be of corrosion-resistant metal or protected with a suitable finish. (3.4.8.13)
43. Avoid threading aluminum alloy into aluminum alloy or magnesium parts. (3.4.8.13)
44. Use positive locking devices rather than taper pins or set screws for securing gear trains and cams. (3.7.7.2)

45. Do not use rivets for mounting parts which may be subject to replacement, or for maintaining electrical continuity. (3.6.6)
46. Do not ordinarily use self-tapping screws. If used, approval must be obtained from the agency concerned. (3.4.8.13)
47. Insure that all screws in a set have one type of head. Cross recessed head screws are preferred to straight slots.
48. Avoid the need to specify the torque requirement for screws and bolts by using fasteners that will satisfy the application requirements over the range of torques likely to be applied.
49. Standardize fasteners with minimum numbers, types, sizes, torques, and tools required.
50. Use different size screws, when different threads are required, to prevent stripping if started in wrong holes. Do not mix metric and nonmetric fasteners in equipment.
51. Preferred thread sizes are: (3.4.8.13)

.112-40 UNC
.138-32 UNC
.164-32 UNC
.190-32 UNF
.250-28 UNF
.312-24 UNF
.375-24 UNF
.437-20 UNF
.500-20 UNF
.562-18 UNF
.625-18 UNF

52. Use combination-head mounting bolts with screwdriver slot and hexagonal head for high-torque use (to reduce the need to drill out bolts with damaged slots).
53. Base the minimum diameter of deck and bulkhead attachment bolts on the minimum load for grade 2 carbon and alloy steel. (3.7.3.6)
54. Secure control knobs to shafts with two set screws. Plastic knobs require metal inserts for set screws. (3.7.8.1)
55. Hexagonal nuts are preferred to other styles. (3.4.8.13)

PRINTED WIRING BOARDS (PWB)

56. Printed wiring boards and printed flexible circuits should be designed in accordance with MIL-STD-275[18] utilizing the most feasible producibility criteria.
57. Layout components for ease of identification, assembly, and orientation. Where possible, lay out all components along the same axis. Orient all polarized components in the same direction. If parts must be oriented in both horizontal and vertical axes, keep all polarized component orientations the same for each axis.

58. Allow spacings between components adequate for automatic insertion techniques even if such equipment is not used in the manufacture of the board; the additional space improves board repairability.
59. Identify component pin 1 for polarized components in the component side metalization by a readily identifiable means. Some suggested means are (1) square versus round or elongated pads, (2) a pin 1 bubble, (3) metalized graphics.
60. Utilize on-board registration targets in all PWB artwork at opposite board corners to improve manufacturing registrations for operations occurring after board trimming, especially when reduced producibility layout criteria must be used.
61. Clearly mark the board name, assembly number, serial number, revision letter, and component reference designators on the board. Markings may be in metalization or by silkscreen or other permanent means. Component reference designators should be on the component side of the board, clearly visible with components in place, and unambiguously associated with the component.
62. Avoid feedthroughs in locations where they cannot be seen (i.e., under components).

ELECTROMAGNETIC COMPATIBILITY

An equipment should be capable of operating in the vicinity of other equipment without causing or responding to undesirable electromagnetic energy. An equipment design should consider electromagnetic interference (EMI) coming from external sources, generated within its own enclosure, or degrading the performance of other equipments.

Electromagnetic compatibility (EMC) involves minimizing the generation of EMI, making the equipment less susceptible to EMI, and reducing the amount of EMI that enters or leaves the equipment. EMI may be minimized by the judicious selection of components and the use of good engineering practice. Failure to give timely consideration to EMI control usually results in an unsatisfactory equipment. Later attempts can seldom resolve EMC problems without a major redesign. MIL-HDBK-238[39] describes numerous electromagnetic radiation hazards and ways to handle them. Use MIL-HDBK-241[40] when designing with power supplies or filters.

GENERAL

1. Design equipment so that electromagnetic interference and undesired radiation are in accordance with MIL-STD-461,[41] MIL-STD-462,[42] MIL-STD-469,[43] and NAVSHIPS 0981-052-8140.[44] (3.5.4) (3.7.6.3)*
2. During early stages, make a predictive study to determine what components may be either a source of, or susceptible to, EMI. (3.7.6) (3.7.6.3)

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*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]

3. Choose components with electromagnetic interference in mind. Other things being equal,
    a. Choose motors without commutators over motors with commutators.
    b. Choose high-vacuum rectifier tubes rather than the mercury vapor types.
    c. Avoid vibrator-type power supplies.
4. Built-in test circuitry must be planned as an integral part of EMC design; adding it later may negate the original EMC design.
5. Determine the interference preventive control measure to use. (3.7.6)
6. Hold EMC education sessions for everyone involved (design, production, and installation).
7. Perform tests during production to determine that EMI standards are adhered to. Carefully check equipment after any production change or field change to ascertain that the change did not introduce EMI.
8. Plan the equipment to operate satisfactorily with other equipment with which it may be associated.
9. Remember that the most effective interference control techniques are those used during the initial design stages of components or systems.
10. Control interferences at the source, along the coupling path, and at or in the equipment affected.

BONDING

11. Furnish the equipment case with provisions for securing bond straps to the rack. Bond each chassis within the case to the case. (3.5.6)
12. Bond to the chassis any close fitting metallic components, such as flange fittings, shield can covers, inspection plates, and joints, which are located within the field of high power radiating devices. (3.5.6.1)
13. Ensure that contact areas are clean and free of protective coatings before bonding. Bond mating surfaces together so as to provide a low-impedance electrical path for radio-frequency current and to reduce noise generation. (3.4.9.13.7) (3.4.11.2) (3.5.6.1)
14. Permanent direct bonds may be achieved by welding, brazing, swaging, soldering or bolting. (3.5.6.1)
15. Make semipermanent direct bonds by mating machined surfaces by bolts and tooth-type lockwashers or clamps. Lockwashers and clamps should be made of, or coated with, a metal lower in the electromotive series than the bonded metals.
16. Use indirect or jumper bonds only when it is not possible to bond directly; for example, when clearance is to be maintained between bonded members or when equipment is shock-mounted.

17. Keep the bonding strap as short as possible compared to the wavelength, maintaining a length-to-width ratio of 5 to 1, or less.
18. Use wide, thin, solid metallic strips, rather than braid, for bond jumpers. (This does not apply to high-current nonradio-frequency jumpers.)

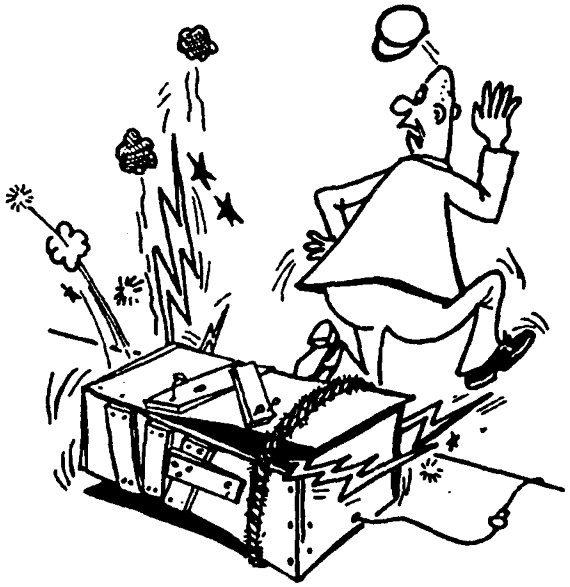
GROUNDING

19. Be conscious of the possibility of ambiguous or multiple ground points in equipment.
20. Remember that proper grounding is not entirely a matter of good bonding.
21. It may be impossible to have two points at the same potential over an appreciable range of frequencies unless the points are close together.
22. Avoid a common ground for both signal and power circuits.
23. Use a separate, low-impedance ground return for signal circuits, avoiding chassis or structure for this return.
24. Avoid the use of long common-ground lines in signal circuits which operate at widely different levels.
25. In sensitive low-level circuits, provide a separate, isolated, shielded ground for each circuit, if needed to eliminate possible interference through ground loops.

26. Ground all cable shields at both ends, and for very long cables, also at intermediate points, unless doing so creates undesirable ground loops.

