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TESSAC ELECTROMAGNETIC COMPATIBILITY SURVEY, (U)

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

TESSAC

Electromagnetic Compatibility

Survey

Richard W. Adler

September 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a summary of the state of technology, the Navy's technical capabilities and the adequacy of specifications and standards relative to electromagnetic compatibility in aircraft and ship platforms. Recommendations for improvement are made.

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TESSAC EMC SURVEY

EXECUTIVE SUMMARY

0.0 EXECUTIVE SUMMARY

Electromagnetic Compatibility (EMC) is the ability of electrical/electronics systems, subsystems, equipment, etc., to operate in an intended operational environment without suffering unacceptable performance degradation or causing the same to occur in other systems. EMC must be addressed through the full life cycle of any system from its initial concept on through its useful life. Failure to adequately address EMC during any of these stages will lead to a host of different problems.

The basic nature of EMC gives rise to many different issues or philosophical points upon which are based the success and deficiencies of the present handling of EMC within the Navy. Some issues are technological and others are financial, managerial, etc. This document summarizes these EMC issues and assesses the Navy's present ability to address them and where deficient, makes recommendations.

One of the prime issues of concern is the consideration of EMC during concept formulation through the subsequent acquisition cycle. The present approach is to build systems with current specifications and standards without tailoring and oftentimes this is not adequate. EMC technology is often not applied at the appropriate time during the cycle. A methodology has been proposed in the EMC report which will insure EMC considerations during the early phases of the system's life cycle. It is recommended that an EMCAB (EMC Advisory Board) be established by system program managers during the conceptual phase to ensure usage of EMC technological tools and tailoring of specifications and standards. The EMCAB should be maintained throughout the life cycle complete with all the associated documentation, reporting, and frequency allocation considerations. Presently, a sufficient technology base exists to support the tailored specification approach, but a tailoring procedure is not available.

Another important issue concerns procedures used during the design cycle to address EMC. Adequate technology is presently in hand to predict, test for, and control the effects of EMC induced electrical energy which is delivered to electronic systems, although the state-of-the-art is such

that rather wide design safety margins have to be used. As the ongoing Navy technology development program progresses, it will be possible to decrease these margins (and implicit costs) appreciably. The fundamental technologies which support EMC in the design phase are numerical analytical processes (COSITE EMC analysis programs). Inherent in the design procedure is the application of this existing technology and often this is not adequately utilized by Navy management (poor technology transfer). There are also problems associated with defining the system's operational electromagnetic environment. For example, the needs of EMC and ECM may be in conflict.

The Navy should develop and maintain a standard intrasystem EMC analysis program with its associated data base for each typical platform and specifications written to support these data bases. Increased emphasis should be placed in technology transfer between technologists and users.

The current standards and specifications are often too lax or stringent, and frequently do not cover important interactions or technologies. Lag in updating standards to reflect current technology tends to be endemic to the system and probably cannot be improved upon. Developing a methodology for tailoring existing standards to specific situations will improve this situation.

In addition to improving specifications and standards, installation and integration practices should be standardized and improved upon. Test procedures to demonstrate adherence to specifications and standards, and integration and installation practices are out of date and in many cases do not provide test data useful for analysis. In this light, it is recommended that test procedures be updated to reflect present needs and technology.

The last phase of the life cycle of Navy systems is one in which inadequate consideration of EMC occurring in the previous phases "comes home to roost." It is usually too expensive and too late to correct built-in deficiencies at this point. The only practical consideration of EMC during deployment involves identification, reporting, and correction of EMI problems and assuring that maintenance, overhaul, and backfit crews exist who are trained. The present status of the Navy's ability to address EMC during deployment can be judged as adequate.

In addition to actually performing the work associated with EMC during the life cycle of a system, a corporate memory is required to remember, share, and learn all the pertinent facets of Navy EMC. At the present time, no such corporate memory or data base exists which serves as a repository for the documented EMC experience and capability of the various Navy agencies and laboratories. It is recommended that a corporate memory be established within the Navy along with a formal procedure for reporting all pertinent EMC documentation to the corporate memory.

In summary, it can be stated that EMC technology is staying current and present efforts should be continued to maintain this status. However, efforts should be initiated to ensure better utilization of existing technology and improve specifications and standards, particularly in the acquisition process. The facilities and staffing of Navy activities are adequate to meet EMC needs at this time, but will require concerted emphasis to maintain a readiness state.

1.0 INTRODUCTION

1.1 Purpose

The purpose of this document is to record the findings of the TESSAC EMC Technical Team. In particular, the team was tasked to:

1. Investigate the state-of-technology in EMC relative to Navy aircraft and ship platforms.
2. Determine Navy Laboratories and Syscoms technical capabilities to collect, measure, analyze, and correct equipment, systems, and platform EMC deficiencies.
3. Examine the adequacy of current specifications and standards in EMC.

The results of this effort will be used by TESSAC to develop detailed plans for the Naval Material Command to insure consideration of EMC effects during the life cycle process and develop a plan for R & D to improve knowledge of EME effects.

In addition, the TESSAC expects the document to be useful to a broad spectrum within the Navy, for example:

- Program Managers
- NAVMAT
- Systems Commands
- Chief of Naval Operations
- Technologists.

1.2 Scope

The EMC Team, under TESSAC, covered these portions of the electromagnetic environment (EME) problem:

1. Antenna Reception
2. Radiated emission and susceptibility
3. Conducted emission and susceptibility
4. Frequency allocation and assignment
5. Lightning, static transient protection
6. EMC system-caused EMI
7. Interference suppression and compatibility enhancement techniques.

Because of the "anti-EMC" goals and character of Electronic Countermeasures (ECM) equipments incorporated on Navy platforms and/or major systems, the special issues, problems and/or deficiencies associated with or caused by ECM equipments or operations from an EMC point of view are treated at the appropriate places in the report. The remaining EME topics which were addressed by the other TESSAC Technical Teams and not addressed by the EMC team are:

1. Power system frequencies when associated with power systems (typically less than 100 KHz) (EM Power Team).
2. Safety aspects of RF energy and atmospheric electricity (EM Safety Team).
3. ECCM system caused EMI (ECCM Team).
4. Shield and hole penetration/reception (EMV Team).
5. EMP engineering (EMP Team).

1.3 Content of the Document

The nature of EMC gives rise to many different issues and philosophical points upon which are based the success and deficiencies of the present handling of EMC within the Navy. Section 2 presents a listing of those issues which are considered significant in determining the present and future course of EMC within the Navy. From these issues it was hoped that a basis could be established to evaluate the adequacy of technology and the adequacy of specifications and standards. The assessment of technology is contained in Section 4 and Section 5 presents the findings on adequacy of specifications and standards.

During the course of the technical team's investigations it became readily apparent that it would be cost effective to incorporate EMC very early in the system's cycle. Although it is difficult to adequately assess present procedures utilized during the design and acquisition phases, it was possible to determine what a preferred course of action should be. Section 3 suggests a methodology which can be established to insure EMC consideration during early phases of a system's life cycle.

Section 6 presents the results of a study to determine the Navy Syscom and Laboratory technical capabilities in EMC. Section 7 presents the technical team's conclusions and recommendations based on the findings presented in Sections 2 through 6. The relationship of EMC to other electromagnetic environment disciplines is described in Section 8.

1.4 Method of Document Creation

The methods utilized to generate this document were as follows:

1. Representatives for the EMC technical team were selected from appropriate syscoms and laboratories.
2. Each team member made submissions to the team's leader in accordance with the 28 September 1976 task statement.
3. Those submissions were reviewed by an executive committee and integrated into a first rough draft document.
4. The rough draft document was reviewed and critiqued by several team members and issued.

This method provides a document which draws upon and combines the knowledge and expertise possessed by working technologists throughout the Navy. As such it is not based on official doctrine but should be reflective of actual situations and needs which currently exist.

2.0 DEFINITION/SCOPE OF EMC AND MAJOR ISSUES

Electromagnetic Compatibility (EMC) is the ability of electrical/electronic systems, subsystems, equipments, etc., to operate in an intended operational electromagnetic (EM) environment without suffering unacceptable performance degradation or causing the same to occur in other systems. Any attempt to insure such compatibility in the development and acquisition of a major Navy system therefore requires a definition of the "intended operational EM environment."

Strictly speaking, an electromagnetic environment refers to the total EM fields contained or present within a given spatial region or volume. To the EMC engineer however, this description is somewhat meaningless since if there are no receivers or detectors within this region to collect or respond to these fields, the problem of EMC is academic. Therefore, EMC engineers prefer to expand the definition of EM environment to include both the generators of EM fields (the active elements of the environment) and the receivers or collectors of these EM fields (the passive elements of the environment). In so doing, a third element is necessary to complete this environment description; i.e., the field propagation characteristics between these active and passive elements.

The active elements of the EM environment consists of all sources or emitters of EM energy. This includes radar, communication, navigational, etc., transmitting antennas as well as antenna-like structures such as cables, power lines, platform structures, equipments, etc., that can emit or irradiate EM energy when intentionally or unintentionally excited. In addition, natural EM sources such as extra-terrestial bodies, atmospheric effects, lightning and molecular motion are also significant.

The passive elements of the EM environment consists of all devices capable of interacting, collecting and/or detecting electromagnetic energy. Each of the elements or devices named as active parts of the environment can act equally as well in the passive or receiving mode. Transmitting antennas as well as cables, equipments, circuits, etc., can all collect EM energy and thus also qualify as members of the passive EM environment.

Taken in the above established sense, the task of defining the "intended operational EM environment" for a specific Navy ship or major system is an exceedingly complex multi-variable interaction and coupling problem. Because of these complexities, existing capabilities to model and analytically determine the EM environment for Navy systems in a deterministic fashion are severely limited. Nevertheless, if EMC for Navy platforms/major systems is to be addressed early in the acquisition process, techniques and/or procedures for characterizing this environment must be developed.

One approach to making this problem somewhat more manageable is to consider the total EM environment in terms of an intrasystem part and an intersystem part. The intrasystem environment consists of that environment made up of the sources, receivers and propagation paths contained on or within the platform or system itself. Thus, EMC at the intraplatform level deals with making all constituent member elements of the intraplatform EM environment compatible with each other.

The intersystem EM environment is characterized by all external sources (man-made and natural) and receivers of EM energy in addition to those of the subject platform itself. This adds several new dimensions and uncertainties to the EMC design problems of a given platform/major system. First of all, the total complement or scenario of external sources/receivers about the platform can be expected to continuously change. Also, the distance/characteristics of the propagation path between all constituent sources/receivers of the intersystem environment will be a time varying parameter. These additional parameters and uncertainties combine to make the modeling of the intersystem EM environment and EMC problem somewhat more statistical in nature than the intrasystem case.

In the following subsections, major EMC issues involved in the engineering, development and acquisition of Navy platforms/major systems are briefly described. Detailed technical/management discussions that support these issues are contained in the major sections of this document.

2.1 Conceptual EMC

The inclusion of EMC considerations in the acquisition process must begin with the first step - the concept phase - if the ultimate goal of acceptable performance in the EM environment is to be attained. DoD Directive #3222.3 (5 July 1967) cites the requirement for ensuring EMC of all equipments, subsystems and systems during conceptual, design, acquisition and operational phases.

2.1.1 EMC Coverage in Operational Requirements

The inclusion of EMC in operational requirements (ORs) was addressed in DoD Directive 5000.2 (21 January 1975) but was dropped from consideration in the 19 January 1977 version.

OPNAV-094 initiated recommendations to overcome this discrepancy by requiring EME (which includes EMC) considerations in operational requirements through the newly proposed OPNAVINST 5000.42B to replace the existing 5000.42A. The replacement is expected to occur by the end of FY77, but until it does there is no document which specifically requires EME or EMC be addressed in an operational requirement.

2.2 EMC Through Operational Procedures

Successful conduct of communications/electronics (CE) systems in combat is directly dependent upon the proper functioning both individually and "in concert" of the CE equipments within the platform and/or task group or force. The procurement of such equipments on a discrete basis makes system integration of them extremely difficult without causing or experiencing EMI and the concurring performance degradation. It is possible to impose design restrictions or performance requirements within the design/procurement process to eliminate or at least minimize the degradation occurring from integration. The cost of doing this might be unacceptably high with the only viable alternative/supplement being controlled use of such systems by suitable operational procedures. In order to achieve maximum compatibility through operational procedures, it is mandatory that consideration is given in the writing of operational requirements and decision coordinating papers where the use of such techniques is incorporated. Equipments which must be operated simultaneously should be totally compatible, while those which are never simultaneously operated may not require compatibility. Optimal integration of equipments and operational procedures can be achieved if consideration is given at the conceptual stage of the acquisition cycle.

2.3 EMC Technology Utilization

2.3.1 Application of Technology by Management

The most significant factor contributing to the lack of EMC consideration in Navy programs is not a lack of technology but a lack of application of existing technology by management. Adequate EMC capability to significantly improve the EMC of the operational forces is resident in the DoD, Navy and civilian EMC community. The majority of this expertise is "in the engineer's heads" with some specialized capabilities such as computer codes available only to certain in-house engineers of particular facilities.

To varying degrees of accuracy, capabilities to predict EM environments, transmitter outputs, antenna performance, coupling, and receiver performance are available. Different facilities have, over the years, developed specific areas of expertise, but during recent years a gradual tendency has developed in which many facilities have branched out to all areas in order to perform overall system support. The result has been considerable competition with the individual EMC program efforts being highly dependent on the marketing ability of the respective individuals. Though this competition may be considered healthy from an academic viewpoint, it has not fostered an overall EMC program with planning and direction. The real challenge is to provide the best overall planning for a unified, coordinated, EMC program concurrent with assuring the "survival" of all participants.

2.3.2 Technology Transfer

In any technological program, a bona fide issue is the transfer of technology from the technologist to the user. In EMC technology, the end product is not a system but rather consists of a set of techniques, components and procedures. It is sheer folly to assume technology transfer will automatically occur. Some technologists, upon observing there were no eager users "awaiting at their door," have applied their own outputs to problems, thus becoming their own users and stopping technology transfer at that point.

The preceding situation points out that the identification of the user is not a trivial task. Even when identified by the technologist, the user may not be receptive because of a communications barrier or even because of the "not invented here" syndrome which often occurs. Technologists can be very technologically oriented and subject to much pressure from peer groups or be consumed with career advancement. In this case, expectations between technologists and users are often unrealistic and uncommunicated. Over complication of simple user problems often leads to "snowing" the user and the rejection of a new technology.

With these partial incompatibilities between users and technologists, the use of third parties of technology transfer personnel is appropriate. The initial task for such personnel, working in concert with technologists and users, is to identify needed technology, such as new methodologies, procedures and computer codes for design. Component and mitigation device development, testing and evaluation technologies are on-going activities. Recently, computer code development for design and analysis has flourished. In the technological sense, all of these items must be transferred to the end user. The transfer process is not one of simply moving items but rather it involves a transformation which must occur before the user can fully appreciate the benefits of the technology. Feedback from users and operational personnel is one vital part of technology transfer which must not be overlooked.

The task of the technology transfer personnel is then to:

1. Identify needed and existing transferable, usable technology.
2. Identify and train new users.
3. Transform or modify technological output from the technologist into a form which is acceptable to the end user.
4. Survey users in fields other than EMC to ensure EMC technology is utilized in all fields to obtain maximum benefit.
5. Provide continuing feedback from users to technologists.

The modification process requires a coordination function in which each party is receptive to others needs and constraints. User identification is an on-going process which must be pursued continually.

Training has to take place regularly but cannot consume huge blocks of the user's time. A program of short courses, seminars, and symposia should be tailored to specific technologies and users. Yearly seminars must be planned well in advance and include an update of new technologies under development and those currently available for transfer. A technology transfer newsletter containing Navy approved models and techniques, etc., could prove invaluable.

To achieve technology transfer, funds and effort must be applied. The technology transfer team will have to be independent of the user and technologist because neither of them have time to perform that function. Finally, the technology transfer team should have impact on the funding of 6.2 and 6.3 projects, while acting as only a lobbyist for 6.4 and above.

2.3.3 Compartmentalization of Technology

Although the various EM specialties all deal with the same set of physical laws (i.e., Maxwell's equations), which require consideration of the propagation and reception of electromagnetic energy, they tend to be highly compartmentalized. For example, EMC, EMV, EMP, ECM and EM safety specialties are all concerned with coupling of undesired energy. But, in spite of this commonality, different specifications and standards, and even units are employed. Measurement procedures and instrumentation (or facilities) developed for one specialty are rarely made available or even discussed with the others. The same can be said for analytical models, design guides and data bases. Often the result is duplication of effort with unnecessary expenditure of manpower and funds.

2.4 EME Definition

The basic definition of EMC is that a platform/system/equipment can operate in its intended operational environment without suffering any unacceptable performance degradation. Any attempt to insure EMC thus requires a definition of the "intended operational environment" composed of two parts from one's own platform and from the external world.

The total environment may be considered to be composed of active (sources or emitters of EM energy) and passive (detectors or converters of EM energy) environments. The propagation medium must also be considered because it affects the character of the total environment.

The requirement to consider the intended operational environment exists in MIL-E-6051. Suggested environments are found in MIL-HDBK-235 and the SEMI (Special Electromagnetic Interference) program. Work is ongoing in the areas of atmospheric noise levels and man-made noise.

Thus the EME definition is required and to some extent is possible to obtain. Failure to do so during procurement must be attributed to management and to a lack of application of existing capabilities.

2.4.1 Data Base

The specification of an EME is only an initial step in proper EMC management. Making the defined environment accessible and usable to all who need it, in the form of a data base, must be achieved. Data must be meaningful, certifiable and repeatable. What data is to be stored, how it is obtained, how it is organized, and the method of distribution is essential. There is currently no existing specification (that is up to date) to provide this data. Agreement is needed on what data is essential and who will provide it. Obviously, funding responsibilities must also be specified.

Although the present Navy 5 Year EMC Plan would lead one to believe that much data is being gathered which potentially could be retained in a data base, little effort is specifically being expended to rectify the existing problem of unavailable and inadequate data bases. Only the EMX program contains a small effort to provide the data required to perform systems engineering analysis and design. The impact of this lack of data and its availability is that systems may get designed and built but without proper engineering they will not perform as desired.

2.4.2 Frequency Management

There are several actions involved in frequency or spectrum management: two of these are frequency allocation and frequency assignment. Allocation is involved with the authorization to develop an equipment which operates in a specific frequency band or on a given frequency. DD Form 1494 (Application for Frequency Allocation) is required to be submitted at the experimental, developmental and operational periods of the acquisition cycle, but unfortunately, this allocation process is frequently not taken seriously by equipment developers or is completely unknown to them. In these latter cases, much grief results from the difficulties which can occur when unacceptable frequencies are blindly chosen in the national or international arena. Equipment must be redesigned with resultant waste of funds and time. The importance of a system having an approved frequency allocation cannot be overemphasized. It not only assures a sponsor protection but may point out deficiencies through the EMC analysis which follows, which can be corrected prior to production.

In frequency assignment authorization is given to use a specific frequency or band for a particular application. To date, the process has been treated almost routinely - spectrum space has been available with little competition. This however, is changing drastically, in all world countries, where spectrum requirements haye increased by several orders of magnitude and the end is not in sight. "Clear channels" just do not exist anymore.

Relief of a form can only be had through the application of available technology, at the appropriate time in the procurement cycle, i.e., minicomputers, simplified propagation algorithms, intermodulation interference technology and others. The frequency resource is limited. The subject is little understood in the field and consequences are not realized until the equipment is operational and that is, unfortunately, often too late for expedient correction.

2.5 Specifications and Standards

A standard is created to serve the designer of some piece of hardware and to control variety. When drafting an equipment specification, a standard is useful for establishing common parameters of interchangeability, compatibility, reliability and maintainability. Control of variety is aided by standards which specify common features.

A specification is intended primarily for procurement. It defines clearly essential technical requirements, expressed in terms of performance and provides the government the instrument for solicitation of competitive bids.

2.5.1 Current Specifications and Standards Lag Technology

Any discussion on the adequacy of specifications and standards will always point out that nearly all standards and handbooks need updating or revision in order to reflect currently practiced technology. History demonstrates that preparation, issuance and revision of these documents probably cannot be accomplished much faster than is currently done, due to the DoD system of Defense Standardization Procedures. The Defense Standardization Manual 4120.3-M of January 1972 established a time cycle guide for "expedited coordination" of military specifications and standards. In idealized situations (no disagreements to be resolved), the cycle is 26 weeks. Disagreements which cannot be resolved by the preparing activity take 6 more weeks for resolution by higher authorities. NAVELEX-510 personnel consider 18 months typical for a "straightforward" standard preparation, through printing. Something as complex as MIL-STD-461A has been in revision since May 1970. Comments and suggestions add to the volume of paper until it presently totals some 400 pages. Optimistic expectations call for the "B" revision to be released by January 1978, seven and one-half years after work started!

Only increased command attention aimed at providing and applying viable conceptual ideas, policies and procedures along with commensurate resources and priorities will achieve a major improvement in this process.

2.5.2 Tailoring of Specifications and Standards

The consolidation effort within DoD which occurred during the 60's aimed at the production of Tri-Service EMC equipment standards resulted in the MIL-STD-461, 462, and 463 series. When applied to a subsystem equipment, these tests will establish a baseline of EMC from which to work. The "work" is then to integrate the equipments into a system whose performance can be determined to satisfy requirements. That process is proper systems engineering. Experience with complex systems has shown that a "reverse trend" was necessary. That is, getting away from the "single applicable standard" to a "scrubbed and tailored" standard which only required those portions of the 461 series (or others) which were necessary for the systems needs.* Additionally, requirements could be added to tighten up and insure EMC when the systems designer discovered it to be necessary. ASPR 1-1201, as modified in DCP #75-8, 21 May 1976, so states these facts.

* A clarifying point to be made here is that when a standard is tailored, that "tailored standard" becomes a specification to be used in procurement of an item. Thus standards are standards and tailoring produces specifications.

Although well meaning, the regulation requiring tailoring cannot provide the sorely needed procedures for tailoring. Engineering personnel involved in systems design need assistance in the form of a systematic approach to design in the EME. The beginnings of this effort in the EMX program of NOSC are noted but they do not specifically identify the need for tailoring procedures to be developed. Until this need is fulfilled, only the more experienced systems engineers will be able to successfully do the tailoring function, and we will continue to procure 461-series approved equipments which will not perform adequately in a system or on a platform.

2.5.3 Integration of Specifications and Standards

Someone who is unfamiliar with the structure of EMC responsibilities in the DoD might question why many of the tests required in the MIL-STD-461 series are partially duplicated in the TEMPEST certification process. The apparent waste of resources and added expense of not providing for an integration or consolidation of all EMC specifications and standards cannot be eliminated by the Navy in platform acquisitions because of the agency responsible for TEMPEST - NSA.

Some consolidation should be fostered in future procurements, especially in cases where a ship specification is to be developed. EMC specifications and standards consolidation in such cases should prove efficient. Duplication of work by agencies responsible for security systems will have to be accepted for the immediate future.

2.6 Corporate Memory

Corporate memory with respect to EMC is aptly described by three words: Remember, Share, and Learn.

2.6.1 Documentation and Distribution of Analysis, Measurement and Test Results

Although numerous DoD directive and Navy instructions require documentation of results of model development, analysis and measurements, many efforts are not reported. Those that are often have inadequate descriptions of important details. Prime examples of this are computer codes for which only program listings are provided. Experience has shown them to be mostly useless to someone attempting to transfer the capability to his agency.

Without detailed descriptions of important capabilities and limitations of the model and user-oriented manuals, no use can be made of them.

Data which is often readily shared can come "packaged with a substantial risk." Important parameters of the equipment used to collect the data must be known or the user may risk erroneous interpretation. An example is instrument bandwidth used to collect radio noise data.

Standards could be supplied with documentation describing the rationale upon which the standard was based. This would prove valuable when considering requests for partial or complete waivers.

The key to preventative and corrective actions for EMI in the fleet is isolation and dissemination of basic factors which are symptomatic of problems which cause performance reduction. The only way to prevent recurrence of such problems is the documentation of them and then having them addressed in practice. The SEMCIP program is approaching these objectives, but cannot be expected within current resources to develop procedures to systematically identify the root cause of an EMI problem and inform and require eradication action. The AWCAP and SMS/DCAP efforts provide possible vehicles for reporting problems on airborne weapons. Action and support at a higher managerial level than SEMCIP must be instituted as a first step toward the above goals.

2.6.2 <u>EMC Capability and Perishability</u>

Trained engineering personnel are necessary to implement any EMC program or doctrine. To ensure that the requisite number of properly trained individuals is available at the right location must be the subject of specific planning. The Navy EMC community is replete with examples of how retirement or untimely demise of specific individuals has depleted an organization of a specific engineering capability. The establishment and maintenance of an EMC engineering capability through directed efforts is vital to follow through an EMC program.

2.6.3 <u>Feedback from Fleet Problems</u>

Distribution of information on fleet EMI problems is too limited. Wider dissemination can provide the feedback needed in order to bring all available technology and experience to bear on correctable problems.

Management awareness via feedback can aid the process of correction which engineering and design forces cannot accomplish alone.

2.7 Integration and Installation Practices

Successful integration and installation of equipment and subsystems is required for sea and air platforms to be electromagnetically compatible. Practices for installation and integration must be approached from the systems engineering viewpoint. Since all EMI cannot be eliminated, an optimal arrangement must take place by considering all installation factors. To date, EMC has not been given high enough priority in the integration process.

Installation and integration practices are standardized only when numerous types of platforms have similar missions. That has not occurred to date but it appears that future planned ship and aircraft types will be fewer in number, giving some promise for future standardization possibilities.

An additional factor which inhibits installation and integration standardization is the mixture of Government Furnished Equipment (GFE) and Contractor Furnished Equipment (CFE) appearing on platforms. Integration responsibilities are not clearly defined in contracts with the result that when an EMI situation appears, a great deal of "finger pointing" occurs between both government and contractor personnel.

Many times EMI data necessary for a proper systems engineering approach is not readily available for a contractor or a Navy engineer to use in an integration design effort. If the data exists, it may be scattered throughout several activities. An example is the F-18 program. Data on the 31 major GFE's had to be collected from seven Navy technical activities.

2.8 EMC Validation

EMC validation refers to the measurement and analysis of measurement results for the purpose of assuring that a deployed system enjoys a state of EMC. Two types of validation are identifiable: Design Validation, which establishes the compatibility of an equipment design, perhaps via the MIL-STD-461 route, and Performance Validation, which verifies that Navy EMC specifications and requirements have been met at the equipment, system and platform levels. Because a very large range of designs can occur, the validation process must be widely varied also.

2.8.1 EMC in TECHEVAL

Procedures must be planned by the Navy for evaluating the effectiveness of the platform from an EMC viewpoint. The present TECHEVAL process seldom, if ever, addresses EMC considerations. If analytical procedures are applied before measurements commence, the evaluation process can be focussed on potential conflicts, with maximum expectancy of resolving conflicts with minimum time and cost.

Without preliminary analytical procedures, inevitably a pattern of measure-patch-measure results, with greater costs and greater chance of unresolved conflicts. Until EMC is included as an integral part of TECHEVAL, the Navy will not enjoy effective EMC in the life cycle of systems.

2.9 Design Practices

EMC design practices are widely varied and involve aspects of both art and science. Very specific requirements can be written for components and "black boxes." For these, it is possible to develop concise formulas for achieving EMC. On the other hand, system layout procedures represent more art than science, especially in missile systems. The "artistically designed" system often are made to be compatible by a series of measurements followed by fixes and more measurements, etc.

2.9.1 Interference and Susceptibility to EMI

When a large number of equipments aboard a platform are subject to intrasystem interactions, a similar situation has prevailed. After selection and arrangement, measurements reveal the need for additional filtering or antenna isolation. When weight, space or cost limits are approached, performance degrading incompatibilities result.

Analytic procedures are becoming available for estimating possible incompatibilities in system layouts. Even though a degree of uncertainty is involved, the analyst can understand the limitations of the procedures and apply reasonable safety factors at a point well before the previously mentioned limits "freeze out" any further design improvements.

Additional effort is deemed desirable to secure more refined analytical techniques.

2.9.2 Analytical Model Availability and Applicability

Certain available computer models for assessing system EMC are applicable to more than one EM specialty. Coupling and some non-linear models are good examples. However, models used in one specialty are rarely used in others. The reasons are several. In terms of availability, documentation is seriously deficient for most computer codes. It becomes virtually impossible to simply secure a complex program and proceed to execute it with any hope of success.

In general, an agency to provide two types of interface is needed. The first function is to produce readable documentation to a varied group of users. Second, an educational program is essential in which users are lead through the usage of the model in a "hands-on" manner where they test its capabilities and discover its limitations.

The level of effort to produce a truly available and applicable model is not insignificant but neither is the cost of frequently developed different programs which inherently do the same job and reside only with the developing agency.

2.9.3 Spectral Utilization

Optimal utilization of the spectrum resource is not wholly accomplished by frequency assignment procedures. It involves design practices in the form of models or spatial and time blanking or filtering techniques to minimize operational degradation from interfering emissions. Large dividends can be gained by investment in this flexibility of design. The present system of procuring isolated and somewhat unique equipments from the lowest bidder mitigates against the use of this technique to achieve EMC. Flexibility built into equipment to allow control of spectral component or timing of transmissions between interfering equipments is an unexploited area.

