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MILITARY HANDBOOK

**Electronic
Counter-countermeasures
Considerations in
Naval Communication Systems**



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DEPARTMENT OF DEFENSE
Washington, DC 20363

Electronic Counter-Countermeasures Considerations In Naval Communication Systems

1. This standardization handbook was developed by the Department of the Navy.
2. This document supplements department manuals, directives, and military standards, etc. It provides basic and fundamental information on electronic counter-countermeasures considerations that should be taken into account to ensure the ability of the communication system being acquired to operate within its design specifications when exposed to hostile electronic countermeasures.
3. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Space and Naval Warfare Systems Command, ATTN: SPAWAR-003-12, Washington, DC 20363, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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FOREWORD

The use of communication (COM) systems by the United States (U.S.) Navy in future combat situations is certain to be countered by severe electronic warfare (EW). Even if hostile efforts are not employed, the proliferation of friendly electromagnetic (EM) radiation or the use of friendly active EW can have the same effect. Electronic Counter-Countermeasures (ECCM), in the control of operating techniques or electronic circuitry to ignore interfering signals, will be essential to maintain the continuity of COM. Unless the system has ECCM built in or can be modified to incorporate ECCM, system usefulness will be severely degraded or even nonexistent.

In new COM systems acquisition, ECCM should be an integral part of the system from the original concept. Under most circumstances, after-the-fact fixes are impractical. Correction of problems after the system is designed or in operation involves considerable expense and yields less than optimum results. The Department of Defense requires the implementation of specific efforts to incorporate ECCM from the early conceptual and design phases throughout the life cycle. To accomplish this, an effective program of ECCM management, assessment, engineering and configuration control is required and must be integrated into the overall design and engineering effort early in the conceptual phase and continued throughout the life cycle.

This handbook provides guidance for establishing an effective ECCM program throughout the life cycle of a COM system. This handbook assumes that the manager is already completely familiar with the acquisition management process and has a background primarily in management. Following the guidelines presented in this handbook will ensure that the proper emphasis is placed on securing adequate ECCM capability in the operational system.

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1. SCOPE

1.1 Scope. This handbook provides guidelines for incorporating electronic counter-countermeasures (ECCM) into United States Naval communication systems during the system acquisition process. While the handbook is specifically addressed to the project or acquisition director, it should be useful to other participants in the acquisition process, particularly cognizant managers in the office of the Chief of Naval Operations (CNO), the Naval Intelligence Center (NIC), the Naval Security Group (NSG), and personnel in the design, development, and production agencies. Because of the gravity of the Soviet threat facing the fleet and the Navy's critical need for command and control in performing its various missions, managers must understand the importance of measures necessary to ensure the capability to communicate in that threat environment. This is the purpose for incorporating ECCM into the design of the communication system. By use of these guidelines, the desired degree of ECCM capability will be incorporated into the communication system from both an operational and a cost effective basis.

1.2 Applicability. Provisions of this handbook are to be applied by procuring activities and by development and operations activities at appropriate times during the acquisition process. The handbook may also be applied by contractors as a guide for establishing and implementing an ECCM program during the contract phase. Although this handbook is intended for use in the acquisition of communication (COM) systems, the handbook can apply equally satisfactorily in the acquisition of other electronic systems.

1.3 Format. To ensure early consideration of ECCM as well as to provide the necessary continuity for achieving and monitoring the required ECCM, the handbook follows the framework of the acquisition process for the system. Section 4 covers the overall approach to be taken. Section 5 covers specific actions to be taken by the manager to implement the approach in Section 4. Together, Section 4 and Section 5 cover the steps to be taken during the acquisition process and the responsibilities of the manager for ensuring that the system has a high probability of continued operation in the predicted electronic warfare (EW) environment. Appendices A through D cover in greater detail the various aspects of ECCM that are to be implemented by the manager.

1.4 Relationship between ECCM and EW. EW is divided into the three areas specified in a through c:

- a. Electronic warfare support measures (ESM): Encompasses the actions to extract information from the opponents EM radiations.
- b. Electronic countermeasures (ECM): Encompasses the actions to prevent, reduce the effectiveness of, or exploit the opponent's use of EM radiation.
- c. ECCM: Actions to ensure effective use of one's own electromagnetic (EM) radiation while denying the opponent's effective use of ESM.

ECCM is divided into anti-ESM consisting of low probability of exploitation (LPE) techniques, of which low probability of intercept (LPI) is a subset, and anti-ECM consisting of anti-jamming (AJ) techniques. The anti-ECM techniques are useful in combatting self-jamming, whether self-jamming is due to intentional jamming of the opponent's systems or interference caused by incompatibility with other friendly users.

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2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this standard to the extent specified herein.

STANDARDS

MILITARY

MIL-STD-188
MIL-STD-463

Military Communication System Technical Standards
Definitions And System Of Units, Electromagnetic
Interference And Electromagnetic Compatibility
Technology

HANDBOOK

MILITARY

MIL-HDBK-235

Electromagnetic (Radiated) Environment Considerations
For Design And Procurement Of Electrical And Electronic
Equipment, Subsystems And Systems

2.1.2 Other Government documents, drawings and publications. The following other Government documents, drawings and publications form a part of this standard to the extent specified herein.

PUBLICATIONS

MILITARY

SECRETARY OF THE NAVY (SECNAV)

SECNAVINST C3430.2

Department Of The Navy Policy Concerning Electronic
Counter-Countermeasures (ECCM) In Electronic Systems

CHIEF OF NAVAL OPERATIONS (OPNAV)

OPNAVINST S3430.21
OPNAVINST 5450.191

Electronic Warfare Operations Security
Commander, Naval Security Group Command; Mission And
Function Of

NAVAL MATERIAL COMMAND (NAVMAT)

NAVMATINST 3882.2A

Threat Support For RDT And E And Weapon System
Selection And Planning

SPACE AND NAVAL WARFARE SYSTEMS COMMAND (SPAWAR)

NAVELEXINST 2410.4

Electromagnetic Environment Effect (E³) Policy
Within The Naval Material Command

NAVELEXINST 4000.9C

Approval Of Systems And Equipments For Service Use
(ASU)

(Copies of standards, handbooks, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer).

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3. DEFINITIONS

3.1 Definitions. The definitions included in MIL-STD-463 and MIL-HDBK-235 shall apply.

3.2 Acronyms and abbreviations. The acronyms and abbreviations of terms used in this handbook are:

A/C	Aircraft
ACAT	Acquisition category
ADM	Advanced development model
AFP	Approval for full production
AJ	Anti-jamming
ARM	Anti-radiation missiles
ASU	Approval for service use
BER	Bit error rate
BITE	Built-in-test-equipment
BLOS	Beyond line-of-sight
bps	Bits per second
CDR	Critical design review
CEP	Circular error probable
CNO	Chief of Naval Operations
COM	Communications
COMSEC	Communications security
CRT	Cathode ray tube
C ³	Command, control, and communications
CW	Continuous wave
dB	Decibels
dB i	Decibels isotropic
dBm	Decibels referred to one milliwatt
dBW	Decibels referred to one watt
DCP	Decision coordinating paper
DF	Direction finding
DP	Development proposal
DSARC	Defense System Acquisition Review Council
DSPN	Direct sequence-pseudo noise
DT and E	Development test and evaluation
ECM	Electronic countermeasures
ECCM	Electronic counter-countermeasures
ECP	Engineering change proposal
EDM	Engineering development model
EHF	Extremely high frequency
EIRP	Effective isotropic radiated power
ELOS	Extended line-of-sight
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMCON	Emission control
EMI	Electromagnetic interference
EMP	Electromagnetic pulse
EMV	Electromagnetic vulnerability
ESM	Electronic warfare support measures
EW	Electronic warfare
E ³	Electromagnetic environmental effects
E _{b/n₀}	Ratio of bit-energy-to-noise-density
FEWSG	Fleet Electronic Warfare Support Group
FH	Frequency hopping
FLTSATCOM	Fleet satellite communications
FOT and E	Follow-on test and evaluation
FSK	Frequency shift keying
GMF	Ground mobile forces
HF	High frequency
IFM	Instantaneous frequency measuring (receiver)
ILS	Integrated logistics support
ILSP	Integrated logistics support plan
IOT and E	Initial operational test and evaluation

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IREPS	Integrated refractive effects prediction system
J	Jamming level
J/S	Ratio of jammer signal level to COM signal level
kw	Kilowatt
km	Kilometers
LOS	Line-of-sight
LPI	Low probability of intercept
LUF	Lowest usable frequency
Mbps	Megabits per second
MECC	Minimum essential communications capability
MENS	Mission element need statement
MHz	Megahertz
mi	Miles
MOE	Measure of effectiveness
MUF	Maximum usable frequency
NATO	North Atlantic Treaty Organization
NAVELEX	Naval Electronic Systems Command
NDCP	Naval decision coordinating paper
NFOIO	Navy Field Operational Intelligence Office
NIC	Naval Intelligence Command
NISC	Naval Intelligence Support Center
nmi	Nautical mile
NSA	National Security Agency
NSG	Naval Security Group
OPEVAL	Operational evaluation
OPTEVFOR	Operational test and evaluation force
OR	Operational requirement
OT and E	Operational test and evaluation
PAT and E	Production acceptance test and evaluation
PDR	Preliminary design review
PM	Project manager
PN	Pseudo noise or pseudo-random noise
PR	Procurement request
PRESINSURV	President, Board of Inspection and Survey
PROPHET	PROpagation ForEcast (a pseudo acronym)
PSK	Phase shift keying
RF	Radio frequency
RFP	Request for proposal
RFQ	Request for quotation
SAT	Satellite
SATCOM	Satellite communications
SDDM	Secretary of Defense Decision Memorandum
SHF	Super-high frequency
SIGINT	Signal Intelligence
SIGSEC	Signal security
S/J	Signal-to-jammer ratio
S/N	Signal-to-noise ratio
SOW	Statement of work
SS	Spread spectrum
STILO	Scientific and Technical Intelligence Liaison Officer
T and E	Test and evaluation
TDOA	Time difference of arrival
TECHEVAL	Technical evaluation
TEMP	Test and evaluation master plan
TH	Time Hopping
UHF	Ultra-high frequency
U.S.	United States
USMC	United States Marine Corps
USN	United States Navy
VHF	Very high frequency

4. INCORPORATING ECCM DURING PROGRAM LIFE CYCLE

4.1 General. Management and engineering personnel must establish and implement a procedure for integrating ECCM into the various phases of the life cycle of the system. This approach is required to ensure early consideration of ECCM, as well as to provide the necessary continuity for achieving and maintaining the required ECCM. The approach should include modeling, analyzing, simulating, and testing to determine the susceptibility characteristics and operational constraints. Final requirements are postulated by tailoring the peculiar characteristics and operational requirements of the system in individual specifications. A general description of ECCM techniques for COM application is specified in Appendix A.

4.2 Life cycle flow. The principal phases in the life cycle of a major COM system are specified in a through f:

- a. Program identification
- b. Concept development
- c. Concept validation
- d. Full scale development
- e. Production
- f. Deployment

A flow diagram depicting an approach designed to integrate an ECCM program into the overall acquisition process is shown in Figure 1.

4.2.1 Program identification. The acquisition cycle begins with the identification of a specific deficiency within a given mission area. A position paper is produced identifying the threat, the deficiency, an estimate of the impact if the deficiency is not corrected, and the necessary corrective action. From these inputs, a mission element need statement (MENS) is produced that initiates the decision process. The incorporation of planning for ECCM in the early position papers and the MENS is essential. The threat environment and the necessary ECCM to permit satisfactory operation of the COM system in that environment can substantially affect the thresholds for cost, scheduling, performance, supportability, and ultimately, the affordability of the system. Approval of the MENS is followed by a Secretary of Defense Decision Memorandum (SDDM) that justifies the start of the acquisition program.

4.2.2. Concept development phase. During the concept development phase, technical and financial baselines for a development and acquisition program are established. Included are definitions of required operational capability, doctrines, and specific material requirements. Critical technical and operational issues will be identified for study and resolution in subsequent phases, whereas performance characteristics are established only in general terms. A statement of work (SOW) and a request for quotation (RFQ) will be prepared where required. Outputs of the concept development phase are alternate concepts, estimated operational schedules, and estimated procurement costs. The importance of the evaluation of design alternatives should be stressed during this phase and not postponed until later phases. Proper consideration of ECCM during the concept development phase will have significant impact throughout the life cycle. An assessment of the ability of the system to perform its function during the life cycle must include a threat analysis using both the friendly and hostile EM environment that may be encountered. These factors must be addressed not only in performing trade-off studies and risk assessments, but also in estimating program costs. The culmination of these activities will be the first major design review by the Defense System Acquisition Review Council (DSARC) I, of the program initiation decision.

4.2.3 Concept validation phase. The primary objective of the concept validation phase is the selection of the single concept that will be carried out through full scale development. To accomplish this, the estimates made in the concept development phase must be refined. Areas of risk must be reassessed to ensure that the risks have been adequately defined and can be resolved or minimized. Frequently, the concept validation phase includes the construction of prototypes to evaluate operational, technical, and environmental factors as well as to refine costs. An SOW and an RFQ for research and development contract support will be prepared, when required. The studies, analyses, and testing is culminated in the second design review, DSARC II, where a decision is made whether to proceed to full-scale development.

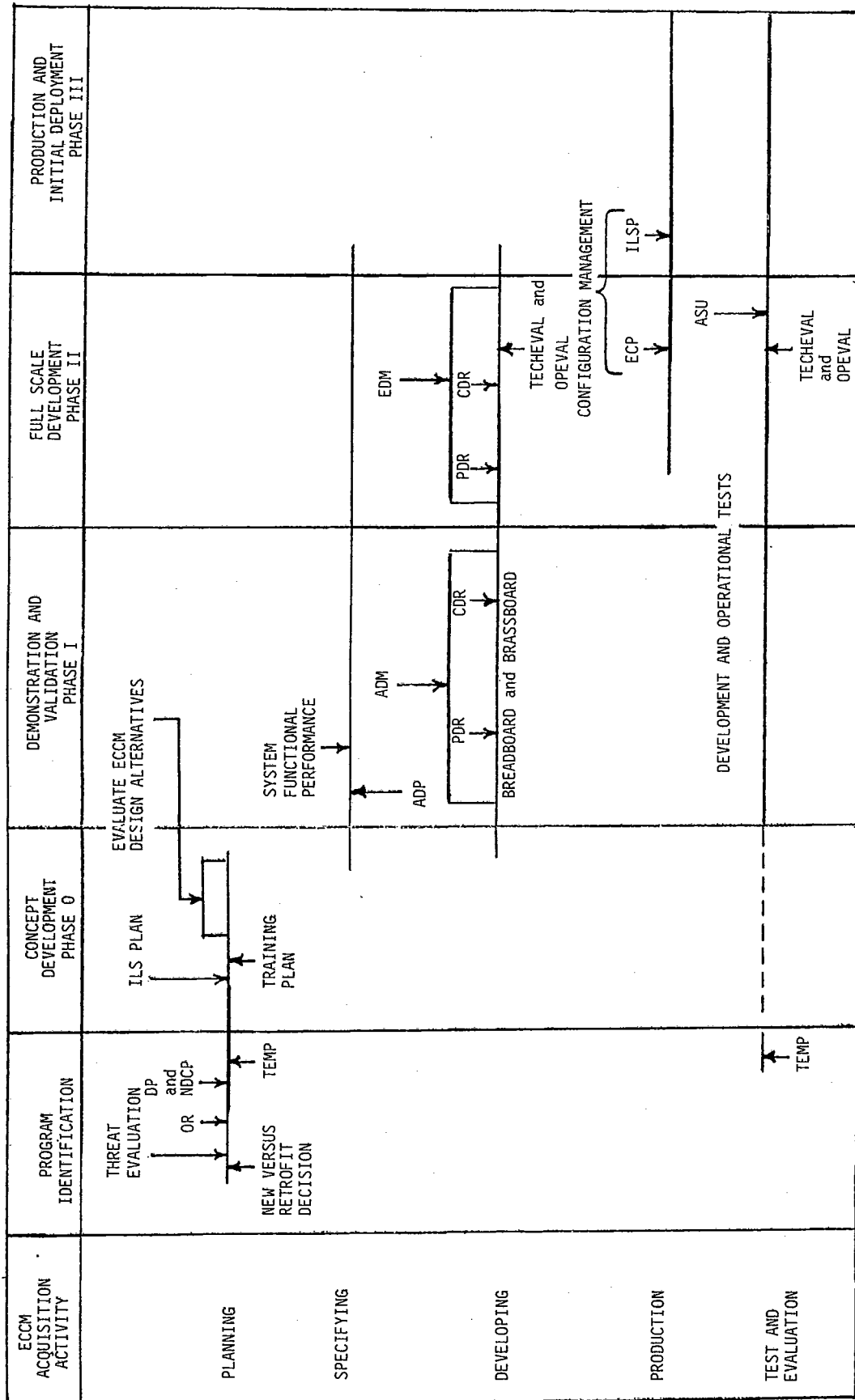


FIGURE 1. Major ECM acquisition activities.

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4.2.4 Full-scale development phase. During the full-scale development phase, the objective is the design and fabrication of an engineering development model (EDM) tailored to the specific procurement, mission, environmental factors, and so forth. The system must be fully tested and evaluated to verify that the design not only conforms to specifications, but that the system performs the specified missions in the operating environment. The full-scale development phase must also provide the documentation, including testing and analysis reports, to enable a decision to proceed to production. An approval for service use (ASU) must be obtained prior to proceeding to production. A SOW and specification will be prepared and used for the development contract.

4.2.5 Production. The period following approval for production through the delivery and acceptance of the last item being procured is the production phase. Acceptance tests will be performed to demonstrate conformance to the requirements in the production specification, as well as to ensure satisfactory performance when the item is in operational use. Strict quality control methods are required to ensure that proposed changes to the configuration do not degrade the performance of the system. When acquisition is complete, responsibility to support the system is turned over to the logistics manager.

