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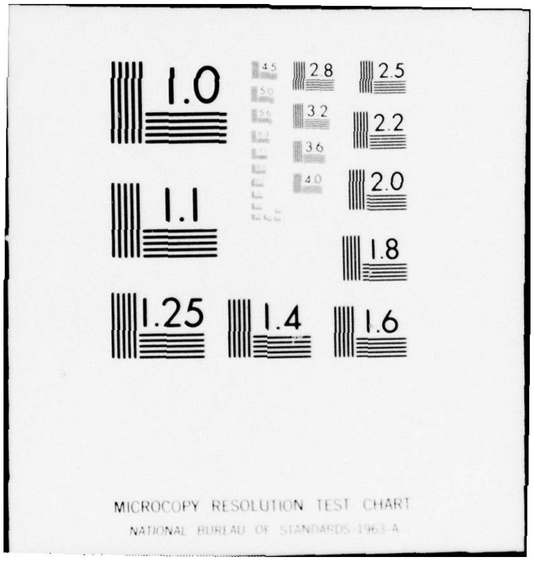

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ELECTROMAGNETIC SYSTEM INTERACTION ALGORITHMS

SEMCA, IPM, TRED, and COSAM are compared with respect to
modeling philosophy, flexibility, data base, noises and
interferences, interference threshold criteria, attenuation
modeling and antenna coupling, and printouts

ST Li

3 January 1977

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

TRED is a system design tool while SEMCA, IPM, and COSAM are mainly used as interference prediction tools. A user-computer interactive program is recommended. It would be based on the TRED design philosophy and would be used during the design stage of shipboard rf communication systems. In addition, a performance evaluation program for shipboard rf communication systems is recommended. The purpose of the evaluation is to predict final system performance in terms of articulation index and bit error rate.

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1.0 INTRODUCTION

This document presents a survey of existing electromagnetic system interaction algorithms. The effort was performed under task area III of the NAVELEX 304 functional area funding program, Integrated Techniques for Electromagnetic Analysis (ITEMA).

1.1 BACKGROUND

1.1.1 ITEMA

ITEMA is concerned with the problem that transmit and receive system performance is seriously degraded by the shipboard electromagnetic environment. The degradation implies the impairment of the system attributes. The system attributes include availability, integrity, and quality. The impairment of system attributes results in a loss of mission effectiveness: the ability to locate a target, to communicate, and to identify a target. The mission that is used here is the mission of the individual transmit and receive systems, but of course they are an integral part of the ship's mission.

The objective of this program is to increase the total mission performance of shipboard transmit and receive systems through the minimization of the degradation caused by such factors as antenna site compromise, intersystem interaction, and nonfunctional emissions. The objective is to be accomplished by developing a synthesis ability which considers transmit and receive system degradation factors in the early stages (and in all stages) of ship design. This ability would be applicable to both new ship design and fleet modernization. The emphasis of this specific objective is on the early stages of design. It is in the early stages of ship design that we have control of more design variables, making it possible to achieve a more nearly optimal design. Further into the design procedure there are fewer design variables, and a less optimal design will result.

With this synthesis ability, it will be possible to avoid many of the so-called "remedial" solutions. Too many times problems are identified only after operation. It is then necessary to "fix" the problems. The fixes are usually costly and result in only partial solution of the problem. This fix approach will become even less successful as Navy ships become more densely populated with advanced equipments.

This synthesis capability is being developed as a two-step approach. The first step is to formulate a system procedure for shipboard transmit and receive system design. A system procedure considers all essential aspects of transmit and receive system performance. Thinking in terms of "system design" is an important step in achieving total electromagnetic system performance. The emphasis is on total performance. It is possible to increase the performance of an individual transmit and receive system, but usually only at the expense of other transmit and receive systems. The second step is to improve and develop the analysis tools and methods essential to the system approach.

As envisioned at the present time, this synthesis capability is a system procedure using iterative analysis to achieve the design goal of acceptable total electromagnetic system performance. The essential tools and methods are those necessary to analyze proposed designs. The output of the analysis is evaluated in terms of the technical performance requirements to determine the adequacy of the design and identify possible deficiencies in it.

Three technical tasks have been defined to encompass the needs of the analysis:

Development of antenna modeling techniques below uhf

Development of antenna modeling techniques at uhf and above

Development of total EM system modeling

1.1.2 DEVELOPMENT OF TOTAL EM SYSTEM MODELING

As discussed in the previous section, the essential tools and methods are those necessary to analyze proposed designs. The output of the analysis is evaluated in terms of the technical requirements to determine the adequacy of the design and identify possible deficiencies in it. This task area provides tools and methods that ensure that the output of the analysis is necessary and sufficient for evaluation.

As depicted in figure 1-1, there are four parameters which completely characterize the total EM system:

Intercomponent interaction

HERO/RADHAZ

System interaction

Performance

Intercomponent interaction is component compatibility. For example, this would determine whether a tuner can tune an antenna. This can usually be determined on the basis of equipment specifications. Thus, this area requires no new tools and methods.

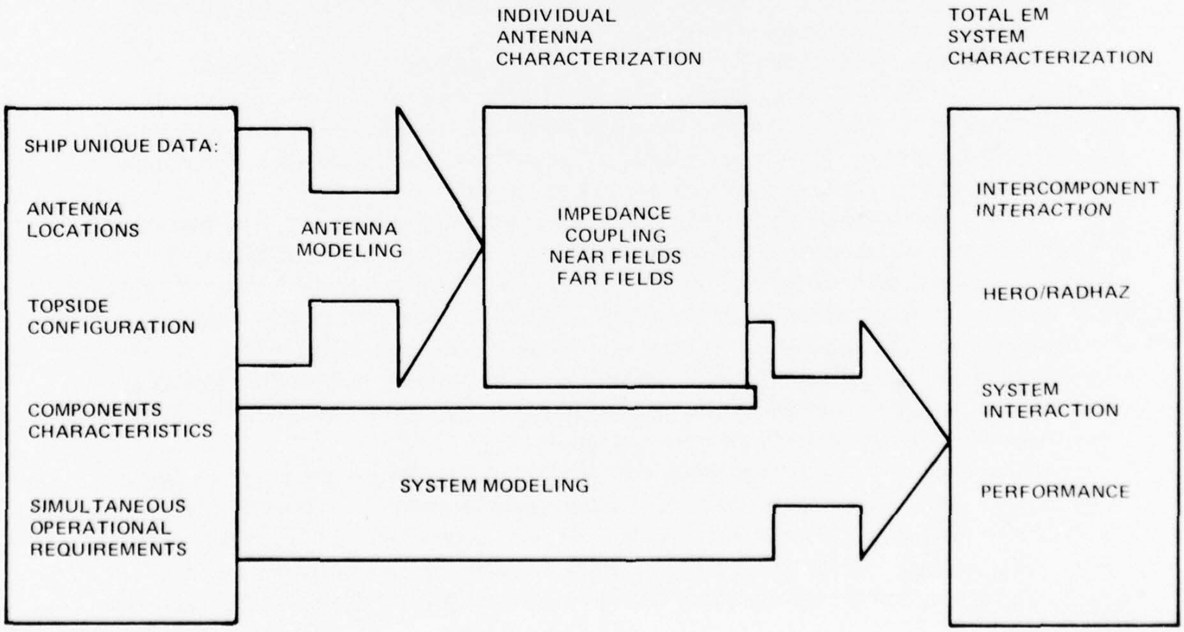

Figure 1-1. Electromagnetic system analysis.

HERO/RADHAZ is used to denote the effect of the antenna on other systems. This determination is being accomplished by specifications and standards developed under other efforts. As in the case of intercomponent interaction, this program again proposes no effort on this parameter.

It is the system interaction and performance parameters that the third task is concerned with. Thus, the objective is to use contractor and in-house Navy expertise to develop algorithms to rapidly and cost-effectively predict system interaction and performance of the transmit and receive systems.

1.1.3 INTERSYSTEM INTERACTION ANALYSIS FOR COMMUNICATIONS

During fiscal year 1976 all effort in the area of development of total EM system modeling was concentrated on the development of a system interaction capability for communications. The effort was divided into three principal work areas:

Survey of existing algorithms
Sample problem exercises
Empirical investigations

This document presents the survey of existing algorithms. The reports on the sample problem exercises and empirical investigations were scheduled for completion at the end of the 1976 transition quarter.

The objective of this survey is to document existing system interaction analysis techniques and compare their capabilities. This is a necessary first step in the definition of a system analysis model (communication) which will adequately support the needs of Navy shipboard transmit and receive system design. A preliminary evaluation of the existing techniques is presented here. The final evaluation will be reported upon completion of the sample problem exercises and empirical investigations.

1.2 EXISTING SYSTEM ANALYSIS MODELS

Modeling techniques implemented by digital computers are becoming recognized as the most cost-effective approach for determination of electromagnetic compatibility (EMC) between communication systems. Communication systems aboard Navy ships consist of topside mounted antennas and rf equipment installed below decks, such as transmitters, receivers, transmitting and receiving multicouplers and filters, and other rf distribution equipment.