2.10 EMC Design Considerations in EW Systems

Electronic Warfare systems present a unique EMC problem on Navy platforms because of their primary function; they listen for threat emissions (ESM) and generate emissions (ECM) to degrade enemy system performance. If enemy EW systems operate in the same portion of the spectrum as Navy platform equipments (i.e. communications, radars and navigation), then:

a. EW system performance against the threat will degrade from EMI caused by own platform emitters to ESM equipment.

b. Other own platform systems performance degrades due to EMI from ECM equipment.

c. Duty cycle limits imposed on ECM equipment by own platform emitters degrades ECM equipment.

Since the enemy largely determines EW equipment characteristics, platform EMC presently comes through frequency agility/diversity in comm, radar or navigation equipment or from blankers and filters. Clearly, after-the-fact fixes must be avoided if possible.

Some relief from the burden of producing compatibility can be had if early in the concept phase, it is determined which combinations of proposed EW and comm/elex systems result in net increase/decrease in platform capabilities when the added complications of EMI problems are considered. After that decision has been reached, analysis should be conducted to determine how much more stringent are EW-EMC requirements than EMC requirements for comm/elex alone. Later, design trade-offs can be conducted where comm/elex and EW designers "share the burden of compatibility."

2.11 EMC During Deployment

The last phase of the life cycle of Navy systems is one in which inadequate considerations for EMC occurring in the previous phases "come home to roost." It is usually too expensive and too late at this point to correct built-in deficiencies. The only practical consideration to EMC during deployment involves identification, reporting and correction of EMI problems and assuring that maintenance, overhaul and backfit crews are EMI-trained and conscious.

2.11.1 Identifying, Reporting and Correcting EMI Problems

Several problem reporting and corrective action programs exist within the Navy and Tri-service at the present time. Most of them do not now address EMI problems, but with proper direction they could do so. Briefly they are:

- The Shipboard Electromagnetic Compatibility Improvement Program (SEMCIP) sponsored by NAVSEA is providing a central clearinghouse (for ships) for EMI problems reported by the fleet and a problem correction service.

- The Airborne Weapons Corrective Action Program (AWCAP) is operated by PMTC and sponsored by NAVAIR and is a management tool for providing a closed loop information system between the fleet and the Navy management/engineering community.

- The Ship Missile System/Deficiency Corrective Action Program (DCAP) is very similar, sponsored by NAVSEA and administered by NSWSES.

- Meaconing, Intrusion, Jamming and Interference (MIJI) is a Tri-service program administered by the Air Force EW center. Instructions require all EMI experienced by operating forces to be reported to AFEWC. Weekly, monthly, and annual summary reports are issued. Presently the Navy does little to use this resource.

The SEMCIP program is obviously more nearly suited to needs being addressed by TESSAC, but covers only one portion of EME problems. The Naval air community has no precise procedure existing to identify, report, and correct EMI problems with aircraft. The unsatisfactory Material/Condition Report (UR) System of the Naval Aviation Maintenance Program (NAMP) provides a means of reporting EMI problems if the problems are identified correctly. Another possibility is the Naval Aviation Maintenance and Material Management (3-M) system which can provide data collection. The Engineering Investigation Program (EIP) provides maintenance engineering assistance and could be set up to include EMI investigations and assign an investigating activity.

It is possible to utilize the existing corrective action and reporting programs in a more coordinated manner, including EMI problems where not already addressed, to improve the feedback from users in the fleet. Such improvements should be accomplished with minimum or no changes in manpower or software/hardware.

2.11.2 EMC in Maintenance, Overhaul, and Backfit

Alterations often change the "configuration" of the platform, i.e., the locations of metallic structures which alter the EM environment to a degree where an EMC evaluation should be conducted to ascertain if any unacceptable EM compromises are being made. Unfortunately, such EMC evaluations do not usually occur.

Aircraft EMI maintenance, overhaul, and backfit procedures are 21 years old. Training for maintenance personnel does not exist. NAVAIR must establish and enforce proper EMC procedures or continue to suffer the consequences.

2.12 Defining an Acceptable Level of EMC

The community of users of EMC technology and management must realize that total EMC can never be predicted nor achieved except in a very simple situation and for limited periods. The nature of the problem of prediction is probablistic, not deterministic. All of the data from which predictions are made have some level of uncertainty or inaccuracy which must be stated in a statistical manner. Managers must accept the fact that during a certain percentage of the time, EMI will occur. The operational community thus has to define a "level of acceptable performance in the EME." This definition must be developed via a cost/benefit tradeoff.

2.13 Summary of EMC Issues

The major EMC issues just presented, represent the overview of action items which the U.S. Navy must address in its acquisition, R & D, and operational support programs in order to significantly improve the quality of EMC on Navy platforms. The remaining portions of this document will address these issues from the acquisition, technological, and support activity viewpoints, giving recommendations which should guide the future EMC program plans of the Navy.

3.0 ELECTROMAGNETIC COMPATIBILITY DESIGN IN THE ACQUISITION CYCLE

3.1 Introduction

At the present time there is no standard and/or concerted approach or procedure for integrating EM compatibility into the various phases of the design cycle for acquiring major Navy systems. This is due to the difficulties and uncertainties associated with modeling, analyzing, and/or testing complex systems to determine emission, susceptibility, and operational constraints and requirements. This is not to say however, that major systems cannot or have not been designed taking EMC into account throughout the various acquisition cycle phases. Examples of highly successful EMC programs in the Navy are the Poseidon and Harpoon.

A general approach employed by most program managers is to invoke the applicable EMC standards and specifications in the procurement documents for the full scale engineering development phase in the acquisition cycle. This approach, while relatively easy to implement, has some drawbacks. The specifications and standards are outdated in some areas resulting in unrealistic EMC design requirements for the intended operational environment. The implementation of EMC considerations this late in the procurement cycle precludes EMC analysis and design benefits which could be achieved in the earlier phases. In order to overcome these deficiencies a systematic approach to EMC throughout the acquisition cycle is needed.

To support the need for more standardization in EMC design, efforts have been initiated recently to develop the handbooks, data bases, design guidelines, and specifications necessary to design and acquire EM compatible platforms in a systematic and cost-effective manner. The objectives and products of these efforts are, for the most part, aimed at developing the ways and means necessary to incorporate EMC design procedures/methodologies into the long established methodologies employed by the services in acquiring major systems and/or platforms. Although these actions are productive they tend to sustain an already weak procedure rather than change it to the needed systematic approach.

A systematic approach to ensure consideration of EMC during the acquisition cycle is proposed in the following sections. The approach postulates the use of tailored specifications and hopefully will alleviate the test-fix, test-fix condition which often prevails during TECHEVAL, OPEVAL, and initial deployment when using the present acquisition policy.

The five principal phases in the acquisition of major Navy systems/ platforms as established by OPNAV Instruction 5000.46 include:

- Concept Development
- Concept Validation
- Full Scale Engineering Development
- Production
- Deployment.

A flow diagram depicting the manner in which postulated EMC considerations and task activities could be integrated in this overall acquisition process is shown in Figure 3.1. These EMC action items are defined and discussed in the following sections.

3.2 Concept Development Phase

Beginning with the concept development phase, the program manager will generally require the assistance of a board of technical people who will then be responsible for incorporating electromagnetic compatibility into the design of the system. This is the EMC Advisory Board (EMCAB). During the concept development phase the objectives of the Program Manager and the EMCAB will be:

- Specify electromagnetic environment
- Determine spectrum utilization requirement
- Perform coupling and interaction analysis for system
- Establish design requirements to mitigate or suppress undesirable EM coupling effects or EMI
- Identify/consider applicable EM mitigation and/or suppression techniques/devices
- Perform a design review to determine that requirements will be met
- Determine risks and uncertainties
- Examine applicability and adequacy of available specifications
- Develop EMI suppression/mitigation designs
- Perform tradeoff studies and establish subsystem EMC requirements from analysis and data base

Fig 3.1 EMC CONTROL PLAN

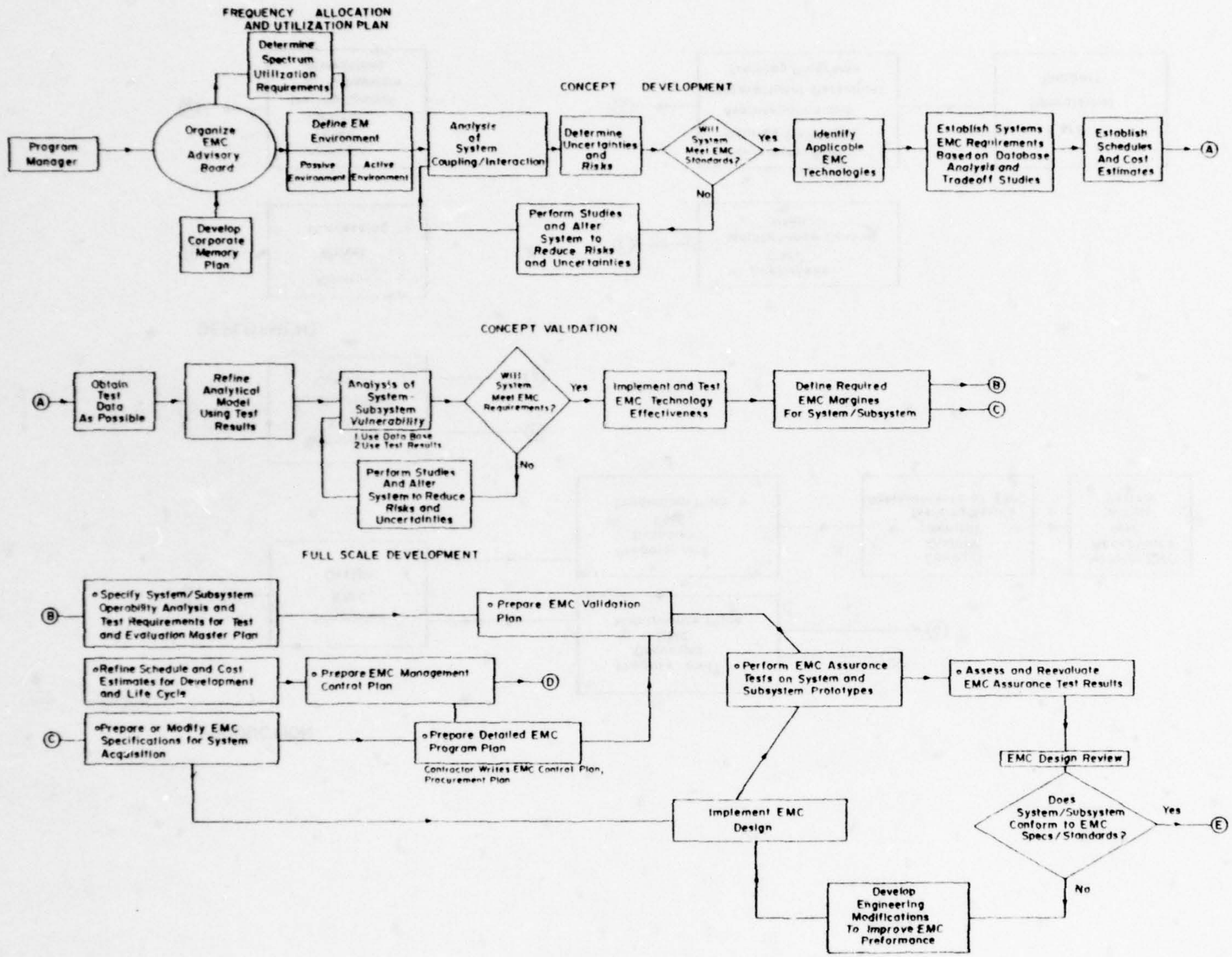
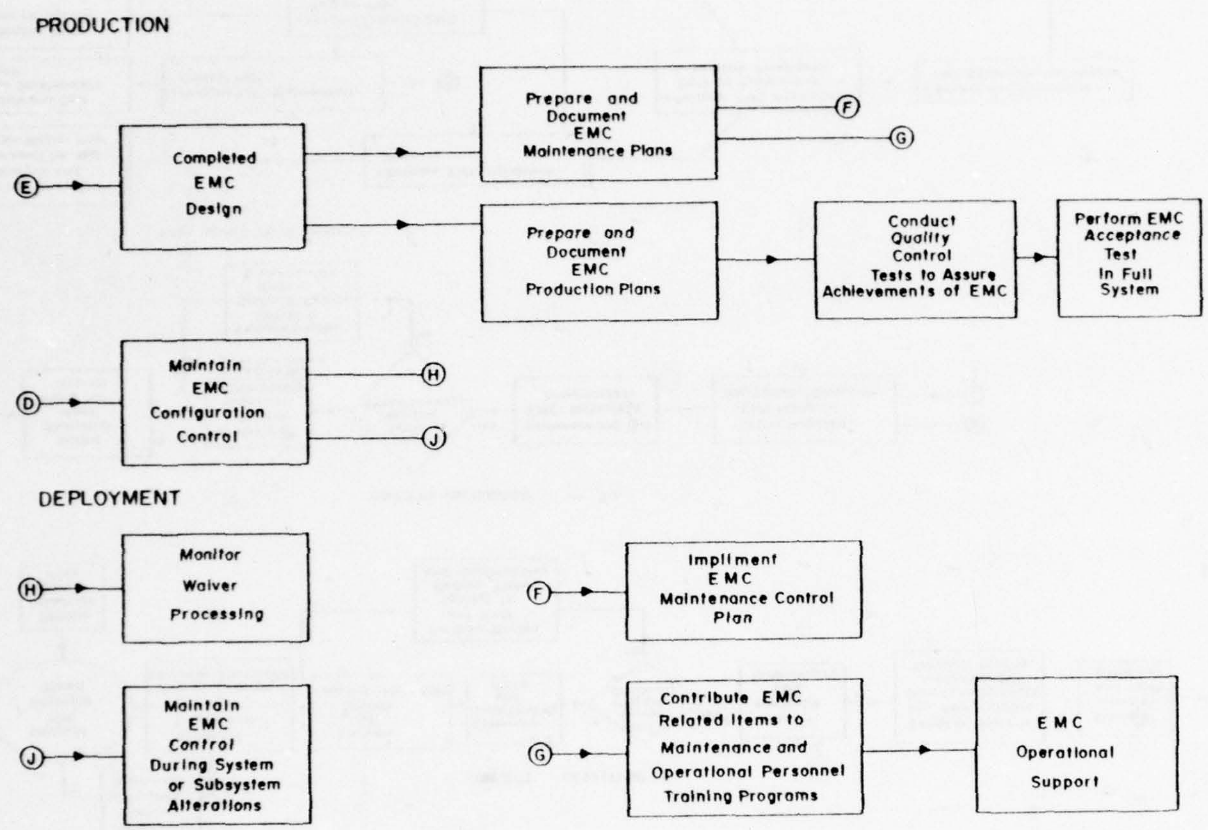


Fig 3.1 EMC CONTROL PLAN (CONT.)



- Establish schedules and cost estimates
- Ensure adequate data base.

One of the actions that should be taken by the EMCAB in the design of a system platform that will be EM compatible with itself and the fleet is to define the EM environment which the system will experience. A spectrum allocation and utilization plan must be prepared. Basically the environment will be externally generated and internally generated, and there are both active and passive environments to consider. This is done by analysis, testing, or use of appropriate data bases (i.e., handbooks, previous analytical results, test data, manufacturer data, etc.). Once the EM environments, both external and internal, are established a design can be analyzed for its EM compatibility. Problem areas or areas of uncertainty and risk can now be defined. The EMCAB can review the system configuration and evaluate the uncertainties and risks and decide on alterations to the configuration or that further studies need to be conducted to reduce the uncertainty and risk.

Once the basic system configuration has been reviewed by the EMCAB, the applicable EMC technologies must be identified and the system design can be refined to a more detailed level. The system EMC requirements can be established and tradeoff studies can begin to decide on optimum EMC configurations. At this time, schedules and cost estimates for the project can be prepared.

There is an additional responsibility of the EMCAB to prepare a corporate memory plan so that the program manager has control over the documentation of the EMC program. This documentation, along with the reported field problems and remedies, can serve as a data bank for the current and future programs and therefore is called the Corporate Memory.

The culmination of these activities will be with the first major design review DSARC I, the program initiation decision. The technologies required to establish EM compatibility during the concept development stage are summarized below:

- <u>EM Interaction and Coupling</u>

  This includes analytical techniques and results, and the data bases necessary to establish EM environments and coupling modes.

- Degradation Analysis
- Cable/Shield Architecture
- Mitigation Techniques

  Preventive devices and hardware.
- Signal Processing

3.3 Concept Validation

In the concept validation phase, the design concepts to mitigate and suppress EMI are reevaluated and further refined to assure EMC. This is done experimentally and analytically. Where appropriate, hardware and/or prototype development will be initiated and development tests will be performed to determine that:

1. The EMC risk and uncertainties are minimized;
2. The engineering is complete;
3. Solutions to the problem are at hand;
4. The system/platform meets or will meet EMC requirements;
5. The analysis models are valid.

The specific action items and tasks are:

- Refine system interaction and coupling analysis and validate with tests as possible.
- Assess subsystem susceptibility using analysis, data base, and test data as appropriate.
- Analyze and/or test to resolve uncertainties.
- Continue design tradeoff and design interaction.
- Implement and test EMC design technology effectiveness.
- Specify system/subsystem operability analysis and test requirements for inclusion in test and evaluation master plan (TEMP).
- Refine schedule and cost estimates for development and life cycle phases.
- Prepare or modify EMC specifications for system acquisition.
- Define required EMC margin for system/subsystem.
- Prepare detailed EMC program plan (EMCPP).

Throughout this validation effort, the proposed technical approach to meeting EMC design requirements for the major system/platform are reviewed, refined and verified. High risk areas and uncertainties are examined to make modifications to either eliminate or minimize these risks. Actual equipments and advanced models are available to make measurements and improve engineering estimates. Another cycle of analysis, EMCAB design review, and alterations takes place using the available test results.

Once the EMCAB reviews the proposed design, analysis and testing in depth is conducted to determine the EMC technology effectiveness. EMC margins for systems/subsystems are defined and a firm specification can be prepared.

With the design at this advanced stage the tailored EMC specifications for system acquisition can be prepared in contractual language. The schedule and cost estimates for development and life cycle and an EMC Management Control Plan are prepared. The Test and Evaluation Master Plan leads to the EMC Validation Plan. A detailed EMC program plan is developed. All of this activity is culminated in the second design review DSARC II, where the decision for *full scale engineering development* is made.

The technologies and capabilities needed to carry out the task efforts in this phase include all those utilized in the concept formulation with the addition of the following:

- <u>Specifications and Standards</u>

  This includes performance, design development and test specifications and/or standards relating to emissions/susceptibility characteristics of platforms, systems and subsystems as well as for EMC mitigation techniques and/or devices.

- <u>Management Program Development and Coordination</u>

3.4 Full Scale Engineering Development

During this phase, all items for the system are fully engineered and developed, built, and tested. The resulting engineering development prototype should be a pre-production system closely approximating the final product. From the standpoint of EMC, the specific task and action items of concern in this phase are:

- EMC design review;
- Prepare EMC management control plan;
- Identify and develop special test equipment needs;

- Perform EMC assurance tests on system and subsystem prototypes;
- Assess and reevaluate EMC assurance;
- Complete the EMC design;
- Prepare and document EMC production and maintenance plans;
- Contribute EMC related items to preparation and conduct of training instructions for operation and maintenance personnel;
- Develop improved EMC technology.

In essence, full scale engineering development of the EM compatible system is the classical design activity in which a prototype is developed to demonstrate that EMC specifications are conformed to. To verify this, EMC assurance evaluations are carried out either by analysis and/or testing using the procedures and test equipments specified in the established procurement specification.

Also included in the output from this phase is the documentation necessary to enter the production and development phases. This includes the EMC management control plan to ensure that EM compatibility is properly implemented, controlled, and maintained throughout the life cycle of the major system or platform.

Also, production quality control, maintenance and repair, and personnel training documents must be prepared that detail the procedures, techniques, test and support equipment necessary to produce, maintain, and control EM compatibility.

When a prototype is available another design review DSARC II B is held where the decision to go into pilot production is made. When the full scale engineering development phase is complete the DSARC III review is held to decide whether or not to proceed into the major production.

The major technologies and capabilities needed to carry out this phase include:

- <u>EMC Mitigation Techniques/Devices Technology</u>
- <u>EMC Quality Assurance</u>

  This will include analytical technologies, test procedures and test equipments/facilities necessary to implement these tests.

- EM Compatibility Production Control

  Procedures, techniques and test equipment.

- EM Compatibility Maintenance

  Training, procedures, techniques, test equipment and service/ repair precautions.

- EMC Life Cycle Management

3.5 Production Phase

During this phase it is the responsibility of the EMCAB to maintain EMC configuration control through production so that the end system will meet EMC specifications. In general, this is assured by carrying out the following tasks:

- Maintain EMC configuration and design control.
- Conduct quality control tests to assure achievement of EMC.
- Perform EMC acceptance test on full system.
- Monitor waiver processing.

Care must be taken to control configuration and parts so that the compatibility of the system remains at the designed level. Quality control tests are performed to assure achievement of EM compatibility. EMC acceptance test in the full system is performed for testing intersystem interference. It is important that waivers to specifications do not result in a compromised EMC design.

3.6 Deployment Phase

EMC considerations during deployment center around maintenance of the EM compatible designs incorporated in the deployed or operational systems. The major action items for this phase are:

- Implement EMC maintenance control plan.
- Contribute EM compatibility items to maintenance and operational personnel training programs.
- EMC operational support.
- Maintain EMC control during system or subsystem alteration via Engineering Change Proposals (ECP's).

One of the principle tasks in operational support of the deployed system is to establish and maintain a problem reporting procedure to assure, the necessary feedback for updating data bases and/or corporate memory which can result in improved future EMC designs and methods.

4.0 STATE OF TECHNOLOGY OF ELECTROMAGNETIC COMPATIBILITY

4.1 Introduction

This section of the report deals with the status of EMC technology. During the life cycle of a platform or system it will be exposed to both its own locally generated EM environment as well as the EM environment created by other systems or platforms. This section covers the analytical, test, management, data base, and mitigation methodologies available to deal with EMC problems which might arise during the life cycle of the system or platform.

When equipments (systems) are located on the same platform (cosite) the interactions between active and passive occupants of the environment via the propagation medium is termed intrasystem EMC while interactions between platforms is commonly known as intersystem EMC. The following sections will discuss the state-of-the-art of this technology. Since some of the technologies differ slightly for the two areas, each will be discussed separately.

4.2 Intrasystem EMC

4.2.1 Introduction

The present methodology for dealing with intrasystem EMC is to invoke EMC standards and specifications in the procurement documents for full scale engineering development. Waivers may be granted during this phase. Whatever EMC problems remain are generally uncovered in the TECHEVAL and/or OPEVAL tests and are remedied by fixes. It has been suggested that tailoring of standards and specifications would be a more cost effective approach to achieving EMC in systems and platforms.

The intrasystem (EMC) will be discussed primarily from the viewpoint of tailoring standards and operational modes to achieve an overall electromagnetically compatible design. Emphasis in these areas is believed beneficial to achieve improved utilization of existing technology since the present intrasystem EMC approaches involve almost exclusively the use of standards and specifications. Embedded in the tailored specifications and modified operational models will be an improved reporting procedure. This will insure prompt addressing of immediate problems and provide input to improve maintenance and training aspects of the EMC problem.

The state-of-the-art which leads to the tailored standards and operational modes will be discussed in terms of five major categories as follows:

- Analysis
- Test
- Management Tools
- Corporate Memory
- Mitigation Techniques.

Table 4.1 summarizes these tools along with various topical subheadings within each "tool group."

From the viewpoint of the tailoring standards or operations, the following must be known:

- Sources and generated environments
- Coupling path loss
- Vulnerable equipment and susceptibility levels
- Prediction capability commensurate with need.

While the above will provide the basic information input, the additional or supplementary information is clearly needed in the following areas:

- Equipment placement/cable routing options
- Effectiveness of mitigation hardware
- Operational mode options
- Standard tests and limits
- Corporate memory listing equipment characteristics
- Accessible listing of fleet EMC problems and fixes
- Training and maintenance implications.

It is seen that the above essentially embodies all of the tools or parts as listed in Table 4.1. Thus, to achieve the goal of the tailored standards and operational procedures involves a comprehensive evaluation of the state-of-the-art in the various tool areas.

The question may be raised as why such a wholistic approach is needed to address the intrasystem problem area. Presently, MIL-STDS-461, 462, and 463 are the major standards used to achieve intrasystem compatibility. In general, as delineated in these standards, test procedures and noted limits are chosen on the basis of engineering judgment only. As a consequence,

TABLE 4.1

INTERNAL EMC INTRASYSTEM INTERFERENCE/CROSS TALK COUPLING CHART HEADINGS

I. ANALYSIS

- A. Environment Prediction
- B. Pick-up Prediction
- C. Degradation Analysis
- D. Limit Apportionment
- E. Cable/Shield Architecture

II. TEST

- A. Mitigation Component Test 220, 285, etc.
- B. 6051 Aircraft
- C. 461 Series MIL-STDS

III. MANAGEMENT TOOLS

- A. Standards - Specifications
- B. Procedures - Methodologies
- C. Maintenance
- D. Training
- E. Problem Reporting

IV. CORPORATE MEMORY

- A. Equipment Characteristics
- B. Data Prediction Base
- C. Summary of Environment Measurements or Publications
- D. Handbooks
- E. Documentation of Problems

V. MITIGATION TECHNIQUES

- A. Shields
- B. Optical Fibers
- C. Cables
- D. Terminal Treatment
- E. Arrangement Decoupling
- F. Grounding
- G. Bonding
- H. Composite Materials

many of the limits are inappropriate--either too high or too low, depending on the situation. Other deficiencies are embedded in specific test procedures. However, if one is to tailor standards and test limits, then test procedures must be altered or tailored to meet the particular situation. To do this, two options are available. Further reliance on engineering judgment, which implies an increasingly larger and larger group of knowledgeable individuals, or reliance on a prediction capability, preferably with its accuracy limits commensurate with the need.

Specifically, the impact of changing the limits associated with a specific test procedure (or modifying the procedure itself) must be assessed in some rational manner. This can be done simply on the basis of experience as remembered by the EMC engineer, or on the basis of analyzing the system, possibly on a first-cull basis. The latter approach seems preferable because once the prediction capability has been adequately developed, further major cost expenditures would not be needed. On the other hand, to maintain a capability needed to tailor standards based on engineering judgment, maintenance of a large group of engineers would be required on a continuing basis. Further, it cannot be assumed that the human memory and analytical processes are up to assimilating and processing the necessary information which would allow even the most rudimentary and crude engineering ball-park guesses. Thus, the emphasis in the succeeding discussions will be directed toward using a fairly sophisticated, at least it can be so regarded at this time, computer-aided approach.

A few words of caution, however, are needed. First of all, the prediction capability should clearly be commensurate with the need. For example, during the concept development phase, a prediction capability having an error within 20 to 40 dB might be quite adequate to identify the major problem areas. The basis for this is that likely interference problems can occur at receiver sensitivities as low as minus 150 dBm along with sources having an output power of plus 90 dBm. Under such a wide dynamic range even a 40 dB accuracy can allow the systems design engineer to identify the major problem areas.

As the development of the system proceeds, the accuracy requirements for any prediction ability will also increase. This is illustrated in Figure 4.1.

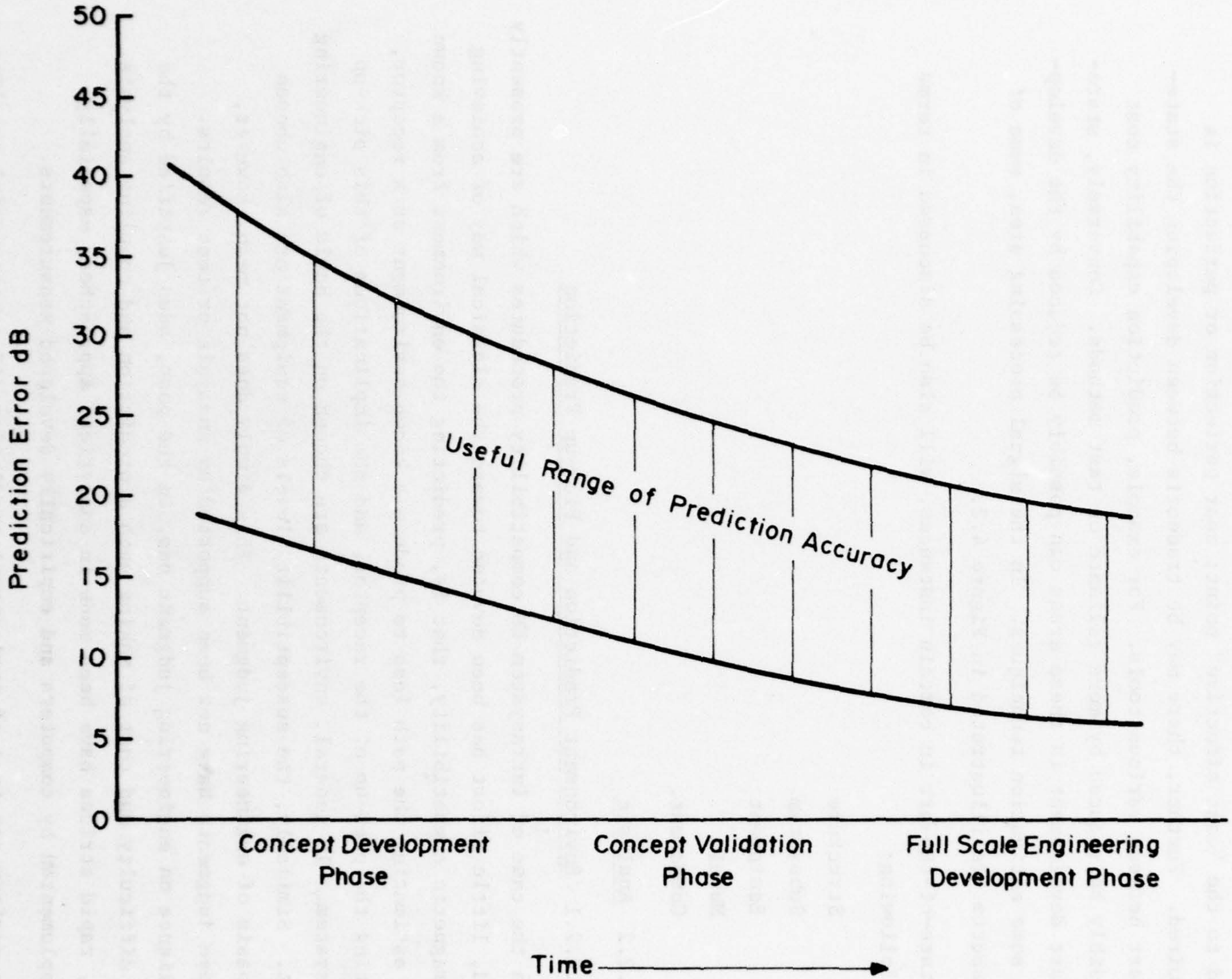


Fig. 4.1 ACCURACY VS. TIME FOR PREDICTION CAPABILITY

The improvement in the capability of any tool, whether it be prediction accuracy or some other aspect, is clearly limited by cost and cost benefit factors. Basically, the state-of-the-art in any tool area need only be improved to the "cost effective" point; near perfection or perfection is not required. Further, there may be tradeoffs between developing the state-of-the-art between various tools. For example, prediction capability cost can possibly be reduced by more reliance on test methods. Conversely, state-of-the-art development in these areas can possibly be reduced by the development of some mitigation techniques. In the signal processing area, some of these aspects are illustrated in Figure 4.2.