SHIELDING

27. Isolate or shield EMI sensitive components (or wires) from components (or wires) likely to cause EMI. When such wires must cross, have them do so at right angles.
28. Choose metal shields that support themselves mechanically. Such shields are thick enough to afford adequate shielding, except at very low frequencies.
29. Keep joints in shields to an absolute minimum.
30. Keep the number of mechanical discontinuities to an absolute minimum. Those required must be electrically continuous across the interface.
31. Use multiple-point, spring-loaded contacts in preference to other methods, to obtain electrical continuity.
32. For most shielding purposes (except for ignition systems and radar modulators), use holes no larger than 1/8 inch diameter for drainage of moisture. Such holes do not cause significant EMI.
33. When possible, shield holes by converting them to waveguides which have cutoff



frequencies above the undesired signals. For example, a 3/4-inch sleeve, 3 inches long will provide 100 dB of attenuation for frequencies below 1000 MHz.

34. Use conductive gaskets if a good seal cannot be made without warping or buckling the mating parts.
35. Use wire mesh sleeving over a neoprene core, aluminum tubing filled with a neoprene core, or wire mesh for the most effective EMI gaskets.
36. To shield openings (ventilation louvers, for example) cover with fine copper wire mesh or other suitable conducting material.

37. If the mesh is not to be removed periodically, solder or weld it in a continuous line around the opening.
38. Do not spot-weld wire mesh over shielded openings.
39. If the mesh is to be removed for access or maintenance, attach it with enough screws or bolts to maintain continuous line contact around the circumference of the hole. Screws should be spaced no more than one inch apart.
40. Be sure pressure applied by means of screws or bolts is evenly distributed.
41. Ensure that a good bond exists in the crossover points of wire mesh shield.
42. Use tightly woven, braided flexible conduit to increase EMI reduction qualities.
43. Do not use interlocked metal hose with insulated cord packing for shielded conduit.
44. Terminate conduit at both ends with suitable fittings. Cable clamps must be soldered to the shield and bonded to the structure with tooth-type lockwashers.
45. Maintain continuous line contact between mating members of conduit.
46. The use of hybrid circuitry can reduce EMI by incorporating many integrated circuits within a shielded (Kovar) package.

47. Select power and audio input transformers that have grounded electrostatic shields. (3.4.8.32.2)
48. Enclose relays and their associated circuits with a metallic shield to minimize transients.
49. If necessary, completely shield and filter switches used to interrupt large currents.

FILTERS (3.4.8.15) (3.4.8.16)

50. Shield all filters and isolate the input leads from the output leads.
51. Mount the filter as close as possible to the filtered equipment and use short, shielded leads as the coupling medium.
52. Run filter leads close to the ground plane. Never loop leads.
53. Do not change the load impedance as seen by the signal source by insertion of a filter.
54. Use a simple capacitor filter in preference to more complicated network filters if it provides the required degree of EMI attenuation.
55. Install capacitors at the brushes of motors and generators.
56. Place RC networks across switch or relay contacts.
57. Place semiconductor rectifiers or varistors across relay coils.

MODULATORS AND TRANSMITTERS

58. Shield thyratrons in radar modulators.
59. Properly bond and shield all power lines within radar modulators.
60. When possible, place all radar modulator pulse cables a minimum of 18 inches away from all other cables.
61. Shield primary leads from transformer to point at which they leave modulator case; ground this shielding.
62. Minimize parasitic oscillations in transmitters by keeping the tube as small as possible. It is possible to detune a parasitic oscillation circuit by shortening grid leads and lengthening plate leads.
63. Reduce parasitic oscillations by inserting a small resistance (1 to 25 ohms) in series with grid or plate lead. A small choke in the plate lead to the next tube will also help.
64. If possible, do not use rf chokes in series with dc supply to both plate and grid. If they must be used, select chokes such that the resonant frequency of the grid is higher than that of the plate.
65. In TR boxes, use a limiting resistor mounted close to the top of the keep-alive electrode to minimize the effects of oscillations in the radio-frequency gap.

RECEIVERS

66. Minimize the number of leads to the receiver.
67. Do not place within the receiver enclosure any device which is not an integral part of the receiver (such as an antenna switching relay).
68. Use power line filters to provide attenuation at a frequency beginning above power frequencies and continuing to 1000 MHz.
69. Use antenna filters to reduce interference having as its source spurious or harmonic radiation of the fundamental frequency being received by the antenna system.
70. Locate and orient the antenna so as to pick up minimum EMI.
71. If possible, use a short, shielded, antenna lead-in wire.
72. Where feasible, use more than one rf stage so as to isolate the oscillator from the antenna and increase selectivity and sensitivity.
73. Design the receiver bandwidth to be the minimum required for reception of desired signals. (Note: If limiters are to be used, a wider bandwidth is needed for the action of the limiters to be effective.)
74. Keep in mind that at least 90 percent of all interference enters a receiver through the input circuits of the first rf stage.

75. Shield rf and i-f coils, gang capacitors, and internal antenna circuits.
76. Shield the rf section from the output section within the receiver case.
77. To prevent rf energy from entering the case from the output lead, use a simply bypass capacitor.
78. Carefully isolate the rf amplifier stage from the mixer.
79. Make the shielded enclosure for the local oscillator as continuous as possible. (Note: A double shield may be necessary.)
80. Fasten the local oscillator shield to next larger support member at points of equipotential to avoid excitation of large surfaces.
81. Filter all power leads entering the local oscillator shielded area.
82. Use a single-point ground system for the oscillator.
83. Orient an oscillator coil so that its field induces minimum current in the surrounding metal.
84. Use limiters and blanking circuits in front of the receiver when interfering signals consist of large-amplitude pulses.
85. Utilize wavetraps when the interfering signal contains only one frequency or a narrowband of frequencies.
86. Use phase cancelling to counteract signals whose character and path of entry are precisely known.

87. Employ audio filters when interfering signals contain only a small number of fixed audio-frequency components.
88. Shield all control cables and isolate if feasible.
89. Design lowpass filters into receiver control circuits.

TEMPEST

For equipment which handles classified information, the following considerations should be helpful. TEMPEST refers to investigations and studies of unintentional data-related or intelligence-bearing signals which, if intercepted and analyzed, disclose the classified information transmitted, received, handled, or otherwise processed by an information-processing equipment.

TEMPEST is similar to Electromagnetic Interference (EMI) in its basic manifestations, its causes, and corrective measures. One of the differences between TEMPEST and EMI is that a TEMPEST signal carries intelligence, whereas an EMI signal need not. This difference is reflected in the respective testing philosophies. EMI tests concern power and frequency ranges which can cause equipment interference. TEMPEST tests concern power and frequency ranges at which intelligence can be recovered.

As with EMI, TEMPEST may be minimized by the judicious selection of components and the use of good engineering practices. Failure to give timely consideration to TEMPEST usually results in rejected equipment and costly retrofits.

Many of the same engineering practices used in good EMI design are used in good TEMPEST design. The evaluation standards for TEMPEST, however, are different from those used for EMI. In general, EMI test standards do not qualify as TEMPEST test standards. For TEMPEST test and evaluation, NACSIM 5100A[45] and NACSEM 5103[46] replace the EMI standard, MIL-STD-461.

TEMPEST is a specialized engineering discipline. All commands and activities within the Naval Material Command should send requests for guidance, technical assistance, and publications directly to the Commanding Officer, Naval Electronics Systems Security Engineering Center (NESSEC), 3801 Nebraska Ave. N.W., Washington D.C. 20390. Industrial organizations performing contracts for commands and activities within the Naval Material Command should proceed through the contracting officer and the sponsoring activity for similar assistance from NESSEC. Other Naval commands and activities should contact NESSEC as a first step in establishing coordination. Non-Navy agencies may contact NESSEC for similar assistance in coordination.

COMSEC

Communications Security (COMSEC) is the protection resulting from all measures designed to deny unauthorized persons information of value which might be derived from the possession and study of telecommunications. COMSEC is accomplished by several means, one of which includes the provision of technically sound cryptosystems and their proper use.

The design of technically sound cryptosystems is a specialized engineering discipline with rigid technical requirements and is performed only by authorized agencies. The various commercial data protection systems available from numerous industrial firms do not meet the COMSEC standards for Federal telecommunications. No engineer should attempt the design of cryptosystems without specific authorization from cognizant authority and the attendant technical assistance.

The proper use of technically sound cryptosystems in telecommunication systems generally requires technical assistance, including guidance with respect to doctrine and policy. Improper usage of cryptosystems in telecommunication systems can lead to inefficient system operation, gross malfunctions at the system level, or worse, compromise of the COMSEC function.