Many computer simulation programs have been developed to predict the potential interferences involving rf communication systems. For example, Shipboard Electromagnetic Compatibility Analysis (SEMCA) developed by General Electric and Atlantic Research Corporation (GE/ARC) and Interference Prediction Model (IPM) developed by Litton are the computer programs which directly address the shipboard interference prediction problem. Co-Site Analysis Model (COSAM) developed by the Electromagnetic Compatibility Analysis Center (ECAC) of DoD, Co-Site Simulation System-1 (COSIM-1) developed by IIT Research Institute, Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) developed by McDonnell Aircraft Company, and Intrasystem Compatibility Analysis Program (ISCAP) developed by Sachs/Freeman Associates are more indirectly related to the rf system aboard ship.

A manual design procedure called TRED (Transmitter and Receiver Equipment Development) was developed by NELC. TRED establishes the electrical performance characteristics required in communication equipments for successful operation on naval ships.

There exist two basic differences between TRED and the other three techniques, which are SEMCA, IPM, and COSAM. First, TRED is an rf system design tool while SEMCA, IPM, and COSAM are mainly used as interference prediction tools. SEMCA, IPM, and COSAM calculate the value of antenna isolation and predict the power levels of direct threats and indirect threats. The direct threats are at transmit frequencies and cause production of interferences in receivers such as receiver cross modulation, receiver desensitization, spurious response, and receiver intermodulation. The indirect threats are at receiver frequencies and are interferences produced outside the receivers such as transmitter broadband noise, transmitter harmonics, spurious emissions, and transmitter intermodulation. On the other hand, TRED follows a step-by-step design procedure to ensure that the interference power levels are short of the threshold of unacceptability. The steps are listed below.

1. Use quasi-minimum atmospheric noise to establish a required antenna deficiency which is employed to design the receiving subsystem. However, if an external natural noise level is below the receiver noise, no antenna deficiency is required.

2. Use the most important direct threat to establish the maximum allowable antenna isolation (antenna coupling).

3. Design the transmitting subsystem whose indirect threats are acceptable.

Note that each step is an iterative process which not only predicts the interference power level but also identifies possible deficiencies of the system.

The second basic difference is that TRED is a manual procedure. A computer program based on TRED has not yet been developed; on the other hand, SEMCA, IPM, and COSAM are computer programs. Recognizing these two basic differences will make the comparison of the four modeling techniques meaningful.

This report presents an evaluation of the communication system portions of SEMCA, IPM, COSAM, and TRED. The other less applicable modeling techniques are addressed as to general capability. The evaluation is based on the documents which NELC has at the present time. These documents are identified by asterisks in 10.0 BIBLIOGRAPHY. In performing the comparison, we consider the modeling techniques from the following viewpoints:

Modeling philosophy
Flexibility
Data base
Noises and interferences
Interference threshold criteria
Attenuation modeling and antenna coupling
Printouts

With respect to modeling philosophy, two questions are considered. First, what system modeling approach is used — deterministic or statistical? If a statistical approach is chosen, what parameters of the rf system are considered as random variables? The second question concerns the approach of receiver modeling. Is a receiver modeled as a black box or is each functional block of the receiver modeled in detail? Does the receiver modeling include the second detector stage and the modulation types of the desired signal and undesired signals?

"Flexibility" concerns the options available to a computer program and the ability to handle subproblems efficiently. It also concerns the ability to evaluate engineering design tradeoffs.

"Data base" concerns the sources of data and the complexity of preparing data. In addition, there are two questions – can modulation spectra be included in the data base, and which rf equipments have data stored in the data base? The problem of the accuracy of the data will not be addressed.

The approaches used to predict and utilize the noises and interferences will be investigated. The approaches use either empirical data or mathematical models. If mathematical models are used, what are the models?

In theory, it is necessary to identify all EMC-related parameters for each system component. For example, approximately 25 parameters were reviewed by the Electromagnetic Compatibility Figure of Merit (EMC FOM) Committee (ref 1). However, in practice, we can consider only the most important ones, which are classified as follows:

- System Indirect Threats
  - Transmitter broadband noise
  - Transmitter harmonics
  - Transmitter spurious emissions
  - Transmitter intermodulation
  - Passive device generated intermodulation
- System Direct Threats Caused by Transmitter Fundamental Frequencies
  - Receiver cross modulation
  - Receiver desensitization (receiver saturation or overload)
  - Receiver spurious response
  - Receiver intermodulation
  - Receiver burnout
- Environmental Indirect
  - Atmospheric noise (ambient noise)
  - Rusty bolt (topside-generated intermodulation)
  - Shipboard man-made noise
- Receiver Internal Noise (Noise Figure)

Having considered each type of interference, we ask what the interference threshold criteria are and where they should be applied. Usually, the interference threshold criteria are set at three locations of the receiving system – input to the rf amplifier stage, output of the last intermediate frequency (IF) filter stage, and output of the detector stage.

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[1] An Electromagnetic Compatibility Figure of Merit (EMC FOM) for Single-Channel, Voice Communications Equipment, IEEE Trans on EMC, February 1975

"Attenuation modeling" concerns the selectivity of filter devices, the insertion loss of filter devices, transmission line insertion loss, and mismatch loss. "Antenna coupling" considers the method for obtaining antenna coupling values or for establishing a required antenna coupling value.

"Printouts" concerns the various types of outputs which each computer program can provide.

Sections 2.0 through 5.0 discuss the four main modeling techniques – SEMCA, IPM, COSAM, and TRED – one by one. Section 6.0 describes other less applicable techniques briefly. Section 7.0 presents a summary of the comparison of the four main techniques. Section 8.0 is a preliminary evaluation of the existing system analysis techniques. Section 9.0 presents conclusions and recommendations.

2.0 SHIPBOARD EM COMPATIBILITY ANALYSIS (SEMCA)

SEMCA was developed by GE/ARC. SEMCA I was completed in 1966 and has been revised four times. The current version, SEMCA V, was completed in 1973. The evolution of SEMCA IV to SEMCA V includes the following points:

- Adding a detector model

  Considering the modulation types of the desired signal and undesired signals

  Obtaining expressions to relate signal-to-noise ratios (or signal-to-interference-plus-noise ratios) between the input terminal and the output terminal of the detector for various modulation types

  Obtaining relationships between signal-to-noise ratio (or signal-to-interference-plus-noise ratio) of detector output terminal and articulation index for various modulation types. Also, the relationships between signal-to-noise ratio (or signal-to-interference-plus-noise ratio) of detector input terminal and bit error rate

  Obtaining a relationship between articulation index (or bit error rate) and intelligibility
- Changing the end point of the CULL3 program from the input of the first mixer to the input of rf amplifier
- Changing power cull criteria from using minimum discernible signal (MDS) to 15 dB below receiver noise
- Changing ambient at-sea noise level (ANL) model
- Changing transmitter noise level (TXN) model
- Adding subroutines BX2007 and BOX43 for couplers CU2007 and SRA 43, respectively
- Changing input and output format and data base according to the above modification

This document is concerned with SEMCA V, which is described by volumes 10A, 10B, and 10C. Volume 10A serves as the user's reference manual. Volume 10B describes the actual subroutines in detail, presents test cases, and gives the listings. Volume 10C describes mathematical models used in the program. At present, the evaluation of SEMCA V is based on volume 10A only, because volumes 10B and 10C are not available to NELC.

2.1 GENERAL DESCRIPTION

SEMCA V consists of CULL3, CULL4, FREQUENCY SELECTION, and COUPLER MAIN Computer programs. The CULL3 program, which is a power transfer program, is used to process transmitter spectra through transmitter channels, space, and receiver channels up to the input to each receiver rf amplifier. The CULL4 receiver program then processes the total interference spectrum through a linear or nonlinear rf amplifier model, the mixer/IF sections, and the detector. The FREQUENCY SELECTION program is used to assign compatible transmitter and receiver center frequencies in the lf through uhf range.

The COUPLER MAIN program is used to develop and exercise coupler models and to plot impedance data in Smith chart form. Figure 2-1 shows how the SEMCA programs fit together and how the programs can be used. A shipboard communication system consists of all the transmitters, couplers, filters, antennas, and receivers. Figure 2-2 represents a typical communication system model which is employed by the SEMCA V program.

The SEMCA CULL3 and CULL4 programs can be used in a single-ship evaluation mode, a multiship intraship evaluation mode, and a multiship intraship and intership evaluation mode.