State-of-the-art in certain instances, will also be discussed in terms of the following:

- Structure
- Subsystem
- Equipment
- Module
- Component.

4.2.2 Analysis

4.2.2.1 Environment Prediction and Pick-up Prediction

In the case of intrasystem EM compatibility procedures which are presently employed, little effort has been devoted toward the classical way of achieving electromagnetic compatibility, that is, predicting the environment from a known source, estimating the path loss to produce a known environment at a receptor, calculating the pick-up of the receptor, and the implications of this pick-up on the system. In general, environments are chosen on the basis of engineering judgment. Similarly, the susceptibility levels of equipment are also chosen on the basis of engineering judgment. This simply does not mean, however, that these judgments have not been supported by analysis or test results. Such reliance on engineering judgment has, in the past, been justified by the extreme difficulty and cost of making such a prediction and coupling analysis. However, rapid strides have been made in analytical approaches, especially when supplemented by computers and empirically developed measurements.

To perform any type of environment prediction and consequential coupling analysis for the intrasystem case, the actual system must first be physically

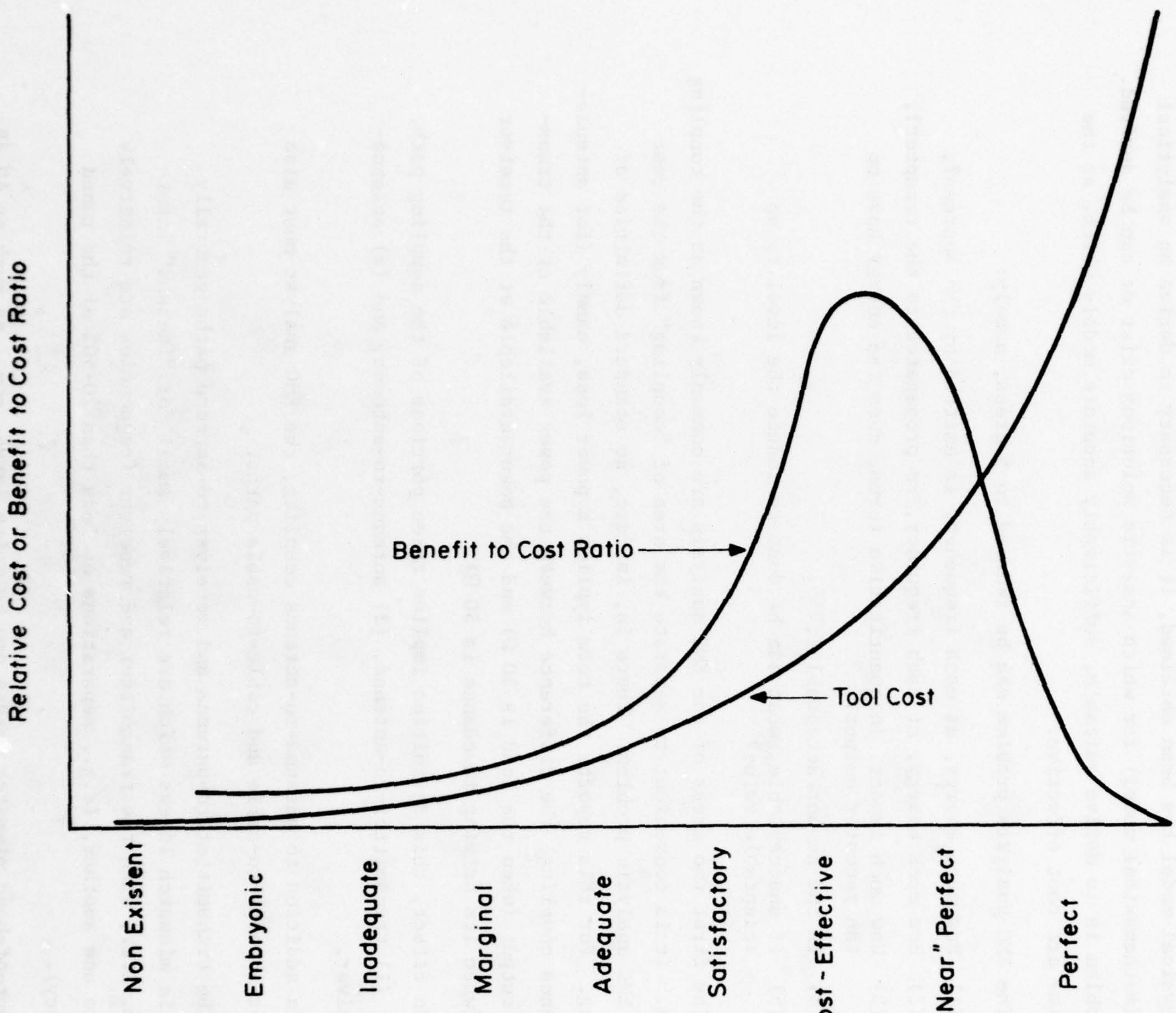


Fig. 4.2 TOOL DEVELOPMENT COST AND BENEFIT AS A FUNCTION OF STATE-OF-THE-ART

modeled (simplified geometry, etc.) to be amenable to analysis. Once a suitable physical model has been obtained, it is necessary to derive an analytical model (mathematical model) for which analytic solutions exist or can be derived. The problem is to derive suitable, sufficiently accurate models which, at the same time are cost effective.

The EMC analysis problem can be reduced to 5 areas, namely:

(1) How much energy, at each frequency, is emitted by the sources?,

(2) How much energy, at each frequency, is propagated to the receptor?,

(3) How much impact, in quantitative terms, does the energy have on the receptor output?,

(4) Is the amount acceptable?,

(5) If unacceptable, what can be done to reduce the level to an acceptable value?

The first two areas of the EMC analysis are commonly known as the coupling problem. It is convenient to separate the area of "coupling" from the rest of the EMC analytic problem. There is, in fact, no standard definition of coupling. For this report, the term implies a power loss, namely (for antenna-to-antenna coupling) the difference between the power available at the transmitter output (when the load is 50 Ω) and the power available at the receiver input (when its driving impedance is 50 Ω).

In effect, this definition implies three portions of the coupling path, namely, (1) transmitter-to-antenna, (2) antenna-to-antenna, and (3) antenna-to-receiver.

In addition to antenna-to-antenna coupling, the EMC analyst must also consider antenna-to-cable and cable-to-cable paths.

The transmitter-to-antenna and receiver-to-antenna paths generally result in mismatch losses which are relatively small for "in-band" interactions, i.e., when the transmitter and receiver frequencies are relatively close to one another, (e.g., separations of less than 20-50% of the tuned frequency).

Out-of-band mismatch losses can be quite large, e.g., as much as 40 dB. Unfortunately, loss characteristics (as a function of frequency separation) exhibit oscillatory characteristics which are largely influenced by parasitic elements which are not specified by circuit diagrams. This results in a difficult analytical problem. For, even if the model is highly accurate, lack of knowledge of the parasitics can result in very large prediction errors.

Procedures for minimizing these errors, without the requirement for measuring every installation, are feasible, but relatively little effort has been devoted to this field. One can adopt a "worst case" approach, but the result will invariably be prediction of too much interference. Such an approach can still reduce the measurement requirement, but it is believed that the state-of-the-art is capable of improving prediction capability in this area considerably.

The modeling of antenna coupling in the far field region of simple linear antennas (i.e., dipoles, whips) will not be discussed since this is well understood and can be accurately done. However, it should be noted that to accurately determine the out-of-band coupling characteristics of simple linear antennas requires knowledge of the impedance of the cables, circuits, etc., connected to the antenna to accurately model the out-of-band coupling. An ECAC modeling concept (TRACE) is one approach to the phenomena. TRACE calculates mismatch losses between transmitters and antennas and receivers and antennas statistically. As linear antennas become large (i.e., rhombic) and complex (i.e., yagi), the mathematical modeling of antenna coupling becomes more difficult. In the past, the far field coupling characteristics were usually modeled via a laborious process of applying Maxwell's equation under the restrictions of a set of boundary conditions determined by the geometrical shape and electrical characteristics of the material used for the antenna. Fortunately, the application of the Method-of-Moments (MOM) formulation and the advent of computers has reduced the difficulty of modeling the coupling between simple and complex linear antennas. The MOM formulation is a tool that can be used in modeling both the far-field and near-field coupling between simple and complex linear antennas. It should be noted that the MOM formulation is restricted to the conditions that the length of the antenna must be >> than the radius and that the radius must be << than the wavelength of concern. These restrictions are usually not a problem in the practical world and all but a few antenna situations can be modeled accurately both in-band and out-of-band using a combination of the MOM and TRACE concepts. Also, whenever the near field region is of concern, the MOM formulations of linear antennas should be validated with some limited measurements.

Several programs have been developed to estimate the coupling between wire antennas, e.g., whips and dipoles. Lawrence Livermore Laboratories have developed the Numerical Electromagnetic Code (NEC) and are continuing to refine the capability. Briefly, the NEC can predict both near and far field coupling between moderately complex wire structures with acceptable accuracy.

This model can also consider far field characteristics of simple antennas that have solid surface pathces, e.g., a monopole on the surface of an aircraft or satellite. NEC has been used to calculate effects of a discone antenna.

The COSAM coupling model is much simpler than, although not as accurate as, the above noted models and has been validated using whips, dipoles, discones and log periodics. The model includes consideration of impedances of transmitters, receivers, antennas, and couplers. Couplers are automatically tuned (as in the case of the NAVSEC SEMCA model), using the Trace mode, off-line.

High gain antenna pattern data are obtained from measurements which are generally made in the plane of the mainbeam, i.e., on-axis. Very little off-axis data are available. No theoretical modeling capability exists to describe the overall gain pattern of high gain antennas, although efforts are being conducted in this area. Note should also be made that the site and neighboring obstacles or terrain will significantly affect pattern characteristics.

Consequently, current models involving high gain antennas involve relatively large uncertainties. More confidence can be placed on on-axis predictions than off-axis predictions.

As indicated, out-of-band predictions are likely to involve even larger errors, for both low gain and high gain antennas. There are relatively little data on out-of-band characteristics.

Finally, some distinction should be made between "near-field" and "far-field" interactions. The generally accepted boundary between the near- and far-fields is said to be $2D^2/\lambda$ where D is the maximum dimension of the antenna and λ is the wavelength. This boundary is largely applicable to the pattern in the vicinity of the main beam and is also of interest to radiation hazard analysts.

Georgia Institute of Technology studies have indicated that near-field gain statistics (which effectively exclude the effects of the main beam) are essentially the same as far-field statistics. Consequently, the accuracy of predictions of near-field effects, if treated statistically, should be of the same order of magnitude as is obtained with far-field predictions.

In brief terms, the current capability can be summarized as follows:

- For in-band interactions, current capability for prediction of situations involving simple, low gain antennas is adequate for consideration of typical EMC problems.
- For in-band interactions, current capability for prediction of situations involving high gain antennas can involve relatively large errors, but if appropriate safety factors are employed, adequate results can generally be achieved.
- Additional effort is needed to improve prediction capability of interactions involving high gain (and more complex low gain) antennas.
- Out-of-band prediction capabilities can involve relatively large errors. As above, safety factors can be applied, but these may be rather large, i.e., 40 dB.
- For aircraft/missiles, no formal capability is available for the frequency range below 30 MHz, though reasonably accurate estimates can probably be made.
- For in-band situations, involving obstructed paths, obtainable accuracy is not well known.

Table 4.2 summarizes in-band capabilities. In addition to the antenna-to-antenna path, it is necessary to consider the impedances of transmitters, receivers, and couplers as well as the effects of transmission lines and wave guides.

Models for estimating the coupling between an antenna and a cable, or a cable and another cable have appeared in the literature. The Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) developed by the Air Force, contains a number of automated algorithms for estimating these types of

TABLE 4.2

ANALYTIC CAPABILITIES INVOLVING IN-BAND ANTENNA-TO-ANTENNA COUPLING
(All vehicle types, near-field/far-field unobstructed paths)

Antenna Type/Orientation	Comments
1. Low gain, "simple" antennas (e.g., whip, dipole, etc.)	
On-Axis	Adequate capability, relatively small uncertainties.
Off-Axis	Adequate capability, somewhat larger uncertainties.
2. Low gain, "complex" antennas (e.g., notch, log periodic, etc.)	
On-Axis	No refined capability, but estimates probably are reasonably adequate.
Off-Axis	Probably adequate capability, somewhat larger uncertainties.
3. High gain antennas	
Main-beam region	Adequate; in near-field region, uncertainties somewhat larger than in far-field.
On-Axis	Reasonably adequate capability; strong reliance on measured data.
Off-Axis	Questionable accuracy; relatively little measured data available.

coupling. (Worst-case models are employed.) Based on limited information, it is concluded that the models can provide useful results, but as in the case of other models of this type, relatively large uncertainties can be expected.

Validation of the models is necessary to establish practical confidence levels. Further, if uncertainties are in fact large, additional effort should be expended to improve prediction accuracy.

It should be noted that the accuracy of coupling models tends to vary over a wide range. Some of the inaccuracy is endemic to the models themselves but a large part of the inability to predict coupling accurately has to do with the variability of the characteristics of the equipment and the coupling path. Since this variability is a fact of nature, it should be recognized that predictions of environments and coupling may have to be presented in probablistic terms rather than deterministic values. Thus one should become familiar with hearing phrases such as the probable environment will be such and such over some range of confidence values, or that the coupling loss is 30 dB, $\pm$ 15 dB with a confidence level of 90%. Information of this nature while not as satisfying as deterministic data, still allows the EMC personnel to establish realistic design margins and perform system tradeoffs.

The present state-of-the-art is that the physical models must be based on simplified geometrical structures. The models for the most part cannot handle the minute details of the platform or structures. For example, it is very difficult to model the aperture in a shielded room or the way in which a routed cable is twisted and bundled with other cables. As the compartment or cable routing portion of the system becomes more complex, then the models will depart more from the actual case, and the analytical prediction becomes less and less accurate.

In case of elements within the structure or platform, the environment prediction or pick-up analysis will clearly evolve around compartment shielding, the way in which cables are routed through the compartment, the way in which cables are bonded to the walls of the compartment, the nature of the sources within the compartment, and how these sources are shielded and grounded.

Similar statements can be made regarding the subsystem equipment, module and component aspects. For example, consider a subsystem which involves some 10,000 parts. The interconnections to these 10,000 parts can also be permuted in a way which can either make very minor modifications, or very gross modifications, to the electromagnetic environment created by that particular subsystem. Thus, there seems to be some finite limit, particularly in terms of costs, as to how the emanations and/or susceptibility at the equipment module, and component level can be accurately predicted.

In spite of the formidable difficulties previously discussed, the Air Force is currently developing an intrasystem analysis program entitled "IEMCAP." This program should be considered in the developmental phase. Extensive validation of this program has yet to take place, but is underway under NAVAIR management using the F-14 as a vehicle for this study.

A limited intrasystem prediction capability has also been investigated by NUSC. Emphasis here was primarily at the power and audio frequencies. Again, the results have not been published, nor has extension of this approach been considered for other areas.

4.2.2.2 Degradation Analysis and Limit Apportionment

As noted before, very little analytical effort is generally devoted toward degradation analysis or limit apportionment. This is occurring because of the engineering judgments regarding environments and equipment susceptibilities embedded in the MIL-STD-461, 462 type tests and the status of current analytical methods requiring some reevaluation of these limits and procedures.

Certain transmitter/receiver interactions are linear in nature, and are, as a consequence, relatively easy to model; however, a number of important interactions are non-linear in nature. (Non-linear interactions can occur when "strong" signals, e.g., larger than -40 dBm, impinge on receivers and transmitters.) These non-linear effects invariably occur in intraplatform situations, though situations do arise where they may also occur when platforms are widely separated.

In effect, the major challenge of EMC analysis, apart from coupling, is the problem posed by non-linear interactions. (Note that the "rusty-bolt" problem is an example of non-linear interaction.)

In the past, EMC analysts have generally relied on measured data to derive empirical models of the various non-linear interactions. Spectrum signatures have been a valuable source of information in this area. However, spectrum signatures are expensive and relatively few have been provided over the past 5 years.

There have, however, been a number of promising theoretical developments which should, if funded adequately, provide EMC analysts with tools which will enable them to predict non-linear characteristics, given circuit diagrams, with reasonable accuracy. Some measurements will still be desirable to validate these theoretical models. New components are continually being developed and, in any event, the confidence levels that can be ascribed to the models should be known so that they can be used intelligently.

This section will discuss each of the major transmitter/receiver interactions and related parameters briefly and note current analytic capabilities in regard to each of them. A distinction will be made between communications and radar systems although, as will be indicated, some degree of overlap exists.

Major communications receiver interactions are: (1) adjacent signal, (2) spurious responses, and (3) IM. Adjacent signal interactions are caused by the simultaneous presence of a desired and an undesired signal and involve both linear and non-linear mechanisms. It is therefore more convenient to consider certain transmitter characteristics in conjunction with this interaction.

Transmitter emission spectra (which include the essential information-carrying portion of the signal) and receiver selectivity characteristics are linear in nature and are modeled with relative ease. Transmitter noise, probably the most significant transmitter characteristic when considering intraplatform communications systems interactions, cannot be modeled adequately at this time. Initial efforts indicate that adequate accuracy can be obtained, but additional development is required.

Non-linear adjacent signal interactions include cross-modulation, desensitization, gain-compression, "saturation" and "beat-note" effects. Procedures for analyzing these interactions in narrow band AM and FM receivers have been developed and partially validated.

Receiver spurious responses are largely influenced by (non-linear) mixer characteristics, although linear characteristics, e.g., RF selectivity and receiver gain, also contribute. Past analytic procedures have not been particularly successful, but recent developments, using "large signal" theory indicate that relatively accurate predictions are attainable.

Receiver IM effects are caused by the mixing of two or more signals in the RF amplifier or the mixer. Analysis of RF amplifier IM non-linearities can be performed by an available automated program (NCAP), (developed by Signatron for RADC), which uses "small signal theory." The program cannot directly consider mixer-generated IM products. However, a "large-signal" approach, being considered at ECAC (mentioned previously), seems to be applicable to this problem.

Radar receivers experience non-linear interactions, for example, spurious responses. Some older radar receivers have essentially no image rejection. Receiver IM is possible if one or both interfering signals are CW rather than pulse-modulated. However, the most typical radar interference situation is due to another radar, operating in the same frequency range. Adequate analytic capability is available to predict radar-to-radar interactions, although submodels are needed to account for the various "special" circuits that are encountered in more modern radar receivers.

Major transmitter characteristics are: (1) emission spectra, (2) transmitter noise, (3) spurious emission, and (4) IM. Adequate capabilities exist to model emission spectra of communications and radar transmitters.

As indicated, development of a transmitter noise model, for communications transmitters, has been initiated; efforts to date are promising.

There is no known capability for modeling spurious emissions or transmitter IM. However, it is believed that "large-signal" theory can be applied to these parameters.

Table 4.3 summarizes current capability to predict major transmitter/receiver interactions if no measured data are available. As indicated previously, analytic capabilities are available to evaluate portions of the various interactions. The state-of-the-art, it is believed, is such that adequate models for all of the interactions can be developed.

It should be noted that many equipments have similar elements, e.g., RF amplifiers or mixers. Consequently, models applicable to certain nomenclatured equipment can be applied to other equipments which have similar components.

TABLE 4.3

CURRENT CAPABILITY TO PREDICT MAJOR TRANSMITTER/ RECEIVER INTERACTIONS WITHOUT MEASURED DATA

	A	B	C
Adjacent Signal		X	
Emission Spectra	X		
Transmitter Noise		X	
Receiver Selectivity	X		
Non-Linear Receiver Interactions		X	
Receiver Spurious Responses			X
Receiver IM		X	
Receiver Local Oscillator Radiation			X
Transmitter Spurious Emissions			X
Transmitter IM			X

A: Adequate Capability
B: Partial Capability
C: Reliance on Measurements

4.2.2.3 Cable/Shield Architecture

Optimizing the cable/shield architecture can lead to major improvement in EMC performance while at the same time minimizing weight, cost, and space factors. NAVSHIPS 0967-283-5010, "Handbook of Submarine Electromagnetic Shielding Practices" covers the shielding and grounding procedures and cable installation practices to be followed to achieve EMC in submarines and surface ships. While the present technology, in terms of basic understanding, is available to allow development of such an optimization methodology, additional programs, particularly user oriented, will be required. In addition, a knowledge of the individual characteristics of various mitigation components, such as cables, cable shields, shielding hardware, such as vents and gaskets, will be discussed under mitigation components.

4.2.2.4 Summary of Analysis

The state-of-the-art in an environment prediction, pick-up prediction, degradation analysis, limit apportionment, and cable/shield architecture is inadequate to achieve the goal of tailored standards and specifications. The present methods used in these areas are either based on engineering judgment or are in the process of development. The prediction capability, however, need not be highly accurate to be quite useful in any of the above areas. Further, because of the complexities of modeling and incorporation of details, a high accuracy prediction capability even with inaccuracies as great as plus or minus 30 dB can be expected to be extremely useful in formulating tailored standards.

4.2.3 Test Methodologies

In the case of intrasystem EMC, most of the tests are conducted to three basic sets of standards. These are as follows:

- Mitigation component tests
- MIL-E-6051 system tests
- MIL-STD-461 type tests.

The mitigation components include the MIL-STD-220 to measure the insertion loss of filters and impedances, MIL-B-5087 to address bonding and lightning problems, and MIL-STD-285 to test the performance of shielded enclosures. Detailed discussion of the mitigation techniques, along with the accompanying standards, including mitigation components, will be discussed in the section on specifications and standards. Nevertheless, suffice to say here, that these standards are marginal at best, to achieve the basic goals of tailored specifications. Specifically, the filter test procedure, MIL-STD-220, measures the performance of the filter only in a 50 ohm test fixture. In actual practice, however, the filter does not see 50 ohms, but some other impedance, and the value of this actual impedance is a major determinant in developing filter performance. However, within the limitations inherent within these standards, most facilities and contractors have the capability to make measurements using these test procedures.

To insure system EM compatibility, MIL-E-6051 is sometimes employed. This specification outlines the overall requirements for systems, electromagnetic compatibility, including control of the system electromagnetic environment, lightning protection, static electricity, bonding and grounding. It is applicable to complete systems including all associated subsystems and equipments. To implement portions of this standard, a variety of system tests are needed wherein the electromagnetic interference is measured at selected test points. From the standpoint of the state-of-the-art, it appears that most major contractors, as well as government agencies, have the capability to conduct most of the tests. However, some problems exist in monitoring the interference pick-up in a way such that the system configuration is not modified to a point which invalidates the experiment.

Subsystem and equipment tests are considered in MIL-STD-461, 462, and 463 series. In addition to providing basic definitions, test procedures and limits, this standard series also covers certain EMC management aspects. Detailed discussions of the standard itself and its various problem areas will be considered under standards section. However, in terms of the state-of-the-art in the ability to make such tests, most major equipment contractors, as well as a number of radio frequency interference consultation firms and a number of government facilities, have the capability to make these tests. However, in the event of a tailored specification, some effort may have to be devoted toward increasing the test levels, as well as resolving a number of technical problems embedded in this particular standard group.

Outside of these procedures, other types of tests conceivably can be considered in support of the tailored standard goal. While considerable automation usually exists in the present MIL-STD-461 test facilities, further automation could usefully be incorporated such that specific emanations or susceptibility levels could be identified during these test series. A similar type of automation in the measurement methods might be useful also to record the actual levels observed in MIL-E-6051 series type tests. Such test results could go into the corporate memory bank to provide a basis for engineering judgments, to set new standards or limits, or to validate computer-aided analytical procedures.

In summary, the state-of-the-art in the test area is deemed satisfactory to meet most of the goals required for a tailored operational interference control procedure. However, some improvements in the automation of the test should prove beneficial, particularly in accumulating information for use in the corporate data bank.

4.2.4 Management Tools

4.2.4.1 Standards/Specifications

One of the most important management tools in implementing EMC is via standards and specifications. Because of this importance, the adequacy of standards and specifications are discussed in detail in the succeeding sections.

4.2.4.2 Control Plans, Procedures, and Methodologies

One of the major deficiencies in issues previously discussed is the lack of an overall EMC requirement which requires that all systems shall achieve electromagnetic compatibility. Although EMC control plans and procedures and methodologies are outlined in MIL-E-6051 and MIL-STD-461, such control plans are often circumvented by either the project office (for lack of money) or the contractor (for similar reasons) simply because the proper management base of power for EMC is lacking. Application of proper management procedures has been carried out with notable success on the Harpoon. On the other hand, where such overall control has been absent, lack of EMC management proves to be the least cost-effective approach.

4.2.4.3 Maintenance and Training

A Navy training program for shipboard EMC has been established within the SEMCIP program. The objective of the training program is to expand upon existing training via a selective integration of EMC into present Fleet training methods. Implementation of the program is currently underway and a series of SEMCIP reference guides is being prepared to provide EMC awareness and technical information for the operational Fleet. Formal briefings for shipyard and dockside EMC related problems are conducted for Headquarters management and operational Fleet personnel.

NAVAIR has produced several EMC films which are available for the purpose of making management and operational personnel aware of EMC. These films have been used to a limited extent by the staff EMO school.

At present, no formal EMC maintenance procedures exist for the various levels of maintenance accomplished by Navy personnel. Without these procedures the EMC design features incorporated in the platform can gradually degrade, thereby reducing its EMC effectiveness.

A need exists to develop additional EMC training material such as films and reference guides to be integrated into the current Navy training school curriculum. A deficiency exists in EMC maintenance which should be remedied by developing EMC maintenance procedures and establishing a formal EMC maintenance requirement in the operational fleet. These EMC procedures should be integrated into the current maintenance requirements and procedures.

4.2.4.4 Fleet and Aircraft Reporting of EMC Problems and Corrections

Lack of reporting of fleet EMC problems has resulted in the lack of awareness of the EMC problems at the management level. In the one instance where such reporting was implemented, considerable deficiencies were disclosed and provided the basis for prompt correction of the deficiencies, either by retrofit or by operation procedures.

Only by instituting such reporting procedures on a formal basis can adequate control of the EMC problem at the fleet and wing level be maintained. Further, such reporting procedures are clearly needed in order to assess the effectiveness of various EMC control programs. Thus, the virtual lack of such reporting represents a major inadequacy.

4.2.4.5 Summary Management Tools

Control plans, procedures and methodologies, maintenance controls, and fleet and aircraft reporting are judged inadequate simply because little activity has taken place in these areas. Some emphasis has been placed on training but its impact on EMC is not known.

4.2.5 Corporate Memory

4.2.5.1 Equipment Characteristics

Detailed equipment characteristics necessary to implement a logical tailored specification are not available. Presently, the MIL-STD-461 type test series involves only go or no-go limits. As a consequence, the degree in which the equipment just passed or just failed the test is not known. On the other hand, some detailed type tests in this regard have been made a part of MIL-STD-449, but such test results are quite limited for the intrasystem problem area.

4.2.5.2 Data Prediction Base

While ECAC maintains some data on avionics components on a system basis, a unified data base simply does not exist for the intrasystem problem area.

4.2.5.3 Summary of Environment Measurements for Publications

Presently, no summaries of environment measurements or predictions are maintained.

4.2.5.4 Handbooks

Over the last two decades a variety of handbooks have been published that dealt with the EMC problem at various levels and at various degrees. Most of these handbooks, unfortunately, have emphasized EMC primarily from a hardware design viewpoint. Clearly some augmentation is needed here which deals with problems associated with tailoring EMC design specifications.

4.2.5.5 Documentation of Problems

No capability or activity is presently available in this area except for the SEMCIP program.

4.2.5.6 Summary of the State-of-the-Art in Corporate Memory

Presently, the state-of-the-art in corporate memory is inadequate to permit implementation of a tailored specification procedure.