All Navy commands and activities should direct inquiries regarding COMSEC policy and doctrine to the Commander, Naval Security Group Command. Commands and activities within the Naval

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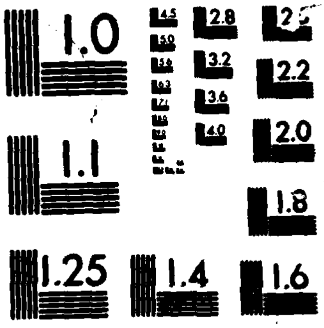

MICROCOPY RESOLUTION TEST CHART

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ELECTROMAGNETIC PULSE

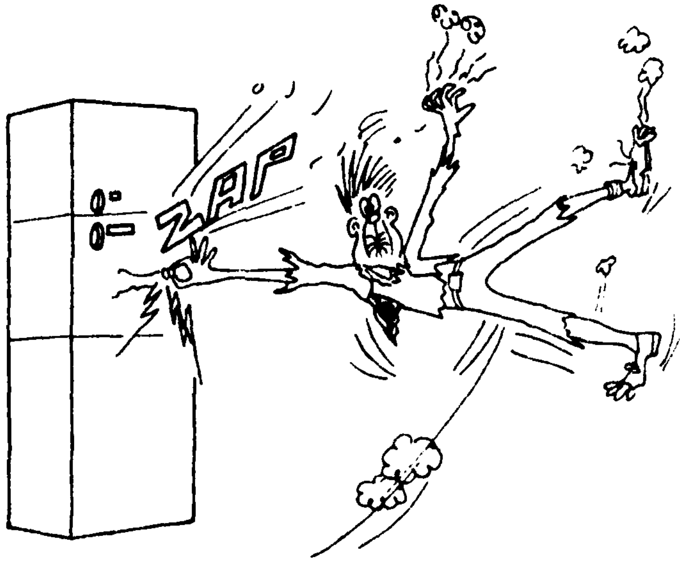
Electromagnetic pulse (EMP) is a phenomenon associated with a nuclear detonation. Unlike the nuclear effects of blast and radiation, which are largely confined to the immediate area of the detonation, EMP can occur hundreds, or even thousands of miles from the actual detonation. The EMP is a high energy, short duration pulse propagated through the atmosphere. It is characterized by a fast rise time (on the order of nanoseconds), a rapid decay (on the order of microseconds), and an intense peak limited by the atmosphere to about 50,000 volts/meter. With such an intense field and such fast transition times, EMP can cause substantial voltage and current transients capable of damaging circuitry before standard circuit protection devices can act. EMP effects should definitely be taken into account in system designs in all vital and semi-vital systems and equipments, even those which are not intended for exposure to combat environments. EMP effects can be minimized cost-effectively if they are considered early in the design phase.

Protection against the effects of EMP are achieved through a combination of techniques: shielding, grounding, special protective devices, selection of resistant components, special signal techniques, and resistant system designs. Standard shielding techniques are applicable but attention to the broad spectral characteristics of EMP are required. Single point grounding techniques are virtually mandated; this especially applies to shielding designs. That is, take care that large current loops are not formed in the shielding; the resulting currents flowing through the shielding will induce damaging transients in underlying circuits. Overlapping, but electrically isolated shields, can be used to avoid current loops through shielding. Some components (electron tubes, relays, synchros, and similar devices) are inherently resistant to damage by EMP. Special fast-acting transient protection devices are available which are effective in clamping EMP induced transients. Such devices should be employed wherever external conductors penetrate shielding, especially power leads, long control lines, and antenna lead-ins, and also across inputs to particularly sensitive circuitry (such as receiver front-ends). Resistant system designs may incorporate fiber optics, electro-optical isolators, and high-order filtering. Special care must be taken in systems handling data, especially when bit-errors and false signaling are disruptive to the system. Data techniques which redundantly interleave data or employ error correction over periods longer than the EMP duration or which store and forward data when an EMP is detected may be necessary. EMP testing should also be taken into account in project planning. See MIL-HDBK-253.[47]

HAZARDOUS ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO) AND ELECTROMAGNETIC ENVIRONMENT (EME)

Systems used in conjunction with or in proximity to ordnance should consider HERO and EME. HERO deals with the direct effects of radiation on ordnance while EME deals with hazardous interactions within or with weapon systems. Systems capable of radiating electromagnetic energy and expected to be used near or on platforms carrying or handling ordnance should be surveyed to determine radiation patterns and field strengths to allow the development of HERO safe guidelines; the measurements should be documented in system technical manuals so that it is available to the operating personnel who must assess HERO risk. EME incorporates EMC, EMI, HERO, and EMP considerations plus the consideration of system misfunctions (erroneous operations) in the presence of electromagnetic radiations. The same design techniques apply to EME as to EMC; however, test requirements and design performance may be more stringent than standard EMC requirements. EME should be applied to weapons associated systems such as launcher controls and fire control systems. Refer to MIL-STD-454[16] Requirement 61, MIL-STD-1399 400 series sections, MIL-HDBK-235[48], MIL-HDBK-238[39], and MIL-HDBK-253[47].

SAFETY



The two main aspects of safety are the prevention of injury to personnel and damage to equipment. The equipment contractor may be required to develop and maintain an effective system safety program. (3.10) The primary safety reference is requirement 1 of MIL-STD-454.[16] The designer should be willing to expose himself to the worst-case personnel hazards his equipment is capable of presenting to Navy personnel.

GENERAL

1. Design for safety in the following order of preference: (3.10.5)*
   - Design for minimum hazard (e.g., fail-safe, redundancy).
   - Use of safety devices.
   - Use of warning devices.
   - Use of safety procedures and precautionary notations.
2. Provide adequate, fail-safe features for preventing injury to personnel and damage to equipment. (3.10.4) (3.10.11.1)
3. It should be obvious how safety features operate.
4. Safety features should be difficult to bypass or deactivate except for specific maintenance bypass circuits.
5. Use conspicuous cautions and warnings with large, contrasting print. (3.10.4)

ELECTRICAL HAZARDS

6. Provide a readily accessible means of removing all power to the equipment. This and other power switches should be located to prevent accidental operation of the equipment. (3.10.11.1)

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*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).¹

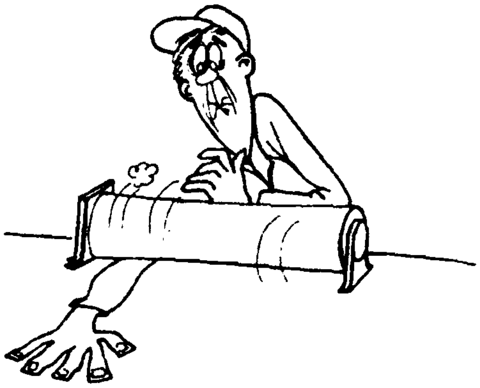
7. Use current limiting resistors where appropriate for safety in high voltage circuits.
8. Ground all external metal parts, control-shafts, and bushings. Antenna or transmission line terminals should be at ground potential except with regard to the energy to be radiated. (3.10.11.1)
9. Safeguard operating personnel from coming into contact with voltage in excess of 30 volts dc or rms. Do not locate adjustment screws or other commonly worked-on parts near unprotected high voltages. (3.10.11.1)
10. For potentials above 30 volts, provide discharging devices that actuate automatically when equipment is opened, unless capacitors discharge to 30 volts in two seconds or less. (3.10.11.1)
11. Resistive bleeder networks should consist of at least two equal resistors in parallel. (3.10.11.1)
12. Provide guards (marked with highest voltage), interlocks with bypass, automatic discharge devices, and grounding rods for potentials between 70 and 500 volts dc or rms on contacts, terminals, and other similar devices. (3.10.11.1)
13. Interlock bypass devices should have a clearly visible warning indicator (illuminated jewel or globe). Bypass devices should reset automatically when the access is closed. (3.10.11.1) (3.10.11.3)

14. Completely enclose assemblies with potentials exceeding 500 volts dc or rms. Clearly mark enclosures: "DANGER HIGH VOLTAGE (maximum voltage) VOLTS." Use white or aluminum color on red background. Provide interlocks without bypass, automatic discharging devices, and grounding rods, as applicable. (3.10.11.1)
15. When practicable, the leakage current of the equipment should not exceed 5 mA to ground. Where more leakage is unavoidable, a warning plate must be attached to the front panel reading: "DANGER — do not energize this equipment unless frame and all exposed metal parts are grounded." (3.5.5) (3.10.11.6)
16. Provide meters or voltage dividers with test points for measurement of voltage in excess of 300 volts peak. Voltage dividers should have at least two equal resistors in parallel between the test point and ground. (3.10.11.1)
17. Do not connect meters in portions of circuits which will cause high voltage potentials between meter and front panel if meter should fail. (3.10.11.1)
18. Use panel meters having nonmetallic zero adjusters. (3.4.8.19.1)
19. For maximum safety, mount meters in high voltage circuits behind a window of glass or thick plastic.