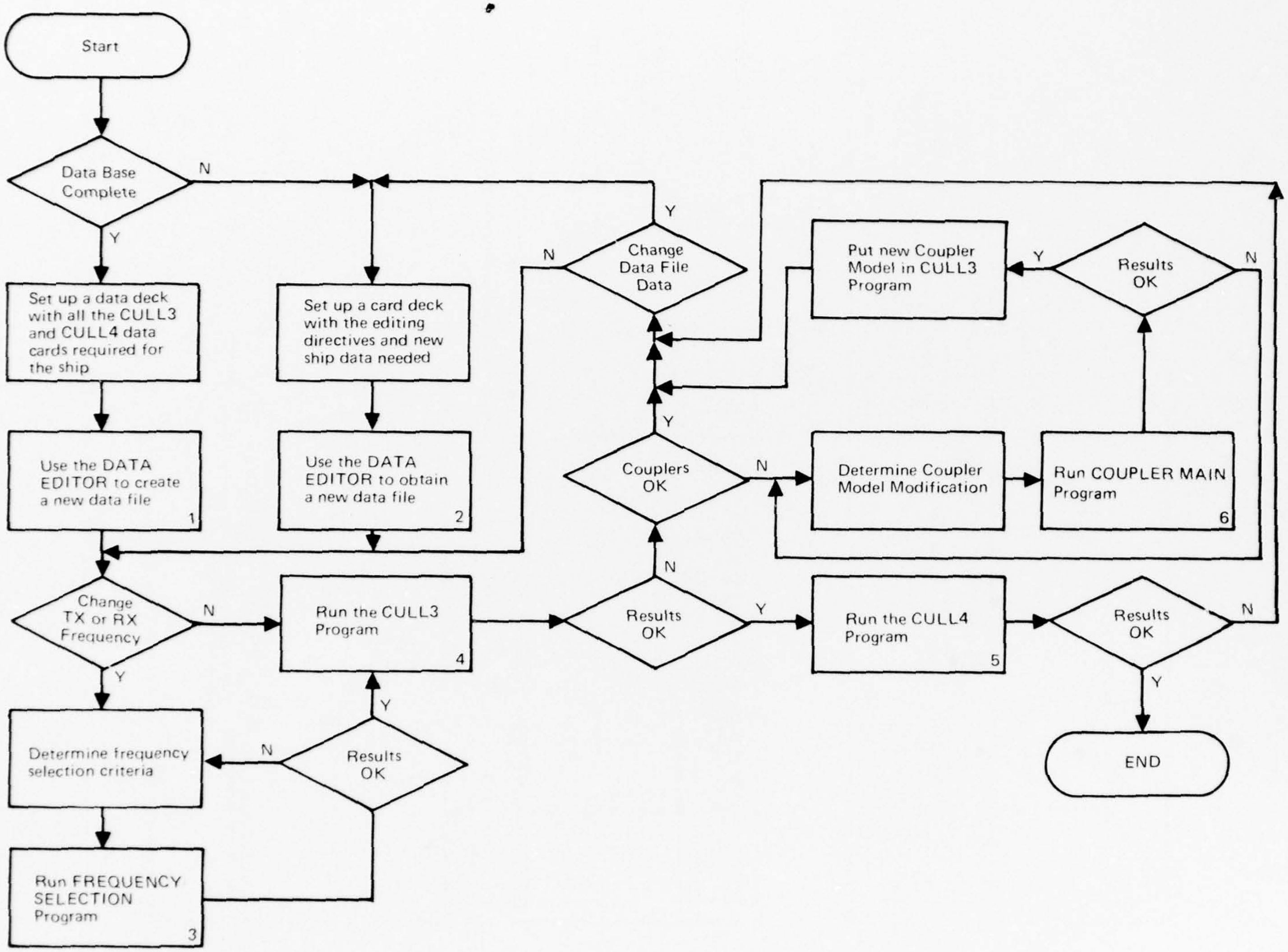

Figure 2-1. Organization of SEMCA program.

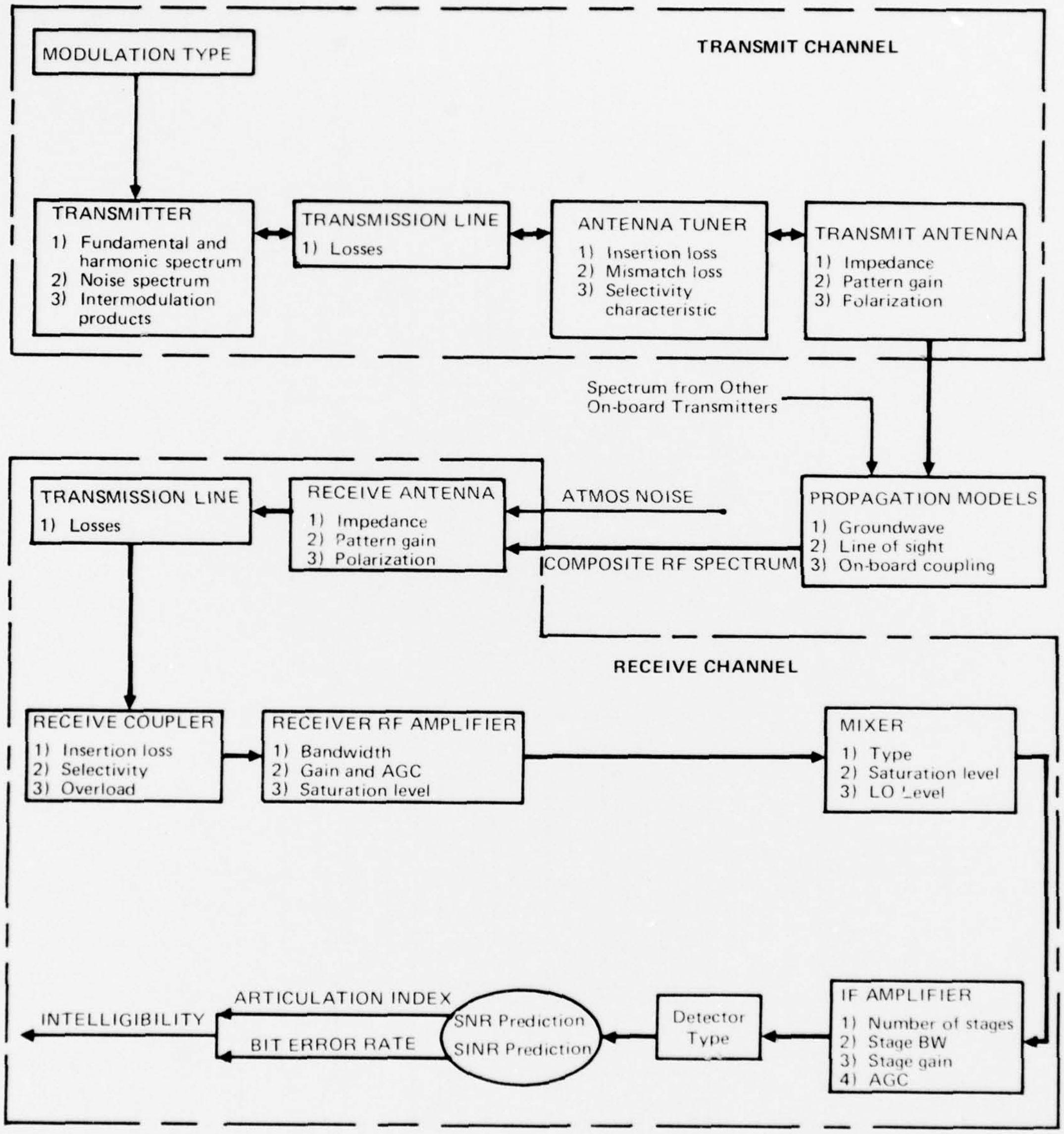

Figure 2-2. SEMCA communications model.

2.2 MODELING PHILOSOPHY

SEMCA uses an incomplete statistical approach in system modeling. A complete statistical approach can answer the following question:

> If the performance of a receiver is graded as acceptable (or marginal or unacceptable), then what is the probability that the receiver performance is acceptable (or marginal or unacceptable)?

To answer this question, the probability density function (PDF) of the signal-to-interference-plus-noise ratio (SINR) at the receiver detector output must be determined, but the SEMCA program does not calculate the PDF of SINR at detector output and cannot answer this question.

SEMCA does treat the desired signal power, antenna coupling, and interference powers as random variables. The interference powers include transmitter fundamental, transmitter harmonics, transmitter intermodulation, spurious emissions, transmitter broadband noise, and ambient at-sea noise. Every one of these random variables is assumed to have a Gaussian PDF. Each Gaussian random variable is defined by a mean value and a standard deviation (σ) which are supplied by the SEMCA program.

It takes a nonlinear operation (division) on Gaussian random variables to obtain the SINR at detector output, which is also considered as a random variable. Therefore, the PDF of SINR at detector output may not be Gaussian. SEMCA does not calculate the PDF of SINR, although it can be obtained by Monte Carlo simulation or analytical derivation.

As to the receiver modeling, SEMCA V models each functional block in detail. The functional blocks and the required information concerning each function block are described below:

RF Amplifier: types of filters (single-tuned, Butterworth, Tchebycheff, Q-constant, etc), bandwidth, gain and automatic gain control (AGC), saturation level, linear or nonlinear amplifier, number of stages

Mixer or mixers (first mixer, second mixer, or third mixer): mixer type (triode, diode, pentode, transistor, or special), mixer operation (single-ended, balanced push-pull, balanced push-push, series double balanced, parallel double balanced), local oscillator (LO) frequency, power level at mixer input, and mixer saturation level

Intermediate frequency (IF) amplifier(s) (first IF, second IF, or third IF): bandwidth, gain, AGC, number of stages

Detector: Modulation type of desired signal (AM, SSB, FSK, FM, pulse) and detector type for a desired modulation type (diode-voice band filter for AM, synchronous-product detector for SSB, product detector for FSK, phase shift discriminator for FM, and diode-wideband output for pulse)

Using functional blocks — namely, rf amplifier, mixers, and IF amplifiers — system direct threats are predicted. The effects of system direct threats include receiver cross modulation, receiver desensitization, receiver spurious response, and receiver intermodulation. The last functional block gives detector transfer functions which relate SNR (or SINR) between the input terminal and the output terminal of the detector for various modulation types. The SNR (or SINR) of the detector input and output terminal are then used to calculate articulation index, bit error rate, and intelligibility.