4.2.6 Mitigation Techniques

4.2.6.1 Shielding

Shields are used as a major component to suppress the pick-up or radiation of undesired electromagnetic signals. From the analysis point of view, rigorous procedures exist which can predict the performances such shields provide although the obscure features cannot be modeled. Presently, formulas are available which can predict the performance of idealized shields of copper or steel which are in the form of spheres and cylinders. More sophisticated approaches can also be included to consider the rectangular shaped enclosures.

However, these idealized approaches generally break down in the practical situation for the following three reasons:

- Apertures in the shields
- Penetrations through the shields
- Discontinuities in the shield structure.

The apertures typically exist in the shield envelope in the form of windows, portholes, and doors. Penetrations are required to allow cable entries through the envelope from the outer exposed areas to inner areas. Skin discontinuities exist typically where a metallic door is used in conjunction with a rubberized gasket. As a result, a high ohmic impedance exists between the door and the remainder of the metallic envelope. In certain cases, such as aircraft, non-conducting composites are sometimes employed which may form a portion of the shielded enclosure for a sensitive subsystem. Again, such nonconducting regions create a discontinuity which causes the current flowing on the outside of the shield to readily penetrate into the interior. Similarly, corrosion can develop between panels attached by riveted joints or bolts. These again have the same effect of introducing a path for current flow between the inside and outside of the enclosure.

4.2.6.1.1 System and Subelement Shielding

The shielding requirements for compartments, bays, subsystems, cable raceways, and small components, can be calculated on an idealized basis. To determine the general shielding requirements for an idealized shield (i.e., the geometry, thickness, and material for the walls), the shielding requirements are first developed. This is usually based on the susceptibility of the equipment within the shield and the environment appearing on the outside of the shield. Similarly, in the case of shielding an EM source, the reverse procedure is true.

Such shielding analysis quite often turns out to be academic because it is often impractical to cause the envelope of the system platform to conform to an idealized shield. Minor modification of the compartment location and raceway positioning can considerably decrease the shielding requirements. Such mitigation techniques can be implemented by system architecture combined with analytical procedures.

4.2.6.1.2 Aperture Control of Shields

Discussions regarding aperture control for shields have been widely presented in the literature. To summarize these, the use of fingerstock to control penetrations through frequently used doors should be applied around the periphery of the doors such that it wipes on a highly conducting and preferably non-corrosive surface. In the case of semi-permanent hatches, the use of an RFI gasket material is recommended. In the case where air passages are required but no visibility is needed, special aperture controls are also available. These include the traditional waveguide below cutoff techniques and the RFI shielded vents.

4.2.6.1.3 Penetration Control

The various penetrations through envelope shields which degrade its shielding effectiveness include cables, piping, air ducts, and typically for movable devices, control cables, hydraulic pistons, and rotating shafts.

In the case of the non-moving penetrations, proper treatment for these elements have been described elsewhere. The recommended approach is to circumferentially bond the exterior of the cable shield, metallic pipe, or penetrating duct to the outer surface of the envelope shield at its point of penetration. Furthermore, whenever practical, it is good design practice to confine such penetrations to a single point or local area of the envelope shield where many such penetrations are required.

The treatment of penetrations by moving mechanical parts has not been considered extensively in the literature. However, for small diameter moving parts, such as a wire shaft which penetrates the shield, a non-conducting element constructed of fiber glass or reinforced laminates, which pass through a wave guide below cutoff shield configuration can be used effectively. In the case of a very large shaft, some attempts have been made to ground the shaft to the wall of the shield by means of contacting brushes, but this has not always proven satisfactory. In cases where only intermittent adjustment or positioning of shafts are needed, special gaskets or clamps, along with tightening nuts, can be employed.

4.2.6.1.4 Skin Discontinuity Control

In theory, the elimination or effective control of skin discontinuities is relatively straightforward. In many practical cases, however, significant problems and/or constraints can be encountered that prevent such straightforward solutions. For example, the use of plastic sealants or bonds to prevent galvanic action between two dissimilar metals is in direct conflict with a desire to maintain electrical continuity across such a junction. Recent studies have been carried out in the use of explosive bonding techniques to provide both the elimination of galvanic corrosion and the preservation of electrical continuity across the junction.

The buildup of corrosion products between metal plates which are held together either by bolts or by rivets, presents a less severe but similar problem area. If the buildup of corrosion products are suspected to be such a problem, the solution in the past has been to weld such joints. This however, is expensive and sometimes impractical.

4.2.6.1.5 The State-of-the-Art in Shields

The state-of-the-art is more than adequate to permit designing of idealized shields. However, other inadequacies associated with nonidealized shield envelopes hampers the design procedures.

The state-of-the-art regarding aperture control appears to be quite adequate.

The state-of-the-art is more than adequate in terms of implementing idealized types of penetration controls. Special problems may exist, however, due to the imposition of other requirements which is mechanical movement or integration with existing hardware.

The state-of-the-art in treating shielding problems associated with skin discontinuities can be regarded as largely adequate for simple types of enclosures. In more complex situations, which involve contact between dissimilar metals or the use of fiber glass as part of the shielding or composites as part of the shielding structure, the state-of-the-art is judged inadequate.

4.2.6.2 Optical Fibers

The transmission of low power signal type information via light pipes or optical fibers is gaining wider acceptance. A number of demonstration projects have demonstrated the use of these optical fibers for use in aircraft or even standard office complexes. The principal advantages of these fibers are their total immunity to radio frequency interference pick-up.

Offsetting these advantages are a number of problem areas, namely the need to supply frequency translating equipment to convert the normal audio or video signals to optical signals and vice versa. Further, some fairly extensive shielding may be required for the equipment terminating the fiber optical system. Another disadvantage is the inability to tap into the cabling system, particularly after installation. There may also be mechanical vibrational problems if the fiber optic system bundles are severely flexed or stressed.

The state-of-the-art to eliminate the problems associated with conventional cables by means of optical fibers is emerging to a point where within a few years this may be considered as standard practice.

4.2.6.3 Cables and Cabling Systems

There are essentially two types of cabling systems which can be considered from a practical implementation viewpoint. These are balanced and unbalanced systems. The balanced system has the advantage of being capable of suppressing the common mode pick-up, and the twisted pairs employed in such a system can also suppress the induced pick-up over limited frequency bands as well. However, the balanced pair cabling system is difficult and costly and therefore is not used unless rigid EMC controls are needed.

The more common cable configurations consist of shielded coaxial cables or shielded multiconductor cables often with a common ground reference. These have the advantage of low cost ease of integration. Various additional and supplementary shields over these cables may also be employed. Disadvantages of these latter approaches is a possibility of pick-up which arises from current flow along the shield or from some other common impedance.

From an ideal point of view, cable shields should be formed from a solid continuous wall without apertures. This configuration is suitable for both balanced and unbalanced types of cable system design. The disadvantage to the solid wall is, of course, its weight, cost and rigidity. Satisfactory solid wall cables also exist in several flexible forms such as convoluted copper or hypernon. The semiflexible shield should be used only if the cost is justified by the most stringent EMC requirements.

Some cost saving is possible like grouping as many cables in one carefully designed and tested conduit shield, where some flexibility is required along with occasional bending. Specially constructed flexible multilayered cable shields are also possible. These employ a variety of shields which alternate the traditional braid along with the more unconventional lossy dielectric separators with conducting wall straps and specially designed ways. Some of these cables have been built and tested and exhibit at least 60 to 80 dB less pick-up than the more conventional single and double braided cable types, such as the RG-213/U and the RG-214/U.

Ordinary single and double braided cables as exemplified by 213 and 214, respectively, do exhibit some intrinsic shielding over the open pairs and can be used where modest cable shielding requirements exist.

Connectors also have been a source of pick-up and the most cited problem is that of a poor electrical conductivity of the backshell (which often is anodized). When the backshell is anodized, the cable shield is often carried through the pins of the multipin connector and such a procedure gives rise to excessive pick-up. However, techniques are possible to obtain conducting backshells with continuous metallic shields which surrounds the multiconductor cable and thereby firmly connects it to the shielding structure.

The state-of-the-art regarding solid wall shields either rigid or semi-flexible appears adequate for the Navy's cabling needs. However, in the case of flexible cables, especially where very high performance is required, off-the-shelf cable designs are not available. While some basic investigations have demonstrated a feasibility of high performance, multilayered cable shields, these need to be further developed in terms of commercial production to suit the Navy's needs.

4.2.6.4 Terminal Treatment

The most typical terminal protection treatment consists of filters located in special entry boxes. In addition to filters, isolation transformers, baluns, and chokes are often considered in this same category.

Filters are most widely used to provide protection that gives the CW type radio frequency pick-ups. However, while these filters are commonly available as off-the-shelf items, they do introduce some intrinsic problems.

This problem comes about by the way in which the filters are tested, which is in the MIL-STD-220 type 50 ohm test fixture. As a consequence, the performance of the filter can only be determined for design purposes for sources and terminations at the 50 ohm level. In practice unfortunately, the source and termination impedance occur at other levels. This leads to the possibility of fortuitous resonances and matches which can completely or nearly eliminate the desired filtering characteristics.

To overcome difficulties with this problem, some improvement in the present MIL-STD-220 test procedure would be highly desirable. On the other hand, some special designs of filters can be employed which are almost immune to the various types of terminating impedances. However, because of their nature, these have limited applications and are generally used to counter the effects of high level electromagnetic radiation from transmitters which might prematurely fire certain pyrotechnical devices.

In summary, the basic filter design technology appears to be more than adequate to incorporate a filter on a theoretical basis. However, in practice, filters are generally purchased according to MIL-STD-220A test data which only provides limited data on the actual performance under actual conditions. As a consequence, the state-of-the-art in filter technology is considered to be marginally adequate.

4.2.6.5 Arrangement Decoupling Techniques

A commonly employed decoupling technique involves placing the more immune equipment in regions which are relatively unshielded and enclosing the more sensitive system in well designed shields. Similar procedures are often used in group conductors. In this case, cables attached to the more sensitive equipments are grouped together and carried within their own separate conduit.

Orienting equipment with respect to each other, and relocating the more sensitive away from the more high powered equipments, is also a standard procedure.

However, in the case of complex ship designs and possibly aircraft as well, grouping and placing of cables and equipments can often become a very complex procedure. Hence, the design of cable architecture and shield and antenna placement by computerized programs should be useful.

In general, the state-of-the-art of available decoupling techniques is such that for the more simple systems, the equipment and cables can be optimally grouped without much effort. On the other hand, in the case of complex systems, no computer-aided approach is presently available to provide this assistance.

4.2.6.6 Grounding Systems

A variety of grounding techniques exists. One is called a single point or crows foot ground system. This can be modified into a fishbone system which consists of a single bus with grounds from various subsystems attached forming a fishbone or "christmas tree" configuration. While these arrangements have been highly touted as the ideal grounding solutions, many practical constraints exist with real systems that limit their application. For example, either on an aircraft or ship, it may be physically impossible to isolate the chassis of a different electrical equipment from the steel hull or aircraft shell. Therefore, other types of grounding arrangements have to be considered.

A commonly used ground scheme for large systems involves an equipotential plane within each system ground with minimum lead links to this equipotential plane. Typically, such a system is called a multipoint grounding system. This system usually works well where:

- The grounding plane has a very low impedance
- The cables are bonded to the grounding plane
- Continuous shielding is employed around the subsystem
- The subsystem is bonded with minimum lead length to the equipotential plane.

A shortcoming in this approach is a possibility of serious ground loops occurring in spite of the fact that the majority of cables can be routed near this equipotential ground plane. Further, even though highly conducting, such a ground plane may exhibit a common impedance with interference sources in highly susceptible equipments.

Some of these difficulties can be avoided by maintaining a regional ground. In this case, each subsystem maintains its own ground reference potential. Separate communication links and power are supplied by isolation or balanced type transformers, thus eliminating the need for common reference ground for each of the subsystems. In many instances, it is possible to use fiber optic data bus systems to eliminate the need for common grounds also.

In the case of the technology that requires prediction of the possible effects and interactions introduced by grounding systems, major deficiencies are indicated. There are no computer programs, analytical procedures, or even conceptual approaches that have been considered which can or would predict the effect of the various obscure coupling mechanisms which arise from the grounding approaches.

In the case of the more conventional and traditional grounding techniques, the state-of-the-art in grounding appears to be adequate. However, in light of more complex problem areas, which possibly involve analysis and the tailoring of specifications, the state-of-the-art in grounding technology must be considered non-existent.

4.2.7 Bonding

Because of its importance, bonding is considered as a separate issue, although it might be considered as part of the shielding technology. Problems with bonds arise in several areas such as:

- Grounding of cabinets to an equipotential ground plane
- The conducting of high level currents associated with a lightning stroke
- Special situations where dissimilar metals occur
- Mechanical movement is desired between two shielding structures having a common wall.

In the case of the first three items, such problem areas are considered in MIL-STD-1310 and MIL-B-5087.

The state-of-the-art in bonding areas is generally considered adequate except under special conditions or unique situations which are generally best handled on a case-by-case basis.

4.2.8 Composite Materials

Fiber reinforced laminates or composites which do not include any metal of any form are currently being used for structural support in modern aircraft shells. In the case of ship systems, plastic reinforced fiber glass laminates have been considered for major portions of the superstructure and could well be considered also for some of the interior compartments as well. If electromagnetic shielding is required, then these nonconducting laminates must also include continuous conducting metal foil. Further, provisions must be made for either welding or continuously attaching, in an acceptable way, segments of these composite shells to each other such that no skin discontinuity exists.

The electromagnetic aspects of concern for EMC are:

- Electrical properties
- Electrostatic (lightning and precipitation static) protection
- Bonding
- Grounding
- Antenna Performance.

The NAVAIR, the Air Force, and NASA are implementing programs to address the known and potential problems by developing technology requirements. A composite materials committee has been established to ensure coordination and technology between programs.

The present state-of-the-art in providing acceptable lightning and EMC performance from composite shells is currently under investigation at ASD-WPAFB, NATC, McDonnell Douglas, and NASA.

Composite materials have been considered for ship superstructures as well as interior compartments. Personnel concerned with EMC performance of ships are monitoring the aircraft efforts in the composites area.

The state-of-the-art regarding EMC shielding from composite materials is judged to be marginal since this technology is in the process of being evaluated by the Navy, Air Force, and NASA. A number of technology unknowns exists for composite materials requiring investigation of EMC aspects of these materials.

4.3 Intersystem EMC

4.3.1 Introduction

For the purposes of the report, intersystem EMC is defined as the interaction of sources aboard one platform with the receptors aboard another platform. In general, although there are exceptions, the interaction will consist of antenna to antenna coupling under far field conditions.

4.3.2 Analysis

4.3.2.1 Environment and Coupling Prediction

The most straightforward definition of EMC is that a platform/system/equipment can operate in its intended operational environment without suffering unacceptable performance degradation. Any attempt to insure such compatibility obviously requires definition of the "intended operational environment."

The Navy is and has in the past, to varying degrees, considered the environment during platform/system/equipment procurements. MIL-E-6051D, for example, requires that a platform be able to function in the operational environment as specified by the procuring activity. MIL-HDBK-235 defines RF environments for various platforms/distances from the emitter, and the Special Electromagnetic Interference (SEMI) program defines RF environments for various operational locations/conditions. Similarly, atmospheric background noise levels are considered to predict the impact of man made noise sources such as power lines and automobile ignition noise is being developed by the Navy.

All electromagnetic environments in which Navy electronics systems must operate need to be considered. Information concerning noise, propagation conditions, and other users is of interest at any location throughout the world.

In the case of stressed environments (deliberate jamming and other ECM or ECCM techniques excluded) interplatform considerations are of prime concern. The environment caused by other members of a friendly taskforce plus the environment caused by non-Navy friendly platforms operating in the same area must be included. Also the environment generated by a hostile platform operating in a manner such as to impact Navy and Marine Corps systems is of interest (ECM/ECCM excluded).

An extensive data base of information on military communications and electronic equipment, both fixed and mobile, plus many computer automated mathematical models and analytical systems exist to predict EME environments for a wide variety of conditions.

The prediction of the active environment is primarily based on the emission characteristics of the sources (generators of EM energy) and their associated antennas (radiator). Characteristics of sources and antennas can and have been measured following procedures set forth in MIL-STD-449. Analytical techniques have been developed to allow prediction of performance when measured data are lacking. Accuracy for in-band is adequate for determination of the EME environment. Out-of-band characteristics on the other hand, are not readily amenable to prediction and, therefore, measured data is frequently relied upon. Measured data does not have a high degree of accuracy since out-of-band characteristics fluctuate as a function of tuned frequency of the equipment. Thus the prediction of the out-of-band environment is subject to greater error.

4.3.2.1.1 Summary of Environment and Coupling Prediction

The EME environment prediction generally is made up of reasonably accurately known in-band radiations whose occupancy of the EME space is as reliable as the input data (i.e., x-y-z geographical coordinates, frequency assignment and power [radiation] characteristics) and somewhat less accurately known (perhaps statistical) out-of-band radiations which comprise the intervals between the more accurately known in-band radiations. Fortunately, in most cases, the intersystem EMC problem will most likely involve in-band interactions. The exceptions occur when systems are closely spaced and side-lobe radiations, spurious response, non-linear interaction, antenna to cable coupling, etc., interactions can occur due to lack of isolation (propagation loss) between the systems. Such situations should be anticipated and problem areas can be treated using intrasystem analysis and test procedures.

4.3.2.2 Degradation Analyses

This phase of interference analysis is an extension of interference prediction beyond the output of the other analysis systems. The other analysis systems usually provide as an output, ratios of power levels being processed by the victim receiver(s). The degradation models provide the means by which the effects of these power levels are translated into a degradation evaluation. Output information is in the form of bit error probability for digital systems, articulation score and articulation index for voice systems and mean square error for analog systems. Table 4.4 is included which summarizes the modulation cases where a model has been developed. Also shown are cases where development is planned.

A degradation handbook has been prepared at ECAC which covers the analysis so far performed in this area.

Except for the most elementary systems, radars are best treated on a case-by-case basis because of the wide variety of signal processing circuits employed by the more sophisticated radars of recent vintage.

4.3.2.3 Shield Penetration, Holes, Cables, Etc.

Since intersystem EMC interactions are usually via antenna-to-antenna coupling, very little attention has been paid to non-antenna pick-up modes for intersystem EMC. Most of the analytical tools used for intrasystem EMC analysis are applicable to intersystem analysis in those relatively rare cases where non-antenna pick-up may be a problem. The reader is referred to the intrasystem EMC analysis for a discussion of these analytical tools.

4.3.2.4 Systems Tradeoff, Sensitivity

Several system models, which effectively predict interference levels and/or performance degradation of a class of communications equipment (i.e., narrow band AM and FM), are available. An NELC report* evaluates four models (SEMCA, IPM, TRED and COSAM), indicating their capabilities and limitations. ECAC is currently engaged in providing a program to NOSC (formerly NELC) which is essentially an expansion of the COSAM program. Given adequate input data, based on measurements or analysis, the program should provide adequate accuracy.

System models include coupling (what has been termed transmitter/receiver interactions) methods for accomodating different types of modulation and some procedures for interpreting predicted interference levels or S/I or SINAD ratios in terms of performance degradation.

The term "transfer function" is used to describe a receiver's so-called "processing gain." In general terms, the output S/I ratio may be greater or smaller than the input ratio. The factor that provides this difference between input and output ratios is called the processing gain. For example, an FM receiver which uses a large deviation will have more processing gain than one that uses a smaller deviation. The use of emphasis/de-emphasis also

*S. T. Li, "Survey of Existing Electromagnetic System Interaction Algorithms," NELC, August 1976.

TABLE 4.4

DESIRED/INTERFERENCE MODULATION CASES COVERED IN THE PERFORMANCE DEGRADATION HANDBOOK

Desired/Undesired Modulation	Description	A1	A2	A3	A3J	A5C	A9B	F1	F3	F9	PO	Noise
A1	CW Telegraphy	(X)		(X)	(X)		X	X	X	X	X	(X)
A2	2-Tone Telegraphy	(X)	X	(X)			(X)	X	(X)	X	X	(X)
A3	Voice	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
A3J	SSB-SC Voice	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
A5C	TV Video	(X)				(X)	X	X	X	X	(X)	(X)
A7J	Multichannel VFT SSB-SC	(X)		(X)			(X)	X	(X)	X	(X)	(X)
A9B	4 ISB Voice Channels			(X)			(X)	(X)		(X)	(X)	(X)
F1	FSK Telegraphy (2 Freqs.)	(X)		(X)			(X)	X	(X)	X	(X)	(X)
F3	Voice (no de-emphasis)	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
F3	Voice (with de-emphasis)	X					(X)	(X)	(X)	(X)	X	(X)
F9	FDM (12 Voice Channels)	(X)		(X)			(X)	(X)	(X)	(X)	(X)	(X)
F9	Wideband Telemetry	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
F9	PCM	(X)		(X)			X		(X)	(X)	(X)	(X)
F9	PSK	(X)		(X)			X	X	(X)	(X)	X	(X)
PO	Pulse	X					X	X	X	X	X	X
P9	Spread Spectrum			(X)			X	X	(X)	(X)	(X)	(X)

NOTE: X indicates cases to be covered by long term objective.

(X) Cases completed and covered herein.

improves processing gain. Relationships exist for a large number of modulation combinations, some of which are contained in COSAM.

Several interference criteria are available to rate communications system performance. SINAD is the most direct measure since it can be readily measured in the laboratory or the field. Procedures for converting SINAD to AS, AI or BER measures are available.

In regard to radar (PPI) degradation, a study has been performed to determine a practical safe threshold. Additional effort is required to establish adequate confidence in this important area.

Capabilities exist to model radar-to-radar (e.g., SEMCAM) and radar/communications interactions, some of which have not been integrated into system models. COSAM considers the effects of radars on narrow band AM and FM receivers, but does not consider communication-to-radar interactions. A system model could be developed to handle these interactions with reasonable accuracy, but additional effort is required for development and model validation.

Fortunately, in the radar area it will generally be found that the analysis relative to the unstressed environment will provide most of the information necessary for assessment of performance in the stressed (i.e., intership) environment. Because of the losses involved in intership EMI coupling most of the second order interactions of concern from an intraship standpoint become insignificant from an intership standpoint. In this context, second order interactions are any that involve other than the fundamental passband of a receiver. It will, therefore, generally be found that the only new interactions which must be addressed are those involving in-band systems not previously analyzed as part of the unstressed environment. These cases will normally involve frequency separation/distance separation tradeoff considerations and will form a basis for developing frequency assignment doctrine for the systems involved.

Given adequate coupling and transmitter/receiver interaction models, and appropriate criteria, the analyst is faced with the problem of assigning frequencies (given a specified frequency list) which will ensure adequate performance.

The problem is quite complex; optimum algorithms may never be developed, particularly if IM interactions are considered. However, considerable effort has been devoted to the subject and several reasonably effective algorithms (and suggested approaches) have been devised. Additional effort is desirable.

It should be noted that present operational procedures are not automated, nor particularly sophisticated. If sufficient resources (i.e., frequency lists) are supplied to the operational forces, current procedures are probably adequate. However, as demands on the spectrum increase, a more sophisticated approach will be required. This will be particularly true if there is a requirement to change frequencies periodically, for security reasons. (NSA has a model of this type, which does not consider intraplatform interactions in detail.)

4.3.2.5 Cable Architecture

Although not a primary source of intersystem EMC problems, the cable arrangements on various Naval platforms can act as "inadvertent" antennas (especially cables running on external surfaces and exposed to ambient fields). These inadvertent antennas couple RF energy to associated receptors via "back door" paths and can cause interference similar to that created by the intrasystem interactions. Cable treatment to mitigate intrasystem EMC problems will generally be effective for intersystem EMC.

4.3.2.6 Architecture (Structural Placement)

System architecture or system arrangement, as it is more commonly known, is primarily based upon operational requirements. Mission critical equipments tend to get priority placement while less critical systems are left with less desirable placement. Effort is made to optimize radiator/receptor antenna placements within the above constraints. In recent years the placement of equipments and associated antennas has been subject to review by EMC personnel. Tradeoff studies to suboptimize antenna placement from an EMC standpoint have been conducted. In general, these studies have concentrated on intrasystem compatibility concerns while the intersystem problems have been the last to be considered if at all.

The few guidelines and procedures available to perform the system arrangement function are barely adequate and are scattered throughout several documents such as handbooks, specifications, standards and even confined to system developers in-house documents. No single document exists which can provide guidance.

Platform-unique data is available but varies in its adequacy in relation to system arrangement. A concerted effort is needed to define useful platform-unique data required for the system arrangement. Other design functions such as antenna locations, equipment location, etc., override the EMC aspect as far as the system arrangement function is concerned.

EME knowledge is not adequate to carry out the system arrangement function for either the stressed or nonstressed environments. MIL-HDBK-235 attempts to define the stressed environment but gives worst case conditions, does not specify flight deck locations, and does not provide test procedures. No document exists which specifies the nonstressed environment except for the requirement of MIL-D-6051D which states the platform will be compatible.

During a ship communication system arrangement there are few documented guidelines and procedures available which are used to perform the system arrangement. In the majority of cases, historical precedence is utilized (i.e., this is what we did on the preceding ship so let's do it on this ship), much of this is engineer-to-engineer communication with little documentation. Perhaps the best documentation to date is carried in NELC TD 356.

Each new ship almost always has somewhat of a new approach. There is no official doctrine which explains priorities but the top level performance requirements are stated. In this case, subsystem priorities are often assumed and total ship performance compromised accordingly. It is often very difficult to assess just how much total ship performance has been compromised.

There is a multitude of examples of how to arrange a ship set forth in the design reports for each individual ship which the Navy has designed during the last decades. These reports can be used to form guidelines and arrangement specifications and standards for a total ship.

The antenna placements will affect the intersystem compatibility problem by influencing the radiating and receiving characteristics of the antennas. Modeling techniques similar to those used for intrasystem compatibility are used to evaluate the EME of such antenna placements. Numerical techniques to simulate the EME are relatively limited. Present MOM techniques are operational for very small structures where the conducting elements in the system can be represented by less than 300 segments. Efforts have concentrated on making method of moment techniques more cost effective. In particular the NEC code developed has been augmented and altered to antenna ship applications. Near fields of various types of shipboard HF antennas have been defined. At present, it is possible to numerically model most of the Navy HF antennas when they are located in a simple environment. Presently, wire gridding techniques are used to simulate them and economic limitation is reached when more than 300 segments are required to represent a system. To alleviate these economic problems new techniques (i.e., finite element and finite difference) have been investigated as a means of handling large planar surfaces. Successful completion of this work will make it possible to more cost effectively and quickly define the EME associated with the shipboard HF antennas.

Although the technology exists for MOM shipboard applications, very little user methodology or engineering practice has been developed. One could say that numerical simulation is currently in design. Before it becomes operational, items in the planning stages will have to be completed and some items not yet planned also completed. User methodology and application falls in the area of not yet planned.

Method of Moments is applicable in the lower frequency range, i.e., HF and below. At UHF and above other tools and techniques are required. Geometric Theory of Diffraction (GTD) tools are currently in design.

To date, efforts have concentrated on developing geometric theory of diffraction (GTD) techniques to simulate shipboard communication antennas in a complex environment. Codes have been developed which predict performance of omnidirectional UHF antennas in the presence of complex structures. At present, development is underway to make it possible to predict the EME in the region around moderately directive UHF communication antennas. Present plans are to complete the ability to model typical UHF shipboard antennas in complex environments. When this is completed, the UHF techniques will be integrated with the lower frequency method of moment techniques and a complete user methodology developed. It is planned to develop a user methodology for this technology. At the present time, the technology useful for omnidirectional UHF antennas in a relatively uncluttered environment is available and used. The ability to predict the EME space in areas around directional UHF antennas located in a complex environment is still in its infancy.

Brass model simulation for ships has been designed and proven to be useful to 30 MHz using 1/48 scale models. Presently, a system is being designed to extend the operational range to 100 MHz. Currently it is felt that 1/48 scale brass modeling will not work at UHF and above. Presently, brass model techniques are used only to simulate topside EME and no plans exist to use it to simulate below decks EME.

4.3.2.7 Frequency Management; Allocations and Assignment

Frequency or spectrum management involves frequency allocation and frequency assignment. Frequency allocation is authorization to develop an equipment within a specific frequency band. The actual and potential restrictions relative to power, bandwidth, operational function, geographic employment, and other factors, e.g., frequency stability on a national and international operating basis are highlighted. Frequency Management has been described as the function whereby:

- Requirements for the use of the radio frequency spectrum are presented, reviewed and satisfied, initially and on a continuing basis; and
- Control of the use of the spectrum is exercised.

The Frequency Manager, in order to effectively manage the radio frequency spectrum, must first have the "requirements for the use of the radio frequency spectrum" presented to him. From here, the rest of his functions fall into place.

The military departments are currently required to submit requests for a frequency allocation at three periods during the equipment acquisition cycle, i.e., experimental, developmental, and operational. The process is particularly significant for military requirements since operational deployment may be world-wide.

Allocation and assignment involves national and international implications. Equipment may be readily accomodated in the U.S. but difficulties may occur in securing approval for use in, or near, foreign friendly countries.

The frequency/spectrum allocation process is frequently not taken seriously by equipment developers or is completely unknown to them. Frequency bands are often selected which eventually result in EMC interference when the equipment becomes operational. R and D personnel frequently become quite indignant when advised that their preferred choice of frequency range would be unacceptable in the national or international arena.

The biggest deficiency at this time is in satisfying the initial requirement of submitted (presenting) a DD Form 1494 (Application for Frequency Allocation). Although much has been said about this requirement, it has been mostly among frequency managers. A program of continuing education to inform the Department of the Navy and its contractors of the need for timely submission of DD Form 1494's is seen as the initial step to correct this deficiency.