4.2.6 Deployment. The deployment phase begins with the acceptance of the first operational system until all systems are phased out of the inventory. There is usually an overlap with the production phase. In-service performance must be monitored by a reliable, established feed-back system to detect, report, and correct operational problems. Modifications, engineering change proposals (ECPs), and overhaul plans must be reviewed in accordance with the program configuration control system.

4.3 Procedural method for addressing ECCM. Figure 1 summarizes the procedures specified in 4.2 and provides the program manager with an orderly and coherent approach for addressing ECCM involving systems. In cases where the detailed design and production are performed by the contractor, the project manager's (PMs) major responsibilities in ECCM are to define the applicable requirements and monitor the contractor's efforts to comply with the requirements. In cases where the detailed design is performed by the procuring activity and a contractor is responsible for production in accordance with Government-furnished information, the program manager must, in addition to the above, conduct all aspects of the ECCM effort, including establishing installation criteria, performing analyses, and so forth. The program manager may delegate those responsibilities to the ECCM authority in his activity.

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5. PROGRAM MANAGER RESPONSIBILITIES AND ACTIONS

5.1 General. Figure 1 shows that the major activities required to provide proper ECCM during the acquisition process are planning, specifying, developing, production, and test and evaluation (T and E). These activities occur to differing degrees at the different stages of the acquisition process and must be provided at the correct time to ensure a satisfactory product for operational use.

5.2 Planning steps. The steps in a through e are necessary in the process of successful ECCM planning:

- a. Obtaining information on the threat:
 1. Scientific and Technical Intelligence Liaison Officer (STILO) assistance
 2. Naval Intelligence Support Center (NISC) assistance
 3. Naval Security Group (NSG) assistance
- b. Preparing the key documents:
 1. The operational requirement (OR)
 2. The development proposal (DP)
 3. The decision coordinating paper and the Naval decision coordinating paper (DCP and NDCP)
- c. Formulating ideas about the ECCM design
- d. Planning for the essential ECCM tests
- e. Planning for the support of the system

Details and comments on some of the ECCM-related aspects in each of the steps in a through e are covered in 5.2.1 through 5.2.6 and a planning and specification outline is supplied in Appendix B.

5.2.1 Obtaining information on the threat. Obtaining information on the threat before the development begins is an important step in the planning process and is crucial to the ECCM design of the system. Without detailed current and projected threat information, it will be difficult to ascertain if the ECCM design is adequate. To this end, all managers should ensure that adequate threat data is acquired, considered, and included in program planning. Managers should specifically include reference to the status of threat assessment updates and the effect, if any, on the system threshold requirements, in milestones and program review reports. The PM is responsible to establish contact with the Command STILO for intelligence support and to review the instructions pertinent to threat support. The STILO office must be the focal point for obtaining threat intelligence throughout the life cycle of the program.

5.2.1.1 STILO support. The Command STILO is responsible to provide the interface between the activity and the intelligence community. The PM will ensure that the STILO is briefed on the project during the early planning stages and that the STILO is kept informed throughout the program's progress. The STILO must be involved in the preparation of the threat support request and shall assist managers in the use of threat support documentation. The STILO shall maintain the NISC-provided Soviet Threat and Capabilities Publications (Pyramid Publications) and other key intelligence documents in a STILO library. These publications should be referenced, as appropriate, in all requests for threat support. NAVMATINST 3882.2A outlines the responsibilities of the STILO relative to coordination of the threat support request and submitting the request to the Naval Intelligence Command. The STILO may directly (or indirectly with the help of STILOs from other commands) provide technical and engineering expertise associated with the threat and ECCM techniques. The STILO should be involved in evaluating overall susceptibility and vulnerability considerations prior to design commitments. (Although it is within the purview of NSG to evaluate signal susceptibility and vulnerability of any proposed design, this function normally occurs after some design decisions are made and the program is underway.) Additionally, the STILO could be helpful in establishing the proper interface with support facilities as the design alternatives are narrowed down to the selected approach.

5.2.1.2 Naval Intelligence Command (NIC) support. To obtain the kind of threat information from NIC (including NISC and the Navy Field Operations Intelligence Office (NFOIO)) that will help in developing an effective ECCM design, items in a through c should be considered:

- a. Use the STILO to help translate needs into questions and to interface directly with the intelligence community
- b. Concentrate on the areas where the system is most sensitive to exploitation
- c. Address the critical intelligence parameters

5.2.1.3 NSG support. The NSG performs cryptologic and signal security (SIGSEC) functions, as outlined in OPNAVINST 5450.191. The function that most directly impacts ECCM is for NSG to evaluate and test the vulnerability of COM systems which are being developed and to make appropriate recommendations to the Chief of Naval Operations (CNO) for minimizing the vulnerabilities. NSG also monitors and analyzes activities associated with the testing of COM and other EM systems and advises of SIGSEC vulnerabilities. For managers of COM system developments with ECCM, it is important to remember the functions specified in a and b support:

- a. The STILO in the PM's command may, in some cases, be the best interface with NSG to convey and request information and to help in understanding the results.
- b. NSG will work closely with the operational test and evaluation force (OPTEVFOR) in developing, for the operational evaluation (OPEVAL) period, a test program that evaluates the ECCM effectiveness of the system against the threat.

5.2.2 Preparing the key documents. The three major planning documents are specified in a through c:

- a. OR
- b. DP
- c. DCP and NDCP

Within these primary documents are found the origin of ECCM needs and possible ways of conforming to them for each system acquisition.

5.2.2.1 ECCM in the operational requirement (OR). The OR covers the operational need for the system, operational concept and performance goals, and a definition of the threat. Guidance for completing the OR is in ECCM-related comments and examples in a through d, and may be of help in preparing or analyzing an OR for a COM system with ECCM.

- a. The threat-related aspects should be developed with assistance from NISC and NSG.
- b. The threat statement should include a brief description of the expected baseline ECM and ESM threat or scenario for the systems' entire life-cycle (these translate into ECCM requirements). Examples are in 1 through 3:
 1. ECM: Decibels referred to 1 watt (dBW) (type) jammer for line-of-sight (LOS) jamming from a minimum range of _____ nautical miles.
 2. ESM: As a minimum, a synchronous signal intelligence (SIGINT) satellite (SAT) in the main beam of the COM system will be capable of detecting a single _____ bits per second (bps) link.
 3. ESM: Location of the (type) COM system is achievable by triangulation using (No. and type) platforms or sensors out to _____ nautical miles (nmi) LOS ranges (maximum).
- c. Include a description, under the Operational Concept, of how the system will function in the presence of the threat (see examples 1 through 3):
 1. Maintain a _____ bps link under maximum jamming conditions.
 2. Provide a minimum essential COM capability (MECC) for secure voice in the presence of a _____ dBW jammer.
 3. Provide LPI qualities such that a minimum COM capability of _____ bps can be achieved LOS up to _____ nmi without detection by a synchronous SIGINT SAT, as long as the SAT is not in the COM signal's main beam.
- d. Under capabilities required (performance goals), specify an achievable level of performance below which the development will not be acceptable (see example 1 through 3):
 1. The AJ capacity shall be sufficient to satisfy a MECC of _____ bps sustainable against a _____ dBW super high frequency (SHF) jammer.
 2. Specified performance shall be achieved with a _____ feet or smaller antenna.
 3. LPI shall be such that a _____ bps link can be maintained between ships and shore without detection by synchronous SIGINT SAT.

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5.2.2.2 ECCM in the development proposal (DP). The comments in a through h pertain to ECCM; the items discussed correspond to those listed in the DP contents:

- a. Since the DP presents the various alternatives and trade-offs to achieve a particular range of capabilities, the DP cannot be limited to a certain number of pages.
- b. Under paragraph I, Background, the ECCM-related items in 1 and 2 may be included:
 1. To supplement the _____ network, a wide band _____ COM system is being developed which will provide AJ and LPI capabilities together with higher throughput rates for command, controls and COM (C³) to Fleet Flag, carriers, and other high-value ships.
 2. The system shall be interoperable with the Navy's AN/_____ and the Army's AN/_____ terminals.
- c. Paragraph II, Issues, may include the items in 1 through 4:
 1. The constraints of interoperability have guided the development of the _____ modem or terminal. The possibility of modifying the _____ (in its _____ mode) to allow it to be compatible with a processing SAT must be explored.
 2. Some antenna alternatives, for example, a _____ ft antenna is needed for gain, but the weight of the _____ ft alternative antenna is the one that fits within the ship's space and weight limitations.
 3. Interoperability options; for example, US Marine Corps (USMC) must reconcile how to use both the ground mobile forces (GMF) and United States Navy (U.S.N.) spread spectrum (SS) terminals, and still be able to operate with North Atlantic Treaty Organization (NATO).
 4. Detectability or LPI must also be considered; for example, given the scenario provided for in the OR, the most dangerous detection threat is from an A/C located _____ nmi (LOS) from the ship.
- d. Paragraph III, Requirements and program objectives, may include a table that summarizes the OR parameters versus whether requirements will be complied with.
- e. Paragraph IV, Program alternatives, may include several outlines (See examples in 1 and 2).
 1. An outline of modem options (various SS direct sequence-pseudo noise (DSPN) and frequency hopping (FH) possibilities).
 2. An outline of antenna and radio alternatives (including effective ECCM antenna and radio techniques).
- f. Paragraph VI, Risk, may cover a tabulation of ECCM risk areas associated with various alternatives.
- g. Paragraph VII, Test and Evaluation, could include an outline of special ECCM related test requirements.
- h. Paragraph VIII, Other factors, may include items as the operational impact of certain electromagnetic environmental effects (E³) factors on system ECCM features, and conversely, the impact of system ECCM features on other platform EM systems.

5.2.2.3 ECCM in the DCP and NDCP. All questions pertaining to the requirements in the OR and the alternatives developed in the DP are resolved in the DCP and NDCP. No additional comments or examples on the ECCM-related aspects of the DCP and NDCP should be necessary; ECCM items from the OR and DP (see 5.2.2.1 and 5.2.2.2) should suffice for examples in this document also.

5.2.3 Formulating ideas about the ECCM design. In preparing the documents for a new COM system development, beginning with the OR and then the DP and finally the DCP and NDCP, it is evident that each one needs to become more specific than its predecessor about the possible design approach(es) that could be used successfully in the presence of the threat. Moreover, once the DCP and NDCP is approved and funds are released to commence the development, a Request for Proposal (RFP) or RFQ will be prepared and circulated to prospective bidders for the initial Advanced Development Model (ADM) design. To be able to effectively prepare all of these documents implies that someone has already determined something about the design of the system. In order to provide managers with some limited assistance on how to formulate ideas about the ECCM design of a COM system, a hypothetical example has been included in APPENDIX C.

5.2.3.1 Estimating the cost of ECCM-protected COM. In planning for the funds required to obtain COM systems capable of operating in the presence of the threat, managers will discover that:

- a. Systems with adequate ECCM protection are generally within the category of an Acquisition Category (ACAT) I or ACAT II.
- b. Development cost is difficult to estimate with any great precision, however, a standard cost model should be developed and used throughout the development.
- c. Comparative ECCM application costs (money and effort) can be qualitatively envisioned (in a general sense) along the lines of Table I (A typical example).

TABLE I. Comparative development costs ^{1/} and level of effort to incorporate ECCM AJ and LPI features in COM systems.

		WIDEBAND TECHNIQUES		ANTENNA TECHNIQUES		PROPAGATION TECHNIQUES		TACTICS OR PROCEDURES	
		COSTS	EFFORT	COSTS	EFFORT	COSTS	EFFORT	COSTS	EFFORT
INCORPORATE INTO OR USE WITH NEW COM SYSTEM DESIGN	BLOS SATCOM	HIGH	MAJOR	HIGH MAJOR (NEW ANTENNA DESIGN MUST BE MATCHED TO SYSTEM DESIGN)		NA	NA	LOW	MINOR
	BLOS HF	HIGH	MAJOR	HIGH MAJOR (ADAPTIVE ARRAY ANTENNA DESIGN MUST BE MATCHED TO SYSTEM DESIGN)	MODERATE (ADAPTIVE ARRAY ANTENNA DESIGN MUST BE MATCHED TO SYSTEM DESIGN)	LOW (USE PROPHET AND FREQUENCY-SPATIAL DIVERSITY)	MINOR	LOW (EMCON ^{2/} AND REDUNDANT TRANSMISSION)	MINOR
						LOW (FREQUENCY-SPATIAL DIVERSITY AND MINIMUM POWER USE AT LUF ^{3/})	MINOR	LOW (EMCON AND REDUNDANT TRANSMISSION)	MINOR
						LOW (USE IREPS AND MINIMUM POWER FOR A GIVEN FREQUENCY)	MINOR	LOW (EMCON AND RELAYED COMs THE COST ^{1/} TO USE EMCON IS THE DELAY OR INABILITY TO SEND COMs)	MINOR
RETROFIT INTO OR USE WITH EXISTING COM SYSTEMS THAT NOW LACK ECCM FEATURES	LOS VHF AND UHF	HIGH	MAJOR	MEDIUM (ADAPTIVE ARRAY MATCHED TO SYSTEM DESIGN)	MODERATE (ADAPTIVE ARRAY MATCHED TO SYSTEM DESIGN)	LOW (USE IREPS AND MINIMUM POWER FOR A GIVEN FREQUENCY)	MINOR	LOW (EMCON AND RELAYED COMs THE COST ^{1/} TO USE EMCON IS THE DELAY OR INABILITY TO SEND COMs)	MINOR
	BLOS SATCOM	HIGH (REDESIGN)	MAJOR (REDESIGN)	HIGH (NEW ANTENNA DESIGN)	MAJOR (NEW ANTENNA DESIGN)	NA	NA	LOW (REDUNDANT TRANSMISSIONS)	MINOR
	BLOS HF	HIGH (REDESIGN)	MAJOR (REDESIGN)	MEDIUM (NULLING AND ADAPTIVE ARRAYS)	MODERATE (EXTERNAL ANTENNA DESIGN)	LOW (USE PROPHET AND FREQUENCY-SPATIAL DIVERSITY)	MINOR	LOW (EMCON AND REDUNDANT TRANSMISSIONS)	MINOR
	LOS VHF AND UHF	HIGH (REDESIGN)	MAJOR (REDESIGN)	MEDIUM (NULLING BEAM STEER SIDELobe CANCELLING ADAPTIVE ARRAYS)	MODERATE (EXTERNAL ANTENNA DESIGN)	LOW (USE IREPS AND MINIMUM POWER)	MINOR	LOW (EMCON AND RELAYED COMs)	MINOR

Development: low = < 1M, Medium = < 20M, high = > 20M

Costs: Effort - minor < 2 years, moderate < 5 years, major = 5-10 years

^{1/} Training costs are included^{2/} Emission control^{3/} Lowest usable frequency

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1. The various categories of ECCM (AJ and LPI) techniques are listed at the top of Table I on the horizontal scale and generic types of COM links are on the vertical scale.

2. In the efforts estimated as medium cost under antenna techniques, antennas will prove to be high cost endeavors.

d. In general, ECCM techniques that make use of propagation phenomena or special tactics and procedures should be utilized whenever feasible, since most of the techniques only require a low cost or minor effort to implement.

e. Table I emphasizes the point that retrofitting or redesigning ECCM into existing systems is not a cost saver (either in time or money), nor is it an efficient process.

The very nature of ECCM requires the use of more sophisticated techniques and complex system designs, which automatically translate into higher operating costs and increased maintenance costs. The longer time period required to fully develop and perfect the designs also translates into increased acquisition costs. Nevertheless, without this protection, vital COM links could be vulnerable to disruption and their associated fleet units imperiled.

5.2.4 Planning for the essential ECCM tests. The necessity for timely and proper ECCM testing throughout the acquisition process places a high priority on advanced test planning for every phase of the program. The essential test areas are specified in a through d:

- a. Test and evaluation master plan (TEMP) preparation
- b. Developmental test plans:
 - 1. Tests in the ADM phase
 - 2. Tests in the EDM phase
- c. Operational test plans:
 - 1. Technical evaluation (TECHEVAL)
 - 2. OPEVAL
 - 3. Total ship tests
 - 4. Other special tests
- d. Maintenance tests

5.2.5 Interoperability issues. The kinds of issues referred to are those concerned with how to ensure the interoperability of COM equipments developed by the different U.S. and NATO forces. The USMC, for example, is currently struggling with this problem as they procure both Army-developed and Navy-developed equipments for use in their tactical and strategic COM nets. The challenge is not only one of interfacing different equipments and systems, but where other services are involved, traditionally different procedures.

5.2.5.1 Factors to be considered. The reason for mentioning these issues in connection with ECCM is that managers need to appreciate some of the salient factors that determine interoperability and how several of them may be ECCM-related. These factors may include:

- a. The need for radio frequency (RF) carrier frequencies and types of signal modulation (waveforms) to be compatible including new developments in microwave (SHF) and millimeter wavelength equipment.
- b. The need for different SS COM systems to have compatible data rates and pseudo noise or pseudo-random noise (PN) clock rates
- c. The need for interoperable modems to have the same PN generation method (for example, shift registers of the same length)
- d. The need for interoperable modems to be able to use the same communications security (COMSEC) devices
- e. The need for interacting COM networks to resolve any basic timing problems; that is, be able to reconcile such problems as an absolute time standard in one net versus a relative time standard in another

Factors a, b, and c have obvious ECCM design implications and factors d and e could, depending upon the particular situation. The on-going MIL-STD-188 (series) projects are being developed as the mechanism for standardizing waveforms used among the Military Services and NATO. (It is imperative that the Military Services agree on the way ECCM is used so that overall COM system operations will not be degraded.) In this respect, the Military Services are taking lead roles in developing the standards specified in a through c:

- a. Army: High frequency and very high frequency (HF and VHF)
- b. Air Force: Ultrahigh frequency (UHF)
- c. Navy: Low frequency and very low frequency (LF/VLF)

5.2.5.2 SATCOM gateway terminals. One approach to interoperability in the SATCOM realm is the use of gateway terminals, which introduces the possibility of a weakened ECCM configuration. The gateway approach requires that dual modems be deployed at a gateway terminal site, such that the first modem is compatible with one of two incompatible terminals (who want to talk to each other) and the second modem is compatible with the other terminal. The COM circuit is completed by connecting the two gateway modems at base band.