2.3 FLEXIBILITY

The SEMCA V program has several options. As mentioned in section 2.1, there are three interference evaluation modes — single-ship, multiship intraship, and multiship intraship and intership. In addition, there are four computer programs — CULL3, CULL4, FREQUENCY SELECTION and COUPLER MAIN. The four programs can be put together to evaluate an rf system EMC problem or they can be used independently to evaluate subproblems.

If we do not wish to consider the modulation types of desired and undesired signals and do not wish to evaluate rf system performance in terms of articulation index or bit error rate, then we have the choice of not using the detector functional block of the receiver modeling. The receiver modeling stops at the last IF amplifier stage. Noises and interferences which will give unacceptable receiver performance are predicted at the output of the IF amplifier stage.

SEMCA has program-supplied data and models, but in many cases a user can use his own data or change the parameter values of the program-supplied models. The options of the models are program-supplied model, user-supplied basic model, user-supplied specific model, and user-supplied model adjustment. A user-supplied basic model will override the program-supplied model, a user-supplied specific model will override the basic model, a user-supplied model adjustment will adjust the basic or specific model. Table 2-1 shows the available options of the SEMCA program models. Models are described in section 2.5.

Finally, SEMCA has options of printouts of desired signal and power summary at various receiver stages.

TABLE 2-1. SEMCA PROGRAM MODELS.

SEMCA Program Models	Program Supplied	User-Supplied Basic Model	User-Supplied Specific Model	User-Supplied Model Adjustment
TX Noise Level	yes	TXNMOD card (section 3.2.49)	TNOISE card (section 3.2.38)	TNLSIG card (section 3.3.26) or TXNADJ card (section 3.2.48)
TX IM Product	yes	IMGAIN BASIC card (section 3.2.31)	IMGAIN card (section 3.2.31)	IMADJ card (section 3.2.47)
TX Output Stage	yes	TXFILT BASIC card (section 3.2.30)	TXFILT card (section 3.2.30)	no
TX Spectrum	no	no	XSPIKE cards (section 3.2.23)	POWADJ card (section 3.2.46) POWINC card (section 3.3.23) POWSIG card (section 3.3.24)
TX Spectrum Level Standard Deviations	yes	no	XSPIKE cards (section 3.2.23)	no
TX Probability-On-Air	yes	no	SETPOA card (section 3.3.2)	no

TABLE 2-1. (Continued).

SEMCA Program Models	Program Supplied	User-Supplied Basic Model	User-Supplied Specific Model	User-Supplied Model Adjustment
TX and RX Impedance	yes	no	RESIST and REACT cards (sections 3.2.12 and 3.2.13)	no
RX IF Noise Bandwidth	yes	no	RXIFBW card (section 3.2.42)	no
RX Mixer	yes	no	MIXER cards (section 4.2.3)	ALIM card (section 4.3.2) AOLIM card (section 4.3.1)
Ambient-At-Sea Noise Level	yes	ANL card (section 3.2.39	no	ANLSIG card (section 3.3.25)
Intra-Ship LF-MF-HF Antenna Coupling	yes	ANTCUP card (section 3.2.26)	no	ACSIG card (section 3.3.27)
Intra-Ship VHF-UHF Antenna Coupling	yes	no	no	ACSIG card (section 3.3.27)
Inter-Ship Antenna Coupling	yes	no	no	ACSIG card (section 3.3.27)

Note: Section numbers in parentheses are the section numbers of *SEMCA V, volume 10A, user's reference manual.*

2.4 DATA BASE

Measured emission spectra of transmitters are used as input data. The measurements include laboratory measurement as well as limited ship-field measurement. If empirical data are not available, the method of predicting transmitter emission is by synthesis from partial or comparable data or by programming analog models of the equipment. The analog computer model is a frequency scaled representation of the actual transmitter, which includes some of the nonlinear stages, tank circuit characteristics, and any other applicable circuit parameters which affect the emission spectrum. The analog model is based on transfer function equivalent circuits which duplicate the dynamic response of the actual transmitter circuits.

Similarly, several types of receiver mixers are modeled on analog computers in order to form an empirical and mathematical mixer model suitable for programming on the digital computer. Intercept values of the mixer output levels versus input level curves have been determined for five input signals and their generated harmonics and are used as input data for each mixer type.

It seems that the analog model method is complicated because either the transfer function or the circuit characteristic of each functional block of the transmitting system or receiving system must be known. Furthermore, the transfer functions or the circuit characteristics may be only approximations obtained from specification sheets.

There are many equipments which have data stored in the data base.

2.5 NOISES AND INTERFERENCES

The SEMCA program treats most of the noises and interferences described in section 1.2 except passive device generated intermodulation, rusty bolt, shipboard man-made noises, and receiver burnout. Mathematical models and data of the noises and interferences which are used in the program are presented below:

Transmitter broadband noise model is:

$$N = -A \log_{10} [|100(f - f_{TX})/f_{TX}|] + B + P_{TX}$$

and $\sigma = 5$ dBm,

where N is the mean value of the noise level in dBm, σ is its standard deviation, f is frequency of interest in MHz, f_{TX} is transmitter frequency in MHz, P_{TX} is transmitter power in dBm, and A and B are constants. In the program-supplied model, A = 80 dB and B = −70 dB, but A and B are input constants determined by the user in the user-supplied basic model. Furthermore, in the user-supplied specific model measurement data of noise level in 3-kHz bandwidth and percentage of frequency deviation are used.

In the receiver detection-degradation analysis, SEMCA treats a transmitter broadband noise as a "noise" instead of an interference. Thus, the term "noise" includes the receiver internal noise, the atmospheric noise, and the transmitter broadband noise.

The program-supplied transmitter intermodulation model generates intermodulation products (IMP) which are described by:

$$f_{IMP} = pfv + qf_I ,$$

where f_{IMP} is the IMP frequency, fv is the victim transmitter frequency, f_I is the interfering transmitter frequency, and p and q are integer coefficients. The mean value of power level of the IMP in dBm is:

$$P_{IMP} = P_v + I_{pq} - |q| (p_v - p_I) ,$$

where I_{pq} is an intercept value which is the function of the p and q values. The values of I_{pq} are listed below:

p	1	2	3	1	2	3	1	2
q	−1	−1	−1	−2	−2	−2	1	−3
I_{pq}	−9.3	−11.0	−13.5	−10.7	−13.8	−12.9	−9.5	−18.2

The variance of the power level of IMP is:

$$\sigma^2_{IMP} = p^2 \sigma^2_v + q^2 \sigma^2_I .$$

There is no program-supplied model for the mean power level of transmitter harmonics and transmitter spurious emissions. Instead, empirical data are used. However, there is a model for the standard deviation associated with the power level of each spike in a transmitter spectrum. The model is:

$$\sigma = \begin{cases} -8(f/fo) + 10 & \text{for } 0 \leq f/fo \leq 1 \\ 4(f/fo)-2 & \text{for } 1 < f/fo \leq 3 \\ 10 & \text{for } 3 < f/fo \end{cases} ,$$

where σ is in dB, f is the frequency of interest, and fo is the transmitter tuned frequency.

The receiver mixer model, which is used to predict receiver intermodulation, takes input signals and mixes them with the local oscillator (LO) 0, 1, 2, 3, and 4 at a time. The mixer output frequencies are of the form:

$$f = \sum_{i=1}^{4} \pm a_i w_i ,$$

where a_i are the harmonic values. The mixer output power levels in dBm are of the form:

$$P = G + I + B + \sum_{i=1}^{4} a_i (P_i - P_{LO}) ,$$

where G is a function of mixer type, I is the intercept value which is a function of mixer type and harmonic values, and B is a function of type of mixer balancing and harmonic values. The values of G, I, and B are supplied by the program. In addition, the user can change the intercept value I.

There is no program-supplied model to predict the frequencies where receiver spurious responses occur and to predict the power level of each spurious response. Measured data are used.

At present, it is not clear whether SEMCA uses data or models to predict receiver desensitization and receiver cross modulation.

The program-supplied model of ambient at-sea noise power in a 3-kHz bandwidth as a function of frequency is shown in figure 2-3. The model is based on CCIR report 322 for average noise power available over seawater from a short vertical antenna at a random time and at a random ocean location. If actual data of noise level at the frequencies of interest are available, they can be used in the user-supplied basic model.

Measured data of receiver noise level are used. SEMCA does not consider the receiver noise level as a random variable, nor is receiver IF noise bandwidth treated as a random variable.