Competition for the use of the radio frequency spectrum is increasing each day. In order to ensure there is spectrum space available for a new system, it must be reviewed, an EMC analysis conducted, and the required coordination with other DoD, government and non-government agencies performed. Upon satisfactory completion of these steps, further development and/or production of the system (or subsystem) is permitted.

The next process is obtaining a frequency assignment (the second part of the description). When a system requires a frequency for operation, a government requested frequency can be assigned. Those systems which have no approval face the possibility of no frequency assignment.

Frequency assignment is the process by which authorization for use of a specific frequency or band for a specific application is granted.

In brief, the process to date has been treated in a routine manner. Spectrum has been available with relatively little competition. U.S. military forces, in particular, have generally been able to secure almost all assignments they have required.

The situation is now changing drastically. Both developed and undeveloped countries have, in recent years, increased their spectrum requirements by several orders of magnitude and the end is not in sight. Finding "clear channels" today is much more difficult than in the past.

From another standpoint, selection of compatible frequencies on a platform is also a difficult task. Some Naval vessels have a requirement for as many as 20 UHF compatible frequencies for narrow band systems. (There is also a large requirement for HF assignments, which are more difficult to secure, due to their potential world-wide impact.) Analytic frequency assignment models (or tools) are available, but there is some question as to whether they are used.

Incidentally, the "rusty bolt" problem represents a unique frequency assignment problem, in that the use of filters and couplers do not alleviate the problem. If rusty bolt effects occur, the <u>only</u> solution (other than "clean-up") is to select frequencies which do not result in unwanted harmonics or intermodulation products.

The frequency assignment procedure can be made more of a science and less of an art. The resource is limited. The subject is little understood in the field and the consequences are realized after equipment is operational.

More effort is needed by all parties concerned to take the frequency allocation process seriously and to develop and use the existing frequency assignment technology before and after equipment becomes operational. The importance of a system having an approved frequency allocation cannot be overemphasized. This not only assures the sponsor protection, but may point out deficiencies which can be corrected prior to production, a very cost-saving benefit.

ECAC has the charter to look at every request for allocation and comment on whether conflicts exist with band allocation, MIL-Standards, frequencies, and any other obvious conflicts. Mobile and low frequency systems in particular need to be carefully reviewed because of potential international conflicts. It is estimated that of requests submitted to ECAC possibly 5-10% need detailed studies to resolve revealed conflicts.

4.3.3 Test Methodologies

4.3.3.1 Environment Measurements

Environment measurements have been mostly limited to local measurements (platform unique) primarily to support intrasystem EMC analysis. The few measurements which have been made of extended environments have usually been for land-based fixed frequency sites. Mobile platforms are difficult to characterize from an intersystems EMC standpoint because of their geographic mobility (variations in propagation paths) and in some cases, their frequency mobility (changes in frequency assignments as function of mission, propagation path anomalies, etc.). For these reasons any environmental measurements for intersystem EMC would tend to be perishable and normally would only be done for specific problems where such information is necessary.

4.3.3.2 461-Series MIL-STD

The 461-Series of MIL-STDS is primarily intended to assure a reasonable chance of intrasystem compatibility. The tests are usually conducted at a number of fixed frequencies and test results reported on a go-no go basis. Test data (plots of output or response as a function of test frequency at a given tuned frequency) are sometimes provided. Such raw data can often be useful if the analysis approach to intersystem compatibility employs the isolation matrix as described in Section 4.2.1. The use of this approach can lead to over-estimated isolation requirements since in the limit each equipment considered (assuming it has met the specification) must be assumed to be operating at the specification limits at all frequencies of interest. This is seldom the case and therefore, isolation requirements would tend to be pessimistic. Analysis of the test data would reveal the extent of the over-estimation.

Enforcement of measured MIL-STD-461-Series data as a deliverable item on government contracts could serve a number of useful purposes for intersystem analysis. This data could be used as follows:

- The raw data could be analyzed much like MIL-STD-449 data and contribute to the data base of measured equipment characteristics.
- The data could be used to develop more accurate statistics of out-of-band characteristics for families of equipments.
- The above statistical data would allow a more realistic criteria for setting cull levels when using cull models in intersystems EMC analysis.
- The data would also be helpful in establishing more realistic specification limits when updating Specifications and Standards.

Deficiencies:

- There does not appear to be a formal procedure for ECAC and other government agencies to obtain MIL-STD-461-series data.
- There is insufficient information as to the adequacy of the basic EMI requirements for new types of equipment such as fiber optics, electro-optics, digital, etc.
- The latest OTP requirements for radars must be incorporated into MIL-STD-469 along with test procedures to determine compliance with the requirements.

4.3.3.3 MIL-STD-449

MIL-STD-449 is the basic document which has been used to measure spectrum signature characteristics of C-E equipments. This data forms part of the ECAC equipment characteristics data file. A considerable number of MIL-STD-449 measurements were made in the past; however, in recent years, the implementation of MIL-STD-449 has become very expensive. As a result, relatively few measurements are made for the full requirements of the Standard. In addition, the Standard does not include procedures for newer equipments. Because of these facts, there is only a minimal data base for up-to-date equipment.

The above situation has indicated the need to consider alternatives. One method, which has been utilized by ECAC, is to be more selective in the numbers and types of MIL-STD-449 measurements required on a particular piece of equipment. Another possibility would be to combine MIL-STD-469 with MIL-STD-449 and create an alternative standard which would include the data needs of both the intrasystems and intersystem EMC communities.

4.3.3.4 MIL-E-6051

MIL-E-6051 is primarily intended for weapons systems and airborne systems. The specification is very general, essentially stating that the system shall be compatible with itself and its environment. The primary responsibility for EMC is placed upon the contractor who must supply interference control and test plans. The contractor and/or government perform a general acceptance test.

There are no test procedures referenced in the specification. Procedures are left to the contractor to specify. There is no definition in this document of the external environment the system is expected to be compatible with. From an intersystem EMC standpoint, the specification is too general to be of much value.

4.3.3.5 Mitigation Components

For the intersystem interference situations which are usually encountered, the mitigation components are usually some form of filter (coupler) which increases the loss in the interference coupling path. This can take the form of couplers or filters which decrease the out-of-band radiation of an emitter or filter to increase the selectivity of a receptor. In most cases, this form of filtering is needed to decrease harmonic and spurious outputs of an emitter and image and spurious responses of receivers. In most cases where commercial components are available, only nominal characteristics of the device are usually available. Performance characteristics under non-ideal (mismatched) and out-of-band conditions are usually not measured and therefore not supplied. In most cases, measurement techniques have not been developed and specified to obtain such data.

4.3.4 Manageme. Tools

4.3.4.1 Specifications and Standards

In the area of specifications and standards as management tools for intersystem compatibility, these essentially do not exist with the possible exception of MIL-E-6051. Most of the specifications and standards which do exist are primarily oriented towards the intrasystem EMC area. It should be noted that a successful intrasystem EMC design usually mitigates a large segment of potential intersystem problems since the local environment is frequently more severe than off-platform generated environments.

MIL-E-6051 outlines the overall requirements for systems electromagnetic compatibility, including control of the system electromagnetic environment, lightning protection, static electricity, etc. It is applicable to complete systems and is applied to airborne systems.

Table 4.5 illustrates the various Specifications and Standards and their applicability.

TABLE 4.5

TYPE AND APPLICABILITY OF EXISTING DOCUMENTS

APPLICABILITY OF DOCUMENT / TYPE OF DOCUMENT	EQUIPMENTS/ SUBSYSTEMS	ORDNANCE AND WEAPON SYSTEMS	PLATFORMS/INSTALLATIONS AIR	SHIP	SUBMARINE	SHORE
SYSTEM REQUIREMENTS	N/A	MIL-E-6051	MIL-E-6051			
DETAILED DESIGN REQUIREMENTS	MIL-STD-461 MIL-STD-469 OTP Manual MIL-STD-1399 MIL-STD-1337	MIL-STD-1385 MIL-B-5087 NAVORD 3565/ NAVAIR 16-1-529	MIL-STD-704 MIL-B-5087	MIL-STD-1399 MIL-STD-1310	MIL-STD-1399	ANSI C1-1968
INSTALLATION REQUIREMENTS	N/A	MIL-B-5087 NAVORD 3565/ NAVAIR 16-1-529	MIL-B-5087 MIL-STD-704 MIL-W-5088	MIL-STD-1310 MIL-STD-1399	MIL-STD-1310 NAVSEA 0967 LP-283-5010 MIL-STD-1399	ANSI C1-1968
DESIGN AND INSTALLATION GUIDANCE	MIL-HDBK-421 AD-1115 DNA 2114 MIL-HDBK-XXX MIL-HDBK-235	NAVSEA OD 30393 MIL-HDBK-238 MIL-HDBK-XXX MIL-HDBK-235	MIL-HDBK-238 MIL-HDBK-XXX AD-1115 MIL-HDBK-235	NAVSEA 0967-LP-000-0150 NAVSEA 0962-LP-266-1010 NAVSEA 0900-058-3010 MIL-HDBK-238 MIL-HDBK-XXX MIL-HDBK-235	MIL-HDBK-238 MIL-HDBK-XXX MIL-HDBK-235	AD-1115 NAVELEX 0101, 106 DM-23 DM-24 MIL-HDBK-238 MIL-HDBK-XXX MIL-HDBK-235
TESTING	MIL-STD-449 MIL-STD-462 MIL-STD-469 ANSI C95.3-1972 MIL-STD-285	MIL-STD-1377 MIL-STD-285	MIL-6051-D MIL-D-8706D MIL-D-8708D	MIL-STD-1605		

TABLE 4.5 (Cont.)

<u>TYPE AND APPLICABILITY OF EXISTING DOCUMENTS</u>

APPLICABILITY OF DOCUMENT / TYPE OF DOCUMENT	EQUIPMENTS/ SUBSYSTEMS	ORDNANCE AND WEAPON SYSTEMS	PLATFORMS/INSTALLATIONS: AIR	SHIP	SUBMARINES	SHORE
MANAGEMENT/ GENERAL TECHNOLOGY	MIL-STD-463 MIL-HDBK-237 MIL-HDBK-XXX MIL-STD-220 ANSI C95.2-1974	MIL-STD-463 MIL-HDBK-237 MIL-HDBK-XXX MIL-STD-220 ANSI C95.2-1974 MIL-E-6051	MIL-STD-463 MIL-HDBK-237 MIL-HDBK-XXX MIL-STD-220 ANSI C95.2-1974 MIL-E-6051	MIL-STD-463 MIL-HDBK-237 MIL-HDBK-XXX MIL-STD-220 ANSI C95.2-1974	MIL-STD-463 MIL-HDBK-237 MIL-HDBK-XXX MIL-STD-220 ANSI C95.2-1974	MIL-STD-463 MIL-HDBK-237 MIL-HDBK-XXX MIL-STD-220 ANSI C95.2-1974

Deficiencies:

- There is no standard which defines the EMC requirements for ships, submarines, and shore installations.
- In the area of standards, which are frequently based on experience or economic considerations, it would be highly desirable to document the rationale on which the standard is based. In this way, requests for partial or complete waivers could be handled in a more objective fashion, noting, for example, that the basis of the standard is inapplicable to the situation being considered. (The standard might be based on the assumption of very close spacing, while in fact, the situation being considered might involve wide separations.)

4.3.4.2 Control Plans/Procedures/Methodologies

MIL-HDBK-237, "Electromagnetic Compatibility/Interference Program Requirements" provides criteria for establishing an EMC program. It provides EMC guidance for the project officer. The use of these guidelines is intended to increase the probability for all subsystems and equipments within a system to be compatible (intrasystem EMC) and for EMC to exist between systems (intersystem EMC). The handbook presents a synopsis of actions applicable during the planning, design, development, test and installation phases of military equipment, subsystems and systems. Figure 4.3 presents a summary of life cycle EMC requirements.

Although much of the content of the handbook are oriented towards intrasystem aspects of EMC, the intersystem aspects are adequately covered. One of the most critical aspects in this area involves the question of identifying the intended operational environment. For a mobile platform, which is typical of the Navy, the operational environment geographically may cover a major part of the whole world. Obviously, identification of the EM environment over such large geographical areas is a difficult, if not impossible, task. When EM advisory boards are formed per MIL-HDBK-237, ECAC personnel frequently participate as advisors in the intersystem area. MIL-HDBK-237 does not adequately reflect all of the factors which must be considered to obtain a compatible and electromagnetically effective system.

4.3.4.3 Maintenance

At present no maintenance procedures exist specifically for intersystem EMC. Such maintenance as exists is a by-product of maintenance for intrasystem EMC.

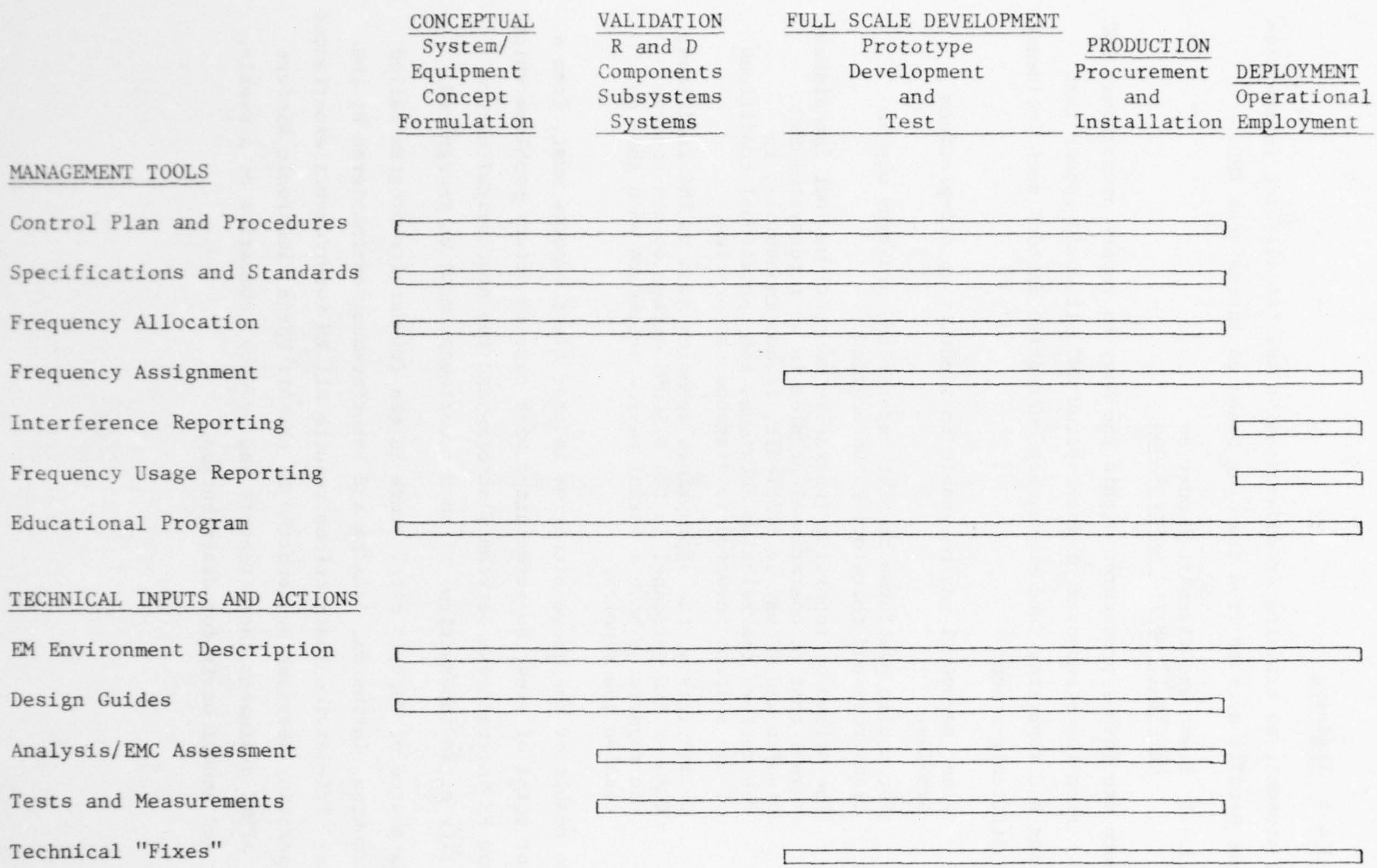


Figure 4.3 SUMMARY OF EMC-RELATED MANAGEMENT TOOLS TECHNICAL INPUTS AND ACTIONS RELATIVE TO SYSTEM/EQUIPMENT LIFE CYCLE

4.3.4.4 Training

At present, no training procedures exist specifically for intersystem EMC. Some benefit accrues from training based on intrasystem EMC.

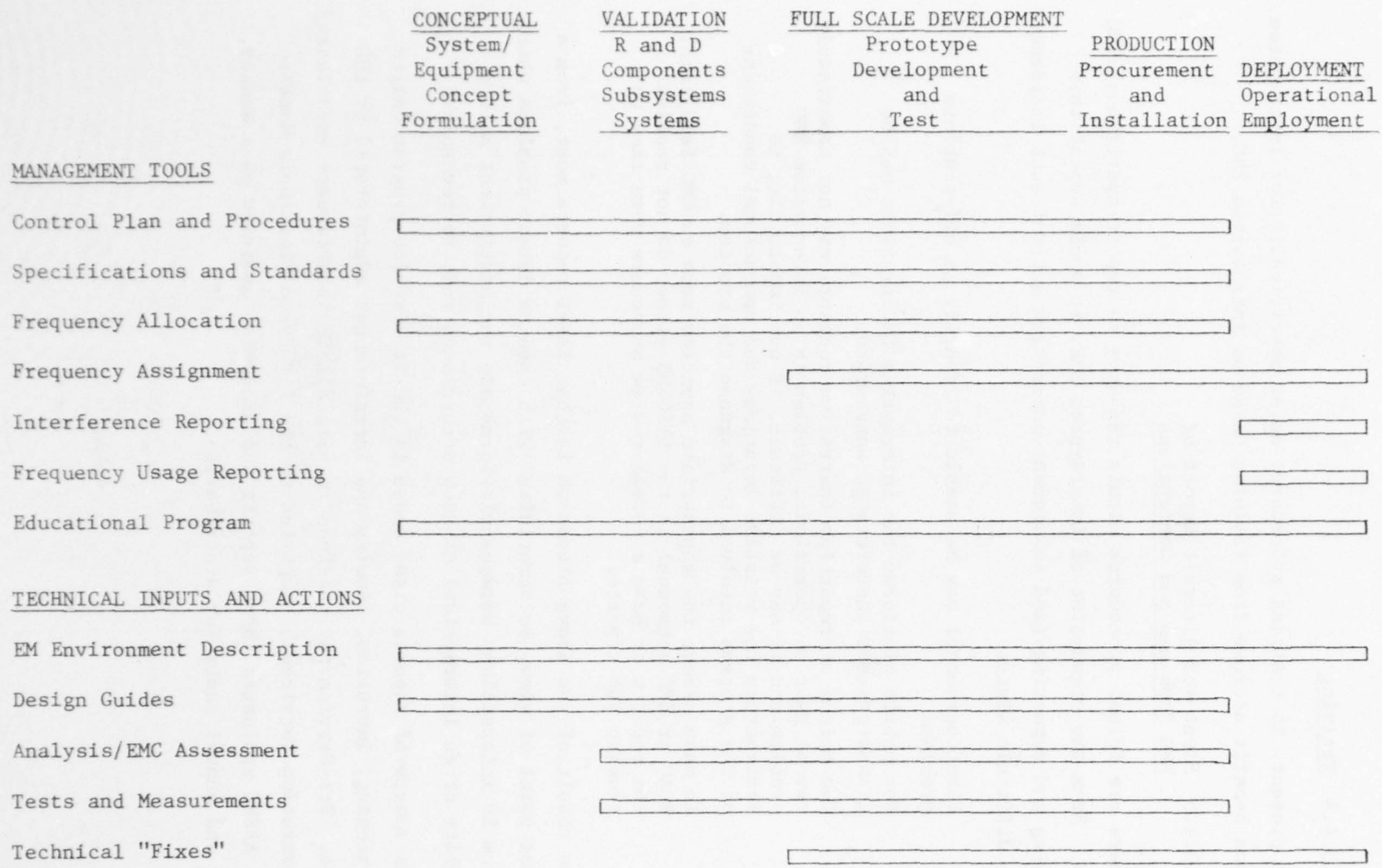
4.3.4.5 Fleet and Aircraft Report of EMC Problems and Corrections

There are formal procedures within the Navy to report operational EMC problems. From the standpoint of intersystem EMC, it would appear that identifying and reporting (and subsequent corrective action) such incidences would be difficult since:

- Fleet personnel may be unable to identify an off-platform problem.
- For mobile platforms the intersystem EMC problems may be transitory and therefore go unrecorded.
- The method of reporting (narrative content) may not immediately reveal that an operational problem is an intersystem EMC problem and it may be difficult, if not impossible, to restructure the relative locations and operational conditions of the systems involved to diagnose the problem.
- In many cases, the appropriate agencies such as EMC lead labs, ECAC or EMC personnel in the SYSCOMS either do not receive the reports or have a formal review procedure when they do receive the reports.

The result of the above situation is that fleet reports must, from a management point of view, be scrutinized with care to detect problems which arise from EM interactions between platforms and the statistical nature (probability of an interaction) of such occurrences must be recognized.

One source of reports cited above is the Tri-Service program called MIJI (Meaconing, Intrusion, Jamming and Interference) administered by the Air Force. Tri-Service instructions require all EM interference experienced by the operating Services be reported to the Air Force Electronic Warfare Center. AFEWC evaluates these reports and produces summaries on a weekly, monthly, and annual basis for distribution.



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4.3.5 Corporate Memory

4.3.5.1 Equipment Characteristics

The largest and possibly most up-to-date file on equipment characteristics is located at ECAC. The Nominal Characteristics File (NCF) consists of nominal characteristics extracted from appropriate technical documents and is organized into a system section and a component section. The system section is designed to identify the transmitter, receiver and antenna components that make up a system. The component section contains detailed characteristics. Measured data (such as MIL-STD-449 data) is generally maintained in report form in the ECAC Technical Library. These files are accessible to all DoD organizations.

Most of the measured data within the Navy resides in reports which are kept in individual's files or libraries of the agency. There is no specified central location for this information. In any case, the Navy per se, has no corporate memory for equipment characteristics, nominal or measured.

The situation as stated above should be rectified by either establishing within the Navy a corporate memory center or utilize the ECAC capability by assuring that appropriate information is forwarded to ECAC. This action would be particularly useful, if as stated previously, measured data from MIL-461-Series tests would be a contract deliverable item and the Navy corporate memory center and ECAC retained the data.

4.3.5.2 Data Prediction Base

For intersystems analysis, the generic types of models and programs used to manipulate the equipment characteristics for EMC analysis are as follows:

- Subsystem Models
- Propagation Models
- Environment Analysis Models (General Prediction Models)
- Cosite Analysis Systems
- Spectrum-Management Analysis Models
- Degradation Analysis Models
- Statistical and Numerical Analysis Programs
- Data Base Accessing Programs.

A number of Naval agencies have cosite analysis models which could be expanded for use in intersystem EMC analysis by appropriate modification of the propagation model. In terms of corporate memory, these models, the data base needed to exercise them, and the results that are obtained from them are frequently problem or program unique. The information derived usually has limited distribution, is often not fully documented, and the corporate memory resides in the minds of a few individuals who did the work. Effort should be devoted to making the results of these efforts more widely distributed and included in some form of Navy corporate memory.

4.3.5.3 Summary of Environment Measurements or Publications

Outside of the environment specified in MIL-STD-235, there do not appear to exist any "canned" environments. It is understood that ECAC has "packaged" some typical environments. Again, it must be stated that since the Navy deals mostly in mobile platforms, the definition of specific intersystem environment becomes very difficult. Some statistical characterization of such environments becomes a practical necessity. Such statistical environments are usually tailored to the specific platform.

4.3.5.4 Handbooks

There are not many handbooks devoted primarily to intersystem EMC. Most handbooks which have been published cover the subject of intrasystem in considerable detail. ECAC has published some handbooks which are pertinent to the intersystem problem and sections of the other handbooks have some application to this problem area also. The ECAC handbooks deal with the following topics:

- Environmental Data
- Measured Data
- Organization Platform Allowance
- Spectrum Allocation and Use
- Radiation Hazards
- Topographic Data
- Future Systems
- Frequency Resource Records
- J-12 System File
- Antenna and Transmitters
- Satellite Systems
- Band Surveys
- Radar Special Circuits

4.3.5.5 Documentation

Navy agencies, in general, do not have dedicated EMC libraries or sections of libraries. Therefore, the corporate memory for documentation of problems is, at best, divided among a number of individuals or groups of individuals within each agency. That is to say, the corporate memory is parochial. Each individual or group of individuals has documentation pertaining to his or their own areas of interest. There does not appear to exist a Navy corporate memory for EMC problems, to say nothing about EM problems in general.

In some cases, problems continually manifest themselves by repeated occurrences. When this happens, the interacting systems are often extensively studied and great amounts of data are generated on the particular systems on the particular platforms. Oftentimes this data is documented and the pertinent solutions gleaned. However, many times dissemination of the data becomes a problem because of the large, diffuse number of organizations who may have an interest in particular data.

In some cases, the EMC corporate memory may reside primarily in Navy contractor's facilities rather than at Navy agencies. This may be especially true in the early stages of concept and design where such problems tend to be treated as "design" problems rather than EMC problems.

Although numerous DoD directives and Navy instructions such as DoD Instruction 3200.6, "Reporting of Research, Development and Engineering Program Information," ASPR's, and SECNAVINST 5233.1 for Computer Program Documentation require documentation of model development, measurement and analysis results and other generally applicable outputs, many such efforts are never documented. And when efforts are documented, far too often it is inadequate for another organization to be able to utilize the results or run the program in the case of computer models or codes.

Numerous examples can be cited of capabilities, e.g., analytical models, or test and validation data which are inadequately documented or, if documented, are not distributed to agencies who could make use of them. Complex automated models require detailed descriptions, apart from program listings, which supply information relative to the capabilities and limitations of the model, user-oriented manuals, engineering formulations, and reference to validation tests (and confidence levels) when available. In many situations, only program listings are supplied.

Frequent examples exist (particularly in the man-made noise area) where data are supplied, but important parameters, such as instrument bandwidth, are not supplied. In effect, data of this type are misleading and, consequently, the user runs the risk of erroneous results in any use of the data.

4.3.6 Mitigation Techniques (Preventive Devices and Hardware)

4.3.6.1 Decoupling

Discussions with ECAC personnel have indicated that in their experience, which by now is quite extensive, the following priorities exist in intersystem EMC problems.

For Communications Systems:

1.	Co-Channel Interference	Most Likely
2.	Adjacent Channel Interference	Next Most Likely
3.	Spurious Response or Intermodulation	Unlikely

For Radar Systems:

1.	In-Band Interference	Most Likely
2.	Image Response Interference	Next Most Likely
3.	Spurious Response	Unlikely/Rare

In view of the above, the mitigation techniques most likely to be employed (other than frequency reassignment schemes) involve some sort of additional decoupling in the coupling path. This may take the form of specialized multi-couplers, and/or filters to decrease radiated spectral occupancy of transmitters and/or to sharpen the selectivity skirts of receivers. An up-to-date file on nominal and measured data for filtering devices is being kept and include an analytical model of a dozen or so couplers in the TRACE capability.

4.3.6.2 Blanking

Blanking techniques may be used; however, this technique is usually restricted to single platforms. If the platforms are mobile the technique is inapplicable. ECAC maintains blanking capabilities as part of their nominal characteristics file.

4.3.6.3 Signal Processing

A number of signal processing techniques have been developed for specific projects. These techniques are usually developed and applied on a case-by-case basis and are not generally available as off-the-shelf hardware. As systems get more complex and automated, such signal processing techniques become part of the software, usually as subroutines which are called upon when needed. This is a fruitful area for coordination with the ECCM discipline since there is a commonality of threat, even though one is intentional and the other is not.

4.3.6.4 Side-Lobe Reduction

In systems where directional antennas are used (i.e., radars, etc.) the probability of main beam to main beam interaction is very improbable. Thus, most interference situations tend to be side-lobe to side-lobe. This problem is quite common and is an important aspect of intrasystem EMC. A considerable amount of effort has gone into reducing the side and back lobes of antennas and these techniques are well documented.

4.3.6.5 Nonlinear Mitigation Methods

Although filters are generally the best approach to decoupling, other methods sometimes are useful. As examples:

- Low gain RF stages compensated by high gain IF stages increase the figure-of-merit of receivers.
- Higher levels of local oscillator power increase the figure-of-merit of receivers, but create an attendant L.O. radiation problem.

4.3.6.6 Composite Materials

Although mostly a potential intrasystem problem, the use of composites with the attendant decrease in shielding capability may create additional intersystem problems. Mitigation techniques developed to solve intrasystem problems would also tend to mitigate the intersystem effects.

4.4 Summary

The state-of-technology in EMC is highly variable. Analytical capabilities range from high confidence for predicting in-band antenna-to-antenna coupling over unobstructed paths to low confidence in predictions for antenna-to-cable or cable-to-cable coupling over obstructed paths in complex environments. Complex structures are difficult to model with any degree of accuracy. R and D activities are continuing to improve the Navy's capability to perform analytical predictions more accurately.