5.2.5.2.1 Reasons for avoidance of the gateway terminal concept from an ECCM viewpoint. Gateways are an appealing compromise for system designers and users because they offer a direct way to establish SATCOM connectivity between parties having incompatible modems and terminals. The technique allows maximum flexibility for the users and avoids having to wait for new developments or modifications to occur before COM links can be established. However, from an ECCM point of view, these advantages are offset by the additional errors that are incurred by double-hop transmissions through the satellite. This situation could be particularly worrisome in a jamming or high-interference environment where the AJ advantages of expensive ECCM designs in either or both terminals might be nullified. Double-hop transmissions are also wasteful of the limited satellite resources (power, duty cycle, and available channels) that are needed to conform to the Military's ever burgeoning COM requirements. The bottom line is, that from the beginning of the design process, where interoperability and ECCM can be properly accounted for, inefficient, and wasteful compromises can be avoided.

5.2.6 Maintenance and ECCM. The subject of maintenance is mentioned because it may have some relationship to the complexity of an ECCM design. Maintenance costs and maintainability factors suffer in direct proportion to the complexity of the system design. Managers should be careful therefore to avoid specifying unrealistic goals for the maintainability factors of COM systems that require complex ECCM designs to function in the presence of the threat. One of the maintenance features that should be specified and incorporated into every ECCM-hardened COM system is automatic built-in-test-equipment (BITE) routines which allow on-line confirmation that the system's ECCM features are functioning properly.

5.3 Specifying ECCM in COM systems. The requirements for specifying ECCM in COM systems are specified in 5.3.1 through 5.3.5.

5.3.1 General. The material and commentary provided herein are directed not so much at specification writing or specification preparation in general, but rather at helping PMs describe and specify those aspects of a COM system that determine the ECCM design features. It is assumed that users of the handbook are already familiar with standard specification practices and specification writing. The ECCM specification for a COM system is not usually separate from the general specification for that system. Instead, the incorporation of ECCM is an integral part of the system's overall functional and performance specification. Examples of this are given in this handbook.

5.3.2 Baseline specifications. When ECCM capabilities are required in a system, it is important that the functional baseline be specified flexibly from the beginning to avoid undesired premature commitments to detailed requirements that would be difficult and expensive to change later. In a major COM system development, the initial baseline identification could well be a preliminary system description of a range of proposed broad performance parameters or characteristics which could be used to facilitate the evaluation of alternative design approaches as performance and cost trade-offs are made.

5.3.3 Coordination with OPTEVFOR. In addition to the basic performance requirements of the system under controlled (laboratory) conditions, the PM must consider mission effectiveness in an operational environment. The PM should work jointly with OPTEVFOR in the planning and selection of meaningful measures of effectiveness (MOEs) for ECCM related to the operational requirements and the system specifications. The specifications shall provide sufficient quantitative requirements and constraints so that quantifiable measures can be developed. These measures may be used as acceptance criteria during T and E (see 5.6).

5.3.4 Parameter guidelines. The nature of ECCM in COM systems is varied and complex and therefore does not readily lend itself to one standard set of parameters for specification purposes. However, within the many items that describe any COM system's functional and performance characteristics, there are certain ones, which taken together, translate into ECCM requirements. It is in these areas of the specification that the ECCM is addressed directly or indirectly. The outline given in Appendix B can be used as a guide in obtaining the parameters to be analyzed for development of the specifications.

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5.3.4.1 Some clarifying points about the guidelines. Some clarifying points about the guidelines are specified in a through e:

a. The list is not representative of all the items that might be included in a COM system specification, but reflects the kinds of information that a contractor would need in order to develop the ECCM design of the system.

b. To help managers think about the ECCM needs and features of a wide variety of COM system designs, the guidelines contain as many potentially useful items as possible.

c. It is not likely that all of the ECCM-related items listed would be incorporated into any one COM system design.

d. Such items as processing gain and the specific wide-band signalling techniques required to obtain it (for example, SS, PN, and FH) are not called out in the list because they are usually left to the contractor as options among design choices (what kind of ECCM and how much), as long as the contractor provides enough ECCM (both AJ and LPI) to counter the threat.

e. Restricting the design to certain specific techniques from the beginning may only serve to limit the contractor's freedom so that the most cost-effective design for the system is never realized.

5.3.4.2 Some suggestions and cautions about the guidelines. Some suggestions and cautions about the guidelines are specified in a through e:

a. Trying to specify and design an effective ECCM-hardened COM system without a precise knowledge of the threat (which includes threat parameters and scenario and usage information) is a risky endeavor both operationally and monetarily. The more information (detailed and quality-wise) provided, the better the contractor will be able to respond with an effective ECCM design.

b. Care should be exercised in specifying the kinds of tests to be used for ECCM validation purposes at various stages of the acquisition process.

1. While ECCM-related tests with the hardware are important at each stage of the development process, the tests performed during TECHEVAL and OPEVAL are by far the most important. For this reason, it is essential that program test plans provide for adequate ECCM test funds during the TECHEVAL and OPEVAL phases and reflect caution in specifying the types of ECCM tests required for the other phases. Without careful planning and restraint, the cost of using expensive test facilities and equipment (for example, ships, A/C, and so forth) can quickly exceed program test budgets.

2. Allowing for an option to use computer-based simulation tests for validation purposes (if that is not too costly) or even a paper analysis might be appropriate in some of the early test phases of the program.

c. The use of error detection and correction coding in the message data bits can provide a degree of AJ protection for a COM circuit if the jamming or interference results in a bit error rate (BER) of about 10^{-2} or less. Once the jamming exceeds this level however, the effectiveness of coding rapidly disappears. In fact, at moderate and higher levels of jamming where coding actually becomes counterproductive, the best technique for getting the message through is probably to use simple redundancy, that is, send each bit many times.

d. In developing a system's ECCM performance requirement from the threat description, managers should not only be guided by the threat parameters themselves, but also by a common sense and practical assessment of the operational situation. Unrealistic specifications and costly designs can sometimes be avoided. The supporting data behind the threat description should be examined to ascertain its practicality and feasibility.

1. The operational features may not be practical for the enemy to use on any large scale. For example, a threat may be postulated to radiate energy at enormous power levels, but is it likely to be available to the enemy in a wide range of operational scenarios?

2. Concern for system operation in the presence of the threat should not deal exclusively with a worst-case condition. For many systems, the worst-case condition might occur only once or twice in the life of the system, while the best or average would be the norm. Any analysis of the system's operational effectiveness should also consider best-case and average conditions. Insistence on an ECCM design that will fully handle the worst-case scenario may result in a prohibitively expensive and complex system.

3. LPI concerns about the system should be reasonable. For example, if it were known that the enemy possessed a satellite-mounted radiometer capable of detecting the presence of a particular SS COM signal, would this really constitute a threat. It maybe that the enemy could locate the system with only one satellite or it may be necessary for the enemy to possess multiple satellites at the appropriate positions to locate the system by triangulation

e. Managers will usually need to have in mind some general ideas about the design of the COM system before writing the performance requirements for the first RFP that leads to the advanced development phase. Managers may obtain these ideas from their own experience, from Government and industrial sources of expertise and from this handbook.

1. As a starting point in developing the system's ECCM design features, managers may find the ECCM design guides in Appendix B to be helpful.

2. Threat material, available from the NIC, may also provide a useful addition to the existing threat data and design alternatives outlined in the OR, DP, and DCP, and NDCP documents.

5.3.5 Writing the specifications. Regardless of the scope of the requirements in a COM system specification, each requirement should be stated so as to present exactly what the developing activity wants. Requirements should be worded to provide a definite basis for rejection when testing reveals unsuitability. Care should be exercised to avoid unrealistic requirements that will only add to the cost of the development and may, in the end, prove counterproductive to a timely realization of the development goals for the program. Unless reasons exist for specifying the exact technique that is desired in order to achieve the desired ECCM, the choice of techniques should be left to the developer and the specifications limited to the desired result. The specifications must concisely state the desired result and the tolerances allowable.

5.4 Developing ECCM-hardened COM systems. These requirements draw attention to certain steps in the advanced development and engineering development phases of the system acquisition process, where ECCM would generally be incorporated or evaluated. In addition to discussing the ECCM aspects of these steps, brief comments are also provided on contracts and contractual issues, in general, for the benefit of PM orientation. ECCM-related steps are marked and labeled as shown in Figure 2 which represents a simple chronological picture of the events that occur from the beginning of the system's advanced development phase to culmination in the OPEVAL of the EDM hardware.

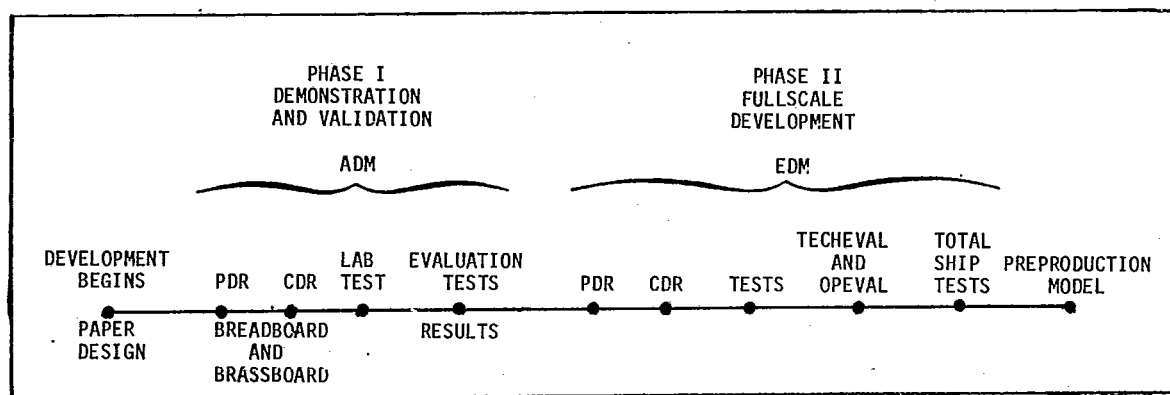


FIGURE 2. Overview of development phases.

5.4.1 Advanced development and engineering development phases. The objectives of the advanced development phase are to demonstrate the technical feasibility of a design, determine the ability to conform to existing performance requirements, secure engineering data for use in further development, and where appropriate, establish the technical requirements for contract definition. Successful completion of this phase allows an EDM of the system to be designed, fabricated, and tested. The objectives of the engineering development phase are to prove technical adequacy and operational effectiveness of the EDM. At this point, a cost trade should be performed using the standard model previously developed. At the end of this phase, TECHEVAL and OPEVAL will validate the design and establish the product baseline and specification.

5.4.1.1 Advanced development model (ADM). The advanced development phase can be realized only through the development of hardware for experimental and operational tests. The hardware is referred to as the ADM and should incorporate all of the features necessary for an operationally effective COM system, especially any ECCM-related capabilities. From the earliest planning stages it is imperative that the system's ECCM features be considered and decided upon so that the features are fully incorporated into the design and building of the ADM. To inadequately address ECCM in this phase will result in excessive delays and costs to correct the design later in the engineering development phase.

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5.4.1.2 Engineering development model (EDM). The intended output of the engineering development phase is an EDM whose performance and reliability have been proven experimentally, along with the documentation needed for inventory use. The system or platform must be fully evaluated and tested to verify that the design not only conforms to the specifications, but satisfactorily performs the stated mission in the operating environment. It is in this stage, therefore, that the ECCM design becomes fully hardened and tested in both the TECHEVAL and OPEVAL phases. ASU must be obtained prior to proceeding to production.

5.4.2 Contracts. The contracting process is initiated by preparation of the Acquisition Request (AR). The AR should provide a complete and technically adequate statement of what is required. This can be used first in the solicitation document (RFP or RFQ), and then later in the contract statement of work. The AR should contain sufficient threat-related information and performance requirements for the COM system so that the prospective contractor understands the technical and operational problems involved in developing the ECCM aspects of the proposal. A presolicitation conference may be held prior to promulgation of the RFP or RFQ to clarify any questions concerning the proposed contract and to elicit the participation of prospective contractors. The information in the bid package may be supplemented by a bidders conference which is a meeting arranged by the contracting officer to answer questions and assist prospective bidders in understanding the Government's technical and operational requirements.

5.4.2.1 Contract proposal evaluation. Contractor proposals should be evaluated for:

- a. The degree to which the proposals conform to or exceed support specifications
- b. The comparative credibility of life-cycle estimates
- c. The demonstratability of specifications, goals, and requirements. Adequacy of ECCM

design features should be an important factor in the evaluation of criteria. Successive iterations of proposal activities are often necessary to select the best equipment design concept and support approach.

5.4.2.2 Statement of work (SOW). A SOW should be prepared for each phase of the acquisition cycle. Key milestones and prerequisites should be in the form of specific input and output objectives, and should satisfy minimum essential data requirements. In preparing a SOW for a given phase, the RFP writer must take into account the work performed in earlier phases and the work to be accomplished by the Government during the given phase.

5.4.3 Testing and demonstration in the advanced and engineering development phases. The basic objective is to accomplish the testing required at discrete points in order to gain confidence that the system or equipment will ultimately conform to the mission and associated operational requirements for which it was intended. Too much testing is costly, and too little will not provide the confidence needed. The wrong type of testing is also costly and will not provide worthwhile or meaningful results. Design reviews should be performed intermittently to determine if the objectives are being met. The equipment configurations used in the demonstration should be representative of the operational system to the maximum extent possible. Preparation tasks may involve selecting the test model by serial number, defining incorporated versus unincorporated changes, and ensuring that the model is available for formal test. Test samples should be based on the variances of the tasks to be presented, the equipment complexity, and the probability of expected error. It is desirable to select a sample size large enough to be representative yet small enough to be compatible with total program cost and schedule requirements.

5.4.3.1 Advanced development testing. Testing and demonstration during the advanced development phase provides assurance to the Government that the design developed for the system can perform in an operational environment. Informal breadboard and brassboard model tests are conducted by the contractor with customer approval on an as-required basis. These tests are performed throughout the equipment design, development, and qualification stages. Although the tests are not formal demonstrations and are not representative of production equipment in a truly operational environment, information obtained from the results is used to evaluate the performance of the overall hardware configuration. Tests to gain confidence in the ECCM design of the system are necessary in this phase.

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5.4.3.1.1 Testing benchmarks. An advanced development plan or equivalent guidance document should establish benchmarks and milestones during this phase, including a preliminary design review (PDR) and a critical design review (CDR). The PM should ensure that the objectives of each of the reviews, especially for ECCM adequacy, are clearly established beforehand with criteria for acceptable progress. The PM may prefer that the review process be dynamic and reactive; that is, the results achieved at one milestone determine the schedule or provide for updates of follow-on milestones. The check list specified in a through f identifies critical areas which require special attention and should be provided for during the advanced development test and demonstration phase:

- a. Test facilities and resources
- b. Specification test personnel
- c. Identification of operational and maintenance technical manuals
- d. Identification of support equipment
- e. Supply support
- f. Identification, design, and procurement of unique items of test equipment that are integral to the overall system

5.4.3.1.2 Results of testing. The resulting test data must first be analyzed to demonstrate that the data reflects preplanned corrective actions correlated with program contingency planning. In this phase, test data analyses and corrective actions must be tailored mainly to those characteristics that informal breadboard model type testing can investigate. The advanced development phase concludes with the testing and demonstration of a successful brassboard model and essential ECCM features. The system design is then ready to enter the full-scale engineering development phase.

5.4.3.2 Engineering development testing. During the engineering development phase, the design evolved from the advanced development phase is committed to a more permanent and operationally testable hardware configuration. By this time, most of the technical risk areas have been reconciled. Engineering development includes the product design and engineering tasks required to make the COM system reproducible, while maintaining the performance, reliability, maintainability, and human engineering characteristics which were determined to be required in the validation phase. Throughout the engineering development phase, tests should be scheduled to verify the technical adequacy and operational effectiveness of ECCM. Finally, data obtained during TECHEVAL and OPEVAL will be used by the NSG to determine the system's vulnerability to hostile ECM and ESM. If the previous testing has been well planned, the end result of NSGs vulnerability assessment should be favorable to the system.

5.5 Production and support. When the acquisition process has reached the production stage, a system's ECCM features will normally be well-developed and tested. This means that the principal ECCM concerns for a manager will involve such matters as configuration management, integrated logistic support, training, and any changes that need to be made in the system's basic design as a result of ECCM weaknesses revealed in either the OPEVAL tests or any post-OPEVAL total-ship tests. While the processes for addressing these issues are specified herein in general terms, their application to ECCM or any other design features or changes should be evident.

5.5.1 Evaluating the ECP from an ECCM viewpoint. ECPs should be the primary vehicle for initiating changes in an existing COM system design that needs ECCM improvements or in a redesign to incorporate new ECCM features. For proposed changes, deviations, or waivers, appropriate ECCM analysis should be conducted by all interested parties. This means that planning, programming, and contractual documentation provide for ECCM requirements, analyses, measurements, and T and E. Adequate funding should be requested to perform the analyses and measurements to ensure compliance with the applicable ECCM requirements and instructions, and to resolve any existing fleet ECCM problems. In evaluating changes, it should be noted that the possible effect on system ECCM features may be so complex, that a comprehensive ECCM impact evaluation is required. Some actions the PM should consider are specified in a through d:

- a. Maintain a log of proposed changes, deviations, and waivers, together with the assignment of deadline dates
- b. Perform an initial engineering evaluation to categorize proposed changes that affect ECCM capabilities.
- c. Arrange for the provision of an advisor to attend Change Control Board meetings to provide assistance in those matters that affect ECCM
- d. Maintain a record of actions taken, and their results

Prior to full scale production, there may be a need after the engineering development phase to incorporate any ECCM-related findings from the TECHEVAL, OPEVAL, full-ship or any other tests into a preproduction model of the system.