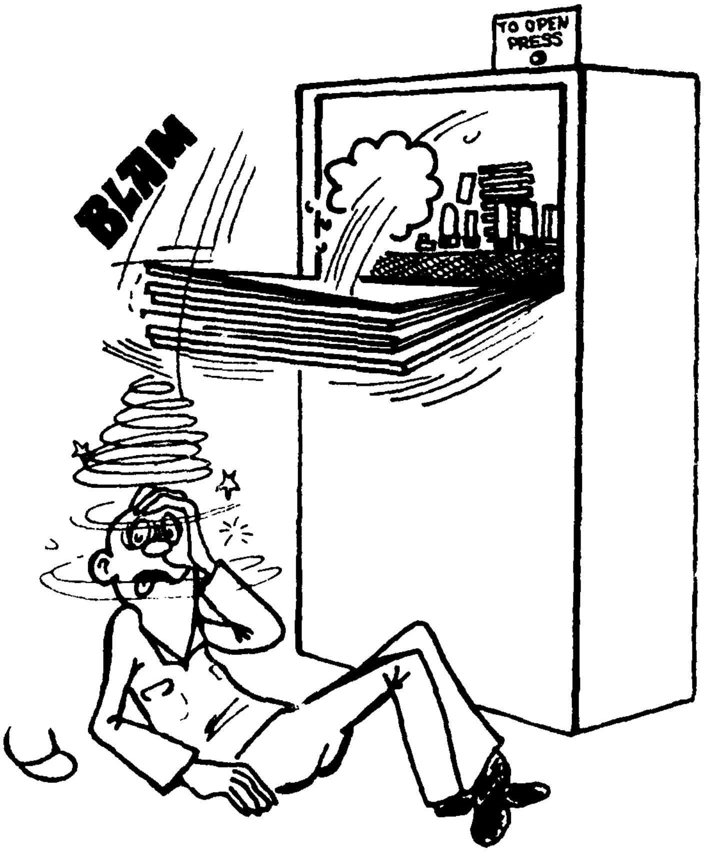
20. Provide screwdriver guides to adjustment points which must be operated near high voltages or thermally hot components, or are difficult to locate. Screwdriver handles should also be clear of obstructions and hazards.
21. Specify special tools or adequate insulation for tools used near high voltages.
22. Ventilation holes should be small enough to prevent inadvertent insertion of test probes or fingers.
23. Exposed pins on plugs and receptacles should not be energized (hot). Only socket type contacts should be energized after unmating. (3.4.8.10.2) (3.4.8.10.3) (3.10.11.1)
24. Include a safety ground in all cable assemblies that plug into convenience outlets. Connect the grounding pin of a three pin conductor to the green wire of a three conductor cable (black/white/green). (3.10.11.2)
25. Keep microwave and X-radiation to safe levels and warn personnel with appropriate markings or labels. (3.10.11.1)

MECHANICAL HAZARDS

26. Provide large rotating assemblies with a local power safety switch (e.g., at an antenna).
27. Provide guards to protect personnel from moving mechanical parts such as gears, fans, and belts. (3.10.11) (3.10.11.1)



28. Use rounded edges (0.04 inch min.) and corners (0.5 inch min.) on enclosures, doors, and hinged covers. The length of projecting and overhang edges should be held to a minimum. (3.7.2.5) (3.10.11) (3.10.11.1)
29. Protect personnel from cutting edges, burrs, and pointed objects. Protrusions should be avoided, padded, or conspicuously marked. (3.10.4) (3.10.11)
30. Use recessed handles rather than the extended type to conserve space, preclude injuries, and minimize catching on other units, wiring, or structures. (3.10.11)
31. Design locking mechanisms for doors and drawers to prevent injury to the operator when the lock is released. Accidental release of locks should also be prevented as this could cause injury to personnel or equipment damage. (3.10.11.1)
32. Protect personnel from imploding cathode ray tubes. (3.10.11.1)

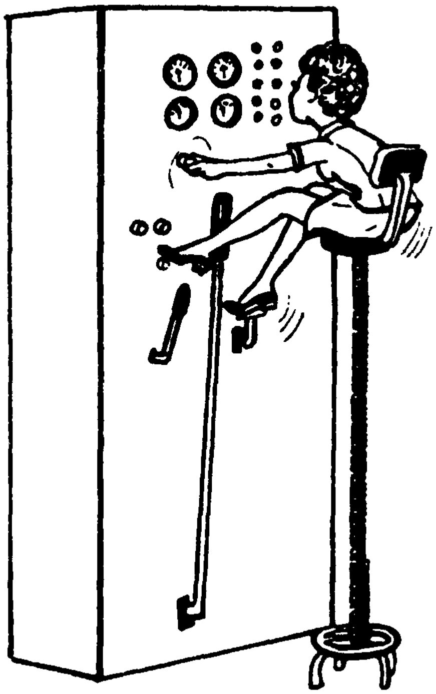


OTHER HAZARDS

33. Prevent toxic fumes, corrosive fluids which cause chemical burns, combustible mixtures, or explosive gases from reaching personnel, even if parts are damaged or broken. (3.10.11) (3.10.11.1)

34. Specify nonsparking tools for use in flammable or explosive atmospheres.
35. Equipment in a hazardous atmosphere should be properly enclosed (explosion-proof housing, hermetically sealed, embedded, or pressurized) and electrically bonded to ground. (3.10.11.1) (3.10.11.4)
36. Design so that the temperature of any exposed part, including enclosure, does not exceed 60° C at an ambient temperature of 35° C. Front panels and controls should not exceed 43° C. (3.8.3) (3.10.11.1)
37. Do not locate thermally hot parts near commonly worked-on components.
38. Avoid bare metal handles on tools or controls for use in extreme heat or cold.
39. Beware of claims of flame-retardant, fire-resistant, or self-extinguishing plastics. If safety dictates such a requirement, test the material in the actual application.
40. Warn personnel by marking or labeling equipment using radioactive materials. Protect personnel from dangerous exposure. (3.10.11.1)
41. Keep audible noise as low as possible, but at least below safe exposure levels. (3.3.2.4) (3.4.8.3) (3.7.5)
42. Protect personnel from intense light such as from lasers and provide appropriate warning labels.

HUMAN ENGINEERING



Electronic equipment is usually a man-machine system. The failure to integrate human engineering considerations into the overall system is a common design weakness. The designer can best integrate the man-machine interface considerations into equipment by soliciting comments from operator and maintenance personnel during the early planning and design stages. Operator interaction with equipment during advanced and engineering development will aid in finding and eliminating human engineering problems before the service test demonstration and final production design specifications. Electronic equipment should be designed to compensate for human limiations while permitting full utilization of human capabilities.

One guiding principle to remember: If equipment can possible be misused, someone will find the way. Any possibility of human error should be eliminated, insofar as practicable, by good initial design.

Additional information can be found in references 49 through 52.

VISUAL DISPLAYS

1. Discuss the design with those who will have to operate and maintain the equipment.
2. Mount visual indicators as nearly perpendicular to the operator's line-of-sight as possible to reduce parallax and reflection.
3. Use scalar displays for qualitative information if information shows direction and/or rate of change.
4. Use digital indicators if the application calls only for a quantitative readout.
5. Use Go/No-Go indicators for either/or states.
6. Make changes in visual indications easy to detect.

7. Scalar displays should have graduation fine enough for precise reading but not finer than necessary.
8. Provide sufficient separation between graduations and numerals on a dial to allow accurate reading.
9. Design instrument pointers to reduce parallax. They should not overlap numerals or graduations. (3.7.8.10)*
10. When multiple scales are involved on one dial or instrument, provide positive identification of the scale in use.
11. Avoid the use of more than two pointers on a single dial shaft. (3.7.8.7) (3.7.8.8)
12. When several instruments must be read at once as in check reading, orient the instruments so that the normal operating positions of all pointers are aligned (preferably at the 9 or 12 o'clock position).
13. For multirevolution dials, orient the zero position at 12 o'clock.
14. Utilize similar numbering and scale progressions for dials on the same panel.
15. Use scale breakdowns of units, fives or tens. Avoid irregular or non-linear scale breakdowns.
16. Avoid fractions or decimals on dial scales.
17. Minimize the requirement for mental translations of units and symbols. Instru-

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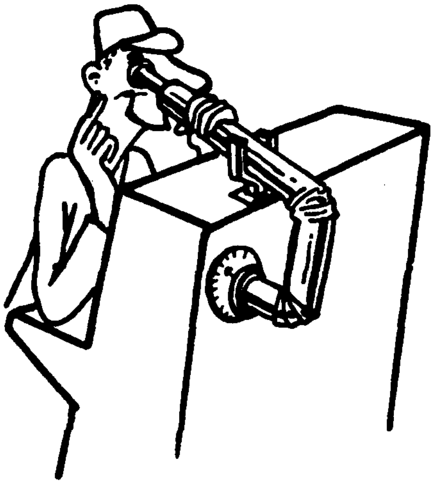
*Numbers in parentheses indicate applicable paragraphs in MIL-E-16400G (NAVY).[1]



ment readouts should be in directly usable form.