A reasonably complete capability exists in the measurements area. Equipment and procedures for measuring most parameters of interest are available. Cost of performing the measurements remain high, however, some economies can be achieved by combining and simplifying MIL-STD measurements and also be automating the measurement process. Test methods for some of the newer technologies such as microprocessors and fiber optic systems remain to be developed.

Management tools for EMC control are available but not too well developed. Present methods of quoting EMC standards and specifications in procurement documents are inadequate because these documents are outdated and not suitable for newer technologies. A new methodology employing tailored specifications has been recommended for development. A need for a Navy corporate memory has been discussed to provide for better documentation, reporting, storage, and retrieval of EMC related data and information to aid management of EMC.

Mitigation techniques, in general, are adequate. Technology exists to develop special EMC fixes and off-the-shelf components are frequently adequate for use. In the latter area, there exists a need for out-of-band performance characterization of components. In some cases, such as filters, a procedure to determine component parameters which would allow prediction of performance in a non-ideal (i.e., mismatched) application would be desirable.

It is deemed that the status of technology is adequate to deal with most EMC problems occurring in the in-service equipment. The ability to analytically predict anticipated EMC performance for future systems and platforms is a function of the availability of appropriate data and analytical models. Measured data is usually needed to achieve a higher confidence level in predicted results, but useful information can be obtained for tradeoff decisions in conceptual phases based on engineering estimates and statistical data.

5.0 ADEQUACY OF STANDARDS AND SPECIFICATIONS IN EMC

Almost by implication a standard is designed to control variety. It may concern materials, items, features, engineering practices, processes, codes, symbols, type designations, definitions, test methods, inspection procedures, packaging approaches, and preservation methods, definition and classification of defects, and standard marking of materials, items, parts and components. The distinction must be made between standards and specifications. A specification is intended primarily for use in procurement. It defines clearly and accurately the essential technical requirements usually expressed in terms of performance and provides the instrument for solicitation of competitive bids from the largest possible segment of industry. A specification quite frequently embodies the use of standards. Such standards can be the common base for interchangeability, compatibility, reliability and maintainability. The developer of a specification can utilize standards and establish a common base of uniform descriptions and control the variety which is not necessarily needed.

Military EMC specifications and standards have as their objective minimizing the effects of electromagnetic emission and susceptibility, which can be encountered through the use of electromechanical, electrical, and electronic equipments, subsystems, and systems. Along with various departments within the Department of Defense, the Federal Communications Commission and the Office of Telecommunications has also been active in controlling interference, in many cases by the implementation of standards.

The impetus for standardization arises to avoid costly handcrafted engineering modifications needed to solve EM interaction problems. Unfortunately, either through ignorance, or lack of funds, many of the existing standards have not been effectively implemented and this has resulted in unsatisfactory and unreliable operation which can only be remedied by costly fixes in the field.

On the other hand, where such existing standards have been carefully implemented, the full benefits of cost tradeoffs are not often realized because of the inflexibility intrinsic within the existing standards. For example, in many cases, the test environments embodied in MIL-STD-461 are not sufficiently high to cope with many expected environments already found in the field. Conversely, many of the test limits have been regarded as far too stringent, and as a result, significantly increased the cost of the equipments.

The solution to the foregoing problems is a uniform implementation of the "tailored" standard. Presumably, such a standard is so constituted that many of the basic features are, in essence, true standards while at the same time allowing flexibility in a selection of test limits and possibly other requirements. Thus a successful "tailored" standard becomes a compromise between a highly rigid and inflexible standard as opposed to the undisciplined high cost engineering inherent in the handcrafted EM compatibility programs.

As discussed earlier, the goals of such a tailored standard should be to avoid maintaining large groups of individuals whose "engineering judgment" is the principal basis for the tailoring of existing standards. The best alternative seems to be the development of a specification or a standard tailoring process which relies on the intrinsic automation capabilities inherent in computer-aided analysis. Specifically involved in the tailoring process are four principal steps as follows:

- Source and/or environments
- Coupling path loss
- Vulnerable parts and susceptibility levels
- Prediction capability commensurate with need.

To implement the above, most of the elements within the state-of-the-art will have to be drawn upon. The principal areas within these elements include the following:

- Effectiveness of mitigation hardware/techniques
- Equipment placement/orientation routing options
- Standard test procedures and limits
- Corporate memory of equipment characteristics
- Operational and maintenance problems and controls.

Figure 5.1 illustrates a possible methodology to evolve "tailored" standards and "allocated" requirements. This diagram essentially outlines the thought process generally involved in "engineering judgment" selection,

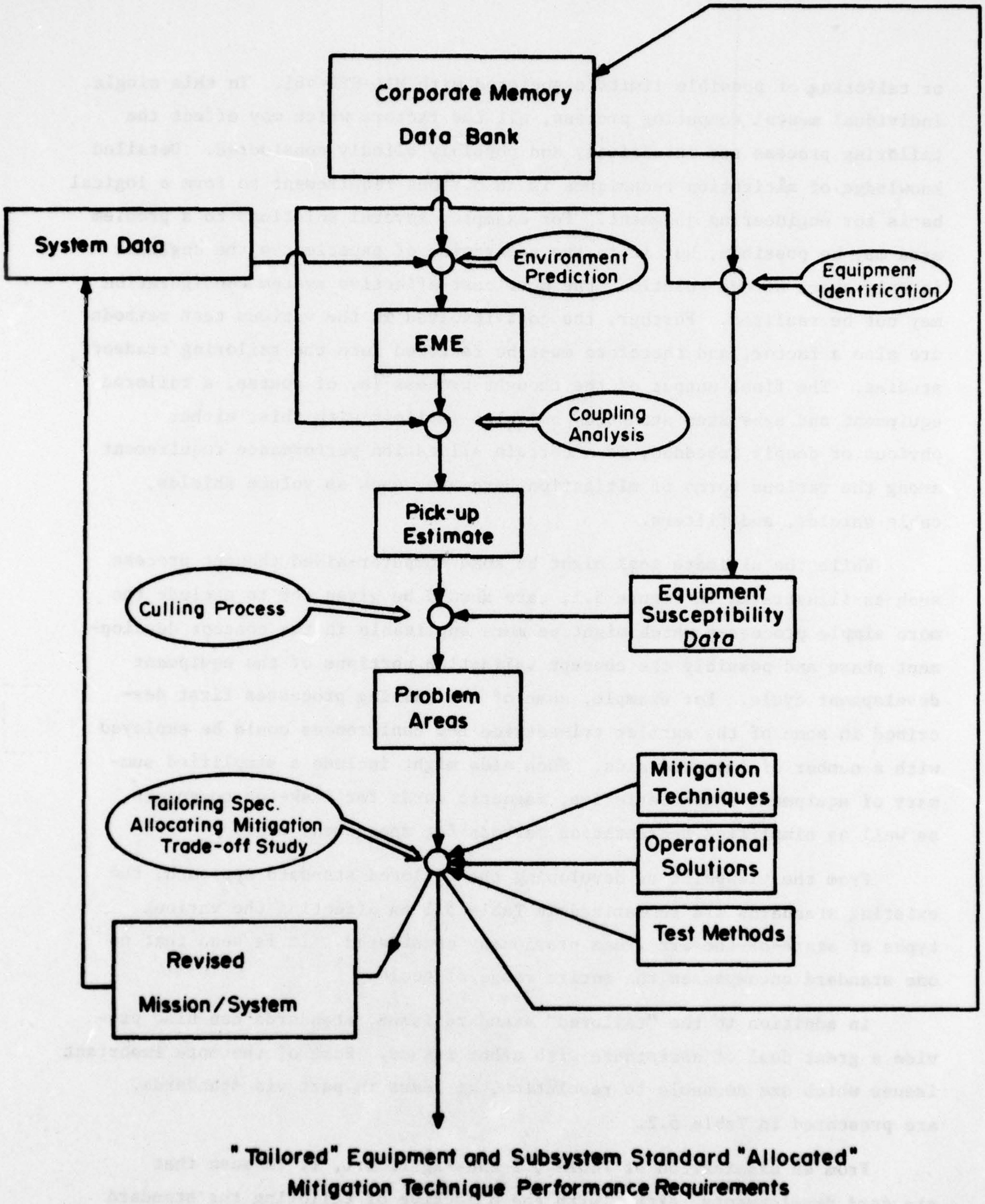

Fig 5.1 POSSIBLE METHODOLOGY TO EVOLVE "TAILORED" STANDARDS AND "ALLOCATED" REQUIREMENTS

or tailoring of possible limits associated with MIL-STD-461. In this single individual mental computing process, all the factors which may effect the tailoring process are intuitively and possibly blindly considered. Detailed knowledge of mitigation techniques is an obvious requirement to form a logical basis for engineering judgment. For example, several solutions to a problem area may be possible, but if in the repertoire of experiences the engineer is only aware of one solution, the most cost-effective system configuration may not be realized. Further, the cost involved in the various test methods are also a factor, and therefore must be factored into the tailoring tradeoff studies. The final output of the thought process is, of course, a tailored equipment and subsystem standard, but also implicit with this, either obvious or deeply imbedded, is a certain allocation performance requirement among the various forms of mitigation hardware, such as volume shields, cable shields, and filters.

While the ultimate goal might be some computer-aided thought process such as illustrated in Figure 5.1, care should be given not to exclude the more simple processes which might be more applicable in the concept development phase and possibly the concept validation portions of the equipment development cycle. For example, some of the culling processes first described in some of the earlier tri-service EMC conferences could be employed with a number of improved aids. Such aids might include a simplified summary of equipment characteristics, magnetic cards for desk-top computers, as well as simplified presentation methods for management use.

From the viewpoint of developing the tailored standard approach, the existing standards are summarized in Table 5.1 as affecting the various types of state-of-the-art areas previously considered. It is seen that no one standard encompasses the entire range of tools.

In addition to the "tailored" standard issue, standards can also provide a great deal of assistance with other issues. Some of the more important issues which are amenable to resolution, at least in part via standards, are presented in Table 5.2.

From an examination of Table 5.2 and Figure 5.1, it is seen that standard developments, either with the objective of tailoring the standard or to resolve some of the other issues, must be developed in harmony.

TOOL / STANDARD	ANALYSIS	TEST	MANAGEMENT	CORPORATE MEMORY	MITIGATION TECHNIQUES
MIL-STD-220					X
MIL-HDBK-235	X Inter Only				
MIL-HDBK-237			X		
MIL-STD-285					X
MIL-STD-449D	X Inter Only	X		X	
MIL-STD-461		X	X		
MIL-STD-462		X	X	X	
MIL-STD-463		X	X		
MIL-STD-469	X Inter Only	X	X	X	
MIL-STD-1310					X
MIL-B-5087					X
MIL-E-6051-D		X	X	X	
MIL-F-15733					X

Table 5.1. SUMMARY OF PRINCIPAL STANDARD AND S.O.A AREAS

TABLE 5.2

ISSUES AMENABLE TO RESOLUTIONS VIA STANDARDS AND PRESENT STATUS

- EMC IN CONCEPT PHASE

  * EMC overall requirements via O.R.'s is currently not required either in standards or otherwise.

  → EMC management aspects are partially considered in MIL-STD-461 and MIL-E-6051.

- EMC DURING DEPLOYMENT

  * Reporting of fleet and wing EMC problems could be handled routinely by existing methods using standard reporting formats.

  → No formats presently exist.

- EME DEFINITION

  * Frequency management in concept design could be implemented via standards.

  → Partial consideration of this is handled on a project-by-project basis via MIL-STD-469 for radars.

- CORPORATE MEMORY

  * Documentation of analytical and test results could be facilitated by standard reporting format and standard test procedures.

  → No format exists for intrasystems except where implemented via MIL-STD-449 and MIL-STD-461.

- INTEGRATION AND INSTALLATION PRACTICES

  * Installation guidance can be provided by fabrication and design standards.

  → Only limited guidance is available via MIL-B-5087 and MIL-STD-1310.

TABLE 5.2 (Cont.)

- **SPECS AND STANDARDS**
  - * Costly overdesigns incurred by inflexible standards can be avoided by standards designed to be "tailored."
  - → No standards are presently available which are amenable to "tailoring."
- **EMC VALIDATION**
  - * Key aspects of any validation procedure can be implemented and controlled via standards.
  - → No standards are presently available for this purpose.

For example, the standard needed to implement a corporate memory also has a bearing on how the tailoring of standards are accomplished. Thus, a unified standard approach is clearly required. This is opposed as to the present method of standard development which has been divided among the various services, and among various organizations within each service, to the point where standard development has indeed become a very complex and sometimes lengthy process. Indeed, the complexity and number of existing standards has grown to a point where it has been proposed that the coverage embodied in each standard, along with overlapping areas, be fed into a computer system for easy retrieval of the applicable standards and for ready identification of the various interrelationships between the identified standards.

In fact, the whole standards evolvement process should be carefully scrutinized, such that the standards evolvement is oriented toward solving the entire system problem in a unified and wholistic manner. This isn't to say that the present standards have not met their objectives with regard to EMI mitigation equipment which were originally set forth.

In summary, existing standards are quite inadequate to serve as a base for developing "tailored" specifications and allocation requirements for mitigation hardware. However, many of the procedures, test methods, and definitions can be used as building blocks to develop a more comprehensive standard.

The present status of the existing standards are discussed in detail in the following sections. These are essentially broken into two major groups: mitigation hardware standards; and test, management and analysis standards. Typical criticisms of all areas of standards fall into two general categories. First of all, the specifications are written in a general way so that tailoring is usually called for. Further, there is no standard approach or philosophy which will permit tailoring or modification of the specifications or limits in a logical way. Secondly, specifications and standards are sadly out of date and need revision. There are long lag times associated with revision and the specifications are quite frequently lagging behind new technology. These lags occur in dealing with new mitigation-type hardware, such as fiber optics, or new developments in aircraft such as the use of composite materials. The mitigation hardware standards will be considered first.

5.1 Filters

Present test methods for this important mitigation element are defined in MIL-STD-220. MIL-F-15733 also embodies the MIL-STD-220 test procedure. Unfortunately, the response test procedures specified in MIL-STD-220A for determining filter performance are not adequate. Filter performance is based on 50 ohm input and output impedances whereas the real world impedances are not standard 50 ohm. Two technical papers that could solve the problem of determining filter performance have been presented at the 1975 IEEE Electromagnetic Compatibility Symposium. These papers are as follows:

1) "Determination of Filter Performance for any Arbitrary Source or Load Impedance Based on Experimental Measurements," by J. E. Bridges of IITRI.

2) "Assuredly Effective Filters," by Heinz M. Schlicke, Fellow, IEEE, Interference Control, Milwaukee, Wisconsin.

In summary, if tailored specifications and mitigation hardware allocations are to be implemented, better knowledge of the performance of filters in the actual equipments will be needed. While highly detailed knowledge probably is not necessary for most of the applications, some method of accurately predicting the performance to perhaps within a factor of plus or minus 20 dB most assuredly is needed. The present error or potential errors, associated with MIL-STD-220A test procedures, embody areas as large as plus or minus 80 dB. Some of these difficulties are avoided by recently issued test procedures delineated in DNA 3286H, DNA "EMP Preferred Test Procedures." These procedures can be possibly readily modified for use in the EMC area.

5.2 Shielded Enclosures

The present military standard for the measurement of shielding effectiveness for room size and smaller enclosures is MIL-STD-285. The test methods employed are somewhat out of date since this document was issued in June 1956. To improve this situation, some 18 years ago a study was initiated to improve upon this standard. The result of this effort is embodied in IEEE 299.

IEEE 299 overcomes many of the deficiencies existing in MIL-STD-285. Such deficiencies include methods to overcome standing waves within the room, better methods to account for seams and apertures and other skin defects.

In fact, MIL-STD-285 does not contain a procedure for the microwave measurement of the shielding effectiveness of rooms, whereas IEEE 299 does.

Both IEEE 299 and MIL-STD-285 are primarily oriented to the measurement of shielding effectiveness of room size enclosures or smaller. Hence, some test procedures need to be evolved to consider the effect of the free field environment on fairly large structures such as aircraft or ships.

In summary, MIL-STD-285 appears to be completely outdated and can be superseded by a much improved standard such as IEEE 299. Further improvements in IEEE 299 are possible with principal emphasis on devising test methods suitable for evaluating performance of large platforms.

5.3 Shipboard Bonding and Grounding Techniques

MIL-STD-1310 sets forth methods for shipboard bonding, grounding and the utilization of nonmetallic materials for the purpose of electromagnetic interference reduction and the protection of personnel from electrical shock. In addition, some aspects of this standard are useful for reducing "intermodulation" hull noise or the rusty bolt effect. In addition, methods for the installation of shipboard ground systems are also provided.

This is a fairly recently issued standard and as a result, comments to date have been rather limited. The only possible addition would be the incorporation of EMP type procedures which involve the grounding of cable shield envelopes as they penetrate the hull.

5.4 Lightning Effects Bonding Standard

MIL-B-5087B covers the characteristics, application, and testing of electrical bonding for aerospace systems, as well as bonding for the installation inter-connection of electrical and electronic equipment therein, and especially for lightning protection. One deficiency of this test procedure is that standard lightning test wave forms and techniques are not available for testing of equipment/systems to determine their compliance with MIL-B-5087. Presently, the detailed bonding test procedures provided by MIL-B-5087 depend on the measurement of dc resistances. In many cases, the ac impedance of the bond can be sufficiently high that under transient lightning conditions, severe problems could be introduced.

5.5 Cables

For either inter- or intra-system interference problems, cables undoubtedly provide the most promiscuous source of pick-up through the system. Yet, within the EMC community there has been no standard test procedures which can evaluate, on an empirical basis, the pick-up characteristics of many of the cables employed. There has been some activity within the Society of Automotive Engineers, A-4 Group, to provide standardized ways of measuring the pick-up associated with cables. These have proved interesting and useful but have been criticized because of the difficulty of extending the test results to situations not comparable to those employed during the test.

Considerable emphasis has been placed in a related area by the Defense Nuclear Agency to develop preferred test procedures for a variety of cable types. These have been published for the more simple cable types in DNA 3286H. Procedures attempt to develop intrinsic penetration/emanation parameters. From a knowledge of these parameters and the remainder of the cable configuration, it becomes possible to predict the pick-up or emanation of the cables where specific field excitation or cable currents are known.

Since the performance of cable shields has such a vital influence on the pick-up of any system, it is almost mandatory that more definitive information regarding the cable shielding characteristics be included in any EMC specification tailoring process. As such, the procedures outlined in DNA 3286H entitled, "DNA EMP Preferred Test Procedures," can possibly be modified for EMC purposes.

5.6 EM Shielding Hardware

EM shielding hardware includes among others, electromagnetic gaskets and EM vent shields. The present specifications do not consider any test procedures for these important elements of the mitigation hardware. A rough, but not necessarily detailed knowledge of the performance features of such materials as gaskets or vent shields is needed in order to provide a rational basis for the tailoring of specifications. Of great importance is the degradation of the EM gaskets as a function of time under stress and corrosion conditions.

At least two attempts have been or are under way to evolve better test procedures for EM gaskets. One test procedure which has been published is DNA 3286H. It is also understood that similar developments are also underway within the SAE A-4 committees. One activity of the IEEE standard group is the development of improved gasket test procedures. This will quite likely parallel the test procedures set forth in DNA 3286H.

No test procedures are available in military standards regarding the performance of EM shielding vents. The most closely related test procedure appears in the DNA EMP Preferred Test Procedures of DNA 3286H. This procedure could readily be modified to the EMC situation. Comparable activities within the SAE or IEEE apparently are not taking place.

In summary, no military specifications exist which are relevant to shielding hardware. Specifications are needed in order to provide a rational basis for tailored standard and allocated mitigation requirements. However, standards developed elsewhere in this area can undoubtedly be modified for this purpose. One major lack in all existing standards, either for gaskets or for vents, is a lack of procedures which would develop data relevant to corrosion and other aging factors.

5.7 Conduit and Coupling

Similar to cable shields, conduit and coupling methods also provide a major role in determining the interference pick-up experienced by cables within these elements. At present, there is no military standard yet issued to cover the performance measurement of these critical elements.

However, such test procedures from an EMP viewpoint are spelled out in the DNA Preferred Test Procedures, DNA 3286H. These can be adopted with minimum effort to the EMC situation.

5.8 Optical Fibers

Optical fibers are being recommended in an increasingly large number of situations as a solution for many of the cable related EMC problems. Two problems exist with optical fibers. First of all, their mechanical stability under adverse environmental conditions; and secondly, the EMC aspects associated with terminating equipments.

Presently, no specifications exist regarding the performance of optical fiber data links. However, sometime in the near future the development of such a standard which covers both the mechanical performance of the fibers and the EMC performance of the terminal elements will be needed.

5.9 Arrangement/Decoupling

Arranging equipment in certain preferred locations greatly reduces the other aspects of the EMC problem, such as shielding requirements or frequency allocations. This is done by placing high powered sources in one location which is quite some distance away from the more susceptible equipments. Similarly, higher powered cables are routed in different trays than the more critical low level signal carrying cables. However, on complex platforms such as ships and possibly aircraft, such an arrangement becomes so complex that it cannot be done on a quasi-intuitive basis, as can be done for the more simple systems.

In this case, some sort of standard procedure, possibly aided by computers could be utilized for this purpose and should be developed.

5.10 Grounding

A wide variety of grounding techniques are often employed. However, it is usually best to harmonize the grounding approach for a given system. This harmonizing of the grounding approach involves selection of the types of cables, such as if they are balanced or unbalanced. It also concerns how the cabinets are bonded to the common reference point.

Various arguments have been set forth to enumerate the advantages and disadvantages for various grounding systems. Such systems include single point, crows foot, herring bone, equipotential, and isolated. Regardless of the advantages or disadvantages of each system, a clear-cut unified approach is required, if major EMC problems are to be avoided. Further, such grounding plans should be harmonized with existing standards such as MIL-STD-1310 and MIL-B-5087.

In summary, it appears that some form of standard which insures harmonizing the grounding system with other aspects of the systems emission requirements is needed and eventually should be evolved.

5.11 Composites

Standards are also needed to evaluate the performance of composites under adverse electromagnetic conditions. This includes both EMC, EMP, P-static, and lightning situations.

Efforts should be made to initiate the involvement of such a standard, preferably one which unifies EMC, EMP, P-static, and lightning protection.

5.12 Test and Measurements Standards

MIL-STD-461A covers the requirements and test limits for the measurements and the determination of the electromagnetic interference characteristics of electronic, electrical and electromechanical equipment. These requirements are to be employed for general or multi-service procurements and single service procurements as specified in the individual equipment specification or contract. In the case of MIL-STD-462, this standard establishes the measurement procedures used to test equipment to the limits noted in MIL-STD-461. MIL-STD-463 provides a definition and system units applicable to the test procedure limits set forth in 461 and 462.

This series of standards has evolved over the years and has proved eminently useful in combating, on a general basis, some of the more severe situations associated with radio frequency interference. Most of the test limits and procedures have evolved simply on the basis of good engineering judgments. However, in many cases, these have been supported by analysis and by direct experiences with working systems.

Nevertheless, as the years have gone by, this system has not been updated as rapidly as necessary. This has come about partially because of lack of interest on the part of companies in the aerospace field to provide the time necessary for their engineers to participate in the necessary standards development conducted under the auspices of the SAE. As a result, the document has aged to a point where some of the test procedures have become highly questionable and the limits which are set forth have either resulted in costly over or under designs. Some of the specific comments regarding these procedures are outlined as follows:

First, the MIL-STD-461 test procedure series is inadequate for the development of a data base. The test procedures are employed on the basis of a go or no-go test. However, these could be readily modified to provide some crude but important data of the specific levels of susceptibility or emissions. Further, where equipment has been subjected to the MIL-STD-461 tests, test results are not readily retrievable. Hence, it is often necessary for a manufacturer to simply retest the equipment again when it has already been tested several other times by other groups.

The test procedures employed in the MIL-STD-461 tests have often been questioned because of the problems introduced by conducting the tests within the shielded enclosure. Under such a test procedure, standing waves are introduced within the room and it is never clear as to what the field eminations actually are. Such potential errors can occur particularly for narrow CW emissions or susceptibility is in the order of plus or minus 40 dB. While there are procedures to overcome this basic limitation, particularly at the higher frequencies, they have not yet been implemented within this standard.

The RS03 radiated susceptibility test specified in MIL-STD-462 is incorrect for the type of antenna used. Also, the RS03 field intensity level of one volt per meter does not represent a realistic level for most equipments or systems.

In the case of MIL-STD-461 RS02, the spike test is not adequate to simulate aircraft mission system transient conditions. A shorter duration pulse should supplement the present RS02 test limit to provide sufficient harmonic energy in the high frequency range.

In regard to MIL-STD-462, test procedures in many of these are very difficult to implement, particularly the RS03 radiated susceptibility test specified which is incorrect for the type of antennas used. Further, as previously mentioned, there are problems associated with internal electromagnetic resonances within the enclosure.

5.12.1 MIL-STD-469

As with the previous standards, a number of minor and some major deficiencies have been identified. For example, an insertion loss measurement of filters is required in Paragraph 5.2, but the source and load impedances are not appropriately delineated. Paragraph 6.7.4 states that radar receivers shall not exhibit any radiation in excess of -67 dBm measured at the receiver terminals. Current technology allows better suppression than this -67 dBm figure. Further, many receivers apparently available have sensitivity much better than the -67 dBm and if they were in close proximity at the radar receiver, they could detect radiation from the radar receiver creating an interference situation.

Further, the measurement techniques and equipments listed in the appendix do not reflect current available techniques and equipments. For instance, frequency measurements can be made with current off-the-shelf frequency counters well above the 12.4 gigahertz without the need of harmonic mixing and transfer oscillators or frequency converters.

A number of additional sections need major update which include the method described for receiver radiation. Procedure outline on antenna measurements in Section 5.0 is also in need of major updating.

5.12.2 MIL-E-6051

The specification requires the establishment of an EMC board to govern system EMC and to provide a means of expediting solutions to problems as well as establishing high levels of coordination. The details of operation on the charter board is determined by the contractor. Based on comments, more influence on the part of the procuring activity in these roles is deemed highly desirable.

In implementation control plan, a similar deficiency has been noted that almost the entire responsibility and authority is vested with the contractor. This apparently greatly weakens the ability of the procuring agency to enforce good EMC designs. Other deficiencies exist. For example, the frequency range to be considered for the test site ambient electromagnetic environment in Paragraph 4.8 is too restrictive in view of current technology and continued advances. The frequency range should be expanded to below 10 kilohertz and up to 40 gigahertz at the minimum.

While guidelines are provided in Paragraph 4.3.4, as to the quantity of lightning tests that should be performed, there is no reference as to specification standards or procedures to conduct these tests. This is due largely to the fact that standard lightning test wave forms and techniques are not available.

5.13 Summary

It is commonly acknowledged that specifications and standards are outdated and need revision. The time lag between specifications and new technology needs to be shortened to keep the specifications as current as possible. There is a cost/benefit to be gained in tailoring specifications to the application at hand, but there is no standard approach or philosophy which will permit modifications to specifications in a logical way. Standards and specifications need to be developed for mitigation components which incorporate measurement of parameters which can be used to accurately predict the performance of the component under a wide variety of conditions.

At the present time, there are no specifications or standards dealing with EMC aspects of cables and shielding hardware such as gaskets, vent shields, conduit, stuffing tubes, etc. Knowledge and control of the EMC performance of such features is needed in order to provide a rational basis for tailoring of specifications.

A standard which addresses the integration and harmonizing of the grounding system with EMC and other installation requirements is needed. New technologies such as fiber optics, electro-optical systems, composites, and microprocessors should be included in the updated standards and specifications.

6.0 NAVY LABORATORIES AND SYSTEMS COMMANDS CAPABILITIES IN ELECTROMAGNETIC COMPATIBILITY

6.1 Introduction

The ability of the Navy establishment to support the five phases of system platform life cycle is addressed here. The Tables 6.1, 6.2, 6.3, and 6.4 give an overview of capabilties, which facility is involved and what personnel are contact points. The tables are divided into the two major EMC categories; Tables 6.1 and 6.2 deal with Intersystem and Tables 6.3 and 6.4 cover Intrasystem capabilities. Table 6.5 specifies at which part of the acquisition cycle the capabilities are used, and also summarizes the preceding four tables.

6.2 EMC Capabilities in the Acquisition Cycle

6.2.1 Conceptual Support

Qualified personnel are available to serve on EM Compatibility Advisory Boards and to perform those functions described in Chapter 3, i.e., review designs, prepare plans, etc. In the Preparation of Requirements, the ability to provide operational procedure recommendations for achieving EMC has not generally been tested. It is quite probable that such work could be done by the same individuals who serve on the EMCABs.

6.2.2 Technology Development and Utilization

In the area of measurement techniques and instrumentation, substantial advances during the past two years have provided several full-spectrum measurement facilities and a capability for determining the shipboard EME. Use of fiber optics for instrumentation of anechoic chambers has been developed at NSWC/DL, enabling full threat level testing of missiles. An important area of measurement is the validation of analytical and prediction computer codes. NOSC and NAVSEC both pursue measurement programs which support their code development. Automated facilities are in development or in planning for the larger activities as they prepare to collect an increasingly greater amount of data during future systems acquisitions.

6.2.3 Analysis and Performance Prediction

Analysis performance capabilities are growing continuously and have demonstrated their validity and cost-effectiveness in many instances.