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5.6 T and E. These requirements are intended to provide managers with an overview of the T and E phases that occur during the system acquisition process, with emphasis on ECCM-related items and issues. The complete picture of testing from the beginning to the end is extremely important. Adequate planning for ECCM in the early stages of the testing program will prevent surprises by the time of TECHEVAL and OPEVAL, and users will feel confident in the system's ability to function effectively in the presence of the threat.

5.6.1 ECCM T and E policy. SECNAVINST C3430.2 provides that:

Assessment of ECCM capabilities of electronic systems will begin with paper assessments done early in the conceptual design phase. ECCM assessment will be included in each phase of system acquisition and in each phase of operational test and evaluation (OT and E). The extent of the assessment will be based on the total investment in, and criticality of, the system. Each electronic system shall be evaluated to identify ECCM attributes such as operating frequencies, modes of operation, coding, and waveforms, which shall be utilized only in time of war or with the specific concurrence of the Chief of Naval Operations or Commandant of the Marine Corps, as appropriate. Many ECCM features in COM systems are inherent characteristics of the design and are not operator-selectable, such as SS. Restrictions for T and E of selectable and nonselectable features are specified in OPNAVINST S3430.21. In general, adequate attention must be given to T and E ECCM features in such a manner as to prevent possible exploitation by the enemy.

5.6.2 T and E phases. T and E is an integral part of all phases of the development process for COM systems and equipments. T and E planning is a requirement for program initiation; a section on T and E must be included in the DCP and NDCP. This initial testing plan is formally documented in the TEMP. The TEMP is organized around an orderly sequence of project milestones and decisions made during the acquisition phases and the associated tests and demonstrations, which provide factual information for those decisions. There are three categories of T and E performed during the acquisition cycle: developmental test and evaluation (DT and E), OT and E, and production acceptance test and evaluation (PAT and E).

5.6.2.1 Development test and evaluation (DT and E). This category of T and E is conducted under the sponsorship of the PM, and is undertaken for the specific purpose of facilitating the evolution of a system. DT and E is conducted to assist the engineering design and development process and to verify attainment of technical performance specifications and objectives. There are four major phases of DT and E. DT-0 is conducted to support the program initiation decision. DT-I is conducted during the demonstration and validation phase to demonstrate that technical risks have been identified and minimized. DT-II is conducted during the full-scale engineering development phase and must demonstrate that advanced development engineering and production prototype models conform to design specifications in performance, reliability, maintainability, availability, logistic supportability, survivability, vulnerability, and other factors. Design specifications should also include the total spectrum of E³; for example, electromagnetic compatibility (EMC), electromagnetic interference (EMI), electromagnetic pulse (EMP), ECCM, electromagnetic vulnerability (EMV), and radiation hazards to personnel, ordnance and volatile materials (radiation hazard), within the range of environmental parameters prescribed for operational employment of the system. This leads to a TECHEVAL which is conducted to determine whether the system or equipment is functioning in a technically acceptable manner, whether the system or equipment conforms to the design and technical performance specifications, and is technically suitable for OPEVAL. DT-III is conducted after the production and deployment decision to verify the effectiveness of product improvements or corrections to design deficiencies discovered during TECHEVAL, service acceptance trials, OPEVAL, follow-on operational test and evaluation (FOT and E), or fleet employment.

5.6.2.2 Operational test and evaluation (OT and E). OT and E is conducted to estimate a systems's operational effectiveness and operational suitability, identify needed modifications, and provide information on tactics, doctrine, organization, and personnel requirements. All OT and E is planned by, and conducted under, the supervision of the Navy's independent testing activity, Commander, OPTEVFOR. Commander, OPTEVFOR reports directly to the CNO. OT and E is accomplished in two phases: a) Initial operational test and evaluation (IOT and E) consisting of OT-0, OT-I, and OT-II, and b) FOT and E consisting of OT-III and OT-IV. OT-0 may be conducted during the program initiation phase to support the demonstration and validation decision, but most acquisition programs do not require it. OT-I is conducted

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during the demonstration and validation phase to support the full-scale engineering development decision. The objectives of OT-I are to provide an early estimate of projected operational effectiveness and operational suitability of the system, initiate tactics development, when feasible, estimate program progress, and identify operational issues for OT-II. OT-II is conducted during the full-scale development phase to support the production and deployment decision. OPEVAL is the final subphase of OT-II. OPEVAL normally uses preproduction prototype or pilot production hardware, validated computer program software, and maintenance and support equipment and personnel planned for fleet use. OPEVAL should normally begin not sooner than 1 month after completion of TECHEVAL testing. OT-III is that FOT and E conducted after the production and deployment decision, but before production systems are available for testing. OT-III objectives include testing of fixes to be incorporated in production systems, completion of any deferred or incomplete corrections of IOT and E discrepancies, and continuing tactics development. Normally, OT-III is conducted with the same preproduction prototype or pilot production systems and support equipment used in OPEVAL. OT-III will continue until the objectives specified in the approved TEMP for this phase have been met, regardless of the date of deployment of production systems. OT-IV is conducted on production systems. An initial objective of OT-IV is validation on the achievement of program objectives for production system operational effectiveness and operational suitability. Other objectives may include testing the system effectiveness in new environments, new tactical applications, or against new threats.

5.6.2.3 Production acceptance test and evaluation (PAT and E). PAT and E is conducted on production items to demonstrate that systems conform to specifications and requirements. Most PAT and E is the responsibility of the PM. However, acceptance trials of new construction of major conversion ships and new model aircraft are the responsibility of the President, Board of Inspection and Survey (PREINSURV).

5.6.3 Responsibility for T and E. T and E for ECCM in COM systems is executed primarily by three Naval commands: NISC, NSG, and OPTEVFOR. Special test support functions are provided by the Fleet Electronic Warfare Support Group (FEWSG), STILOs, and the Chief of Naval Education and Training. The responsibilities of these commands in the area of ECCM T and E only are specified in 5.6.3.1 through 5.6.3.3.

5.6.3.1 NISC responsibilities. The NISC under the guidance of the NIC is mainly responsible for providing supporting information on the threat.

5.6.3.2 NSG responsibilities. NSG will perform tests, evaluate the susceptibility, and assess the vulnerability of EM systems to the ECM or ESM threat. NSG shall make recommendations, as appropriate, to the appropriate SYSCOM, Commandant of the Marine Corps, or Commander, OPTEVFOR concerning levels of ECCM provided in the assessed systems.

5.6.3.3 OPTEVFOR responsibilities. The Commander, OPTEVFOR carries out assigned responsibilities as an independent test activity under the command of the CNO and serves as principal advisor to the CNO for all Department of the Navy matters pertaining to OT and E. The specific functions specified in a through i are assigned to Commander, OPTEVFOR:

- a. Ensure early involvement in the development cycle of an acquisition program which requires OT and E
- b. Review acquisition program documentation in a timely fashion to ascertain that the documents are adequate to support the development of a meaningful T and E program and that they address and provide for resolution of critical issues. Results of each review will be reported to the CNO.
- c. Report to the Department of the Navy Systems Acquisition Review Council on the objectives and results of OT and E on Navy programs, as required, to support decisions under consideration.
- d. Ensure that security requirements are met during fleet OT and E support, scheduling and operations.
- e. Develop tactics and procedures for the employment of COM systems which undergo OT and E, or as otherwise directed by the CNO.
- f. Coordinate with NSG and other appropriate activities for the provision of signal susceptibility testing and signal vulnerability assessment services required for operational testing.
- g. Report the evaluation of ECCM capability on applicable equipments.
- h. Monitor and report on such other T and E efforts as directed by the CNO.
- i. Make recommendations to the CNO concerning the adequacy of Navy ranges, test facilities, simulators, and other assets used for OT and E.

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5.6.4 TEMP. T and E is conducted in accordance with a TEMP prepared jointly by the PM and the staff of the Commander, OPTEVFOR (and PREINSURV when appropriate). The purpose of the OT and E is to demonstrate the achievement of the COM system development program objectives for operational effectiveness and suitability to support a production and deployment decision and, in addition, to continue the development of tactics for the use of the new weapon systems. Threat intelligence data is required for all phases of the T and E program with periodic updates. The most critical application of threat intelligence support information is for the OT and E process, the results of which are key inputs to the decision at Milestone III for commitment to production and deployment. The basic program documents are a source for determining what T and E is necessary for the successful acquisition, deployment, and operation of the equipment or system. The CNO operational requirement specifies the equipment and system performance parameters and criteria. The NAVELEX development proposal contains program risks, listing the critical performance tests to be performed in development to resolve such risks. The DCP and NDCP specifies the major tests and evaluation to be carried out for the program to provide information for the milestone descriptions. In addition, command policy and good engineering judgement determine certain testing, such as a test, analysis, and fix program as a means of measuring progress toward a specified reliability goal. Each phase of T and E from program initiation through production and deployment will have various objectives and criteria for successful completion of that phase. During the initial submittal of the first draft of the TEMP, the measures of performance, MOEs, and pass and fail criteria should be considered. As the TEMP and other associated testing documents are defined and updated, the measures must be firmly established and used as a basis for the decision processes. The PM should consult with Commander, OPTEVFOR and other testing activities to agree upon criteria for tests. As required, analytical studies should be instituted early in the program to select and quantify measures and determine the relevancy and criticality of parameters. For example, a measure of effectiveness of COM ECCM under jamming conditions might be the mean error rate in words missed per message with a specified signal to jammer power ratio measured at the input to the receiver. All cognizant parties must agree beforehand how the measurement is to be performed and evaluated. In particular, the method of counting missed words, the complexity of the message, the characteristics of the jamming signal (modulation, and so forth) must be stipulated. In addition, factors such as reliability, maintainability, and availability, as well as other logistics factors may need to be considered. In some cases, sensitivity studies need to be performed whereby a performance parameter is varied and the effect on the MOE analyzed. Generally, tolerances for unexpected situations or overstressed conditions should be provided where cost, time, and engineering constraints permit.

5.6.4.1 ECCM guidelines for the TEMP. The guidelines specified in APPENDIX D may be used for ensuring proper inclusion of ECCM considerations during preparation of the TEMP. Only those items which are ECCM significant are addressed.

5.6.5 Technical evaluation (TECHEVAL). TECHEVAL is performed for the purpose of investigating systems or equipments and collecting information which will aid in answering technical questions and issues. This testing and analysis permits the PM to determine whether the system or equipment is functioning in a technically acceptable manner, conforms to design and technical performance specifications, and is technically suitable for OPEVAL. (TECHEVAL and OPEVAL are complementary test programs and complete the initial developmental and OT and E phase.) With respect to ECCM, TECHEVAL is the culmination of all developmental tests to ensure that the ECCM features work as intended. The tests should attempt to verify the results of theoretical susceptibility and vulnerability analysis performed by NSG. Specifically, the tests should demonstrate how the effect of susceptibility of the COM system to detection, geopositioning, classification and identification, jamming, and anti-radiation missiles (ARM) are reduced by the application of ECCM. Data are collected using calibrated recorders and emitters, and an empirical analysis is performed. The empirical and theoretical results are then compared and used to determine acceptance of the system.

5.6.6 Operational evaluation (OPEVAL). OPEVAL usually begins about 1 month after completion of TECHEVAL and includes demonstration of program objectives for operational effectiveness, operational suitability, and continuing tactics development. OPEVAL is conducted by OPTEVFOR under as realistic an operating condition as possible. Like TECHEVAL, OPEVAL provides an opportunity to gather empirical data. With respect to the ECCM, the data will be useful in evaluating susceptibility and vulnerability, and determining whether the system can operate as specified in the presence of the threat. The results of OPEVAL are used in deciding whether or not to proceed with production of the system.

5.6.7 Total ship tests. After satisfactory completion of TECHEVAL, OPEVAL, and initial production model tests (preproduction model), there still remains an important validation test. The total ship test verifies that the system will function effectively in a total ship environment. The concern is that all of the EM radiators on the ship constitute a potential threat and hazard to the COM system, especially when the EM radiators are all emitting simultaneously. Moreover, it must be ensured that the COM system does not destructively interfere with other sensitive shipboard receiving systems.

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5.6.8 Other special tests. Tests, other than those previously specified herein, may be deemed appropriate to demonstrate the capability of the ECCM against specialized threats. FEWSG and Fleet Air Reconnaissance Squadron support may be required and shall be specified, if deemed essential.

5.6.9 Approval for full production (AFP). AFP is a separate determination made prior to the program review considering the production and deployment decision (Milestone III). The PM should initiate the request for ASU in accordance with NAVELEXINST 4000.9C. The request for ASU states the results of the T and E conducted and plans for correcting deficiencies identified in TECHEVAL and OPEVAL. It must also document the basis for assuring that the system or equipment can effectively operate in the anticipated EM environment, in conformance with NAVELEXINST 2410.4. Specifically, the PM must show that the ECCM features of the system or equipment can effectively counter the threat of intercept or jamming, or both.

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6. NOTES

6.1 Subject term (keyword) listing.

Acquisition life cycle
Anti-jamming
Communication systems (Naval)
Electromagnetic compatibility
Electronic counter-countermeasures
Electronic counter measures
Electronic warfare
Electronic warfare support measures
Jamming

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ECCM TECHNIQUES FOR COM APPLICATION

10. SCOPE

10.1 Scope. This Appendix covers the ECCM techniques for COM application.

20. APPLICABLE DOCUMENTS

This section is not applicable to this Appendix.

30. TECHNIQUES

30.1 General. ECCM is one of the major subdivisions of EW which involves actions taken to ensure friendly effective use of the EM spectrum despite the enemy's use of ECM. Therefore ECCM can be defined broadly enough to include both anti-ECM and anti-ESM techniques. The concern is with measures to not only counter the effects of enemy jamming but also, where possible, to reduce the probability that the enemy will be able to detect, locate, intercept, and disrupt COM sources and links. Table II lists ECCM COM techniques and indicates whether their use in a system offers the potential for enhancing AJ or LPI features, or both. Five general categories of techniques and procedures are listed, and these are further divided into specific applications. Included are features incorporated into the COM system as an inherent part of its design, and exploitation of propagation phenomena and tactical ways of using the system to enhance system ECCM, AJ, and LPI capabilities. For each application, bullets in the appropriate columns indicate the manner in which ECCM is effective; that is, anti-ECM or anti-ESM. The list by no means exhausts all possibilities and variations that could be used, but it is representative of the most commonly used techniques. The ECM threat and ECCM techniques described in this Appendix are limited to the RF spectrum (primarily HF and up). The matrix in Table II provides a quick-reference index for the techniques described in 30.2 through 80.3.

TABLE II. ECCM techniques in COM systems.

Technique	Application	Reduced susceptibility to jamming (anti-ECM)	LPI techniques (anti-ESM)
Wideband signalling techniques	DSPN	•	•
	FH	•	•
	TH ^{1/}	•	•
Receiver techniques	Time domain trap (notch filter)	•	
	Wide dynamic range design features	•	
	Null forming steering	•	•
Antenna techniques	Beam positioning	•	•
	Sidelobe cancelling	•	•
	Adaptive arrays	•	
	HF path prediction	•	•
Propagation techniques	Refractive effects prediction		•
	Meteor burst communications	•	•
	Use of maximum/minimum usable frequency		•
	Redundant transmissions	•	
Tactics procedures	Indirect path (relayed COMs)	•	
	Frequency changing (oper. control)	•	•
	Emcon (oper. control)		•
	Minimum power usage (oper. control)		•

1/ Time hopping

30.2 Wideband signalling techniques. SS modulation produces a wideband, low power density signal which has statistical properties similar to random noise. As a result, this signal is not readily detected or recognized by conventional surveillance receivers; hence, the origin of its LPI qualities. Spectrally, this signal's bandwidth occupancy has been expanded to be much wider than the bandwidth normally required for transmitting the basic message. The principal techniques for this expansion are direct DSPN, FH, TH, and hybrid combinations thereof. The primary purpose

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for spreading the signal bandwidth is to obtain processing gains against jamming signals and other sources of interference. The potential gain (G) is roughly the decibel (dB) equivalent of the ratio of the expanded bandwidth to the data or message bandwidth; that is, 3 dB for a 2:1 ratio and 30 dB for a 1000:1 ratio. The spectrum of the basic data signal at the transmitter can be spread out by such ratios as 100:1 (20 dB G) or 10,000:1 (40 dB G) depending on the format, the data rate being used, and the bandwidth available. At the receiving end, correlation techniques are used to collapse the spectrum of the desired signal, while the uncorrelated interfering signal remains spread out and diluted across the band. Thus, the operation results in processing G , since spread jammers have less energy in the information bandwidth of the desired signal. At HF, the picture changes somewhat, in that opening (widening) the bandwidth in this part of the spectrum produces a greater increase in noise than the proportionate bandwidth increase (atmospheric noise is very high in the HF band) which reduces the theoretical G from spreading.

30.3 DSPN techniques. Use of a PN code is the primary basis for implementing the SS technique. This use implies an apparently random sequence of binary digits that can be reproduced by any authorized receiving terminal. While this sequence, which is produced by a PN code generator, appears to be random, it can be reproduced by any recipient with a receiver capable of correlating the received signal with a replica of the transmitted PN code. At the transmitter end, the wideband noise-like signal from the PN code generator is viewed as a carrier on which the desired message is imposed. Upon reception, the SS modulation is removed by correlation, which permits the message to be demodulated by conventional means. The processing G for DSPN applications would be the ratio of the spread bandwidth to data bandwidth.

30.4 FH techniques. FH-SS channelizes the available bandwidth into frequency slots (usually contiguous) and transmits each successive pulse in one of the slots selected under control of the PN code generator. In this process, the microwave carrier jumps (incoherently in most cases) over many frequency slots selected in a pseudo-random fashion. Data modulation is impressed on each pulse typically by frequency shift keying (FSK); hence, the slot width must be at least as wide as the data bandwidth. The AJ capability is realized because the enemy does not know the next frequency slot to be used and must, therefore, spread his jamming energy over a very wide band. The processing G for a frequency hopper equals the total number of frequency slots that are utilized; that is, processing $G = \text{dB equivalent of number of frequency slots}/1$. For example, if 1000 frequency slots are available, the processing G of the system would be 30 dB ($10 \log (\text{number slots})$).