18. Display only needed information. Display no redundant information unless specifically required by the application. (3.4.8.18)
19. Provide displays that can be easily located and identified without undue searching.
20. Orient numerals on fixed displays in the upright position. (3.4.8.18)
21. Make numerals and letters simple in design, similar to Leroy lettering guides. Avoid extra flourishes.
22. Make numbering systems increase from left to right, or bottom to top. (3.4.8.18)
23. For dials which have a finite scale, provide a definite scale break between the end of the scale and the zero position.

24. Do not place critical limits at either end of a scalar display. (3.4.8.19)
25. Utilize maximum contrast between the lettering and its immediate background. (3.7.8.6) (3.7.8.8)
26. Avoid shadow effects on displays.
27. Use flag or Go/No-Go indicators which change state by snap action thus allowing no chance of an intermediate, uncertain condition.
28. Select counter types in which the numerals snap into place. (3.4.8.18)
29. Avoid counter designs which have too much space between the numerals of a whole number.
30. Select counters which read from left to right.
31. Counters should change slowly enough to be read (not faster than two numbers per second). (3.4.8.18)
32. Mount counters and dial faces close to the panel window so that numbers are not obscured by bezel openings. (3.7.8.10)
33. Allow for viewing at least two numbers through the opening of an open-window tuning dial, except for digital tuning indicators. (3.7.8.11)
34. Use a fixed dial scale with moving pointer in preference to a fixed-pointer/moving scale design.
35. Provide clear, brief, legible labels, readable from the operator's position. Use

standard abbreviations. Be consistent in placing labels either above or below controls and displays.

36. Use capital letters for labels, but use standard capitalized and lower case type for extended copy.
37. Use optimum numeral and letter height-width-stroke ratios. Numeral and scale designs are dependent upon the reading distance. (3.9.5)

Maximum Viewing Distance	Minimum Character Height
20 in (51 cm)	0.09 in (0.23 cm)
36 in (91 cm)	0.17 in (0.43 cm)
72 in (183 cm)	0.34 in (0.86 cm)
144 in (366 cm)	0.68 in (1.72 cm)
240 in (610 cm)	1.13 in (2.87 cm)

High vibration applications require derating the minimum character height by adding the relative vibrational displacements in the 1 to 20 Hz band to the minimum character heights given above.

38. Consider the relative legibility of alternate words on labels.
39. Use a separate indicator light for each function.
40. Keep visual displays as simple as possible, within the informational requirements, to permit quick, easy, and accurate reading.

ILLUMINATION

41. Control ambient illumination surrounding a cathode ray display for detection tasks at about 0.1 millilambert.
42. Provide adequate shielding for CRTs used in high ambient illumination to prevent specular reflection.

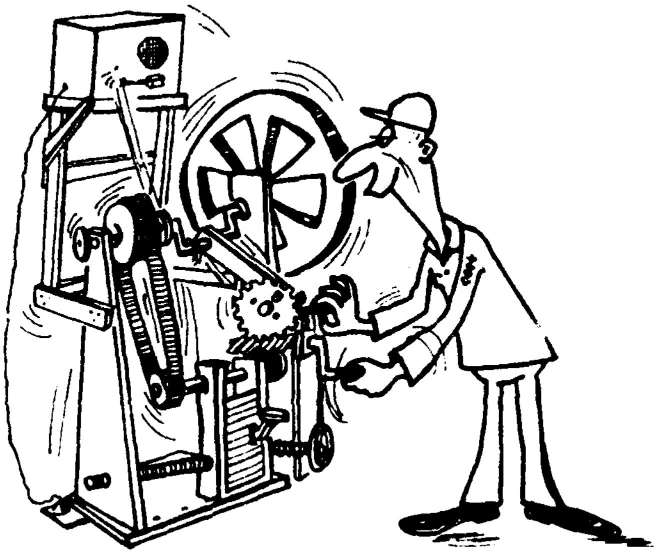
43. Surfaces adjacent to CRT should be finished in dull matte.
44. Insure that any glass used is non-distorting, glareproof, and shatterproof. (3.4.9.9) (3.7.8.5)
45. CRTs should have uniform brightness over scope face.

46. Minimize vibration of visual displays to reduce eye fatigue.
47. Provide uniform illumination in all parts of a visual indicator. (3.7.8.2)
48. Dials and other displays should be readable in illumination from 28 footcandles (fc) (white) to 0.03 fc (red). (3.7.8.2)
49. All light sources should be dimmer controlled, singly or in a group, optically or electrically, from minimum discernible intensity to full brilliance. (3.7.8.2)
50. Prevent direct glare from the light source.
51. Consider luminescent markings for use in low illumination.
52. Make a careful analysis of the entire lighting system so as to prevent later makeshift remedies. Do not assume that general ambient illumination will be adequate for individual tasks. (3.7.8.2)

53. Design enclosures to prevent extraneous light escape. (3.7.2.2)
54. When dark adaptation is necessary, use red light only (wavelengths longer than 620 millimicrons). (3.7.8.5)
55. To reduce reflection and glare, use the minimum level illumination that permits adequate visibility on the surfaces which might be reflective. (3.7.8.5) Contrast filters, polarization filters, and anti-reflection matte finishes are effective means of reducing reflection and glare when high levels of illumination are necessary.
56. Legend lights are preferred to simple indicator lights except where design considerations demand that simple indicator lights be used. (3.4.8.18)
57. Reduce reflection with dull matte finishes. Avoid glossy surfaces or highly polished metals. Use anti-glare coating on transparent instrument covers when possible. (3.7.8.5)
58. For aircraft cockpits or other specialized military applications, consult recommended lighting-level tables for both the ambient and specialized lighting. See MIL-E-5400[4].

CONTROLS

59. The ratio of control to display movement should be appropriate for the task.
60. Make control panel markings self-explanatory.
61. Mark controls to indicate direction of operation.



62. Provide a positive indication of push-button activation (e.g., snap feel, audible click or integral light). (3.3.2.4)
63. Pushbuttons should be concave and large enough that the finger or thumb will not slip off (0.38 to 0.75 inch diameter). (3.3.2.4)

64. Be certain push-button activation pressure is not excessive or inconvenient (10 to 40 ounces). (3.3.2.4)
65. Position controls, which must be located by the operator without being seen, in forward areas rather than to the side or behind the operator.
66. Place often-used controls between elbow and shoulder height. (3.7.8.13)
67. Space controls for easy manipulation and prevention of accidental activation. (3.7.8.13)
68. Protect sensitive adjustments and critical controls from accidental disturbance (by means of positive locking devices, mechanical guards, or electrical interlocks). (3.7.8.1)
69. Plan control movement to be in the expected direction; that is, movement of a control forward, clockwise, to the right, or up should turn on the equipment or cause the controlled quantity to increase or move forward, clockwise, to the right, or up. (3.7.8.1)
70. Alignment or adjustment controls should be neither so fine that a number of turns are required to obtain peak (desired) value nor so coarse that peak position is quickly passed.
71. Design and position cranks with respect to the speed of load which they administer; that is, use small cranks at elbow height

for fast wrist action and light loads; use large cranks oriented for full arm motion for heavy loads.

72. Wherever adjustment can be limited to a number of discrete settings, use controls that snap into any one of a limited number of positions (detents). Insure that switches cannot be left between detents. (3.4.8.30)
73. Use switches with great enough displacement to allow easy determination of state or position. (3.7.8.1)
74. Let knobs operated principally by the fingers project 1/2 to 1 inch from the surface of a panel.
75. Provide adjustment knobs, operated principally by the fingers, that are 0.38 to 4.0 inches in diameter. Use knobs only for very light torques.
76. Knobs, levers, and handles should be easy to grasp and manipulate. Use round knobs for controls requiring smooth, continuous movement. Use bar or pointer-type knobs for detent switching.
77. Make markings or pointers clearly visible on rotary controls. (3.7.8.1) (3.7.8.10)
78. Make control actions smooth and positive without being sticky or stiff. (3.7.8.1) (3.7.8.11)

79. Arrange controls to permit smooth and rapid manipulation. Provide adequate end stops on controls with limited degree of motion. (3.7.8.1)
80. Keep number of operator controls and indicators to a minimum.
81. Design joystick movement to be equally free in all directions. Small joysticks on table or desk-top installations should be mounted so that the hand has a resting place for steadying the control movement.
82. Provide for control identification both by sight and touch. Controls should be clearly distinguishable from each other by color, size, shape, and location. (3.7.8.1) (3.7.8.6)
83. Use consistent color-code techniques to define operating and danger ranges and to simplify check-reading. (3.7.8.6)
84. Color coding of indicator lights and instruments should conform to (3.4.8.18) (3.7.8.6)

- **Flashing Red:** denotes emergency condition. Requires immediate operator action. Personnel or equipment hazard.
- **Red:** system or equipment inoperative. Requires operator action. Emergency condition exists, but has been acknowledged.
- **Yellow:** condition is marginal or unsatisfactory. Calls for caution or recheck.