TABLE 6.1
EXTERNAL EMC INTERSYSTEM INTERFERENCE / ANTENNA - ANTENNA

Agency/Individual	Analysis								Test					Management Tools					Corporate Memory					Mitigation Technique									
	Environment Prediction (Mil-Handbook 235 Specifies Environment)	Pics - 98	Degradation Analysis	Systems Trade-Off, Sensitivity	Frequency Allocations	Shield Penetration, Holes, Cables, Etc.	Structural Placement Architecture	Cable Architecture	Environment Architecture	461 Series Mil. Std.	449	6051 Aircraft	Mitigation Components (Land Facilities)	Standards - Specifications	Control Plans/Procedures/Methodologies	Maintenance	Training	Fleet and Aircraft Reporting of EMC Problems and Corrections	Equipment Characteristics	Documentation of Problems	Handbooks	Summary of Environment Measurements or Publications	Data Prediction Base	Cables/Cable Shielding	Decoupling	Blanking	Signal Processing	Shields	Bonding	Optical Fibers	Side Lobe Reduced Antenna, Array Controls	Nonlinear Mitigation Methods	Composite Materials
1 Naval Electronics Systems Command Washington D.C. 20360																																	
S. Caine/C. Neill Elex 51024														x							x												
2 Naval Air Systems Command Washington D.C. 20361																																	
Cdr. R. Short/J.J. Fisher Air 5330														x	x	x	x	x		x	x	x	x										
3 Naval Sea Systems Command Washington D.C. 20360																																	
Cdr. R. Grove/J.C. McEachen Sea 06T															x	x	x	x		x	x	x	x										
4 Electromagnetic Compatibility Analysis Center Annapolis, Md 21402																																	
J. Hodges ACY	x	x	x	x	x	x							x	x	x			x	x	x	x	x	x	x	x	x	x	x	x			x	
5 Naval Ocean Systems Center San Diego, Ca 92152																																	
R.O. Jensen/J.W. Rockway O16	x	x	x	x	x		x		x					x	x			x		x	x	x									x	x	x
J.D. Witt/W. Chase/G. Salisbury 81			x	x	x		x		x							x		x															
6 Naval Surface Weapons Center/Dahlgren Dahlgren, Va 22448																																	
L. Lysher DF-50	x	x				x			x	x	x		x	x	x	x		x		x	x	x			x	x	x	x			x		
7 Naval Air Test Center Patuxent River, Md 20670																																	
R.F. Lane SY-83	x								x	x		x		x	x	x	x	x	x	x	x	x	x					x	x				x
8 Naval Weapon Center China Lake, Ca 9355																																	
R.J. Christiansen/F. Harris 3525	x	x	x	x		x		x	x	x	x		x	x	x	x		x		x		x	x										
9 Pacific Missile Test Center Pt Mugu, Ca 93042																																	
K. Cinage 3242/R.L. Harp 1234	x				x				x	x	x	x		x	x	x	x	x		x		x	x										
10 Naval Weapons Support Center Crane, In 47522																																	
R. Von Wahlde/R. Plew 3026										x	x			x								x											
11 Naval Air Development Center Warminster, Pa 18974																																	
R. Nussbaum 2033	x								x					x	x							x	x							x			
12 Naval Ships Engineering Center Washington D.C. 20360																																	
J. Roman/F. Prout 6174	x		x	x			x		x					x	x				x	x			x										
13 Naval Postgraduate School Monterey, Ca 93940																																	
R.W. Adler/J.E. Ohlson 62		x	x	x	x				x						x		x				x	x	x			x	x						x
14 Naval Avionics Facility Indianapolis, In 46218																																	
D. Fossberg B/441	x								x	x	x	x		x								x											

TABLE 6.2

EXTERNAL EMC INTERSYSTEM INTERFERENCE / ANTENNA - ANTENNA

Agency/Individual	Analysis: Environment Prediction (MIL-Handbook 235 Specifies Environment)	Pre-IIP	Degradation Analysis	Systems Trade Off, Sensitivity	Frequency Allocations	Shield Penetration, Holes, Cables, Etc.	Structural Placement Architecture	Cable Architecture	Test: Environment Architecture	461 Series Mil Std	449	6051 Aircraft	Mitigation Components (Land Facilities)	Management Tools: Standards - Specifications	Control Plans/Procedures/Methodologies	Maintenance	Training	Fleet and Aircraft Reporting of EMC Problems and Corrections	Corporate Memory: Equipment Characteristics	Documentation of Problems	Handbooks	Summary of Environment Measurements or Publications	Data Prediction Base	Mitigation Technique: Cables/Cable Shielding	Decoupling	Blanking	Signal Processing	Shields	Bonding	Optical Fibers	Side Lobe Reduced Antenna, Array Configs	Nonlinear Mitigation Methods	Composite Materials
15 Naval Ship Weapon Systems Engineering Station, Port Hueneme, Ca. 93043, F.W. Ervast 6220										x	x			x	x	x		x		x													
16 Naval Underwater Systems Center, New London, Ct 06320, W. Prysner/D. McQueeny/R.J. Johnston EA33	x	x	x			x	x	x	x	x	x			x	x	x		x		x	x	x	x	x				x	x	x			
17 Naval Research Laboratory, Washington D.C. 20375, L. Rohaka/R. Anderson 8320			x	x	x				x				x	x					x			x				x	x			x	x		
18 Naval Civil Engineering Laboratory, Pt. Hueneme, Ca 93041, D.B. Clark L62	x								x		x			x								x	x										
19 Lawrence Livermore Laboratory, P.O. Box 808, Livermore, Ca 94550, E.K. Miller L156	x		x	x		x									x		x			x	x	x	x										x
20 I.I.T. Research Institute, 10 W. 35th St., Chicago, Il. 60616, J. Krstansky/J. Bridges Div. E	x	x	x	x	x	x		x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x		x	
21 G.A. Tech/Engineering Experiment Station, Atlanta, Ga 30332, H. Denny	x	x	x	x		x	x		x	x	x		x	x	x		x				x	x	x	x	x	x	x	x	x				
22 Southwest Research Institute, P.O. Drawer 28510, San Antonio, Tx 78284, W. Carey		x				x	x		x	x	x			x								x		x	x			x	x				
23 Sanders Associates Inc., Nashua, N.H.	x		x	x	x				x	x	x	x		x	x	x		x	x	x		x	x		x	x	x						
24 McDonnell Aircraft Co., Box 516, St. Louis, Mo 63166, D.W. Clifford/E.H. Schulte												x										x											
25 Boeing Aerospace Co., P.O. Box 3999, Seattle, Wa 98124, L. Carlson	x	x	x	x		x	x		x	x	x	x		x	x	x						x	x	x	x			x	x				x
26 University of Pennsylvania, Philadelphia, Pa, R. Showers		x				x		x																x	x		x	x	x				

TABLE 6.3

INTERNAL EMC INTRASYSTEM INTERFERENCE/CROSS TALK COUPLING

	Analysis					Test			Management Tools					Corporate Memory					Mitigation Techniques							
	Environment Prediction	Pickup Prediction	Degradation Analysis	Limit Apportionment	Cable/Shield Architecture	Mitigation Component Test 220, 285, etc	6051 Aircraft	461 Series Mil-Stds	Standards-Specifications	Procedures-Methodologies	Maintenance	Training	Problem Reporting	Equipment Characteristics	Documentation of Problems	Handbooks	Summary of Environment Measurements of Publications	Data Prediction Base	Shields	Optical Fibers	Cables	Terminal Treatment	Arrangement Decoupling	Grounding	Bonding	Composite Materials
1 Naval Electronics Systems Command Washington D.C. 20360 S.Caine/C.Neill Elex 51024									x							x										
2 Naval Air Systems Command Washington D.C. 20301 Cdr. B Short/J.J. Fisher Air 5330									x	x	x	x	x		x	x	x	x								x
3 Naval Sea Systems Command Washington D.C. 20360 Cdr. R. Grave/J.C. McEachen Sea 06T										x	x	x	x	x	x	x	x	x								
4 Electromagnetic Compatibility Analysis Center Annapolis, Md 21402 J. Hodges ACY	x	x	x	x					x	x				x		x	x	x	x		x	x	x	x		
5 Naval Ocean Systems Center San Diego, Ca. 92152 R.O. Jensen/J.W. Rockway 016	x	x	x						x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
J.D. Witt/W. Chase/G. Salisbury 81			x							x	x		x		x											
6 Naval Surface Weapons Center/Dahlgren Dahlgren, Va. 22448 L. Lysher DF-50	x	x			x	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	
7 Naval Air Test Center Patuxent River, Md 20670 R.F. Lane SY-83	x		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x	x
8 Naval Weapon Center China Lake, Ca. 9355 R.J. Christiansen/F. Harris 3525	x	x	x	x	x	x		x	x	x			x		x	x	x	x	x		x		x			
9 Pacific Missile Test Center Pt. Mugu, Ca. 93042 K. Cmaga 3242/R.L. Horn 1234	x					x	x	x	x	x	x	x	x		x		x	x								
10 Naval Weapons Support Center Crane, In. 47522 R. Van Winkle/R. Plew 3026						x		x	x								x									
11 Naval Air Development Center Warminster, Pa. 18974 R. Nussbaum 2033	x		x					x	x	x	x		x	x	x	x	x	x								
12 Naval Ships Engineering Center Washington D.C. 20360 J. Romm/F. Prout 6174																										
13 Naval Postgraduate School Monterey, Ca. 93940 R.W. Adler/J.E. Ohlson 62		x								x		x				x	x	x								
14 Naval Avionics Facility Indianapolis Facility D. Fossburg B/441	x						x	x	x	x				x			x									

TABLE 6.4

INTERNAL EMC INTRASYSTEM INTERFERENCE/CROSS TALK COUPLING

Agency/Individual	Analysis								Test			Management Tools					Corporate Memory					Mitigation Techniques				
	Environment Prediction	Pickup Prediction	Degradation Analysis	Limit Apportionment	Cable/Shield Architecture	Mitigation Component Test 220,285,etc.	6051 Aircraft	461 Series Mil-Stds	Standards-Specifications	Procedures-Methodologies	Maintenance	Training	Problem Reporting	Equipment Characteristics	Documentation of Problems	Handbooks	Summary of Environment Measurements of Publications	Data Prediction Base	Shields	Optical Fibers	Cables	Terminal Treatment	Arrangement Decoupling	Grounding	Bonding	Composite Materials
15 Naval Ship Weapon Systems Engineering Station, Port Hueneme, Ca 93043																										
F W Ervast 6220								x	x	x	x		x		x											
16 Naval Underwater Systems Center, New London, Ct 06320																										
W Prysner/D McQueeny/R J Johnson EA-33	x	x	x	x	x			x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	
17 Naval Research Laboratory, Washington D.C. 20375																										
L Ruhnke/R Anderson 8320	x					x																x				
18 Naval Civil Engineering Laboratory, Pt Hueneme, Ca 93041																										
D B Clark L62																										
19 Lawrence Livermore Laboratory, P.O. Box 808, Livermore, Ca 94550																										
E K Miller L-156	x	x	x							x		x			x	x	x	x					x			
20 I.I.T. Research Institute, 10 W 35th St., Chicago, IL 60616																										
J Krstansky/J Bridges Div. E																										
21 G.A. Tech/Engineering Experiment Station, Atlanta, Ga 30332																										
H Denny	x	x	x	x	x	x		x	x	x		x				x			x		x		x	x	x	
22 Southwest Research Institute, P.O. Drawer 28510, San Antonio, Tx 78284																										
W Carey		x				x		x	x																	
23 Sanders Associates Inc, Nashua, N H	x		x			x	x	x	x	x					x	x			x	x	x			x	x	
24 McDonnel Aircraft Co, Box 516, St Louis, Mo 63166																										
D W Clifford/E H Schulte	x	x			x	x	x	x	x								x		x		x	x	x	x	x	x
25 Boeing Aerospace Co, P.O. Box 3999, Seattle, Wa 98124																										
L Carlson	x	x	x	x	x	x	x	x	x		x								x		x	x	x	x	x	x
26 University of Pennsylvania, Philadelphia, Pa																										
R Showers	x	x	x	x	x														x	x	x	x	x	x	x	

TABLE 6.5

EMC CAPABILITIES IN THE ACQUISITION CYCLE

	CONCEPT	VALIDATION	FULL-SCALE DEVELOP.	PROD.	DEPLOYMENT
CONCEPTUAL SUPPORT					
EMCAB/Control Plan & Procedures	*	*	*	*	
Requirements Preparation	*				
TECHNOLOGY DEVELOPMENT & UTILIZATION					
Measurement Techniques/Instrumentation		*	*	*	*
Analysis & Performance Prediction	*	*	*	*	*
Interference Reduction Techniques	*	*	*	*	*
DESIGN GUIDES					
Mitigation Devices		*	*	*	*
DATA BASE & INFORMATION EXCHANGE					
EME Definition & Simulation	*	*	*	*	*
Equipment Characteristics	*	*	*	*	*
TEST & EVALUATION					
Platform, System, Equipment & Component		*	*	*	*
SPECIFICATIONS AND STANDARDS					
Define, Revise, Modify	*	*	*	*	
FREQUENCY MANAGEMENT					
Allocation	*	*	*	*	
Assignment			*	*	*
Usage					*
TRAINING & EDUCATION	*	*	*	*	*
PRODUCTION SUPPORT				*	
OPEVAL/TECHEVAL SUPPORT					
FLEET SUPPORT					
Identify, Report & Fix Problems					*

The Numerical Electromagnetic Code (NEC) has matured into a useful tool for design and validation of shipboard HF antenna systems. VHF and UHF capabilities will soon be added. NOSC is cosponsoring the NEC development in conjunction with the Air Force Weapons Laboratory (AFWL).

6.2.4 Interference Reduction Techniques

Interference reduction techniques consist of varied capabilities from the location of worst source of intermodulation interference to ferrite circulators for the isolation of transmitters and receivers. Efforts are underway to develop adaptive filters, electronically tunable filters and fiber optics systems.

6.2.5 Design Guides

Design guides for EMC are mostly in the personal libraries of qualified engineers at each laboratory. As a result, it is not easy to locate a particular type of guidance quickly.

6.2.6 Mitigation Devices

Development and utilization of mitigation devices is on a par with the rest of the EMC community. Recent developments include digital filters, wideband multicouplers, power system filters, high power rotary joints, low susceptibility receiver front ends, fiber optics lines and devices for handling frequencies above 40 GHz.

6.2.7 Data and Information Handling

In general it is quite difficult to obtain current, accurate, usable EME and equipment characteristic data when trying to determine system performance. ECAC should provide a central location for data but one finds needed data scattered through the Navy and in many different formats.

6.2.8 Test and Evaluation

The one aspect of EMC support which is most widely distributed is the test and evaluation (T&E) capability. Most T&E facilities are NAVAIRs, used on aircraft and missiles. Ships do not undergo full scale threat T&E in closed facilities but rather in normal sea environments. The EMPASS aircraft maintained by NSWC/DL provides this capability for ships. Widespread capabilities also exist for T&E equipment and components.

6.2.9 Specifications and Standards

The lag in updating and developing specifications and standards is not due to a lack of capability by NAVELEX but is rather a characteristic of the DoD process of iterative review and approval. Additional personnel support would help to effect some improvement in this situation.

6.2.10 Frequency Management

Electromagnetic Compatibility Analysis Center (ECAC) has overall capability for frequency management, and is qualified to assist in analysis of Navy Frequency Management Center's work. Technical support is available at NSWC/DL and NOSC. Overall capability is usable but not optimum.

6.2.11 Training and Education

A Navy-wide coordination of EMC training efforts is possible, but has not yet occurred. Potential resources exist at locations such as NATC, NWC, NOSC and NPGS. When fully utilized, the capability can be assessed.

6.2.12 Production Support

Excellent facility support exists and is readily available to production contractors. Many locations can provide such assistance, i.e., NWC, NATC, NAFI and NOSC.

6.2.13 OPEVAL/TECHEVAL Support

The vast test and evaluation capability within the Navy can be exploited for OPEVAL/TECHEVAL support when needed.

6.2.14 Fleet Support

The SEMCIP Program administered by NAVSEA and supported by NAVSEC, NAVELEX, NSWC/DL, and NOSC is the major fleet EMC support effort. Problem identification is the most critical phase and most difficult to achieve.

6.2.15 Summary

The Navy in-house capability to provide EMC support at all phases of the acquisition cycle is adequate at the present time. Successes in achieving EMC can be traced to wide management usage of the available resources.

6.3 Deficiencies in EMC Capabilities

The following discussions demonstrate that in spite of possessing a very useful EMC capability, the U.S. Navy has many areas of deficiencies which should be investigated and if improved upon will make a noticeable impact on the state of compatibility of air and sea platforms.

6.3.1 Technology Development and Utilization

The most critical need is to provide a management and support program to ensure the effective transfer of technology to the ultimate user and system. Insufficient utilization of technology has restricted the application of EMC early in the acquisition cycle. NAVMAT must provide the plan to transfer technology and NAVAIR, NAVSEA and NAVELEX must execute that plan. Sibling rivalries of laboratories must be set aside, perhaps by coordination through some "neutral" agency.

6.3.2 EMC Design Practices

Navy-wide EMC design practices should be promulgated through the development of analytical models which are made available to all users through the mechanism of user training. Again, NMC must control that process.

The EW design community can be criticized for not properly considering EMC in ECM/ESM designs. NRL is identified as playing the lead role in the reduction of EMI and the increase of effectiveness in EW systems.

6.3.3 Analysis

In the area of analysis and performance prediction, the NMC-coordinated efforts to produce automated numerical methods for EMC such as system performance degradation, design guides and installation and integration practices will improve our capability to:

A. Establish operational procedures at the conceptual phase which can reduce EMI in situations where fix-up or redesign is impractical.

B. Introduce EMC analysis into the TECHEVAL process to reduce costly patch-ups which are less than optimal.

C. Perform the systems design functions of selection, arrangement and performance determination more completely than now is possible.

Under NMC's guidance, current computer code developments should continue at NOSC, NUSC, NAVSEC, and ECAC, but only if proper coordination is forced. Reduced financial and manpower resources demand this be the case. Wasteful competition, if continued, can only delay this vital work.

6.3.4 Performance Criteria for Analysis Tools

An assessment of the relative merits of particular analytical procedures for different applications is unavailable to the user. ECAC should develop user orientated performance criteria and conditions of applicability for program manager level people. Doing this, and making the results available to the EMC community will increase the usage of such techniques throughout the DoD, and give the user a rational basis on which to make decisions.

6.3.5 Data Base Management

ECAC is the DoD agency designated as the manager of an up-to-date, rapid access data base so vital to increased utilization of environment/equipment/system data. The increased utilization of machine analysis techniques simply cannot occur without data base availability. Any further delay in ECAC's efforts in this area will seriously affect the desired improvements in EMC analysis in all acquisition cycle phases.

6.3.6 Test and Evaluation

Capability to perform tests and evaluations is greater than the capability to perform measurements to verify system performance and compatibility. All test and evaluation facilities need to actively pursue this in conjunction with the development by technologists of system performance codes. No machine capability is useful unless a validation effort parallels it so that confidence in it is established in the eyes of the users.

6.3.7 Specifications and Standards

The most needed capability improvement in this area is to develop tailoring guidelines for use by engineering personnel. NAVELEX 051 as designated agent cannot perform this function alone. NMC must provide support to NAVELEX in the form of experienced system engineers. NUSC, NATC, NOSC, NSWC/DL and NWC have all demonstrated capability and should be considered prime candidates for providing this support.

The streamlining of the specifications and standards revision process to keep specifications and standards more current than they are at the present time can be accomplished by identification and utilization of the most qualified personnel and by the reduction of number of participants in the revision process, and by provision of additional funds. DoD, NMC and NAVELEX are responsible agents for this action.

Standardization of installation and integration practices for platforms with similar missions has been cited as a needed capability. This is difficult to accomplish in that it requires Navy-wide coordination and study but the payoff of optimized platform configurations is deemed worth the effort. NMC again provides the lead in identifying all Navy facilities involved in platform integration and installation practices.

A central area in specifications and standards is the needed update to consider new systems employing phased arrays, spread spectrum, digital signal microprocessors, software, etc.

6.3.8 <u>Frequency Management</u>

Improved frequency management capabilities through use of currently available technologies will improve operational effectiveness by relieving current spectrum congestion and optimizing future spectrum usage. ECAC is a logical agency for coordinating this activity with groups at NSWC/DL and NOSC.

6.3.9 <u>Training and Education</u>

Increased EMC awareness by management personnel has been given only lip service to date. It is now time to establish on-site customized short courses and updates and to establish technical information exchange programs in order to increase EMC technology utilization, especially early in the acquisition cycle. NMC-directed efforts by NPGS can tap resources throughout the Navy technical community.

6.3.10 <u>Fleet Support</u>

Upgrading EMC support during deployment through training of fleet personnel in identifying and reporting EMC problems will assist in the correction of those problems. Ship improvements are currently being pursued by SEMCIP teams but NAVAIR has no aircraft counterpart and must be directed to develop one at once. The present process of going back to airframe contractors is too costly and too slow. Maintenance, overhaul and backfit personnel should be able to call EMC evaluation teams on a QRC basis. OPNAV, NMC, NUSC, NOSC, NAVSEC, NATC, and NWC have primary responsibility in this capability improvement. Operational problem feedback should become a part of the documentation that comprises the Navy corporate memory and should be stored in a centralized location for easy retrieval.

6.4 Summary of Deficiencies in EMC Capabilities

The Navy capabilities in EMC are not currently being fully utilized by cognizant management personnel. Support to acquisition cycle personnel is available but increased usage will not happen without awareness enhancement and without orientation of the technology towards the user, by being both accessible and timely. Most EMC technology is being put to some use, if only by the developers of it. Technology transfer will change that and start producing a higher rate of payoff for those continuing 6.2 technology programs by placing new capabilities in the hands of the users. NMC holds the keys of authority to initiate the needed capabilities improvements. Additional funding will most likely not be available for this work, therefore, more efficient utilization of currently available resources and manpower has to be instituted by NMC, simultaneously with capability enhancement. All existing personnel in laboratories and facilities can be assured of the continuation and improvement of present efforts which should relieve competitive pressure.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The following sections will discuss the conclusions and recommendations which are an outgrowth of the EMC survey. The conclusions and recommendations will be grouped under general headings for ease of reference even though overlaps between topics exist.

7.1 Analysis

The status of analysis technology is mixed. Ability to conduct EMC analysis ranges from high confidence for in-band antennas to antenna calculations to low confidence for out-of-band antenna to cable interactions in a complex environment via obstructed paths. Shielding and cable coupling theory is adequate for complex shapes and complex environments. It should be recognized that detailed high accuracy mathematic models and computer-aided analysis are not always necessary. In the early stages of a program such as concept formulation and validation, low precision models are adequate to perform concept design tradeoffs and EMC culling procedures. Thus, the prediction capabilities and accuracies required of analysis should be commensurate with the needs at the various phases of the acquisition process. In order to support these analytical needs, the technologists should provide interim outputs from their efforts which, although not perfected to the level desired by the technologist, provides useful tools and procedures to the user community.

Any model or computer-aided analysis procedure requires input data to produce a result. At the present time, a comprehensive data base, including spectrum signature data for recent equipment, is not available. This is mostly due to the cost of collecting spectrum signature data and the fact that measured data from MIL-STD-461 type tests is frequently not submitted to the Navy or ECAC. Some of the data which might be useful for EMC analysis is scattered through the various Navy agencies and is difficult to locate and retrieve.

A number of efforts are ongoing to implement or adapt various intrasystem analysis computer programs such as COSAM, IEMCAP, etc., to meet Navy needs. There may be a tendency for each laboratory to develop its own unique version of this capability.

In view of the above comments the following recommendations are made.

- The Navy should develop a standard intrasystem (cosite) EMC analysis program such as an adaption of COSAM, IEMCAP or a combination of the best features of available programs to be used by all Navy agencies.
- A centralized data base, either at ECAC or within the Navy, formatted for use with the standard intrasystem program should be established.
- A specification should be developed, possibly a combination of MIL-STD-461 and MIL-STD-449, to provide the measurement techniques and data formats to measure simplified spectrum signature data for the centralized data base.
- Effort should be continued to improve model subroutines for the analysis program. Models for cable coupling and shield penetration should be developed as part of this effort.

7.2 Test

Current test procedures, as outlined in standards and specifications, are outdated and in many cases do not provide test data useful for analysis. In some cases, such as MIL-E-6051, the procedures are too general. Instrumentation and test procedures for measurements in complex environments are inadequate. Test procedures for in-situ EMC tests and maintenance are essentially nonexistent.

At the platform level, with the possible exception of aircraft, there are no formal EMC acceptance test procedures. Improvements are needed in MIL-E-6051 to address the intrasystem EMC. Intersystem tests and environments for ships are not usually defined. NATC is developing such a capability for aircraft.

The following recommendations are made:

- A modified spectrum signature measurement procedure should be developed to reduce costs of conducting these tests.
- Test procedures should be developed for EMC acceptance tests of Navy platforms. The question of whether to include an external environment capability in these tests should be addressed.

- In-situ test procedures for maintenance and system acceptance should be developed.
- A cost/benefit study should be conducted to determine what data is both practical to measure and useful for EMC analysis.
- A centralized test data bank should be established.
- A standard method should be developed to record and document system and platform test results for inclusion in the corporate memory.

7.3 Management Tools

One of the most useful tools a program manager can employ is the EMCAB (EMC Advisory Board). In order to be most effective, the EMCAB should be established in the conceptual stages of the project or program. The EMCAB should be maintained throughout the life cycle of major systems even though EMCAB personnel may change as the system progresses through various phases of the life cycle. The establishment of an EMCAB provides the program manager a method of controlling his EMC program.

The program manager and the EMCAB, as part of their EMC program, should ascertain the status of existing technology that is applicable to their program and plan to utilize these resources. A documentation and reporting plan and schedule is required in order for the program manager and EMCAB to know what is going on. In addition, an important facet of the documentation is that it be included in the corporate memory.

Management should be made aware that it is impossible, in a practical sense to achieve 100% EM compatibility. The nature of the coupling interactions in a typical platform is so complex that at best, the results of analysis and tests must be treated statistically. Thus, the program manager must expect that on a statistical basis, he will experience interference during the operational phase of his system.

In general, program managers do not appreciate the importance of frequency allocation and assignment either as a requirement for their system or its applicability as a technique for mitigating operational EMC problems.

Standards and specifications should be applied realistically. This can be done by appropriate tailoring of the specifications for the specific application.

There is a need for a systems oriented approach to EMC. An integrated EMC program which includes integration of technology development, specification tailoring, and installation practices and harmonizing this procedure with other EME disciplines appears to offer cost/benefit returns.

A need exists to establish formal EMC training and maintenance procedures and to generate appropriate documents to be incorporated into current training and maintenance procedures for the operational Fleet. The following recommendations are made:

- The program manager should establish an EMCAB in the conceptual phase of his program or project.
- A documentation and reporting schedule should be established. Documentation generated on the program should be sufficiently detailed to be included in the corporate memory.
- The importance of frequency allocation and assignment as a requirement and operational EMC technique should be documented and distributed to the appropriate program managers and EMC personnel.
- EMC should be included in the operational requirements.
- Program managers should be made aware of the capabilities and techniques available to achieve EMC, the advantages and limitations of the techniques, and the need for timely use of these capabilities.
- A technology transfer function should be established to bridge the gap between technologist and user.
- EMC should be incorporated into the current training curriculum.
- EMC maintenance procedures should be developed and integrated into current maintenance requirements of the operational Fleet.

7.4 Corporate Memory

At the present time, the Navy has no centralized corporate memory (CCM) or data bank which serves as a repository for the documented EMC experience and capabilities of the various agencies and laboratories. Some data exists at ECAC in their data files, however, much useful data is scattered in the files of individuals at the various Navy agencies and laboratories. There is a need for this information and data to be centralized for ease of location and retrieval.

The potential sources for the corporate memory include:

- Program documentation on the various Navy projects. The EMCAB should arrange to provide the appropriate EMC data to the CCM.
- Results of standard and specification testing, i.e., MIL-STD-461 or MIL-STD-449.
- EMC problem feedback from the fleet, i.e., SEMCIP.

Development of a corporate memory would overcome some deficiencies in current procedures such as lack of data, redundant efforts, inconsistent documentation, etc.

Rationale for choice of EMC standards and specifications and decisions on tailoring specifications or waivers on requirements should be documented and made part of the corporate memory.

The following recommendations are made:

- A centralized corporate memory (EMC library) should be established within the Navy or ECAC.
- A formal procedure for reporting procedures to the corporate memory should be established.
- A corporate memory plan should be established by each program or project. The plan should require appropriate documentation of all EMC activities related to the project over the life cycle of the system.
- The EMC documentation from programs, projects and laboratory activities should be submitted to the centralized corporate memory.
- The corporate memory information should be made readily available to other interested parties within the Navy and DoD or by appropriate channels to it's contractors.

7.5 Mitigation Techniques

A high level of Navy capability exists with mitigation techniques. This capability is satisfactorily supporting the operating fleet. However, more application of this technology is required at an earlier stage in the acquisition cycle, so that costly retrofits can be avoided.

Many mitigation techniques are developed on a case-by-case basis and are not shared with the EMC community. Proper documentation and storage in a central data base will greatly assist engineers in trouble shooting. Off-the-shelf components frequently do not have enough design data for application in "non-ideal" situations, i.e., mismatched impedances, etc. Out-of-band performance of components is not adequately measured and documented for EMC applications. This information needs to become part of a central corporate memory.

The specifications and standards in regards to mitigation devices are essentially non-existent. Standards are needed to measure performance parameters in a variety of environments and situations. These parameters can be used in analysis prediction and also serve in the corporate memory in a variety of ways.

The rapid developments in the microwave semiconductor, digital and microcircuit technologies are having an impact on Navy equipment. The EMC aspects of microwave semiconductors, microprocessors and digital controllers needs to be addressed. There are both hardware and software aspects to investigate.