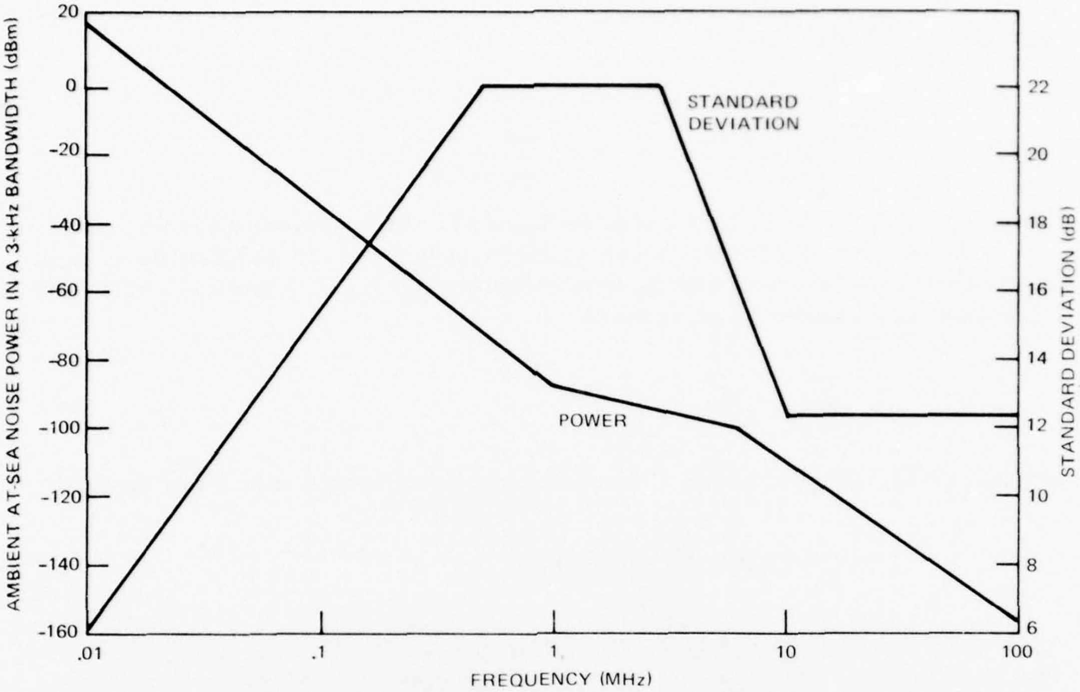

Figure 2-3. Ambient at-sea noise power.

2.6 INTERFERENCE THRESHOLD CRITERIA

Since SEMCA has the option of using CULL3 and CULL4 programs independently and the option of whether detector processing will be done, the interference threshold criteria are set at the following three locations of the receiving system: input to the rf amplifier, output of the last IF, and output of the detector. First, the criterion at the input to the rf amplifier is 15 dB below receiver noise. However, the value of dB below receiver noise can be changed if the user desires to change it. The rf spectrum present at the receiver rf front end is power culled with respect to this criterion. Second, at the IF output, the resultant signal combinations, which are at levels greater than a criterion related to sensitivity, are printed out with the frequency and the sources of the interferences. At present, the exact criterion is unknown. Third, at the output of the detector, articulation indices (AI) of 0.7 and 0.4 are the interference criteria. The SINR detector outputs that result in AI numbers of 0.7 or above are classified as acceptable for voice communication systems. When the AI number is degraded to below 0.7 and above 0.4, the voice communication system is classified as marginal. When the AI number is further degraded to below 0.4, it is classified as unacceptable. In the case of data reception such as teletypewriter (TTY) systems, a BER of 2.5×10^{-3} is established as the dividing point between acceptable and unacceptable. This BER criterion is based on an approximate 1% character error rate for synchronous and independent start-stop TTY systems.

2.7 ATTENUATION MODELING AND ANTENNA COUPLING

The SEMCA V program considers the selectivity and the insertion loss of filter devices. Filter devices of rf systems include filter, tuner, coupler, and multicoupler. A user may use either the program-supplied filter models or tabular data. The filter models are transfer functions which calculate filter gain as a function of frequency. Thus, we obtain the selectivity characteristic and the insertion loss.

The program also considers mismatch loss. The program-supplied transmitter and receiver impedance model is 50 ohms for all frequencies. However, a user may use his own measured impedance values. Transmission line loss can be calculated if the type and length of the transmission line are given. However, SEMCA does not consider the effects of cable length on the transmitter intermodulation and transmitter broadband noise power levels. An experiment done by NELC showed that the effects are significant.

SEMCA has the following three antenna coupling models which are used to calculate the space portion of coupling:

Intraship lf-mf-hf coupling model. The model is obtained as the best fit to many data points taken by measuring coupling between antennas on a scaled ship model. This is the maximum coupling between antennas assuming conjugate impedance matches.

Intraship vhf-uhf coupling model. Friis relationship for free-space coupling is used; coupling = 37 – 20 log (D F) dB, where D is antenna spacing in feet* and F is frequency in MHz.

Intership coupling models. Two intership coupling models are employed. In the frequency range below 150 MHz, a groundwave model based on the results by K Norton of National Bureau of Standards is used. For frequencies above 150 MHz, a groundwave model based on results by LV Blake of Naval Research Laboratory is used.

These models are used to calculate the space portion of coupling. Their application is indicated in figure 2-4. In addition, the Scattering and Propagation Simulator model (SCAPS) is employed to determine lf and mf power transfers in a closely coupled antenna network. A scattering matrix approach provides a method for calculating the power transfers by including all network interactions and impedance mismatches. These interactions lead to multiple coupling paths in the multiport antenna network.

The shortcoming of the SEMCA antenna coupling model is that it does not consider the effects of a structure which is located between antennas. This case is studied under the first technical task of this project — the development of antenna modeling techniques below uhf.

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*1 ft = approx 0.3 m

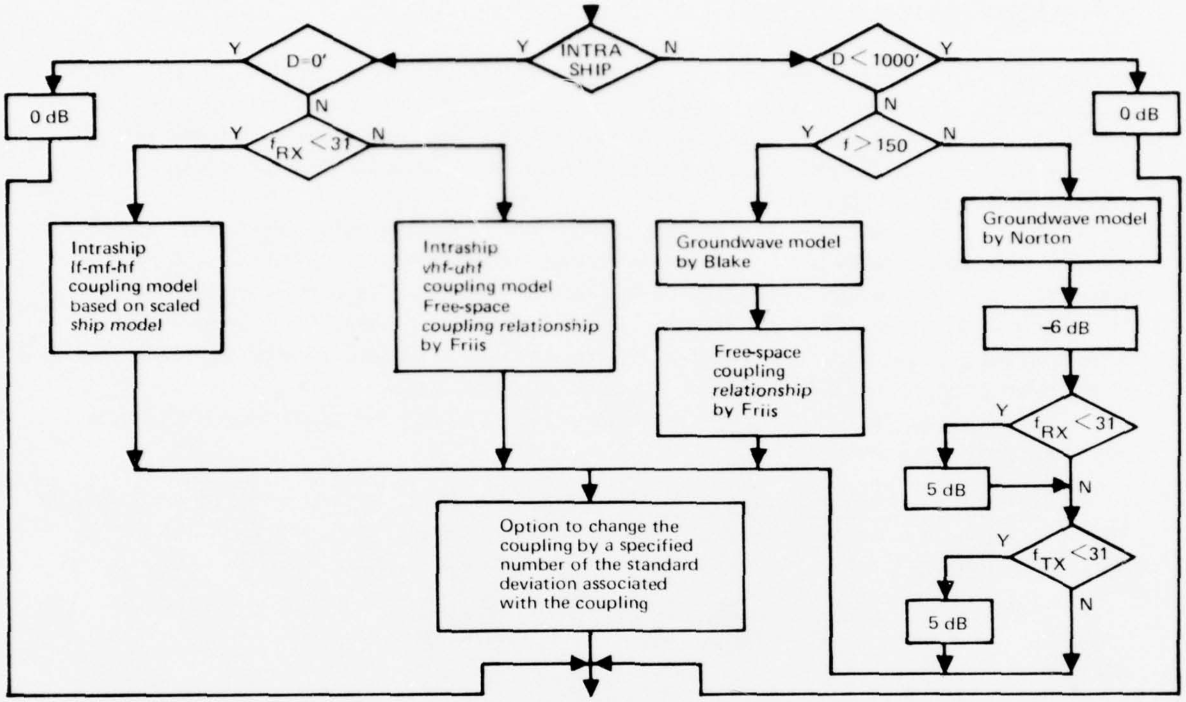


Figure 2-4. Space portion of coupling.

2.8 PRINTOUTS

SEMCA consists of CULL3, CULL4, FREQUENCY SELECTION, and COUPLER MAIN computer programs. Each program has various outputs.

The CULL3 program gives the following printouts:

Transmitter summary printout which gives transmitter spectrum and spectrum at antenna in dBm

Transmitter intermodulation printout

Receiver interference printout

The printouts of CULL4 are listed below:

Printout of desired signal noise and interference power summary at various receiver stages including mixer stages and IF stages

Detector operation printout, which gives articulation index or BER for each interference and the detector input SNR margin for acceptable performance. The receiver is graded as acceptable, marginal, or unacceptable according to the AI or BER. Note that the frequency of each interference must be the same as the victim receiver tuned frequency.