- **Green:** equipment is in tolerance; condition is satisfactory; all right to proceed.
- **White:** conditions not having "right" or "wrong" implications.
- **Blue:** advisory light (avoid preferential use of blue).

85. Balance the apparent brightness of different colored lights.

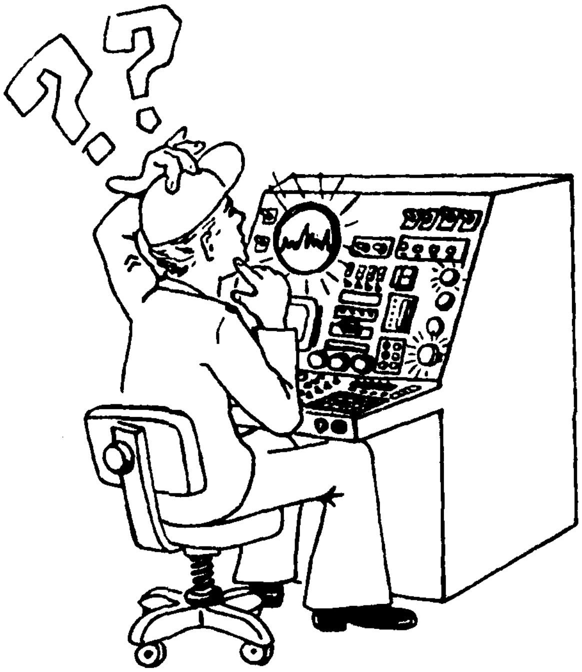
ALARMS

86. Flash rates for flashing warning lights may vary from 3 to 5 per second, with approximately equal amounts of ON and OFF time. (3.4.8.18)

87. Warning signals should not be obtrusive longer than necessary to attract attention and should be used for warning purposes only. Provide a means to silence audible signals and cause flashing lights to remain steady.
88. When selecting warning lights, make sure they are compatible with the ambient illumination levels expected. A dim light will not be seen in bright sunlight, and a bright light may be detrimental to dark adaptation. Utilize dimmer controls if necessary. (3.4.8.18) (3.7.8.2) (3.7.8.4) (3.7.8.5)
89. Isolate critical warning lights from other lights and make them brighter for greatest effectiveness.
90. Audible warning signals should have a frequency range of 250 to 2500 hertz, identifiable on the basis of components under 2000 hertz. Each signal should be different from other signals by means of intensity, pitch, beats or harmonics. (3.3.2.4)
91. Audible warnings should have a sound pressure level of at least 20 dB above the maximum anticipated ambient noise level. Warnings should not exceed maximum safe exposure levels or cause discomfort or ringing in the ears. (3.3.2.4)
92. Make vital alarms easily distinguishable from non-vital alarms. Vital alarms should be both audible and visual.

93. An open in a vital circuit or loss of power to the equipment should be indicated automatically by an audible and visual alarm.
94. If the main power source should fail, emergency power should be supplied to alarms and vital controls.
95. Minimize the possibility of false alarms due to warning devices and associated circuitry. (3.3.2.4)
96. Present information so that any failure or malfunction in the display or display circuitry will become immediately apparent.
97. Be certain flag or Go/No-Go indicators will not indicate an in-tolerance condition if power fails.

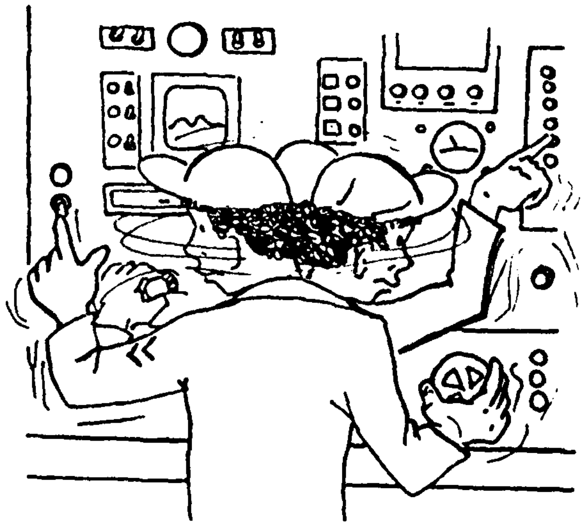
PANEL LAYOUT



98. Make panel layout as functionally simple as possible. Eliminate superfluous elements.
99. Locate receptacles so that cables do not interfere with controls or displays.
100. Front panels should not have trademarks, company names, or other markings not related to the panel function. (3.9.5)
101. Front panel markings should include the Government-assigned identification and serial numbers. (3.9.4)

102. Mount adjustment controls required for periodic alignment or calibration behind quick-access panels or doors. (3.7.8.1)
103. Infrequently used controls should be readily accessible for servicing when the equipment is opened for maintenance purposes (3.7.8.1)
104. Label in terms of what is being indicated rather than the name of the indicator (rpm not tachometer, voltage not voltmeter).
105. Mount vertical visual displays 41 to 74 inches (preferably 50 to 69 inches) above the floor when they are to be viewed from a standing position.
106. Mount vertical displays 6 to 48 inches (preferably 14 to 37 inches) above the sitting surface when they are to be used by a seated operator. Specify the chair height along with the console dimensions.
107. Controls should be located 34 to 74 inches (preferably 34 to 57 inches) above the standing surface.
108. Controls for seated operators should be located 8 to 35 inches (preferably 8 to 30 inches) above the sitting surface.
109. Use a 28-inch arm reach, measured from the operator's shoulder, as a limiting figure for the placement of controls which are to be used often.
110. Activity for both hands should be evenly distributed. Give preference to right-hand operation of the most important controls. (3.7.8.13)

CONTROL-DISPLAY RELATIONSHIPS



111. Do not require the operator to perform too many functions at the same time. Do not expect him to handle information at too fast a rate. Remember that all operators have different capabilities.
112. Design to avoid hand and arm interference with visual tasks. Generally, control-display organization should be such that visual displays occupy central areas, at proper eye height, and controls occupy peripheral areas. (3,7,8,13)
113. When desk positions are required, consider height of writing surface, working width and depth, knee and foot room, and elbow room if more than one operator is involved.

114. When multiple man-machine combinations are grouped together, make sure that operators' primary control manipulations are not restricted.
115. When group activity demands use of a central visual display, make sure that lines of sight to the display are not blocked by poor arrangement of people or equipments. (3.7.8.13)
116. Group controls on the basis of similarity of function or by sequence of use and, insofar as practical, maintain a similar orientation of the related indicators. (3.7.8.13)
117. Emphasize functional organization of displays and controls by using symmetry of grouping and/or differential plan of mounting. (3.7.8.13)
118. Provide suitable coding or labeling on both the display and control to tell which control affects which display. (3.7.8.13)
119. Locate controls near the display which they affect when this does not conflict with other manipulatory requirements. (3.7.8.13)
120. Position handles for comfort. Minimum handle dimensions for use by the ungloved hand: Handle diameter: 1/4-1/2 inch under 25 lbs., 1/2-3/4 inch if over 25 lbs. Finger clearance: 2 inches. Handle width: 4-1/2 inches.

121. Where consoles are designed for seated operators, utilize good seating principles, such as optimum dimensions for the expected population of users. This applies to backrests, armrests, footrests, cushioning, adjustability, etc.

122. Signals and changes should be readable while operating adjustment controls. (3.7.8.13)

123. A two-way voice communication path should have an articulation index of at least 0.35 in the worst-case ambient acoustic noise environment.

124. Where audibility is critical, there should be a signal-to-noise ratio of 10 dB at the audible frequency band in which the background noise is lowest.

DOCUMENTATION

Three broad categories of documentation concerning the design engineer are the engineering data which describe his equipment, documents used to control design changes, and documents to support operation and maintenance of the equipment. The essential documents of each category are described in the following paragraphs.