30.5 TH techniques. TH, which is used much less frequently than DSPN or FH, can be viewed as a form of SS, which channelizes via time slots and employs a burst transmission within the slot. Provided that the transmitter can operate at a high peak power (but low duty factor), the processing G (as it is with frequency hoppers) is given by the number of slots available in a repetition frame. The slot in which the transmitted pulse occurs is selected under the control of the PN code generator. TH is seldom employed by itself, but is used occasionally in conjunction with other SS techniques.

30.6 Techniques analogous to bandwidth spreading. Processing G s against jamming can also be achieved in other domains in the same sense that it is achievable in the frequency domain. These include:

- a. Time domain applications - where the same information is sent over longer periods of time (redundancy)
- b. Spatial domain applications - where wider apertures are employed

30.7 SS COM reception. Acquisition (acquiring the initial synchronization) is the major problem associated with SS COM. Before any data can be derived from a SS system, the code patterns between the transmitter and receiver must be aligned to eliminate timing uncertainties. Specific timing alignments must be established within some fraction of the smallest time element; that is, a chip length, where each data message consists of hundreds and thousands of chips. For a DSPN system with a 10 megachips per second PN code rate, a chip would be 0.10 microsecond (μs) long. Acquisition is generally easier for FH systems (those changing frequency noncoherently) than for DSPN systems, because the timing alignment requirements are usually much less severe. For example, synchronization in a FH system that is changing frequency (noncoherently) every 10 μs (a 10 μs chip length) is two orders of magnitude easier than with a similar PN system having a 10 Mbps data rate (0.10 μs chip length). Because of this synchronization, FH systems are usually designed to hop incoherently unless there are special reasons to preserve the RF phase.

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30.8 Combined techniques and cost considerations. SS COM systems, which combine both FH and DSPN techniques, are found among the more sophisticated designs being developed for future Naval use. The addition of TH features in such systems is also a possibility, but it is less likely to be used than the first two. Decisions about whether to use only one or a combination of these techniques in the design depends upon such factors as: the total bandwidth available, how rapid the acquisition time must be, the phase and amplitude linearity required across the band, the nature to the threat and the processing G required, the maximum data rate and BERs permitted, the way the system will be used, the platform and environment in which the system will be mounted and operated, and the total funds available to do the job. A tradeoff or compromise decision might typically be made to use a combination of DSPN and FH techniques to obtain half of the needed processing gain with each one so that some of the advantages that each has to offer are realized. Thus, mutual benefits could be derived from the fact that some DSPN systems are basically simpler and more efficient than some FH systems, while the noncoherent FH types would acquire synchronization faster and be less affected by phase distortion across the band. It is vitally important that the additional funds needed for the ECCM-hardening of the system not be compromised or eliminated for economy reasons. Managers must understand that without adequate ECCM protection, none of these critical COM systems will be capable of fulfilling its military mission in the presence of an active threat. Where there is a choice, it is better to incorporate advanced ECCM techniques into the design of new equipment, rather than retrofit old equipment. The integrated design approach produces a superior product and is more cost effective. Additionally, a modified design might require compromises in other areas of system performance.

40. Receiver techniques. While most of the jamming resistance in the radio portions of a COM system are obtained through the SS techniques described herein, some things can be done in the receiver to further enhance its AJ qualities. Typical of these might be the use of a notch filter (or time-domain type) in the front end, or intermediate frequency section to suppress the effect of narrow band, continuous wave (CW) jammers. In general, design features in the receiver that tend to widen the dynamic range will probably help, AJ-wise. These could include the use of log vice linear receivers, linear vice square-law detectors and various automatic gain control noise suppression and limiting circuits.

50. Antenna techniques. One of the simplest and best ways to obtain some jamming resistance; that is, AJ, or signal enhancement, or both, in COM systems, is through the use of certain types of directional antenna systems and special null and beamforming techniques. Even conventional antennas have been designed for inherently low side lobes (e.g. -40dB or better). These may vary from the simplest of antenna structures to very complex, sophisticated arrays, which can be used with existing COM systems or incorporated into new COM developments. The main concern is to ensure that the antenna is properly matched to the system. For example, if an SS COM system (which covers a broad frequency band) is not carefully matched to a beam and null forming array (whose null and lobe patterns are sensitive to frequency changes) the anticipated AJ and nulling capabilities of the combination may not be realized.

50.1 Null and beamforming and steering array. In its simplest form, this would be an array of two or more elements equipped with some means of controlling its phase and amplitude characteristics to form nulls in the radiation pattern and be able to steer them, so that the effects of jamming and interference from a given direction can be minimized. Conversely, lobes can be formed in a similar fashion and pointed in the direction of a communicating party to enhance the COM link between them. Under the right conditions, antenna pattern nulls in excess of 30 dB can be formed and used operationally on board ship.

50.2 Sidelobe cancelling techniques. Sidelobe cancelling techniques refer to methods for cancelling or suppressing the effects of unwanted signals received into the COM systems through the sidelobes of the antenna. The ultimate objective is to be able to discriminate between those signals arriving through the main beam and all others. Thus, signals from jammers and other sources of interference would never enter the system through side or backlobes while the main beam was pointed away from them and in the direction of a desired COM source. Such techniques will typically work for a given system over a limited dynamic range and frequency range.

50.3 Adaptive arrays. The term adaptive refers to the ability of an antenna array to adapt, modify or adjust its radiation pattern in accordance with changes in the EM environment. In its elementary AJ form, the adaptive array will sense when a jamming signal comes on and will automatically steer a null toward it. As the jammer moves, the null will follow. More sophisticated versions of these arrays could be programmed to automatically generate nulls against multiple jammers and at the same time form beams in directions where COM paths are desired.

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60. Propagation techniques. The techniques employed with COM systems to utilize propagation phenomena to counter their possible vulnerability to enemy jamming or intercept are also viewed as forms of ECCM. Several techniques are described in 60.1 through 60.5.

60.1 AN/TRQ-35 chirpsounder. The AN/TRQ-35 system combines a transmitter, a receiver and a spectrum analyzer, and provides information in real-time about which HF frequencies are actually propagating between the transmitter and the receiver, the relative signal strengths of the received signals, the actual propagation path modes, and the time occupancy of the frequencies throughout the band in the recent past. The system employs a CW transmitter that is linearly swept in frequency through the band (hence the origin of the name chirpsounder) and an extremely narrow band receiver, whose local oscillator is synchronized in time to the transmitter. Any signal received has its time delay displayed on a cathode ray tube (CRT). Therefore, the receiver display can be interpreted to show that a certain frequency is presently capable of propagation and each mode of propagation of that frequency, for example, Sporadic E, F-1, F-2, and so forth. The display shows a second trace on the CRT representing the strength of the signal received at each frequency. To reduce the multipath interference, frequencies showing only one propagation mode and satisfactory signal strength are selected as candidates. These frequencies are then examined on the spectrum analyzer display which provides information about the percentage of time that frequency has been used during the last 5 minutes or the last 30 minutes. Then the user can choose an operating frequency that has an extremely high probability of propagating successfully with the lowest probability of interference.

60.2 HF path prediction. The techniques for prediction of propagation paths are common knowledge. The techniques are sufficiently established to have been adapted to computer-based systems. Long range HF COM is possible because the radiated energy is refracted by the ionosphere toward the earth. Then, the radiated energy is reflected from the earth to the ionosphere where it is again refracted. This process continues until the energy is sufficiently dissipated to become unusable. The refraction is a function of the frequency of the emission and the composition and structure of the ionosphere. The composition and structure of the ionosphere is primarily influenced by solar emissions and is quite predictable if those emissions remain constant. However, during solar disturbances, ionospheric conditions change rapidly. Obtaining solar activity in real-time and processing the information immediately enables continuously accurate prediction of the propagation paths. The U.S. Navy has developed a propagation assessment and forecasting terminal (dubbed PROPHET) designed to use satellite and other information on solar activity to produce ray traces, which depict the path of the EM wave fronts. These traces not only show the lowest usable frequency (LUF) and the maximum usable frequency (MUF), but also show areas in which no communication is possible. Proper selection of frequencies would then allow some ability to optimize the propagation path to the desired receiver while minimizing the path to an unwanted receiver; thus enhancing an ECCM capability. While early versions of PROPHET were constrained to operate with large computer-augmented shore installations (for example, at Naval COM area Master Stations), technology improvements have produced a tactical prediction module for ship-to-ship use which uses a small desk-top graphics computer, and is completely mobile. Another small portable (mobile) shipboard version of the system for SIGINT and SIGSEC applications called CLASSIC PROPHET, which is used to support the Navy's large land-based HF direction finding (DF) nets, is available.

60.3 Refractive effects prediction. Development of integrated refractive effects prediction system (IREPS) methods and models have made it possible for Naval units at sea to predict the local propagation conditions in near-real time, including the existence and nature of both elevated and surface ducts in the lower atmosphere. With this information, path loss versus range, and detection range versus altitude for specific COM signals can be predicted. As an anti-ESM measure, these predictions could be used in some tactical and strategic situations to help communicators use their equipment to minimize the possibility of being detected and attacked by the enemy.

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60.4 Meteor burst COMs. This technique uses ionized trails in the upper atmosphere (primarily in the E-Region, 100 kilometer (km) altitude) as reflectors of a COM signal that one party desires to send to another. These trails, whose life-span is of the order of seconds or fractions of a second, are produced by meteors transiting the upper atmosphere. For the brief interval that these trails exist, short bursts of information can be reflected off them from one party to another. Because the transmission path is fairly unique, detection by, and interference from other parties is made more difficult. The primary users of such COMs would be shore stations (with large high gain antennas) sending messages to ships. A link might typically be established with a ship by having the shore station (knowing the ship's location) beam a constant signal in the ship's direction at an elevation angle which illuminates the upper atmosphere (E-Layer) at a mid-point in the path between shore station and ship. When a meteor trail appears, the signal will simultaneously appear in the ship's receiver. Within the brief life-span of the trail, the ship will signal the shore station that a path exists, whereupon the shore will burst communicate its message to the ship. Some of the operational considerations in meteor burst COMs are specified in a through f:

- a. Frequency response is best in the low VHF band (television band), which limits the frequency slots available for use.
- b. The frequency of useful meteor trail appearances during one day can be as high as several per minute with occasional waiting periods as long as 2 minutes to 5 minutes. (Morning and evening rates will be higher and lower.)
- c. Computer storage and release of messages are ideal for high data rate burst COMs
- d. The bandwidths of these COM circuits (paths) are fairly broad and coherent, which permits high data rate, short burst COMs.
- e. The operational implementation of these techniques requires high costs.
- f. Operationally, in spite of their excellent AJ and LPI features, these techniques will probably be utilized only for backup, rather than for primary COM systems, because the circuit is not continuously available and lends itself to only a two-party usage at one time.

60.5 MUF and minimum usable frequency. This LPI technique is used to select the frequency and power combination in a given scenario that will result in sufficient propagation loss over a given COM path to minimize the possibility of intercept beyond the intended recipient.

60.6 Millimeter wavelength frequencies. The use of millimeter wavelength signals, i.e. in the general region of 60 GHz, for short-range (up to several miles) takes advantage of the high attenuation rate of such signals that makes them undetectable beyond a few miles.

70. Operational tactics and procedures. The techniques specified in a through f can be used with COM systems, in general, to increase their ECCM, AJ and LPI capabilities:

- a. Redundant transmissions - to reduce the information rate using multiple transmissions or wrap-around procedures (sending the second half first) to increase the probability of message reception
- b. Indirect path (relayed) COMs - using a third party to relay messages between two other parties that are unable to communicate because of interference (or jamming) in the direct path between them (a potential application for directional antennas)
- c. Frequency changing - to avoid set on jammers
- d. Parallel keying - (simultaneously in separate channels) to avoid jamming or interference and improve the probability of message reception
- e. EMCON - to provide for a central capability onboard ship or in a task force for turning off any or all of the emitting equipment as needed, in order to minimize the possibility of enemy detection, targeting, jamming and attack by ARM or conventionally guided weapons
- f. Operator actuated variable power control - to provide COM operators with the ability to either reduce or increase the RF output of a COM system if it needs to remain hidden (LPI), or to try to override any interference that is causing problems (AJ).

80. COM links. The generic types of COM links (HF and up) required by the Navy and Marine Corps to conform to their varied mission needs (both tactical and strategic) are listed in 80.1 through 80.3 for reference purposes. The necessity for having ECCM-hardened COM systems in these links is evident in light of the possible threat capabilities. The special links lying below the HF band are omitted from these lists for security reasons.

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80.1 Beyond line-of-sight (BLOS) COM links. The purpose of BLOS COM links is to conform to the Navy's needs for long-haul (greater than 300 nmi) COMs. These links consist of:

- a. The primary BLOS link (using satellite communication (SATCOM) relays):
 - 1. UHF - Fleet satellite communication (FLTSATCOM) (existing)
 - 2. SHF - FLTSATCOM (in OPEVAL)
 - 3. Extremely high frequency (EHF) - FLTSATCOM (in development)
- b. The backup BLOS link:
 - 1. HF skywave COMs (existing)
 - 2. Improved HF skywave (in development)

80.2 Extended line-of-sight (ELOS) COM links. ELOS COM links conform to the Navy's COM needs from 20 nmi to 300 nmi. They include:

- a. HF groundwave (existing)
- b. Improved HF groundwave (in development)
- c. New UHF direct (LOS) and relayed COMs (in development)

80.3 LOS COM links. LOS COM links comprise:

- a. UHF - For ship-to-air, air-to-air, and ship-to-ship COMs
 - 1. UHF COMs (existing)
 - 2. Improved UHF COMs (in development)
- b. VHF - For ship-to-ship and ship-to-shore COMs
 - 1. VHF COMs (existing)
 - 2. Improved VHF COMs (in development)
- c. EHF - For ship-to-ship COMs
 - 1. In development

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APPENDIX B

PLANNING AND SPECIFICATION OUTLINE

10. SCOPE

10.1 Scope. This Appendix provides a planning and specification outline for use in incorporating ECCM into COM systems.

20. APPLICABLE DOCUMENTS

This section is not applicable to this Appendix.

30. REQUIREMENTS

30.1 Planning and specification outline. The planning and specification outline is intended to be used as a guide to stimulate the thinking of managers about the ECCM aspects and features of COM systems during planning and specification preparation.

PLANNING AND SPECIFICATION OUTLINEA. What type of COM system is involved?1. SATCOM

- a. UHF
- b. SHF
- c. EHF

2. BLOS

- a. HF
- b. UHF
- c. Other

3. ELOS

- a. HF
- b. UHF
- c. Other

4. LOS

- a. UHF
- b. VHF
- c. Other

5. SATCOM type

B. Does the following exist? (Yes or No)

- 1. OR
- 2. DP
- 3. NDCP
- 4. Type A system specification
- 5. TEMP

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APPENDIX BC. Has assistance been requested or obtained from the following? (Yes or No)

1. STILO sources _____
2. NISC, NFOIO and National Security Agency (NSA) sources _____
3. NSG sources _____
4. Experts in:
 - a. Systems Command _____
 - b. Navy Laboratories _____
 - c. Industry _____

D. Questions relating to the threat

(Threat parameters and capabilities)

1. What are threat ECM characteristics?

- a. Estimated power out (effective isotropic radiated power (EIRP))
 - (1) Peak _____ dBW
 - (2) Average _____ dBW
 - (3) Duty cycle _____ percent
- b. Anticipated signal waveform(s)
 - (1) Modulation type(s) _____
- c. Probable operating frequencies _____ megahertz (MHz)
 - (1) Stationary _____ MHz
 - (2) Swept (limits) _____ upper _____
lower MHz
- d. Anticipated radiation modes (yes or no)
 - (1) Continuous _____
 - (2) Burst _____
 - (3) Intermittent _____
- e. Estimated antenna characteristics
 - (1) G _____ dB
- f. What are threat ECM tactics and operations?
(Anticipated operational settings for ECM threat systems and platforms)
 - (1) Describe anticipated threat versus COM system geometries _____
 - (2) Estimated ranges at which ECM threat will be employed (maximum and minimum) _____ nmi

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(3) Probable threat densities _____

(4) Platform(s) on which ECM threat is likely to be mounted _____

2. What are threat ESM characteristics?

a. Probable types of detection systems

- (1) Superhets _____
- (2) Instantaneous frequency measuring (receiver) (IFMs) _____
- (3) Tuned radio frequencies _____
- (4) Crystal video _____
- (5) Spectrum analyzers _____
- (6) Radiometers _____
- (7) Other _____

b. Estimated operating sensitivities of above systems (including antenna gains and installation losses)

- (1) _____ decibels referred to one milliwatt (dBm)
- (2) _____ dBm
- (3) _____ dBm
- (4) _____ dBm

c. Estimated DF accuracies (at operating sensitivity specified in D2b)

- (1) From ships + _____ degrees
- (2) From A/C + _____ degrees
- (3) From shore sites + _____ degrees
- (4) From SAT sites + _____ degrees

d. Estimated location capabilities of threat (triangulation, TDOA, and so forth) against USN COM signal sources

- (1) From multiple ships, circular error probable (CEP) _____ nmi radius
- (2) From multiple A/C, CEP _____ nmi radius
- (3) From multiple shore sites, CEP _____ nmi radius
- (4) From multiple SAT, CEP _____ nmi radius

e. What are threat ESM tactics and operations?