The major noise, which is the most important noise among the ambient noise, the receiver noise, and the transmitter broadband noise

Performance degradations due to cross modulation and receiver densensitization

The printout of the FREQUENCY SELECTION program gives the assignment of transmitter and receiver frequencies in any band from lf to uhf. Finally, COUPLER MAIN program produces coupler rejection characteristics, a Smith chart of antenna impedance data, and transmitter or receiver impedance data.

3.0 INTERFERENCE PREDICTION MODEL (IPM)

3.1 GENERAL DESCRIPTION

IPM was developed by Litton Systems Incorporated for the purpose of designing the DD 963 class ship for electromagnetic compatibility in 1971. Simulation of the topside electromagnetic environment and the various electronic subsystems by the IPM was used to facilitate EMC analysis. The generality of simulation possible with the IPM is shown in figure 3-1. Basically, IPM simulates the emission of a transmitter, processes this emission through filter devices and coupling devices to a receiver, and determines whether this receiver will be affected by the emission. In addition to the transmitted spectrum of transmitters, intermodulations which include transmitter intermodulation, passive device generated intermodulation, topside generated intermodulation, and receiver intermodulation are indicated in the figure. Also shown are the different types of output information – power density, rf saturation, IF power, and interferences. Figure 3-2 illustrates spectrum treatment; in particular, the procedure for determining interference power.

The IPM program consists of six distinct sections as shown in figure 3-3 – data base, problem definition, interference prediction, power summary, electromagnetic radiation, and rusty bolt. Generally, the first two sections must be run first, then one or more of the remaining sections can be run accordingly.

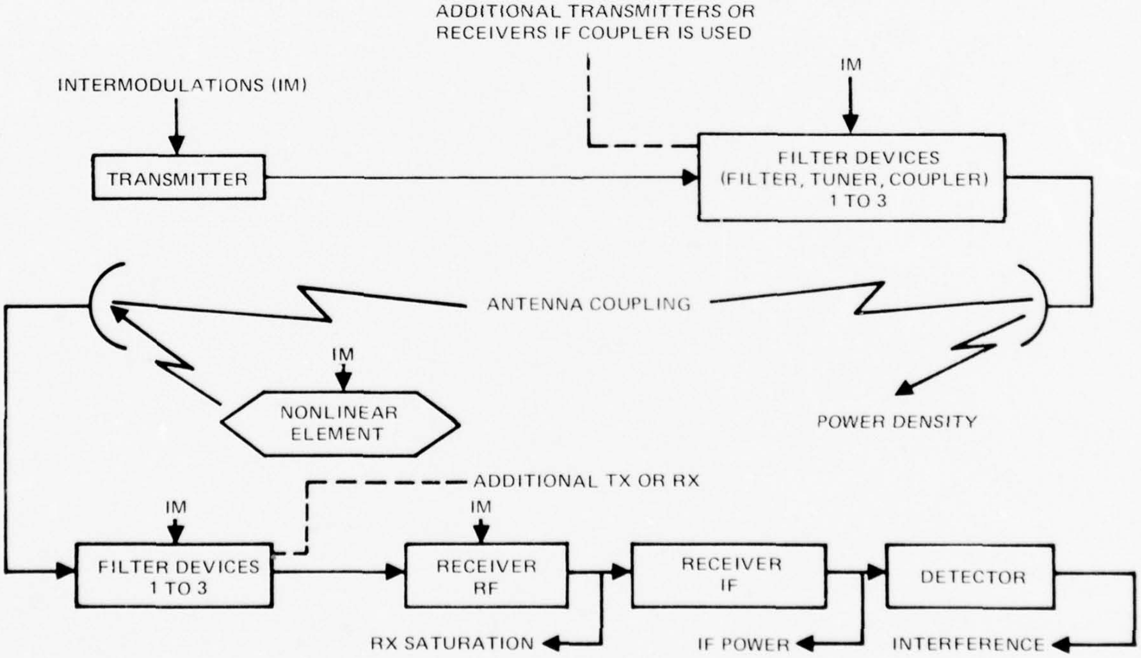
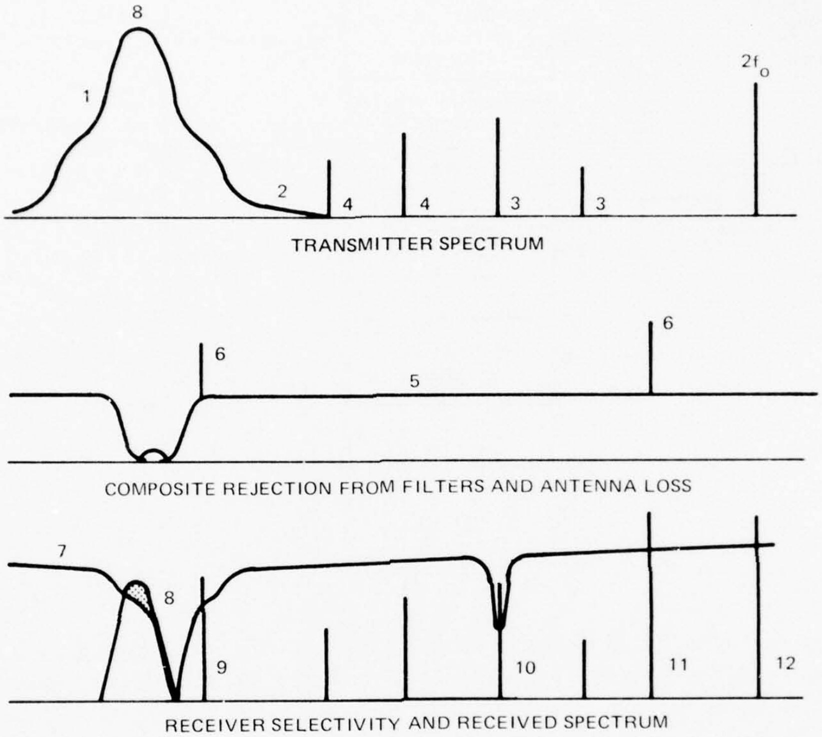


Figure 3-1. Rf signal flow within the IPM.



NOTES:

1. CENTER EMISSION AND SIDEBAND SPLATTER DEFINED BY 21 POINTS.
2. SKIRTS DETERMINED BY TRANSMITTER NOISE, EXTRAPOLATED EXPONENTIALLY FROM LAST TWO SPECIFIED POINTS.
3. SPURIOUS EMISSIONS.
4. INTERMODULATIONS (IM).
5. SKIRTS OF INDIVIDUAL DEVICES REJECTION EXTRAPOLATED AT CONSTANT LEVEL FROM LAST POINT.
6. IM ADDED BY FILTER DEVICES, EXTERNAL NONLINEAR ELEMENTS, OR RECEIVER.
7. SKIRTS EXTRAPOLATED EXPONENTIALLY FROM LAST TWO POINTS.
8. INTEGRATED SHADED AREA EQUALS LEVEL OF FUNDAMENTAL INTERFERENCE TO FUNDAMENTAL RESPONSE.
9. IM INTERFERENCE TO FUNDAMENTAL RESPONSE.
10. SPURIOUS INTERFERENCE TO SPURIOUS RESPONSE.
11. IM INTERFERENCE TO FUNDAMENTAL RESPONSE (EXCEEDS OUT-OF-BAND REJECTION).
12. HARMONIC INTERFERENCE TO FUNDAMENTAL RESPONSE.

Figure 3-2. IPM spectrum treatment.

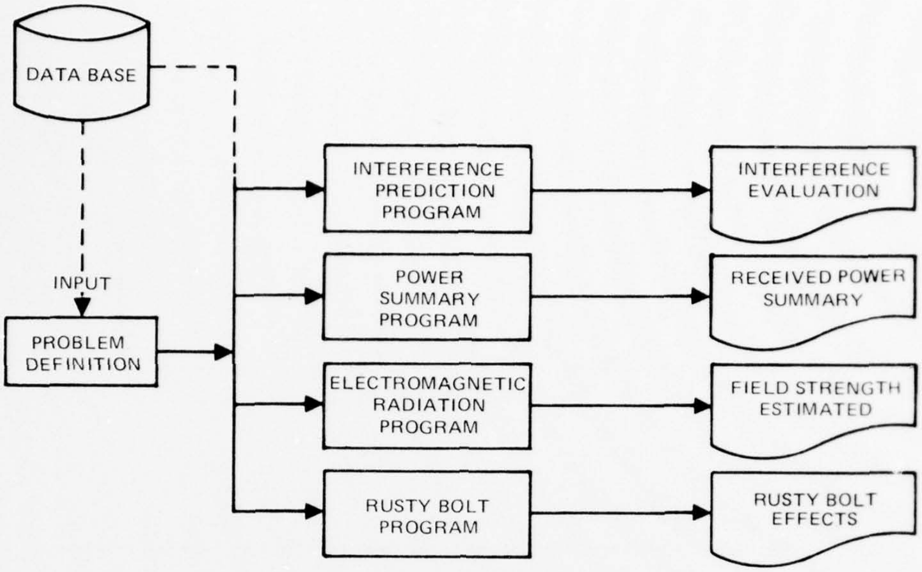


Figure 3-3. IPM software sections.