ENGINEERING DATA

SPECIFICATIONS

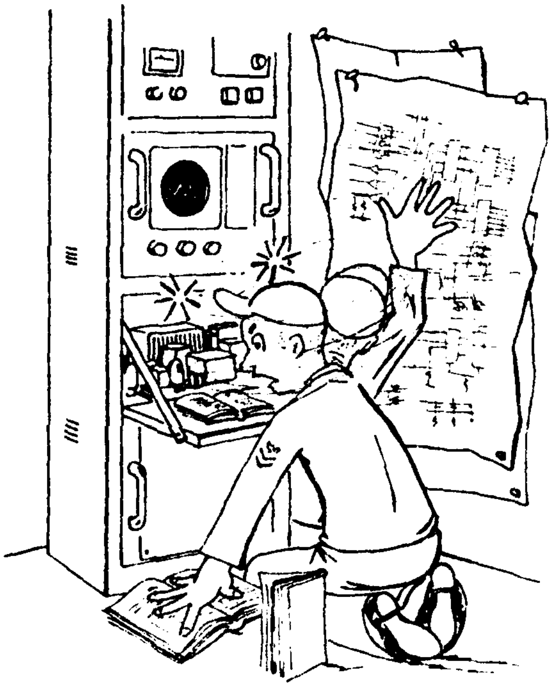
Specifications provide narrative details of performance and physical characteristics and their quality assurance requirements for systems and equipments. Development-type specifications are prepared to establish initial baseline configurations for developing prototype models. Product-type specifications reflect the finally developed configurations and are used to procure operational models. Specifications are prepared to commercial/industry or military standards. Program-peculiar military specifications are required by MIL-S-83490 which covers the requirements for Forms 1a, 1b, 2 and 3 and Types A, B, C, D, and E specifications. The detail requirements for Form 1a specifications of all Types are presented by MIL-STD-490, while MIL-STD-961 provides overall requirements for military specifications in general.

An engineer, whether he is a circuit designer or has the total responsibility for the overall system design, should be familiar with MIL-STD-490[54] since it provides the guidance for writing specifications which will be followed through the various stages of a military systems development. A specification which is too narrow (i.e., does not consider the initial quantitative reliability requirements, the human engineering, support documentation, maintainability, logistics of the system, or the operational environment it will be subjected to during its lifetime) will practically guarantee higher support costs during a system's scheduled lifetime and can contribute to a shortened duration of that lifetime.

ENGINEERING DRAWINGS

Engineering drawings are the designer's primary means of communication. They may be prepared in accordance with manufacturer/industry or military standards. The Department of Defense recognizes three general categories of drawings based on the intended use of the drawings (DoD-D-1000).[55] These categories may contain several of 46 different types of drawings (DoD-STD-100).[56] Military required drawings may be prepared to Level 1, 2, or 3 standards in accordance with DoD-D-1000.[55]

The levels of drawing documentation are defined by DoD-D-1000 within the context of a time-phased/activity-coordinated program to minimize the number and cost of drawings while ensuring an adequate level of design disclosure. The numbers and types of drawings tend to increase as the design progresses. While DoD-D-1000 articulates the requirements well, it is suggested that the designer keep in mind who needs the information that, initially, only the designer has; the engineering drawings serve to transmit the designer's knowledge to those who follow (production personnel, test personnel, quality assurance, maintenance personnel, and logistics personnel). Drawings should be made within any level which are adequate to communicate the requisite design features to others, keeping in mind, also, that design features which will be changed require a less thorough disclosure than those which are firmly established and unique to the design.



TEST PROCEDURES AND REPORTS

Developmental and production models require procedures and reports for tests of equipment specified performance and physical characteristics. They are prepared by the development activity and manufacturer in accordance with their own or the buyer's requirements. Various requirements documents of the several military services and agencies address the content and format of test procedures and reports and may be imposed on the preparer.

ENGINEERING REPORTS

During equipment development, reports often are required by the purchaser on such engineering aspects as reliability and maintainability predictions and demonstrations, human engineering, and safety. The specialty engineers involved prepare such reports to their own in-house requirements or may, in the case of items for the military, have to comply with applicable military specifications and standards.

ENGINEER'S NOTEBOOK

Keep an engineer's notebook from the moment a new design is begun. Include instructions, dates, findings, decisions, reasons, conclusions, etc. A notebook's value varies with the circumstances and the extent of its contents. Potential benefits of a notebook include: patent rights, applications to future projects, defense of actions taken, information for anyone who joins the project, and general future reference.

DESIGN CHANGE CONTROL DOCUMENTATION

Equipment configuration management is a normal activity of most companies and Government developers. Effective configuration-change control employs a system of recorded change data subject to review and approval. The design engineer provides the technical inputs for this documentation.

ENGINEERING CHANGE PROPOSALS (ECPs)

Configuration changes are formally initiated by a change-proposal form/document which must be reviewed and approved before the subject change(s) can be incorporated in the design of equipment. The designer himself may initiate the proposal or may cooperate with another engineer who has the original idea for a change. In either case, the designer must describe how the proposed change affects his area of design responsibility by completing the change proposal form/document and including appropriate drawing and specification (see Specification Change Notices) revisions for reference as well as required costs and schedule revision information. The military services must follow, and cite to contractors, the requirements of MIL-STD-480[9] which employs DD Form 1692 as the engineering change proposal document, which is filled out only to the extent necessary. Variations of this form may be used by industry and DoD for in-house-only applications. The completed form/document is reviewed by a configuration control board which may immediately decide for or against the proposal or return it to the originator(s) with a request for additional information. A signed, approved ECP constitutes authorization to proceed with the change, a process that normally includes the preparation of engineering change orders and specification change notices (see following).

ENGINEERING CHANGE ORDERS

Properly authorized engineering change orders provide the technical and procedural information necessary to fully implement the authorized change to the design/equipment and to the engineering documentation that baselines the configuration of the design/equipment. An engineering change order may be called a "Notice of Revision," "Engineering Change Notice," "Revision Directive" or other similar term according to local practice. The designer will be required to contribute technical information within his purview to this document.

SPECIFICATION CHANGE NOTICES (SCNs)

Whenever a change to a design or equipment is authorized, the pertinent specification and engineering drawings must be changed accordingly. Instructions for document revision should be contained in engineering change orders. An approved specification-change-notice sheet should be included with these instructions along with the detailed information needed to produce revised copy for the specification. The SCN sheet and revised pages prepared for the specification eventually are attached to the latest approved version of the specification, thus updating the specification to agree with the updated configuration of its item. Military program-peculiar specifications must be changed only by using DD Form 1696 as prescribed by MIL-STD-490.[54] Changes to specifications not under military control may be controlled by other specification-change-notice practices peculiar to the individual developer or manufacturer. In any event, the designer may be called upon to prepare or review revised portions of specifications as required by specification change notices (which themselves usually are prepared by configuration management personnel).

OPERATIONAL SUPPORT DOCUMENTATION

While the engineering data and design change documentation delineated above are primarily applicable to the design and development cycles, the design engineer may be called upon to provide engineering data and information required for the preparation of such operational support documentation as technical manuals, maintenance standards books, computer programming documentation, operating instruction charts, field change documentation, and others.

TECHNICAL MANUALS

The design engineer generally is not required to prepare such documentation himself, as technical manual writing is a specialty occupation, but he may be required to develop the source data for the manuals and is in the best position to review and approve manuscripts for completeness, accuracy, and adequacy of purpose. Technical manuals are usually written to military specifications and standards. Commercial manuals purchased with commercial off-the-shelf items should be required to meet the minimum standards for such documentation as delineated in MIL-M-7298.[58] Manuals for systems and equipment developed by or for the military services must be prepared according to the applicable military specifications and standards. Each service has its own requirements reflected by its own "limited" specifications. The military specification most commonly used for Navy electronic equipment manuals is MIL-M-15071.[59]

MAINTENANCE STANDARD BOOKS

These documents provide the equipment maintenance instructions in some cases (when the Programmed Maintenance System is not in effect) to Navy personnel in the field. While these documents can be prepared mainly from data already in the associated technical manuals, engineers may be required to provide some additional information to technical writers preparing such books. Maintenance Standards Books are prepared in accordance with MIL-B-21741.[60]

OPERATING INSTRUCTION CHARTS

Operating instruction charts can usually be prepared by technical writers from information available in the technical manuals. They may infrequently require some input from an engineer.