(Anticipated operational settings for threat ESM systems and platforms)

- (1) Describe anticipated threat versus COM system geometries and tactics _____
- (2) Estimated ranges at which threat will be employed (maximum and minimum) _____ nmi
- (3) Platform(s) on which ESM threat is likely to be mounted _____

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APPENDIX BE. What are COM system parameters?1. Operating frequencies

- a. Operating frequency bands _____
- b. Frequency limits _____ MHz lower _____ MHz upper

2. Signal waveform (modulation type(s))

- a. For voice circuits _____
- b. For data circuits _____

3. EIRP _____ dBW4. Data rate(s)

- a. Maximum (no jamming) _____ bps
- b. MECC (maximum jamming) _____ bps

5. BER

- a. Maximum allowable _____ 10- _____
- b. For given ratio of jammer signal level to COM signal level
(J/S) ratios _____ 10- _____

6. Total G and processing Gain (G_p) required?

- a. Minimum to meet threat _____ dB
- b. How much of total G can be achieved with antenna-derived gain (G_A)?
_____ dB.
How much with G_p ? _____ dB

7. Antenna characteristics

- a. G (main beam) _____ decibel isotropic (dBi)
- b. Sidelobe levels (relative to main beam)
- (1) 1st sidelobe - _____ dB
 - (2) 2nd sidelobe - _____ dB
 - (3) Backlobes - _____ dB
 - (4) Null depths (maximum) - _____ dB
 - (5) Sidelobe suppression (dynamic range) _____ dB

8. SAT characteristics (For SATCOM systems)

- a. Which SAT is utilized? _____ dBW
- b. Up-link power levels _____ dBW
- c. Down-link power levels _____ dBW
- d. SAT antennas characteristics
- (1) Number of beams _____

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- (2) G (maximum) _____ dBi
- (3) Is antenna nulling available _____ (yes or no)
(If so, how much _____ dB)
- (4) Does SAT have processing? _____, how much _____ dB

F. What are the operational requirements and features of system

1. Maximum operating range _____ nmi (no jamming)
2. Minimum operating range _____ nmi (maximum jamming)
3. System acquisition time _____ seconds
(Does system have to operate coherently _____)
4. Types and numbers of COM circuits
 - a. Voice _____
 - b. Data _____
5. LPI requirements
 - a. Must not be detectable by _____ ESM system on
_____ platform beyond _____ nmi
 - b. Other _____
6. Describe special operating modes, features, and characteristics of system.
 - a. Will propagation prediction methods be used? _____
 - b. EMCON control features? _____
 - c. Are there special receiver requirements? _____
 - (1) Such as: time domain traps (notch filters)? _____
 - (2) Other? _____
 - d. Antenna null-generation and control features? _____
 - e. Other? _____
7. Describe interoperability concerns.
 - a. On COM system platform _____
(What platform(s) will system be mounted on?)
 - (1) Ships _____ type _____
 - (2) A/C _____ type _____
 - (3) Shore _____
 - b. In task force and area-side operations _____
 - c. In interservice operations
(Which COM system(s) must it be interoperable with?)

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- (1) Army _____ type(s) _____ model,
type(s) _____
- (2) Air Force _____ type(s) _____ model,
type(s) _____
- (3) Navy _____ type(s) _____ model,
type(s) _____
- (4) NATO _____ type(s) _____ model,
type(s) _____

G. Define E³ issues

1. EMC-related _____
2. EMI-related _____

H. Will there be special test requirements?

1. Automatic BITE routines for an on-line check of ECCM effectiveness _____
2. Other _____

I. Are there special security requirements?

1. For testing the system and the ECCM features
2. Related to the security of the system's synchronization code(s) and the minimum time to achieve COM synchronization?

J. Have all areas of the specification been examined to apprehend unrealistic or over-specified portions that may greatly increase program costs?

1. In testing prescribed for the earlier (pre-TECHEVAL and OPEVAL) stages of the development? _____
2. In making use of as much of the less-expensive ways to achieve G_p as possible (for example, tactical procedures, propagation, and certain antenna techniques) rather than relying solely on SS methods.
3. Other? _____

K. ECCM analysis1. ECCM AJ analysis

Answers to the questions in a through m will help to characterize the systems ECCM-AJ features

Under maximum jamming and the MECC data rate(s) for LOS links:

- a. What is the J/S ratio for the maximum allowable BER? _____ dB
(see Appendix C, Figure 4)
 - (1) J/S - BER ratios for voice ? _____ dB
 - (2) J/S - BER ratios for data ? _____ dB

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- b. What is the jamming level (J) into the COM receiver at minimum range (Di) dBW (use antenna gains and EIRPs listed and propagation losses from APPENDIX C, FIGURE 3 for the calculation.)
- c. What is the COM signal level signal power (S) into the COM receiver at maximum range (Ds) dBW. (Use antenna gains and EIRPs listed and propagation losses from APPENDIX C, FIGURE 3 for the calculation.)
- d. What is the difference in dB between the J/S ratio from the two calculations in b and c and the J/S ratio from the tables used in step a? _____
- e. The difference in step d (in _____ dB) represents the total G that must be obtained in the system through SS G_p and possibly some G_A .
- f. The magnitude of G will determine whether it can all be supplied by SS G_p or whether some G_A will be required. (G 40 dB is probably the practical upper limit to obtain by G_p alone).
- g. If hiding the signal (from conventional intercept receivers) is important, then as much of G_p as possible should be obtained with SS G_p .
- h. Determine which SS technique to use in obtaining G_p :

(1) DSPN = _____ dB

(2) FH = _____ dB

If critical requirements (5.7F3) call for minimum acquisition time and no phase coherency, then FH is probably the way to go.)

- i. Has NSA been consulted to ensure that the specified system acquisition time is compatible with the security requirements for the link
- j. Is the synchronization pattern of the link such that enemy deception repeaters may be able to effectively break the synchronization of the system
- k. If G (under maximum jamming) is too large to achieve practicably with a combination of $G_p + G_A$, can a special notch filter in the receiver (see F6c) be used to make up the difference _____
- l. If G_A is supplying part of needed system G against the threat and D1f describes the issue of multiple jammers, how many and what depth of nulls will be required to counter the jammers
 - (1) Number of nulls _____
 - (2) Depth of nulls _____ dB
- m. If the system is a BLOS SATCOM type, then the calculations of J, S, G, G_p , and G_A will have to consider values from E8.

2. ECCM LPI analysis

Answer to the questions in a through d about the ESM intercept case will characterize the system's ECCM-LPI features:

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- a. What is the average power (P_{AV}) from the COM transmitter arriving at the input of the hostile intercept receiver (on same platform as jammer) (Use estimated average sidelobe levels of COM antenna and propagation losses from APPENDIX C, 30.2.1.2 for the calculation).
- b. If the value of P_{AV} exceeds the operating sensitivity of the hostile detection system (see D2b), then the COM system is detectable. (However, the probability of detection will be determined by such factors as the hostile interceptor's use of scanning or fixed antennas and scanning or fixed-tuned receivers, the scanning rates, and whether the COM system is transmitting continuously or in bursts).
- c. IF P_{AV} exceeds operating sensitivity of the detection system by _____ dB, can a null-steering or very low sidelobe antenna be used by the COM system to reduce the signal level even further in the direction of the ESM threat _____
- d. Can the probability of detection of the COM system be reduced even further by using some of the propagation and tactics and procedural techniques shown in TABLE II

3. ECCM specification factors

The factors in a through f summarize a few of the more obvious factors that can be used to specify the ECCM characteristics (both AJ and LPI).

- a. From K1d, obtain the G needed in the system to overcome the jammer.
- b. Whether the total G (see a) is to be obtained by a combination of G_p and G_A can be specified in advance or it can be left up to the developer of the system to propose his own design approach and the rationale.
- c. If a manager's concern is to maximize the LPI qualities of the system and still obtain the required AJ G, he should probably obtain most of the AJ G through $SS G_p$ (for example, by spreading the signal bandwidth) rather than with G_A .
- d. There are certain critical requirements that almost mandate some system ECCM design features (see K1g, h, i, j, and k)
- e. An important part of the ECCM design is to characterize special antenna arrays (for example, beam gains and null-depths in dB with respect to the main beam) needed to counter both the ECM and ESM threats (single and multiple).
- f. The factors specified in D through J may either directly or indirectly effect the system's ECCM design to some degree, and should be reviewed carefully item by item. Other potentially critical items are:
 - (1) Interoperability requirements
 - (2) ECM and EMI factors
 - (3) Platform constraints

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APPENDIX C

ESTIMATING THE KIND AND QUANTITY OF ECCM NEEDED

10. SCOPE

10.1 Scope. This Appendix provides a guide to estimating the type and quantity of ECCM required.

20. APPLICABLE DOCUMENTS

20.1 Issues of documents. The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this Appendix the extent specified herein.

NAVAL ELECTRONICS LABORATORY CENTER

TD 504 Volume VII

NELC/TECHNOTE 2722

NELC/TECHNOTE 2762

Navy C³ System Design Principles And Concepts, APPENDIX J,
Vulnerability To Jamming Deception And Intercept 15 August 1976
Detection Of Covert Signals
Propagation Of Covert Signals

NAVAL RESEARCH LABORATORY

NRL/Memo Report 2873

Fundamentals Of Covert Communications

(Copies should be obtained from the Commanding Officer, Naval Research Laboratory, Washington, DC 20375.)

(Copies of publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

20.2 Other publications. The following documents form a part of this Appendix to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

MEGATEK CORPORATION

Report

Coverage Estimation Of Tactical LPI Communications
Systems Analysis

(Application for copies should be addressed to Megatek Corporation, 7700 Leesburg Pike, Falls Church, VA 22043.)

INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS (IEEE)

IEEE Transactions,
Volume AES-9,
NO. 2, March 1973

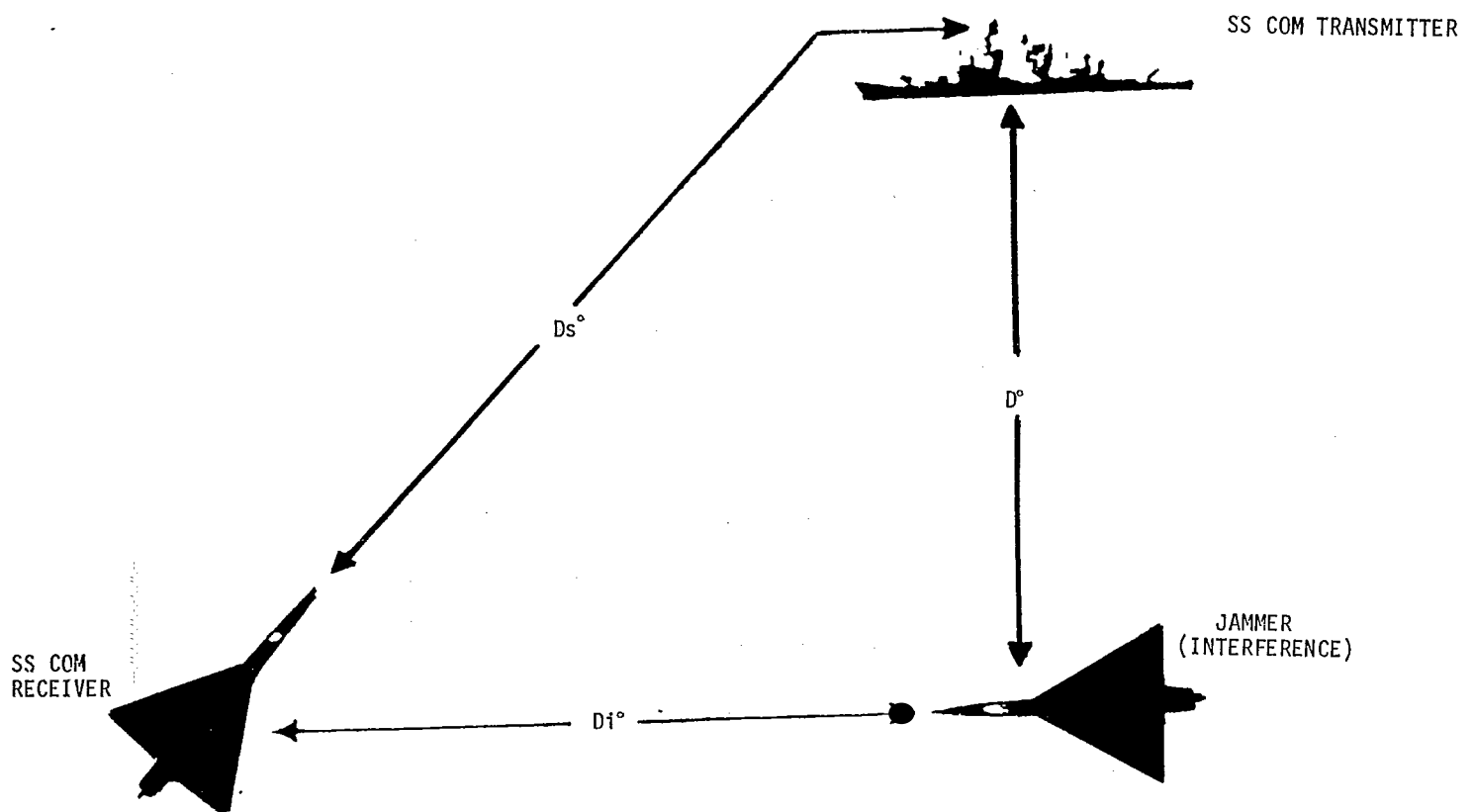
Application Of Adaptive Arrays To Suppress Strong Jammers
In The Presence Of Weak Spots

(Application for copies should be addressed to the Institute of Electrical and Electronic Engineers, 345 East 47th Street, New York, NY 10017.)

30. REQUIREMENTS

30.1 General. The ability to make a reasonable estimate of the type and quantity of ECCM required to operate successfully in the presence of the threat is an important factor in the early stages of planning for ECCM in a system. A greatly simplified operational situation and diagram are proposed to illustrate how the estimation process might begin. These data, with several figures and tables, are then utilized for analysis.

30.2 Hypothetical example (oversimplified for illustrative purposes). The need for a new phase shift keying (PSK)-modulated COM system has been identified and the threat which it must face, has been defined. The scenario implied in the OR, DP, and NDCP indicates that a CW jamming (ECM) threat and an intercept (ESM) threat are to be considered. It is desired to estimate (roughly) the type and quantity of ECCM needed under worst-case jamming conditions. Figure 3 illustrates this analysis.

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NOTE: All distances are LOS

FIGURE 3. COM transmitter, receiver, and jammer relationships.

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30.2.1 Salient factors in the jamming threat case. Salient factors in the jamming threat case are specified in 30.2.1.1 and 30.2.1.2.

30.2.1.1 ECCM for AJ. Parameters of ECCM for AJ are specified in a through c:

- a. Jammer parameters. Jammer parameters are specified in 1 through 5:
 1. Frequency (MHz) _____
 2. Transmitter Power _____ dBW
 3. Antenna G _____ dB
 4. Signal type CW
 5. The minimum LOS range (D_j) to the COM receiver _____ nmi
- b. SS COM system (transmitting terminal) parameters. SS COM system (transmitting terminal) parameters are specified in 1 through 5:
 1. Frequency (MHz) _____
 2. Power _____ dBW
 3. Antenna G _____ dB
 4. MECC under maximum jamming _____ bps
 5. Modulation type PSK
- c. SS COM system (receiving terminal) parameters. SS COM system (receiving terminal) parameters are specified in 1 through 5:
 1. Maximum allowable BER 10^{-3} (typical for COM system)
 2. Signal-to-jammer (S/J) ratio in for a BER out of $10^{-3} = 3$ dB (see FIGURE 4)
 3. Receiving antenna G (in the direction of the COM transmitter) _____ dB
 4. Receiving antenna G (in direction of jammer) _____ dB
 5. Maximum operating LOS range (D_s) to COM transmitter _____ nmi

30.2.1.2 Analysis of the jamming case. Analysis of the jamming case is specified in a through n:

- a. The total power (P_T) radiated by the jammer (in the direction of the COM receiver) will be the sum of its transmitter power and antenna G in that direction in dBW.
- b. The J at the input of the COM receiver will be P_T minus the propagation loss over the distance (D_j) to the jammer, plus the G of the receiver antenna (in the direction of the jammer) in dBW or dBm (see Figure 5 for propagation loss estimates.)
- c. The total signal power (P_S) radiated by the COM transmitter (in the direction of the COM receiver) will be the sum of the COM transmitter's power and antenna G in that direction in dBW.
- d. The S in dBW or dBm at the input of the COM receiver will be P_S , minus the propagation loss over the LOS range (D_s) to the COM transmitter, plus the G of the receiver antenna (in the direction of the COM transmitter).
- e. From b and d the S/J ratio at the input to the COM receiver is obtained in dB.
- f. The difference in dB between the magnitudes of the S/J ratios in e and the maximum specified for a BER of 10^{-3} , in Figure 4, represents a deficiency in signal strength below the level needed by the COM system to operate against the threat. This difference has to be recovered in the system by ECCM-derived G from some source(s). Typically, the difference will come from either one or a combination of:
 1. G_p from wideband signalling techniques (using SS techniques such as DSPN and FH).
 2. Antenna techniques where a null is steered toward the jammer or a directional beam is pointed at the COM transmitter.
- g. Which of the ECCM options and in what proportions they are employed in the system design to achieve the needed G will depend on a number of factors:
 1. How large G has to be. If G is of the order of 40 dB or greater, probably a combination of G_p and G_A ; for example, 30 dB G_p and 10 dB G_A will be required.
 2. If the system has certain critical operational requirements, such as minimal synchronization time or insensitivity to phase distortion across the band, a single technique like noncoherent FH may have to be the choice for the G_p portion of the G. (The timing alignment accuracies required for a DSPN or a coherent FH approach are usually much too severe for these applications.)
 3. How feasible or practical it is to match a beam and null forming and steering antenna array (essentially frequency-sensitive) to a broadband SS COM system and still obtain the required G over the jammer. (Null depths and null beam positions will change readily with frequency.)