The data base contains pertinent information about the communication-electronics suite on board the DD 963 ship. It acts as a pool into which all other IPM sections can dip for information to aid in solving their designated problems.

The problem definition section defines the electromagnetic environment which is described by four information categories — equipment, assigned frequencies, equipment connectivity, and antenna locations.

The interference prediction section is run when the user desires output describing transmitter-receiver combinations most likely to cause interference.

The power summary section is run when output is desired which describes power present in each receiver by frequency band, summed either at the receiving antenna, at the receiver input, after receiver rf filtering, or after receiver IF filtering.

The electromagnetic radiation section is run when output is desired which describes power density in dBm per square metre for each prescribed frequency interval at a particular location. This information is obtained by summing fields of all transmitters specified in the problem definition section.

The rusty bolt section is run when the user defines a rusty bolt physical condition on input cards. Such a physical condition contains the rusty bolt number; the location of the rusty bolt; and the third, fifth, seventh, and ninth intermodulation coefficients. Emissions from the rusty bolt condition are processed and compared to receiver characteristics to determine whether an interference condition exists.

3.2 MODELING PHILOSOPHY

The IPM uses a deterministic approach in system modeling. No system parameter is considered as a random variable.

In the IPM program, a receiver is modeled by rf selectivity data, a receiver overall selectivity based on both the rf and IF selectivity data, receiver sensitivity, receiver intermodulation data, receiver spurious response data, and receiver impedance. Basically, the IPM treats the receiver as a linear device by using the receiver overall selectivity. The IPM program in its present form does not consider cross modulation, although other nonlinear aspects of the receiver such as receiver rf saturation, receiver intermodulation, and receiver spurious response are considered.

3.3 FLEXIBILITY

The IPM program can be used to evaluate intraship and intership EMC problems. For each evaluation mode, IPM has four capability options as shown in figure 3-3. These are interference evaluation, received power summary, field strength estimation, and rusty bolt effects. A user can run one or more of these options independently.

The IPM program also gives the option for the user to provide his own antenna coupling data instead of using the program-supplied antenna coupling models.

3.4 DATA BASE

The data base contains all communication-electronics suites on board the DD 963 ship. The equipment characteristics data for use in the IPM are obtained from the following sources:

Nominal characteristics given in technical manuals or maintenance pamphlets

Specification data given in the Litton, Collins, or other design specifications

Spectrum signature data

Synthesis from partial or comparable data or through use of modulation spectra algorithms

In preparing the input data, the frequency separations (ie, Δf's associated with emission spectrum receiver response, intermodulation data, etc) must be in absolute units of frequency; for example, MHz. They cannot be entered as a percent of tuned or base frequency. Computing these Δf's sometimes becomes burdensome to the user.

The transmitter emission spectrum, including modulation spectra, is specified in terms of dB relative to the carrier. In the hf region ranging from 2 to 30 MHz, at most nine base frequencies can be used in the data base. Base frequency is used to indicate the tuned frequency at which an equipment exhibits the characteristics referred to. If a transmitter is tuned to a frequency which falls between or outside specified base frequencies, then the following cases are considered:

- The program linearly interpolates between the two closest values obtained from the specified base frequencies for the assignment of the emission spectrum.

- The tail of the emission spectrum curve is extrapolated past the last specified point by assuming that the value of the last specified point remains unchanged in the extended region.
- The program uses the nearest base frequency to assign harmonic power levels.

However, if an interfering transmitter signal occurs at a Δf and coupling level different from the values specified in the data base, no transmitter intermodulation power level will be assigned. Similarly, no receiver intermodulation level will be assigned if it is different from those stored in the data base.

The program supplies a limited number of algorithms to calculate the frequencies of spurious emissions and spurious responses of the equipments used in the DD 963 ship. If the receiver spurious responses or transmitter spurious emissions of an equipment do not fit the algorithms contained in the program, a new algorithm must be added by the user.

3.5 NOISES AND INTERFERENCES

Generally speaking, the IPM program does not have mathematical models for noises and interferences. Instead, it depends on the user-supplied data which are stored in the data base for EMC analysis.

The IPM classifies receiver interferences into three categories: IF interference, rf saturation, and receiver intermodulation. These interferences are caused by the emission spectra of transmitters which consist of three components: the carrier and associated modulation sidebands, low-level noise sidebands, and spurious and harmonic emissions. It seems that transmitter broadband noise, transmitter harmonics, transmitter spurious emissions, transmitter intermodulation, passive device generated intermodulations, receiver saturation, receiver spurious responses, and receiver intermodulation have been included in some way in the program.

Referring to section 1.2, we can see that the IPM does not consider ambient noise, shipboard man-made noise, receiver cross modulation, and receiver burnout.

Litton claims that the impact of nonlinear regeneration of emissions by topside structure functions or rusty bolts may be assessed by using the rusty bolt section of the IPM program. However, the user must provide the location of the rusty bolt. Also, the coefficients for intermodulation generation and coupling to and from the source must be provided by the user. From the input data, a set of 48 rusty bolt intermodulation emissions is created for each pair of transmitters. The rusty bolt emissions are then compared with the noise threshold of the receiver to determine whether interference occurs. This feature of the program is not acceptable because of the impracticality of supplying the required input data.

3.6 INTERFERENCE THRESHOLD CRITERIA

For each receiver in the DD 963 class ship, some estimate of the desired signal level expressed in dBm must be specified for the performance analysis in the presence of interfering signals. The values of the desired signal level are provided by the user. However, if it is not specified, the program will use receiver sensitivity as the desired signal level. The user may specify more than one desired signal level.

IPM gives three interference identification tables – IF interference, rf saturation, and receiver intermodulation. The threshold criteria for these three types of interferences are discussed below.

In determining the existence of IF interferences, a signal-to-interference (S/I) threshold should be specified. A cull matrix serves as the mechanism whereby the threshold S/I for each receiver-interferer pair is input to the program for use in scoring the degree of interference. Each row of the cull matrix corresponds to a unique combination of transmitter parameters (nomenclature, power output, and modulation), while each column represents a specific receiver nomenclature and modulation type. The entries in the matrix cells are the required S/I for the indicated receiver-interference pair. The values of S/I were based upon studies published by ECAC. These values represent the S/I at the input to the receiver second detector required to achieve acceptable information quality in the presence of the particular interfering modulation type specified. The criteria for acceptable information quality are taken to be a 50% articulation score for AM and FM voice transmission (A3, A3A, and F3 modulation), 1% probability of error for AM pulse (A1, A2) and FSK (F1) digital systems, and 50% correct performance for pulse amplitude and pulse position modulation (P9) systems such as IFF and TACAN. Several deficiencies exist in the use of such generalized performance criteria. Therefore, instead of using the S/I threshold criteria, an alternative performance criterion is developed which is discussed below.

The alternative performance criterion is based on total interferer energy relative to receiver sensitivity. The criterion for interference is defined as the point at which the total interference power within the receiver passband causes a 3-dB or greater increase in receiver effective noise figure. This condition exists when the interference noise power equals the desired signal level required for a 3-dB (S + N)/N at the receiver output.

To identify the rf saturation interference cases, IPM assumes that the level of signal required at the input to the first active rf stage to cause saturation is 70 dB above the receiver sensitivity level. The receiver sensitivity, S_O, is defined in IPM as

$$S_O = -174 + F_N + 10 \log (BW) \text{ dBm},$$

where BW is the IF bandwidth in hertz and F_N is the receiver noise figure. F_N is the desired signal level required for 3-dB (S + N)/N at the receiver output. Note that actually S_O equals receiver noise. S_O is not the input level which produces a standard response of 10-dB (S + N)/N as commonly used.

Finally, in order to identify the receiver intermodulation interference threshold, signal level at the receiver input to produce receiver intermodulation is specified by the user and stored in the data base. If the intermodulation frequency is within the 60-dB IF passband, the levels of the two emissions at the receiver input are compared with the specified threshold value. Interference will almost certainly occur if both emissions are above the threshold level. If either emission level is above the threshold, a potential interference case is noted and an interference message is written.

3.7 ATTENUATION MODELING AND ANTENNA COUPLING

The IPM program considers the selectivity and the insertion loss of filter devices. The characteristic data of the filter devices are supplied by the user and are stored in the data base.

The user has the option of specifying any one of the following antenna coupling algorithms:

Far field coupling
Near field coupling
User's supplied coupling table

For far field coupling, the Friis relationship for free-space coupling is used.

Two approaches have been taken to simulate the near field situation. The first uses linear antenna coupling algorithms. The second centers upon integrated subaperture coupling and is used in conjunctive development with the scattering model. The linear antenna model treats two center-fed antennas having sinusoidal current distributions. This model is used primarily to estimate coupling losses involving large, closely spaced antenna structures in the hf range and below. The utility of the model depends on how well these idealized antennas simulate the actual situation.