FIELD CHANGE DOCUMENTATION

If equipment already in the field is to be modified, the personnel responsible for making such modifications require clear, complete instructions as to the purpose and method of modification, checkout after modification, and other factors. In addition, the existing technical manuals and other support documentation in the field will require changes to reflect the modification. Engineers, whether they were involved in the initial design of the subject equipment or whether the modification itself is the primary task, may be required to provide to the technical writer all the information required by the specification to which the field change and technical manual change documentation is prepared. The specification for field changes is MIL-F-17655.[61]

PARTS PROVISIONING DOCUMENTATION

Normally, provisioning documentation is prepared by a specialist rather than the designer; however, the engineer should be aware of the requirements for provisioning. Provisioning documentation is a direct result of maintainability tasks which determine the type and level of maintenance actions required for a design. The engineer's direct input to maintainability tasks, therefore, indirectly affects provisioning actions and the costs thereof. Provisioning documentation is generally prepared in accordance with MIL-STD-1561.[62]

OTHER SUPPORT DOCUMENTATION

In addition to the engineer's responsibility with respect to the preparation of the support documentation enumerated above, there are sometimes requirements for him to provide data, information, and guidance toward the preparation of other required documents. These documents can include Reference Standard Books, Operators Handbooks, Maintenance Manuals, Training Guides, and other specialized documentation which may be required by installation, operating, and maintenance personnel in the field. Support documentation is prepared mainly by technical writing specialists; however, the engineer is expected to provide the necessary information, and in some cases to contribute written material.

LOGISTICS, PERSONNEL, AND TRAINING

Logistics, personnel, and training elements provide the support for equipment in operation. Provisioning levels, manning levels, training levels, test equipment levels, transportation and handling requirements, support facilities, and support system resources must all be determined for the equipment design. Obviously, a cost-effective design approach cannot be determined without considering the effect of designs on the support systems. Similarly, known support system constraints must be integrated into the equipment design. The tasks which marry the design and the support of an equipment are embodied in the Integrated Logistics Support (ILS) concept. ILS tasks are required to be performed on all DoD acquisitions by DoD Directive 4100.35. These tasks develop specific criteria for reliability design, maintainability design, human engineering, and safety; therefore, the designer has a direct interest in ILS determinations. The designer will also be required to supply design information routinely during the development to support the ILS activities.

The ILS tasks which most impact on the designer comprise the Logistic Support Analysis (LSA). The LSA may result from an informal assemblage of engineering support disciplines or a highly formalized procedure in accordance with one or more military standards and specifications.[63-66] Specific design features may be determined such as test point provisions, built-in-test features, and modular partitioning. Thus, many of the trade-offs evident in the preceding sections may be determined through the accomplishment of ILS tasks. Unless the designer participates in the LSA and makes his views known, he may find his design alternatives severely limited. Conversely, support considerations can be useful tools in establishing favored design alternatives.

NAVMAT P-4000[67] is an ILS guidebook which is available to help determine the appropriate ILS tasks to consider.

APPENDIX A: COMPUTER SOFTWARE DESIGN

Software design for firmware, embedded computers and general purpose processors must be done with discipline to meet current NAVMAT requirements. This discipline requires full documentation to standard, change control over each baselined document and computer program, Configuration Management of each configuration item, and full test and evaluation against the original requirement. As has been the case with hardware development, specifications now require that software quality assurance activities be geared to the life cycle of a project, regardless of project size or duration. Software quality assurance is, therefore, an integral part of software-based projects from project planning to obsolescence.

GENERAL

1. Start the project with a baselined Operational Requirement (OR) OPNAVINST 5000.42B.[68]
2. Develop the Project Management Plan to accomplish the OR.
3. Require support plans for Computer Software Development and for Computer Software Quality Control to be baselined.
4. Ensure that the appropriate Navy software documentation standard is used.

These are:

- a. MIL-STD-490, Specification Practices, for the system specification (Type A) only.[54]
- b. DoD-STD-1679A, Weapon System Software Development, for tactical and/or technical software systems.[69] Also, NAVMAT Tactical Digital Standards (TADSTANDS) as issued by TADSO.
- c. DoD Standard 7935.1-S, Automated Data Systems Documentation Standards, for strategic/intelligence systems, logistics, and management information systems.[70]

TACTICAL/TECHNICAL SOFTWARE DOCUMENTATION — MIL-STD-1679

5. Write and baseline the Software Development Plan.
6. Develop and baseline the Systems Specification to allocate functions between computer processor and the applications software.
7. Develop and baseline the following documents:
   - a. Program Performance Specification (PPS)
   - b. Interface Design Specification (IDS)
   - c. Program Design Specification (PDS)
   - d. Program Description Documents (PDDs)

e. Data Base Design Document (DBD)
f. Program Package Document
g. Computer Program Test Plan
h. Computer Program Test Specification
i. Computer Program Test Procedures
j. Computer Program Test Report
k. Operator's Manual (OM)
l. System Operator's Manual (SOM)

STRATEGIC, LOGISTICS AND MANAGEMENT INFORMATION SYSTEMS — DoD STD 7935.1-S

8. Write and baseline the Software Development Plan.
9. Develop and baseline the Systems Specification to allocate functions between computer processor and the applications software.
10. Develop and baseline the following documents:
    a. Functional Description (FD)
    b. Data Requirements Document (RD)
    c. System/Subsystem Specification (SS)
    d. Program Specification (PS)
    e. Data Base Specification (DS)
    f. User's Manual (UM)
    g. Computer Operation Manual (COM)
    h. Program Maintenance Manual (MM)
    i. Test Plan (PT)
    j. Test Analysis Report (RT)

SOFTWARE QUALITY ASSURANCE ACTIVITIES

11. Ensure consistency of software baseline development.
12. Ensure compliance with design standards.
13. Ensure compliance with programming standards.
14. Ensure adequacy and completeness of testing.
15. Review test results.

SOFTWARE STANDARDIZATION

The goals and techniques of software standardization are essentially the same as those for hardware standardization. Basically, the software product must be reliable, easy to maintain, accessible to the user, testable, modularly supportable, application flexible, and machine flexible. The DoD solution is the ADA programming language as defined in MIL-STD-1815A.[71]

OTHER SOFTWARE SUGGESTIONS

16. When high-order languages are used, provide internal comments to explain the function of program modules, relationships to other subroutines, and hardware interactions under program control whenever the program is not trivially obvious. This improves program readability, especially for maintenance personnel.

17. Incorporate software explanations in technical manuals which describe the functioning of the program and subroutines, subroutine interactions with other subroutines and with hardware, program interface requirements, and unique algorithms utilized.
18. Incorporate critical software elements into firmware.
19. When feasible and warranted, provide error detection and correction.
20. Design software-hardware interactions to account for the non-ideal characteristics of real components such as time delays, contact bounce, noise conditions, and the like.
21. Treat software and hardware design as one integrated activity, i.e., keep the programmers and the hardware designers in communication with each other and heading for the common goal.

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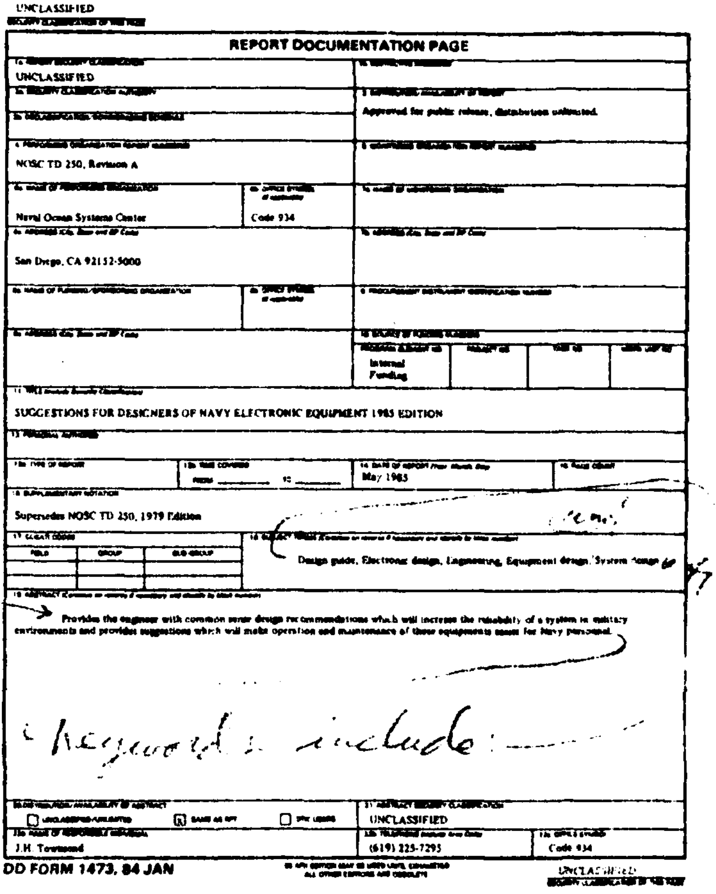

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