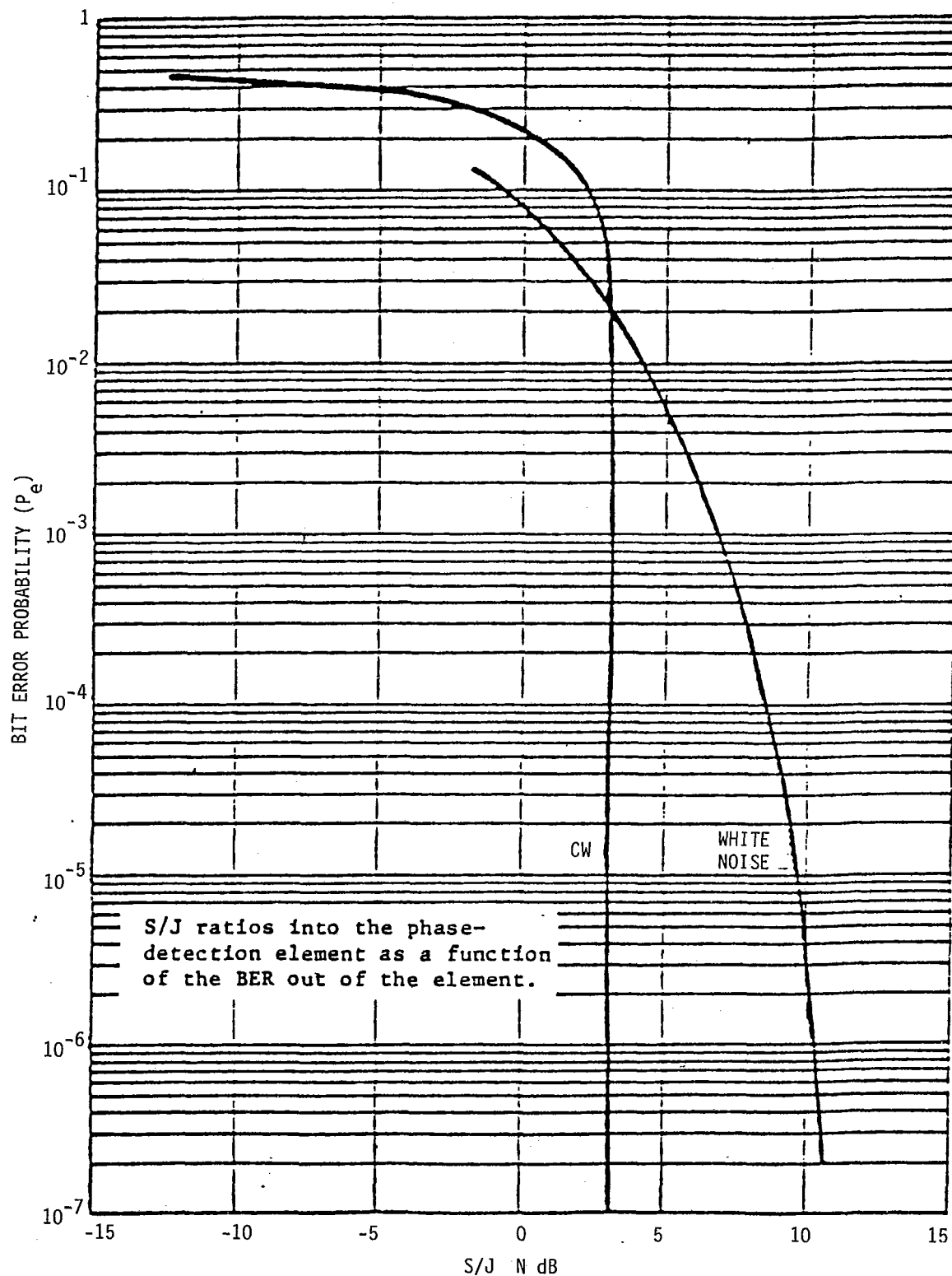
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FIGURE 4. PSK performance for CW and noise interference.

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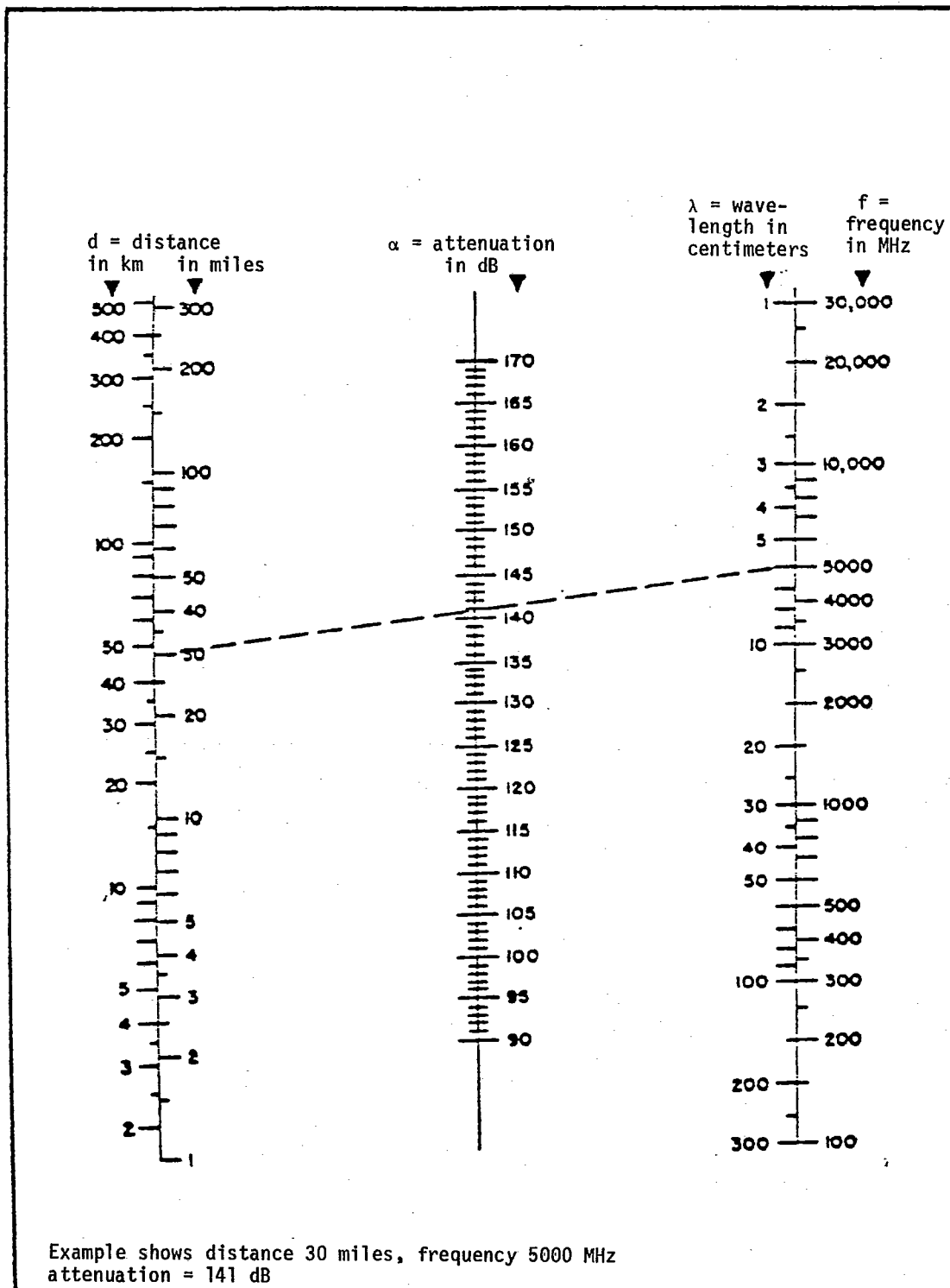


FIGURE 5. Nomogram for solution of path attenuation and between isotropic antennas.

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h. If the G_p required turns out to be 30 dB, the bandwidth of the energy radiated by the COM transmitter will have to be spread (via SS techniques) at least 1000 times wider than the bandwidth of the information being sent.

i. The performance of COM links in general is measured in such terms as those specified in 1 through 3:

1. The BER for digital links (data and voice). The BER jamming thresholds for data and digital voice transmissions will be different.

2. Speech intelligibility (for analog and digital voice links). Analog voice transmissions usually degrade gracefully as jamming increases; digitized voice transmissions usually degrade very little up to a certain threshold, and then fail catastrophically as the jamming is increased further.

3. Message delay. Expressed as a number, message delay represents the relative delays in time to send a message. The number 10, for example, indicates that because of jamming or error-detection coding, there is a tenfold increase in the time required to send the message.

j. To obtain actual numbers in the jamming example used, it is necessary to have curves or tables that will show the BER out of the decision element as a function of the S/J ratio into the element for various types of COM and jamming waveforms, and nomograms or calculations of propagation loss as a function of frequency and range. FIGURE 4 provides one example of the types of curves that are useful for obtaining BER out, versus S/J input ratios (in this case for both a CW and a noise jammer against a PSK COM signal). The FIGURE 5 nomogram (or the equation $= 37 + 20 \log f$ (MHz) + 20 log d miles (mi)) can be useful for estimating free-space propagation loss in dB as a function of range and frequency.

k. The minimum transmitter power required to achieve COM is ultimately determined by the maximum BER which can be tolerated in the receiver in order to maintain acceptable COM quality. For a specific modulation or demodulation technique being employed, it is possible (at least in principle) to relate this BER to the bit-energy-to-noise-density ratio E_{b/n_0} . To cite a few

simple examples: For coherent binary differential PSK with correlation detection, the relationship between BER and E_{b/n_0} is given by the equation:

$$BER = \frac{1}{2} e^{-E_{b/n_0}} \quad (1)$$

With this modulation E_{b/n_0} must be approximately 8 dB for a BER of 10^{-3} and approximately 10 dB for a BER of 10^{-5} . When non-coherent binary FSK is used, the bit error rate is given by:

$$BER = \frac{1}{2} e^{-E_{b/2n_0}} \quad (2)$$

for which E_{b/n_0} must be 3 dB more than is required in the PSK case of equation (1) for corresponding BER performance. Aside from these two modulations, a reduction in the E_{b/n_0} required to produce any given BER may generally be achieved by employing more sophisticated and more costly modulation techniques.

l. Besides the factors analyzed so far in the simple example (FIGURE 3), other factors (also ECCM and AJ-related) will influence the picture in more complex scenarios, as specified in 1 through 4:

1. In scenarios involving SS SATCOM links, the use of a processing satellite may provide as much as 17 dB of additional AJ margin compared with the same links using a repeating satellite.

2. In scenarios involving HF COMs, the use of wideband techniques to obtain AJ G_p will not result in as much G_p (proportionately) as that obtainable at higher frequencies.

Widening the bandwidth at HF (where the atmospheric noise is high) introduce a disproportionately greater increase in noise and a corresponding decrease in the signal-to-noise-ratio (S/N) ratio.

3. For nonLOS scenarios with HF surface wave ELOS links, the effects of widening the COM bandwidth (to obtain SS processing gain) on the achievable COM ranges to a jammed platform are shown in FIGURE 6 and FIGURE 7. The bandwidth has been widened to 100 kilohertz which gives the 75 bps link a theoretical G_p of 31 dB, and the 2400 bps link a theoretical G_p of 16 dB. The

actual range improvement for these links (for some theoretically drawn system in FIGURE 7) is from 55 nmi to 245 nmi for the 75 bps link with the jammer 200 nmi from the receiver, and from 30 nmi to 105 nmi for the 2400 bps link. (For the actual systems involved, FIGURE 7 must be drawn for the frequency to be used, jammer power, COM transmitter power and the system threshold).

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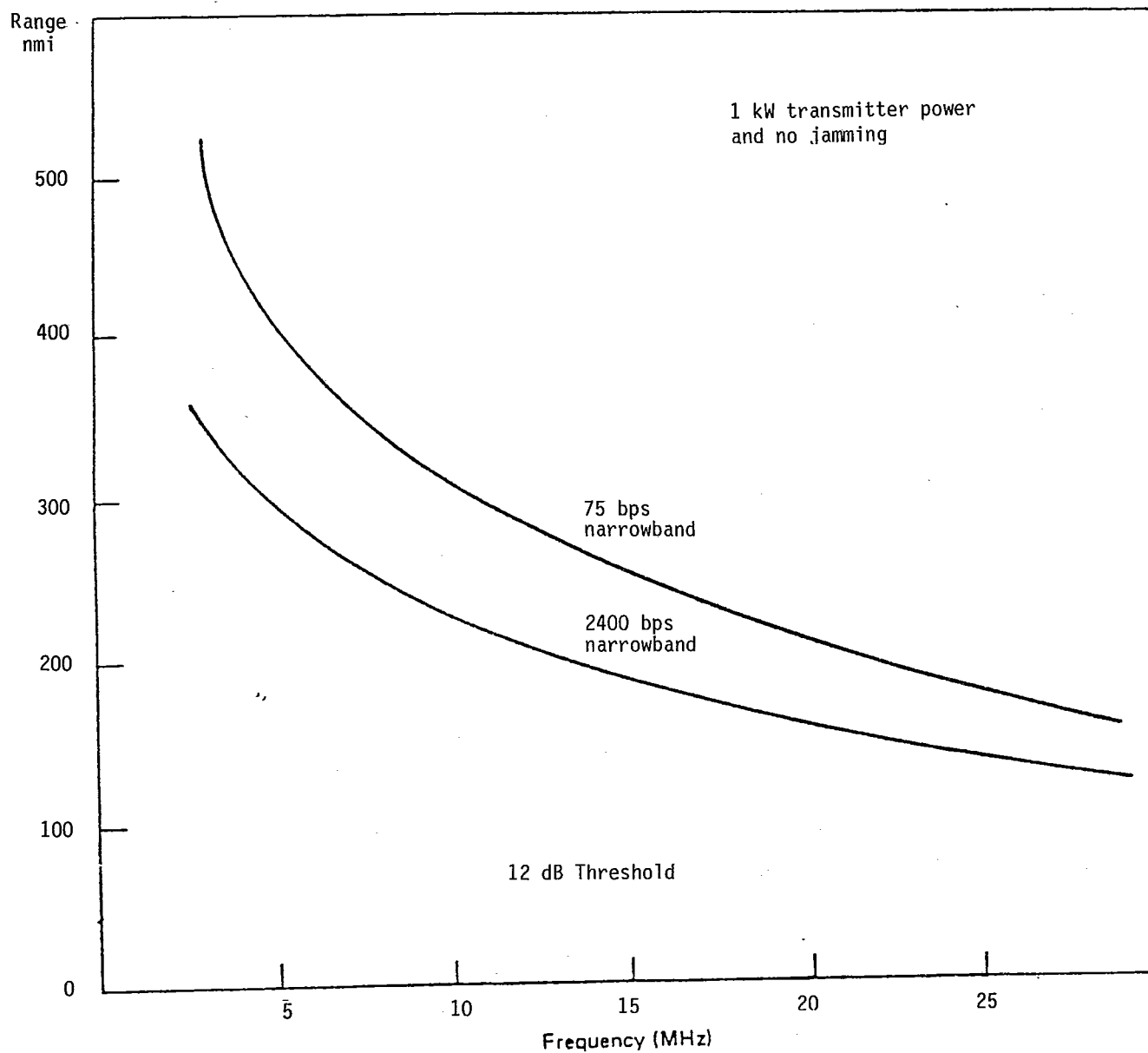


FIGURE 6. HF surface wave COM ranges (maximum achievable path length).

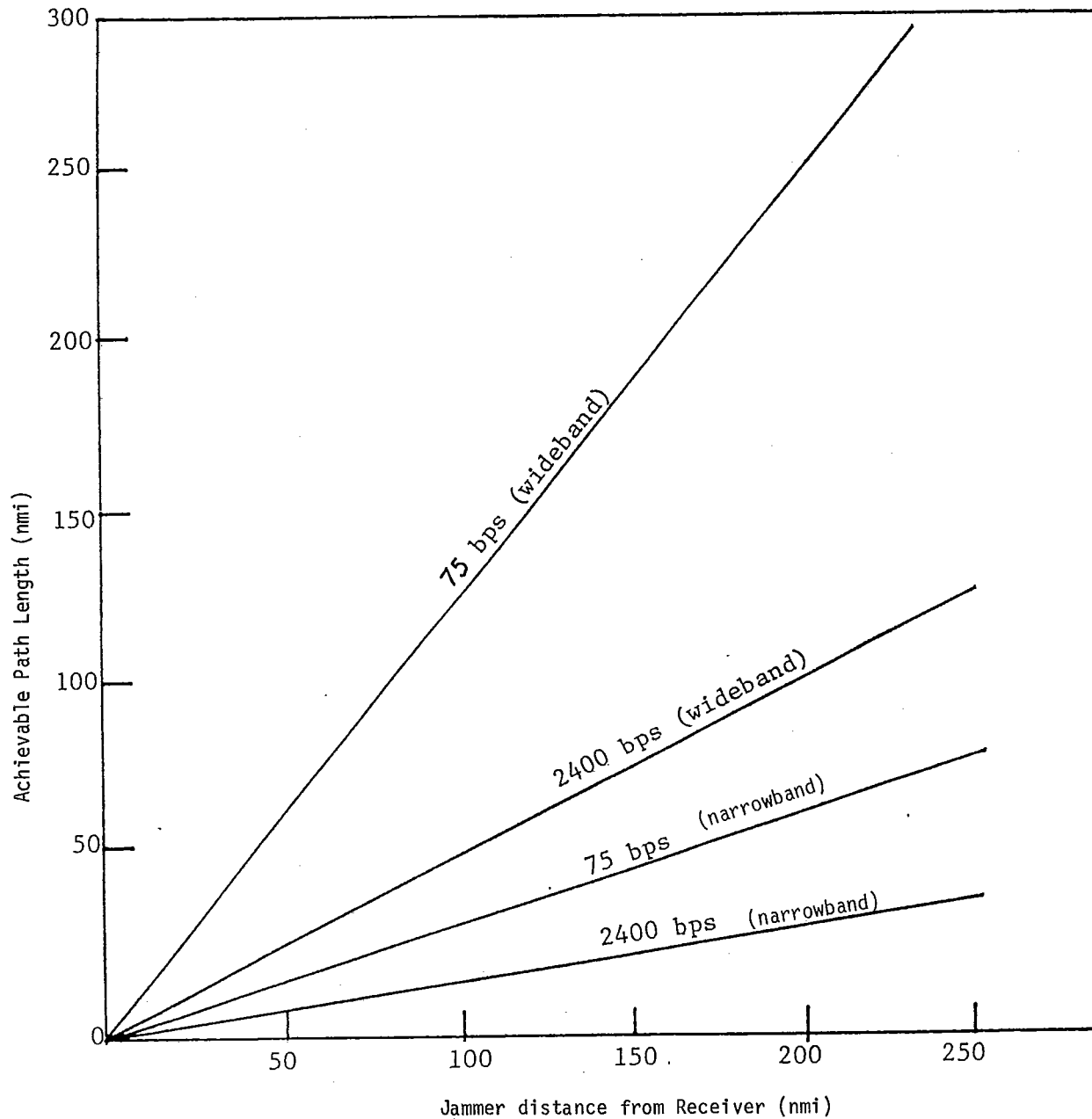
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FIGURE 7. Achievable transmission ranges to a jammed platform for a theoretical use of SS improvement.