New technology, particularly digital equipment, will play an increasingly large part in the Navy's electronic capability. This is particularly true in the mitigation technique field. Efforts to develop the support for these new devices needs to be undertaken.

7.6 Specifications and Standards

Standards require extensive coordination and long periods of time to secure adoption. Because of iterative review and approval processes they are difficult to revise. Current standards and specifications are too lax or stringent, frequently incomplete, and do not cover important interactions or new technologies.

In many instances, specifications and standards are frequently waived even after considerable amounts of funds and manpower are expended, resulting in lack of EMC.

The lag in updating standards is endemic to the system and probably cannot be improved upon. Specifications on the other hand, are capable of being modified for procurement purposes. Thus, specifications can be tailored to suit the particular application after technical/economic tradeoffs are implemented. Various EMC technologies ranging from culling procedures to analytical prediction programs are available to allow the technical tradeoffs to be made. Economic considerations are a management responsibility and would be considered in the technical/economic tradeoff process.

The measurements included in MIL-STD-449 for spectrum signature data are too expensive to implement. The MIL-STD-461 measurements, which are usually specified in procurement contracts, are based on go-no go limits. It appears that MIL-STD-461 could be modified to provide simplified spectrum signature data which would serve the purposes of qualifications testing and provide information for the ECAC and corporate memory data bases.

The following recommendations are made:

- MIL-STD-461 should be modified to provide simplified spectrum signature data and updated to cover new technologies.
- MIL-STD-220 should be modified to obtain filter parameters which can be used for prediction of filter performance in a wide range of applications.
- A procedure should be developed for tailoring specifications to specific situations; for example, reducing or increasing limits, as required.
- Research in the preparation of standards, including technical, economic, and administrative factors, is needed to make standards more objective and usable.
- A procedure should be developed, based on technically and economically objective considerations, for waiving requirements.

8.0 RELATIONSHIP OF EMC TO OTHER EME DISCIPLINES

There appears to be a good deal of commonality among the various EME disciplines. This point has been made in this report as well as by observers of the manner in which the various disciplines ply their trade. In most cases, the similarities are close enough that essentially the same community of people work across the various disciplines. In other cases, such as ECM/ECCM, the discipline has drawn its own dedicated devotees.

Table 8.1 indicates technical areas where some form of commonality occurs. This commonality can range from analytical methodologies to mitigation techniques. This is not to imply that these technologies are readily interchangeable in all cases, but that with some modification of approach the techniques can generally be made applicable to a wider variety of problems.

The EMC discipline has one unique feature not normally considered by the others. This is the area of frequency allocation and assignment. Frequency assignment, judiciously used, can mitigate some forms of interference problems. This technique is, in general, not available to the other disciplines although it should be pointed out that some can be affected by choice of frequency assignments (i.e., safety).

Since the various EME disciplines share a common electromagnetic environment, there is obviously an interaction of all of the EM activities. In most cases this interaction is uncoordinated because of a lack of a centralized responsibility for the activities that impact the EM environment. In view of the commonality indicated in Table 8.1, a fruitful area for optimization of activities affecting the EME should be assignment of responsibility for and coordination of the EME activities of the various users of the EME, either intentional or unintentional, to a central authority.

TABLE 8.1

COMMONALITY AMONG EMC/EMI VS OTHER EME DISCIPLINES

EMC/EMI	EMV	EMP	ECM/ECCM	EM SAFETY	EM POWER
I. ANALYSIS					
ENVIRONMENT PREDICTION	*			*	
PICK-UP	*	*	*		
DEGRADATION ANALYSIS	*	*	*		
SHIELD PENETRATION	*	*		*	
SYSTEM TRADEOFF	*	*		*	
CABLE ARCHITECTURE		*		*	*
STRUCTURAL ARCHITECTURE	*	*		*	*
FREQUENCY ALLOCATION					
II. TEST					
ENVIRONMENT MEASUREMENTS	*			*	*
INTERSYSTEM STANDARDS	*	*			
INTRASYSTEM STANDARDS				*	*
MITIGATION COMPONENTS	*	*	*	*	*
III. MANAGEMENT TOOL					
STANDARDS & SPECIFICATIONS	*	*		*	*
CONTROL PLANS METHODOLOGIES		*		*	
MAINTENANCE	*	*		*	
TRAINING	*	*		*	
FLEET & A/C REPORTING				*	

*Indicates some commonality in technique, method, data, objective, etc.

TABLE 8.1 (CONTD)

COMMONALITY AMONG EMC/EMI VS OTHER EME DISCIPLINES

EMC/EMI	EMV	EMP	ECM/ECCM	EM SAFETY	EM POWER
IV. CORPORATE MEMORY					
EQUIPMENT CHARACTERISTICS	*	*		*	
DATA BASE	*	*		*	
SUMMARY OF ENVIRONMENT PUBS	*				
HANDBOOKS		*		*	
DOCUMENTATION OF PROBLEMS	*			*	
V. MITIGATION TECHNIQUES					
SHIELDS	*	*		*	*
OPTICAL FIBERS	*	*			*
CABLES CABLE SHIELDS	*	*		*	*
DECOUPLING		*	*	*	
BLANKING			*		
SIGNAL PROCESSING	*	*	*		*
BONDING	*	*		*	*
SIDELOBE REDUCED ANTENNAS		*	*		
NONLINEAR MITIGATION METHODS	*	*	*		*
COMPOSITE PROBLEM	*	*		*	

*Indicates some commonality in technique, method, data, objective, etc.

REFERENCES

Cummings, J.R., "Harpoon Missile EMC Management," Avionics Technical Note, McDonnell Douglas Astronautics Company - East.

Dubrul, D., and L. Peters, Shipboard Antenna and Topside Arrangement Guidance, NELC TD-356, 1 September 1974.

NAVAIR AD1115, "Electromagnetic Compatibility Design Guide for Avionics and Related Ground Support Equipment", December 1975.

NAVELEX 0101,106, "Naval Shore Electronics Criteria - Electromagnetic Compatibility and Electromagnetic Radiation Hazards", August 1971.

NAVAIR 5335, "Electromagnetic Compatibility Manual"

AFSC DH1-4, "Electromagnetic Compatibility Design Handbook", January 1975.

NAVSEA 0967-LP-283-5010, "Handbook of Shipboard Electromagnetic Shielding Practices", December 1976.

APPENDIX A

A TABULATION OF MILITARY SPECIFICATIONS AND STANDARDS

SPECS AND STANDARDS

NUMBER		TITLE
MIL-E-6051D	5/68	Electromagnetic Compatibility Requirement Systems.
MIL-STD-461A	7/73	Electromagnetic Interference Characteristics Requirements for Equipment.
MIL-STD-462	2/71	Electromagnetic Interference Characteristics Measurement.
MIL-STD-463	9/66	Definitions and System of Units, Electromagnetic Interference Technology.
MIL-STD-469-1	3/67	Radar Engineering Design Requirements Electromagnetic Compatibility.
MIL-HDBK-235-1	6/72	Electromagnetic (Radiated) Environment of Electrical and Electronic Equipment, Part I.
MIL-I-6181D	6/69	Interference Control Requirements Aircraft Equipment.
MIL-I-11683A Cancelled Superseded by MIL-E-55301		Interference Suppression, Radio Requirements for Engine Generators and Miscellaneous Engines.
MIL-STD-01310B	11/7	Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Compatibility and Safety Reliability Reports.
MIL-STD-1377	8/71	Effectiveness of Cable, Connector and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance, Measurement of.
MIL-STD-1385	4/72	Preclusion of Ordnance Hazards in Electromagnetic Fields: General Requirements for.
MIL-HDBK-237	4/73	Electromagnetic Compatibility Interference Program Requirements.
MIL-F-15733E(2)	4/72	Filter, Radio Interference, General Specification for.
MIL-HDBK-238	8/73	Electromagnetic Radiation Hazards.
AR-43		Electromagnetic Compatibility Advisory Board, Requirements for.
AR-46A		Aeronautical Requirements Hero (Hazards of Electromagnetic Radiation to Ordnance; Requirements for Hero Test, Ordnance and Documentation.
MIL-R-9673B(2)		Radiation Limits, Microwave and X-Radiation Generated by Ground Electronic Equipment (As Related to Personnel Safety).
NAT-STD-3614 NATO STANAG	1/76	Electromagnetic Compatibility.

SPECS AND STANDARDS (Cont.)

NUMBER		TITLE
MIL-STD-1541		Electromagnetic Compatibility Requirements for Space Systems.
NAT-STD-3516	11/7	Electromagnetic Compatibility Test Methods for Aircraft Electrical and Electronic Equipment.
MIL-STD-826A USAF	5/70	Electromagnetic Interference Test Requirements and Test Methods.
MIL-HDBK-54 ARMY	10/6	Electromagnetic Testing for (for Inspection of Material (Handbook H-54)).
MIL-I-16165D SHIPS	8/61	Interference Shielding, Engine Electrical System.
MIL-HDBK-235-1&2 NAVY		Electromagnetic (Radiated) Environment of Electrical and Electronic Equipment, Part I.
WR-101, Part I		Electromagnetic Control Requirement for Advanced ASW Avionics System.
MIL-B-5087B	8/70	Bonding, Electrical and Lightning Protection for Aerospace Systems.
MIL-W-5088C	6/74	Wiring, Aircraft, Installation of.
MIL-P-24014 Cancelled Superseded by MIL-STD-1385		Preclusion of Hazards from Electromagnetic Radiation to Ordnance, General Requirements for.
MIL-D-8706D		Data and Tests, Engineering; Contract Requirements.
MIL-8708B	1/69	Demonstration Requirements for Airplanes.
MIL-STD-449D	1/73	Radio Frequency Spectrum Characteristics, Measurement of.
MIL-STD-454	3/76	Standard General Requirements for Electronic Equipment.
MIL-STD-704		Electric Power, Aircraft, Characteristics and Utilization of.
NACSEM 5100		TEMPEST Requirements.
NACSEM 5112		TEMPEST Control Plan.
AIR-STD-12/19	4/76	EMC Test Methods for A/C Electrical and Electronic Equipment.
MIL-STD-1512	3/76	EE Subsystems Electrically Initiated, Design Requirements and Test Methods.
NVCSF		Survivability A/C
NAVMAT		2410.2
NAVAIR		3920.1
ADO		48.16 dtd 11/71.

SPECS AND STANDARDS (Cont.)

NUMBER	TITLE
EQUIPMENT DESIGN AND TESTING	
MIL-I-61810	Interference Control Requirements Aircraft Equipment dtd 6/50.
MIL-STD-826A	EMI Test Requirements and Test Methods dtd 3/70.
MIL-E-60510	EMC Requirements Systems dtd 5/68.
MIL-I-11683A	Interference Suppression, Radio Requirements for Engine Generators and Miscellaneous Engines.
MIL-I-16165D	Interference Shielding, Engine Electrical Systems dtd 8/61.
MIL-STD-461A	EMI Characteristics, Requirements for Equipment dtd 7/73.
MIL-STD-462	EMI Characteristics, Measurements dtd 2/71.
MIL-STD-463	Definitions and System of Units, EMI Technology dtd 9/66.
MIL-STD-469-1	Radar Engineering Design Requirements, EMC dtd 3/67.
MIL-B-5087B	Bonding, Electrical and Lightning Protection for Aerospace Systems dtd 8/70.
MIL-HDBK-54	EM Testing for (Inspection of Material (Handbook H-54)).
MIL-STD-449	Radio Frequency Spectrum Characteristics, Measurement of dtd 1/73.
WIRING, CABLES, CONNECTORS, FILTERS	
MIL-F-15733E(2)	Filter, Radio Interference, General Specification for dtd 4/72.
MIL-W-5088C	Wiring, Aircraft, Installation of dtd 6/74.
POWER SPECS	
MIL-STD-704	Electric Power, Aircraft Characteristics and Utilization of.
ENVIRONMENT SPECS	
MIL-HDBK-235-1	EM (Radiated) Environment of Electrical and Electronic Equipment, Part I dtd 6/72.
HERO SPECS	
MIL-STD-1385	Preclusion of Ordnance Hazards in EM Fields; General Requirements for dtd 4/72.
MIL-P-24014	Preclusion of Hazards from EM Radiation to Ordnance, General Requirements for.

SPECS AND STANDARDS (Cont.)

NUMBER	TITLE
MIL-STD-1512	Electro-explosive Subsystems, Electrically Initiated, Design and Test Methods for dtd 1/76.
MIL-STD-1377	Effectiveness of Cable, Connector and Weapon Enclosure Shielding and Filters in Precluding Hazards of EM Radiation to Ordnance, Measurement of dtd 8/71.
AR-46A	Aeronautical Requirements HERO (Hazards of EM Radiation to Ordnance Requirements for HERO Test, Analyses and Documentation).
TEMPEST	
NACSEM 5100	TEMPEST Requirements.
SAFETY	
MIL-HDBK-238	EM Radiation Hazards dtd 8/73.
MIL-R-9673B(2)	Radiation Limits, Microwave and X-Radiation Generated by Ground Electronic Equipment (as Related to Personnel Safety).
PROGRAM PLANNING SPECS	
MIL-HDBK-237	EMC Interference Program Requirements dtd 4/73.
AR-43	EMC Advisory Board, Requirements for.
NUCLEAR SURVIVABILITY	
NAVMAT	2410.2
NAVAIR	3920.1
ADO	48-16 dtd 11/71
NUCUF	Survivability A/C

SPECS AND STANDARDS (Cont.)

NUMBER	TITLE
MIL-E-6051D	Electromagnetic Compatibility Requirements, Systems This specification outlines the overall requirements for systems electromagnetic compatibility, including control of the system electromagnetic environment, lightning protection, static electricity, bonding and grounding. It is applicable to complete systems, including all associates subsystem/equipments.
MIL-STD-461A	Electromagnetic Interference Characteristics Requirements for Equiment This standard covers the requirements and test limits for the measurement and determination of the electromagnetic interference characteristics (emission and susceptibility) of electronic, electrical and electromechanical equipment. The requirements shall be applied for general or multi-service procurements and single service procurements, as specified in the individual equipment specification, or the contract or order.
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of This standard establishes techniques to be used for the measurement and determination of the electromagnetic interference characteristics (emission and susceptibility) of electrical, electronic and electromechanical equipment, as required by MIL-STD-461.
MIL-STD-469	Radar Engineering Design Requirements, Electromagnetic Compatibility The engineering design requirements set forth herein are established to control the spectral characteristics of all new radar systems operating between 100 and 40,000 megahertz (MHz) in an effort to achieve electromagnetic compatibility and to conserve the frequency spectrum available to military radar systems.
MIL-HDBK-235-1	Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment - Part I The intent of this handbook is to provide guidance and establish a uniform approach for the protection of Navy electronics from the adverse affects of the electromagnetic environment. Examples of systems, subsystems and equipments for which this handbook may be applicable are as follows: (a) Aerospace and weapon systems and associated subsystems and equipments. (b) Ordnance.

NUMBER	TITLE
	(c) Support and check out equipment and instruments for (a) and (b) above.
	(d) Any other electronic equipment of subsystem which may be exposed to a high intensity electromagnetic environment during its life cycle.
MIL-I-618D	Interference Control Requirements, Aircraft Equipment This specification covers design requirements, interference test procedures, and limits for electrical and electronic aeronautical equipment to be installed in or closely associated with aircraft.
MIL-STD-1385	Preclusion of Ordnance Hazards in Electromagnetic Fields; General Requirements for This standard establishes the general requirements to preclude hazards resulting from ordnance having electro-explosive devices when exposed to electromagnetic fields. The nominal frequency range covered by this standard is from 10 kilohertz (10^4 Hertz) to 40 gigahertz (4×10^{10} Hertz).
MIL-B-5087B	Bonding, Electrical and Lightning Protection for Aerospace Systems This specification covers the characteristics, application and testing of electrical bonding for aerospace systems, as well as bonding for the installation and interconnection of electrical and electronic equipment therein, and lightning protection.
MIL-D-8706B	Data and Tests, Engineering: Contract Requirements for Aircraft Weapon Systems This specification embodies the requirements for engineering data to be furnished and investigations and tests to be conducted under contracts for aircraft weapon systems. This specification does not cover demonstration requirements which are specified in MIL-D-8708 or MIL-D-23222.
MIL-D-8708B	Demonstration Requirements for Airplanes This specification contains the general requirements of NAVAIR for the contractor demonstration of airplanes. It also describes reporting requirements relating to these demonstrations. In the procurement of Navy airplanes, these general requirements will be modified and amplified by contract addenda to this specification. The expression "demonstration" refers to any of the contractor's work (as applied to specific airplane models and contracts)

NUMBER	TITLE
	during development and as specified herein including modifications and amplifications contained in pertinent contractual documents. The modified and amplified requirements may limit the demonstration for a particular contract or airplane model to only a limited number of tests to be performed at a single location and, also, may contain requirements for the demonstration of features and characteristics not included in this general specification.
MIL-STD-704A	Electric Power, Aircraft, Characteristics and Utilization of This standard delineates the characteristics of electric power supplied to airborne equipment at the equipment terminals and the requirements for the utilization of such electric power by the airborne equipment.
MIL-STD-454C	Standard General Requirements for Electronic Equipment This standard covers some of the common requirements to be used in military specifications for electronic equipment.
MIL-STD-463	Definitions and System of Units, Electromagnetic Interference Technology This standard contains general interference definitions, abbreviations, and acronyms used in MIL-STD-461 and MIL-STD-462. Definitions of abbreviations and terms are limited to statements of meaning as related to this and referenced standards, rather than encyclopedia or textbook discussions. A basic fundamental knowledge of the principles of interference is assumed.
MIL-STD-1310C	Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Compatibility and Safety This standard sets forth methods for shipboard bonding, grounding and the utilization of non-metallic materials for the purpose of electromagnetic interference (EMI) reduction and the protection of personnel from electrical shock. In addition, methods for the installation of shipboard ground systems are also provided.
MIL-STD-1377	Effectiveness of Cable, Connector and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance; Measurement of This standard is intended to provide a weapon developer or designer with shielding and filter effectiveness test methods for determining whether the particular weapon design requirements of MIL-P-24014 have been properly implemented.

NUMBER	TITLE
	It is not intended to be a substitute for full-scale electromagnetic hazards evaluation tests of the weapon system, but rather an aid in developing a weapon system with a high probability of successfully passing such environmental tests.
MIL-HDBK-237	Electromagnetic Compatibility/Interference Program Requirements
	This handbook provides criteria for establishing, managing and evaluating an EMC program on electronic, electrical and electromechanical equipments, subsystems and systems. It provides EMC guidance to the project officer. The use of these guidelines should increase the probability for all subsystems and equipments within a system to be compatible (intrasystem compatibility) and for electromagnetic compatibility to exist between systems (intersystem compatibility). For brevity and clarity not all of the details have been included. The user shall consult with the proper departmental staff support organizations for these and other departmental policies.
MIL-HDBK-238	Electromagnetic Radiation Hazards
	This handbook addresses hazards due to electromagnetic radiation of the non-ionizing type except for the ionizing radiation of x-rays produced incident to operating electronic equipment. Electromagnetic Radiation Hazards (RADHAZ) affect personnel, sensitive electronic devices, explosive and fuels. The present state-of-the-art in the evaluation of existing hazards limits the determination of absolute safe levels of all frequencies.
AR-43	Electromagnetic Compatibility Advisory Board Requirements for
(Purpose)	This document describes the objectives, organizational structure, responsibilities and actions of an advisory body needed to assure that electromagnetic compatibility will exist within and between systems, subsystems and equipments to be procured by Naval Air Systems Command through industrial contracts.
(Scope)	This document covers the general requirements applicable to the formation and operation of an Electromagnetic Compatibility Advisory Board (EMCAB) on any contract that has electromagnetic compatibility requirements. The intent of this document is to establish the general framework within which such a board can be organized and operated in an effective manner. EMCAB tasks shall be characterized so that all appropriate tasks can be identified, presented to the members and acted upon as appropriate. Reports, agenda and other documentation are covered in detail.

SPECS AND STANDARDS (Cont.)

NUMBER	TITLE
AR-46A	Aeronautical Requirements HERO (Hazards of Electromagnetic Radiation to Ordnance) Requirements for HERO Tests, Analyses and Documentation This document establishes the procedures to be employed in obtaining HERO evaluation and certification. This document is primarily for use by the designers of air launched weapon systems, items and devices containing EEDs (electro-explosive devices) and their ancillary equipments which are intended for use in high intensity EMR (electromagnetic radiation) environments, such as the flight deck and other weather decks of combatant and ammunition supply ships, and at shore stations.
MIL-R-9673B	Radiation Limits, Microwave and X-Radiation Generated by Ground Electronic Equipment (as related to personnel safety) This specification establishes requirements for the preparation and submission by a contractor of data describing and defining radio-frequency (r-f) power density and x-ray characteristics for ground electronic systems, subsystems, equipments, components and end items procured by the U.S. Air Force, under a research, experimental, development, development-production or production contract. It furnishes guidance relative to Air Force policy regarding permissible levels of exposure to x-radiation and provides for the submission of x-ray survey data to the Air Force. This specification also covers the method by which sources, potential sources and hazards shall be identified.
MIL-F-15733E	Filter, Radio Interference, General Specification for This specification covers the general requirements for current-carrying filters, alternating-current (ac) and direct-current (dc), for use primarily in the reduction of broadband radio interference.
WR-101 Part I	Electromagnetic Control Requirements for Advanced ASW Avionics Systems, A-NEW This specification establishes the general requirements for an organized electromagnetic compatibility (EMC) program for the A-NEW Weapon System. The requirements specified herein constitute a minimum program to be conducted by all contributors to the A-NEW Program. The specification covers design requirements for grounding, bonding, cabling, control plans and electromagnetic interference (EMI) limits and test procedures that will be used as the A-NEW System approach to electromagnetic compatibility. It is mandatory that the design of all systems, subsystems, black boxes, etc., follow the criteria set forth for system EMI control.

SPECS AND STANDARDS (Cont.)

NUMBER	TITLE
MIL-W-5088F	Wiring, Aerospace Vehicle This specification covers the selection and installation of wiring and wiring devices used in aerospace vehicles. Aerospace vehicles include airplanes, helicopters and missiles.
MIL-STD-449D	Radio Frequency Spectrum Characteristics, Measurement of This technical standard establishes uniform measurement techniques that are applicable to the determination of the spectral characteristics of transmitters, receivers, antennas and system couplers.

INSTRUCTIONS

NAVMATINST 10380.9

Electromagnetic Environment Consideration in the Life Cycle of Navy Electronic/Electrical Equipments

This instruction assigns responsibility for promulgation of MIL-HDBK-235 and for insuring that prior to the design of components equipments, systems and platforms, proper consideration is given to the electromagnetic environment which may be encountered during their life cycle.

NAVAIRINST 4210.2

Electromagnetic Pulse (EMP) Protection within NAVAIRSYSCOM Procedures and Requirements for

This instruction provides procedures to be followed for implementing EMP protection within the NAVAIRSYSCOM as established by NAVMATINST 2410.2, "EMP Effects Program: Establishment of."

NAVMATINST 2410.2

EMP Effects Program: Establishment of

This instruction provides policy, assigns responsibilities, and delineates actions within the Naval Material Command to ensure that proper consideration to the potential effects from EMP is given in the life cycle of Navy components, equipments, systems and platforms, and to ensure that adequate guidance and criteria to counter EMP effects are developed and disseminated.

NAVSEAINST 2410.3

EMP Considerations within the Naval Sea Systems Command

EMP protection considerations, requirements and procedures apply throughout the Naval Sea Systems Command in the research, planning, design, development, construction, acquisition, modification, installation, maintenance, and production of individual surface and subsurface platforms and of the electronic/electrical equipments and systems installed therein.

AR-29

Frequency Allocation and Equipment Spectrum Signature Requirements

This document describes the procedures governing the contractor's collection and submission of spectrum signature and frequency allocation data for communication-electronic equipments or systems being developed or produced for the Naval Air Systems Command.

MIL-HDBK-241

Design Guide for EMI Reduction in Power Supplies

(Foreword)

This design guide has been developed to provide information relating to methods and techniques that an equipment engineer may use to reduce electromagnetic interference. Information in this handbook is directed particularly to power supplies since experience indicates that they are the major cause of undesired emanations. Many of the basic techniques of reducing EMI in power supplies can also apply to an entire equipment. Use of the methods and techniques herein should enable an equipment engineer to develop a compromise between the various characteristics and disciplines applied to the equipment design. These characteristics include electromagnetic compatibility (EMC), weight, size, cost, reliability, maintainability, temperature, humidity, human engineering, and performance. Use of this handbook should result in an equipment design that is EMC effective with the fewest penalties to other characteristics.

MIL-STD-220 Method of Insertion-Loss Measurement for Radio Frequency Filters

This standard covers a method of measuring, in a 50 ohm system, the insertion loss of feed-through suppression capacitors, and of single and multiple-circuit, radio-frequency (RF) filters at frequencies up to 1,000 megacycles (MC).

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

This standard covers a method of measuring the attenuation characteristics of electromagnetic shielding enclosures used for electronic test purposes over the frequency range of 100 Kilocycles to 10,000 megacycles.

APPENDIX B

ACRONYMDEX

AFB: Air Force Base
AFWL: Air Force Weapons Laboratory
AI: Articulation Index
AM: Amplitude Modulation
AMP: Antenna Modeling Program
AR: Aeronautical Requirement
AS: Articulation Score
ASD: Aeronautical Systems Division
ASPR: Armed Services Procurement Regulation
AWCAP: Airborne Weapons Corrective Action Program
BER: Bit Error Rate
CCIR: International Radio Consultative Committee
CCM: Centralized Corporate Memory
CE: Communications/Electronics
CFE: Contractor Furnished Equipment
CNO: Chief of Naval Operations
COSAM: Cosite Analysis Model
DCP: Development Concept Paper
DNA: Defense Nuclear Agency
DOD: Department of Defense
DSARC: Defense Systems Acquisition Review Council
ECAC: Electromagnetic Compatibility Analysis Center
ECCM: Electronics Counter-Counter Measures
ECM: Electronic Countermeasures
ECP: Engineering Change Proposal
EIP: Engineering Investigation Program
EM: Electromagnetic
EMCAB: Electromagnetic Compatibility Advisory Board
EMCPP: EMC Program Plan
EME: Electromagnetic Environment
EMI: Electromagnetic Interference
EMP: Electromagnetic Pulse

EMPASS: Electromagnetic Pulse Aircraft System Simulator

EMV: Electromagnetic Vulnerability

EMX: Electromagnetic X

ESM: Electromagnetic Support Measurements

EW: Electronic Warfare

FM: Frequency Modulation

GFE: Government Furnished Equipment

GTD: Geometric Theory of Diffraction

HF: High Frequency

IAP: Intrasystem Analysis Program

IEEE: International Electrical and Electronic Engineers

IEMCAP: Intrasystem Electromagnetic Compatibility Analysis Program

IM: Intermodulation

IPM: Interference Prediction Model

LCDR: Lt. Commander

3M: Maintenance and Material Management

MLJI: Meaconing Intrusion, Jamming and Interference

MIL-HDBK: Military Handbook

MIL-STD: Military Standard

NADC: Naval Air Development Center

NAFI: Naval Avionics Facility, Indianapolis

MOM: Method of Moments

NAMP: Naval Aviation Maintenance Program

NASA: National Aeronautics and Space Administration

NASC: Naval Air Systems Command

NATC: Naval Air Test Center

NAVAIR: Naval Air Systems Command

NAVSEA: Naval Sea Systems Command

NAVSEC: Naval Ship Engineering Center

NAVELEX: Naval Electronic Systems Command

NAVMAT: Naval Material Command

NCEL: Naval Civil Engineering Laboratory

NCF: Nominal Characteristics File

NELC: Naval Electronic Laboratory Center

NMC: Naval Material Command

NOSC: Naval Ocean Systems Center

NPGS: Naval Postgraduate School

NRL: Naval Research Laboratory

NSA: National Security Agency

NSSC: Naval Sea Systems Command

NSWC/D: Naval Surface Weapons Center/Dahlgren

NSWC/WO: Naval Surface Weapons Center/White Oak

NSWSES: Naval Ship Weapon Systems Engineering Station

NUSC: Naval Underwater Systems Center

NWC: Naval Weapon Center

NWSC: Naval Weapons Support Center

OPEVAL: Operational Evaluation

OR: Operational Requirements

OTP: Office of Telecommunications Policy

P-STATIC: Precipitation Static

PMTC: Pacific Missile Test Center

PPI: Plan Position Index

QRC: Quick Reaction Capability

R & D: Research and Development

RADC: Rome Air Development Center

REDCAP: Real Time Digital Computer Analysis Program

RF: Radio Frequency

S/I: Signal to Interference Ratio

SAE: Society of Automotive Engineers

SEMCA: Shipboard Electromagnetic Compatibility Analysis

SEMCAM: Shipboard Electromagnetic Compatibility Analysis, Microwave

SEMCIP: Shipboard Electromagnetic Compatibility Improvement Program

SEMI: Special Electromagnetic Interference

SINAD: Signal plus noise plus distortion to noise plus distortion ratio

SMS/DCAP Ship Missile System/Deficiency Corrective Action Program

SYSCOM: Systems Command

T & E: Test and Evaluation

TECHEVAL: Technical Evaluation

TEMP: Test and Evaluation Master Plan

TESSAC: Tactical Electromagnetic Systems Study Action Council

TRACE: Transmitter, Receiver, Antenna, Coupler Evaluator

TRED: Transmitter, Receiver Evaluation and Design

UHF: Ultra High Frequency

UR: Urgent Report

VHF: Very High Frequency

APPENDIX C

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