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4. To obtain further understanding of the many ECCM related factors that influence the vulnerability of the different COM systems and techniques to jamming, managers should refer to documents like NELC TD-504, Volume VII, Appendix J.

m. Where the SS processing G_p is insufficient to conform to the total AJ requirements of a system, it is appropriate (if funding is available) to consider the use of adaptive antenna techniques to make up the additional AJ gain. The information specified in 1 is instructive on this point. With a family of curves similar to Figure 8, antenna AJ Gs could be roughly estimated for a number of different frequencies and antenna types.

1. Adaptive steering antennas have the capability to automatically perform spatial filtering on a given signal environment. The adaptive processor used in the antenna circuit performs adaptive beam forming as well as the adaptive formation of nulls. The nulls suppress sidelobe interference, and the adaptively formed beam enhances a desired signal having an initially unknown direction of propagation. The adaptive circuit can, therefore, detect weak signals (for example, SS signals are typically weak) in both stationary and nonstationary environments. Depending on the type of system, different criteria (for example, maximum S/N) can be used to generate control algorithms for placing pattern nulls in the direction of interference. In applying the adaptive technique, some a priori knowledge of the desired signal or its statistical properties is used as a reference in the adaptive processor to implement the algorithms mentioned. Figure 8 shows the pattern of a typical null steering, two-element, antenna array before and after adaption. The effectiveness of the null-steering structure can be assessed in terms of adaptivity G A

$$A = \frac{(S/J) \text{ after adaption}}{(S/J) \text{ before adaption}} \quad (3)$$

where S is the desired signal power and J is the interfering (jammer) signal power. From Figure 8 an adaptive G larger than 20 dB is feasible. A well designed steering structure should also have a fast rate of adaptation to signal environments. (see Zahn, C.L., Application of Adaptive Arrays to Suppress Strong Jammers in the Presence of Weak Signals, IEEE Transactions, Vol. AES-9, No. 2, March 1973.)

2. The adaptive antenna circuits concept is applicable to analog and digital COM systems as well as SS systems. The effectiveness of an adaptive scheme in a system depends on the degree of its implementation in hardware form. The objectives of the adaptive antenna usage are in line with that of the SS systems -- specifically, to reduce the effect of jamming or to increase the jamming margin.

n. Looking at another interesting aspect of the jamming problem in Figure 3, if managers want to obtain an estimate of how much farther the COM transmitter can be from the receiver (D_s) than the jammer (D_i) and still operate effectively (assuming the jammer and COM transmitter have the same average power and antenna G), the following example should be considered. The S/J ratio at the input of the victim receiver (S/J)_{in} depends on the distance separations; that is,

$$(S/J)_{in} = 20 \log (D_i/D_s) \quad (4)$$

where D_i is the distance between the victim SS receiver and the jammer transmitter, and D_s is the distance between the victim receiver and the desired SS COM transmitter. This relationship applies to a free-space propagation condition. When the victim SS receiver does not employ any special means for rejecting the interference other than the basic correlator, the signal-to-interference ratio at the output of the correlator (S/J)_{out} is:

$$(S/J)_{out} = (S/J)_{in} + G_p \quad (5)$$

G_p is the correlator processing G (in dB). (S/J)_{out} is also the signal-to-interference ratio at the bit decision circuit, and thus determines the bit error probability. Using equations (4) and (5), (S/J)_{out} can be expressed as:

$$(S/J)_{out} = -20 \log (D_s/D_i) + G_p \quad (6)$$

If the minimum required value of (S/J)_{out} is (S/J)_{ro} the distance separation ratio must satisfy the condition:

$$20 \log (D_i/D_s) \geq (S/J)_{ro} - G_p \quad (7)$$

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APPENDIX C

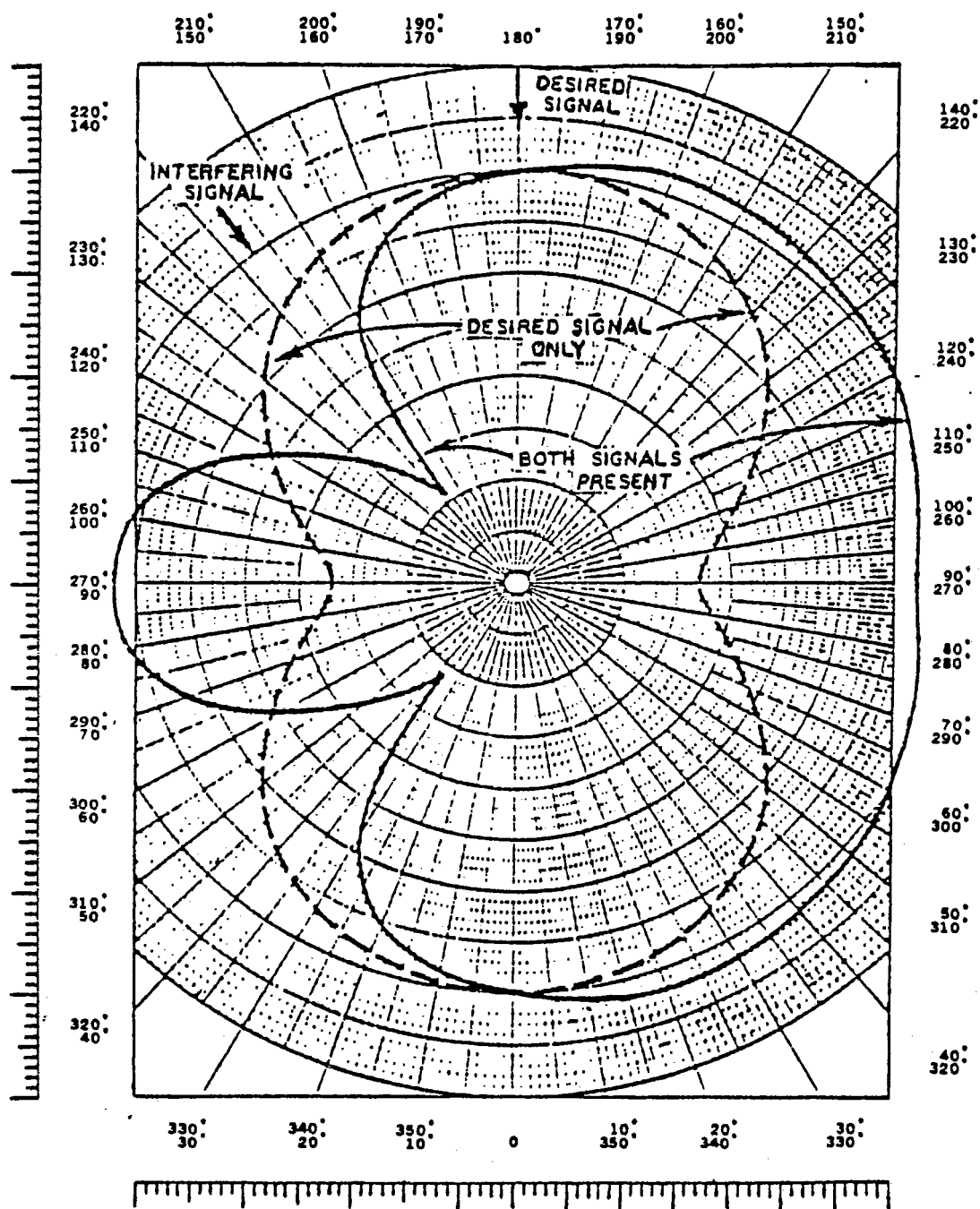


FIGURE 8. Adaptive antenna patterns before and after.

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For example, if $(S/J)_{r0} = 10$ dB and $G_p = 20$ dB the distance separation ratio would have to satisfy the condition:

$$20 \log (D_i/D_s) \geq -10 \text{ dB} \quad (8)$$

$$D_s/D_i \geq 3.16$$

This indicates that for satisfactory operation in the hypothetical example specified in 30.2, the desired SS transmitter should be no farther from the receiver than about three times the distance to the interfering transmitter. This cursory analysis was made assuming free space propagation. If a smooth, spherical-earth propagation model were used, which would be more realistic, the ratio D_s/D_i would most likely be less than the value given. For most Military radio operations, keeping the ratio at such a low value would not be practical. Therefore, SS receivers should embody additional means for rejecting unwanted signals.

30.2.2 Salient factors in the intercept threat case. Salient factors in the intercept threat case are specified in 30.2.2.1 and 30.2.2.2.

30.2.2.1 ECCM for anti-intercept. In the example, specified in 30.2.1 only the ECCM AJ needs were examined. Of equal concern, in some cases, is the susceptibility of the COM signal to enemy detection, location and identification. Besides the parameters specified in the hypothetical example, specified in 30.2, additional factors specified in a through c apply:

- a. The enemy platform in Figure 3 contains the jammer directed at the COM receiver and also contains an ESM receiving system whose purpose is to detect, locate and identify the source of the COM transmissions that are initially hidden.
- b. Key parameters of the hostile ESM system:
 1. Type of receiving system (for example, superhet, IFM, radiometer, and so forth)
 2. Estimated operational sensitivity (operating threshold in dBW)
 3. Receiver antenna gain in the direction of the COM transmitter in dB
 4. The LOS distance (D) in mi to the COM transmitter
- c. Additional key parameters of the COM transmitter to consider:
 1. P_{AV} _____ dBW
 2. Antenna gain in the direction of the ESM Receiver (dB)
 3. Total SS bandwidth in Hz.

30.2.2.2 Analysis of the intercept case. Analysis of the intercept case requires consideration of a through e:

- a. The P_{AV} radiated by the COM transmitter in the direction of the hostile intercept receiver is the sum of the transmitter power, in dBW, and the gain of the transmitter antenna in that direction in dBi.
- b. The S in dBW arriving at the input to the hostile intercept receiver is P_{AV} minus the propagation loss over the distance (D) plus the intercept receiver antenna gain in the direction of the COM transmitter.
- c. Since the energy arriving at the intercept receiver in b has been spread over a wide bandwidth, the enemy (unless he is relatively close to the transmitter) will require special types of receivers to make the detection.
 1. The S/N ratio will be too low for detection with ordinary ESM receivers.
 2. The enemy does not possess a way of correlating the SS energy like the COM receiver does.
 3. The enemy is forced to use techniques that require long integration times:
 - A. Narrowband filters that detect repetitive (slow changing) characteristics in the transmission pattern
 - B. Energy detectors (for example, radiometers)
 4. Just as the detection of SS COMs is more difficult for the interceptor, so is the location of the COM source. This location will require the use of even more sophisticated and expensive techniques.
- d. The ECCM and anti-ESM implications in C2 (analysis of the intercept case) for COM designers and users are specified in 1 through 3:
 1. ECCM-wise, the COM designer's objective is to try to hide the signal as much as possible by making it look like noise.
 2. Repetitive characteristics in the transmission pattern (inherent in the design or in the operational employment of the system) that enhance an enemy's ability to detect and identify the transmitter should be minimized or avoided, if possible.

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3. The COM transmitter, by steering a null or sidelobe toward the intercept receiver and pointing a directional beam at the COM receiver, will be able to enhance COM (with minimum power) and at the same time minimize the probability of being detected by the enemy.

e. For illustrative purposes, this example has described a highly simplified version of a complex intercept problem. Items like propagation paths, instead of being simple free-space LOS connections, will in many instances be complex combinations of skywave, groundwave, scattering, and ducting phenomena. To obtain a greater understanding of the detection processes and propagation phenomena associated with SS COM, see documents such as those referenced in 20.

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APPENDIX D

TABLE III. ECCM guidelines for the TEMP. - Continued.

ECCM issues	Considerations
<u>Required operational characteristics</u> <u>Operational suitability</u> 1. Will test results provide sufficient information to relate ECCM to operational suitability? <u>Critical T and E issues</u> <u>Technical issues</u> 1. Are advanced state-of-the-art or new technologies involved in ECCM attributes used in the system? <u>Operational issues</u> 1. Has the required degree of immunity to interference been specified along with acceptance criteria? 2. Is there a plan to establish a relationship between test data and operational effectiveness? <u>DT and E to date (applicable to TEMP update)</u> 1. Have required tests been bypassed as a result of waivers? 2. Has there been any evidence of susceptibility?	1. Incorporation of ECCM into a COM system increases the complexity and sophistication of the system. Therefore, reliability, maintainability, availability, logistics supportability, compatibility, interoperability, training, safety, EMC, and human factors shall be considered with respect to ECCM features. 2. What are criteria for acceptable performance when item is exposed to self-jamming? 1. Special testing shall be established to provide early assessment of engineering and technological risks. This will allow timely redirection of design where required. 1. What are criteria for acceptable performance when item is exposed to self-jamming or self-intercept? 2. Will test results provide sufficient information to relate ECCM to operational suitability? 3. If T and E for ECCM will not be conducted on production item, provide rationale for assuring that production item will have the same ECCM characteristics as the tested item. 1. Vulnerability analysis shall be presented in terms of operational performance parameters such as BER, and so forth. 1. What was rationale for granting waivers? 2. What is potential operational impact of not having test data? 1. Have all tests planned to date been performed? 2. Have susceptibilities been evaluated in terms of operational performance according to criteria in TEMP?

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TABLE III. ECCM guidelines for the TEMP. - Continued.

ECCM issues	Considerations
3. Have systems been modified for any reason from configuration on which ECCM T and E was performed?	1. Does modification require T and E? 2. If required, has modified system been retested? 3. Has modified system successfully passed tests? 4. Have tests been performed to evaluate possible changes in other operational parameters that could have been changed by modification?
<u>Future DT and E</u> 1. Have required types of T and E been addressed in TEMP? 2. Has ECCM simulation been adequately addressed?	1. If item is a platform, system, or subsystem which utilized various auxiliary support equipment (such as an A/C with ground support equipment, the item should be tested with and without support equipment attached with equipment and platform in various modes of operation. 2. To maximum extent possible, laboratory bench tests shall be utilized in support of TECHEVAL and OPEVAL by providing information related to grounding, leakage paths and relative effects of various modulation parameters, and so forth 1. Full threat-level facilities may be necessary for investigating vulnerability aspects. If full threat-level testing will not be performed, is the rationale available for this decision?
<u>Critical items</u> 1. Has the availability of test equipment facilities, radio frequencies, and trained support personnel been determined?	1. Are adequate facilities available? 2. Can full threat levels, as required, be achieved at available facilities? 3. Are facilities with deficiencies being upgraded or tailored to these particular test requirements? 4. Have long-lead support equipments been properly scheduled? 5. Has special ECCM training been planned for test personnel regarding operation of test item or support equipment?

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TABLE III. ECCM guidelines for the TEMP. - Continued.

ECCM issues	Considerations
<u>OT and E to date</u> 1. Have any desired tests been bypassed as a result of test limitations or schedule conflicts? 2. Has there been any evidence of ESM and ECM susceptibility? <u>Future OT and E</u> 1. Are tests being planned to evaluate item under most realistic conditions possible? 2. Have results of DT and E been utilized for planning OT and E? <u>Critical items</u> 1. Has availability of specialized test equipment and facilities been programmed?	6. Are an adequate number of test items provided? 7. Are test item and test facility schedules sufficiently flexible to allow contingencies based on test results? 8. Are test frequencies and schedules sufficiently flexible to accomplish desired objectives and allow contingencies based upon test results? 1. What is possible operational impact of not having test data? 2. What is rationale for not performing tests? 1. Has susceptibility been properly evaluated in terms of operational performance according to evaluation criteria provided in the TEMP? 1. Items should be tested with all transmitters and receivers normally required for simultaneous operation. This includes all receivers and transmitters on the item as well as those on the same or nearby platforms. 2. Unless previously checked, platforms, systems, or subsystems which utilize auxiliary support equipment shall be tested with and without equipments attached and in various modes of operation. 3. For those systems which cannot be protected from all operational environments, tests shall be performed to exercise the item in that environment. 4. What rationale has been utilized for the selection of ECM and ESM parameters during OT and E? 1. If DT and E has revealed potentially troublesome areas, has OT and E been planned to evaluate operational impact? 1. Equipments such as those required for implementing ECM on target are long lead times.

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APPENDIX DTABLE III. ECCM guidelines for the TEMP. - Continued.

ECCM issues	Considerations
2. Have plans been made to train personnel to recognize adverse EM effects? <u>PAT and E</u> 1. Has evaluation of intersystem and intrasystem compatibility been addressed? 2. Include T and E for ECCM in total ship test plan.	1. Have arrangements been made, as applicable, to monitor EMCON effectiveness? 2. Special training is required to distinguish EM problems from other operational problems. 1. Operate transmitters and receivers on adjacent channels to identify potential problem areas. 2. Simultaneously operate receivers and transmitters to demonstrate total platform compatibility. 3. Identify intermodulation products generated from various transmitter-receiver interactions. 1. Review prior considerations of TEMP to determine those applicable to ship acquisitions.

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Preparing activity:
NAVY - EC

(Project EMCS-N109)

User activities:

Navy - OS