The integrated subaperture model considers first-order scattering effects due to topside structures. It provides the capability for estimating fields in the near field of aperture and dipole array antennas in the presence of one cylindrical member and one flat plate structure, but it does not use the approach which involves numerical solution of the integral equations that describe a system of surface currents and associated fields. It is, therefore, not applicable to boundary value problems.

In addition to the various near field and far field algorithms, the IPM offers the capability to store and access tabular functions of coupling loss versus frequency for specific antenna types. This option is useful when measured data or other off-line coupling algorithms are available.

3.8 PRINTOUTS

The IPM program has four options — Interference Prediction Program, Power Summary Program, Electromagnetic Radiation Program, and Rusty Bolt Program. The outputs of these options are discussed below.

The outputs of the Interference Prediction Program include:

Problem specification data

Interference summary tables which give the number of times that any transmitter, receiver, or antenna is involved in cases of interference

Interference identification tables which consist of IF interference identification, rf saturation, and receiver intermodulation interference tables

The Power Summary Program gives available power at any of four points in the signal processing chain on the receiver side:

At the receiver antenna output
At the receiver input
After receiver rf filtering
At the receiver IF output

The power calculated may be the total power in all emissions, or it may be the power levels in each of a selected set of frequency intervals.

The output of the Electromagnetic Radiation Program provides the spatial power density in watts per square metre in each frequency interval for a specified location. It also provides the field strength in volts per metre in each frequency interval for the specified location.

Finally, the output of the Rusty Bolt Program shows the frequency and the power level of each topside-generated intermodulation. The transmitters associated with the intermodulation are also indicated.

4.0 TRANSMITTER AND RECEIVER EQUIPMENT DEVELOPMENT (TRED)

4.1 GENERAL DESCRIPTION

TRED was developed by NELC in 1971. It was intended to establish the electrical performance characteristics required in hf communication equipments for successful operation on naval ships. TRED is a manual design procedure which is based on obtaining equality of Quasi-Minimum Atmospheric Noise (QMAN) and receiver internal noise at the receiving subsystem input for hf band and below. When frequency increases above 30 MHz, it is increasingly likely that the receiver noise exceeds the external natural noise level. In this case, TRED uses the receiver noise as an interference criterion.

As described in section 1.2, TRED follows a step-by-step design procedure to make sure that the interference power levels are below the acceptable maximum. Figure 4-1 shows TRED rf system design procedure. The procedure can be divided into three main steps. First, a required antenna deficiency is established by the application of QMAN. The required antenna deficiency is then used to determine the receiving subsystem. Second, the minimum allowable antenna coupling is established by using the most important direct threat. Finally, a transmitting subsystem is established such that the indirect threats are less than the receiver noise. However, in the first step, if the natural noise power level is below receiver noise, no antenna deficiency is required.

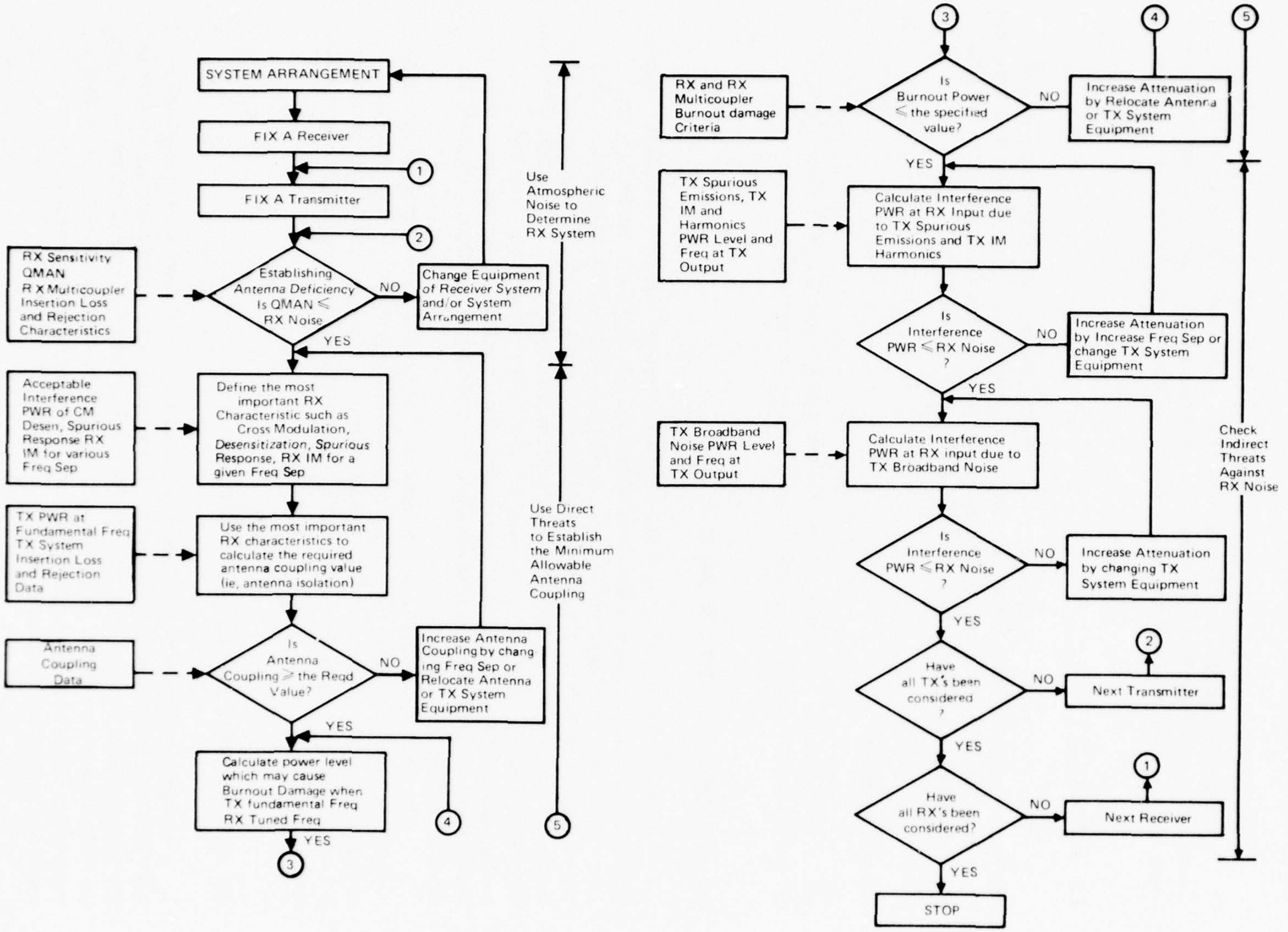


Figure 4-1. TRED rf system design procedure.

4.2 MODELING PHILOSOPHY

TRED uses a deterministic approach in system modeling.

TRED does not model each functional block of a receiver. It treats a receiver as a "black box" which is modeled by measured data of receiver sensitivity, receiver cross modulation, densitization, receiver spurious responses, and receiver intermodulation.

4.3 FLEXIBILITY

Since TRED is a manual design procedure, it is flexible. It follows a step-by-step development of problems and provides visibility of possible solutions to them. If a computer program of the TRED approach is to be developed in the future, flexibility would be possible. Perhaps the computer program would be of the interactive type.

4.4 DATA BASE

TRED requires measured data and spectrum signature data. No modulation spectra are included in the data base. At present, only limited data are available.

4.5 NOISES AND INTERFERENCES

TRED considers most of the noises and interferences described in section 1.2 except passive device generated intermodulation, rusty bolt, and shipboard man-made noises.

Although TRED does not address the problem of rusty bolt, an approach to it has been developed by NELC. The approach is based on finding the strongest of the unknown number of intermodulation contributing sources, removing it, and then repeating the process with the remaining sources until an acceptable interference signal level is reached. The method of identifying the strongest source of intermodulation interference in the topside environment of a ship involves a two-frequency test procedure and the use of an elementary direction finding technique.

A number of investigations were conducted at hf to find the normal topside intermodulation level. In general, third-order intermodulation is about –47 dBm for ships not having improvement programs, when the level of transmit fundamental frequency powers is 1 kW. This topside-generated intermodulation power level can be reduced to the QMAN level as required.

4.6 INTERFERENCE THRESHOLD CRITERIA

A basic criterion is that the receiver output due to the signal-plus-atmospheric-noise input $(S + N_A)$ should not be impaired by more than 3 dB by internal receiver noise or by any system-related interference. This condition exists when the receiver internal noise and the QMAN are made equal at the receiving subsystem input. The receiver internal noise is expressed in terms of receiver noise figure, which is the level of receiver noise power with respect to thermal noise power in dB.

The QMAN levels are based on two sources: a comprehensive examination of expected noise at many locations and for all seasons using data from the National Bureau of Standards Noise Measurement Program; and shipboard measurements made at sea in a typical low-noise region. The quasi-minimum values are based on judgment rather than on specific computations.

Two antenna system parameters have been established in the system design: the antenna deficiency required to match QMAN and receiver internal noise and the transmitting-to-receiving antenna isolation required to keep the level of impact of transmitting fundamental power at the receiver down to the receiver internal noise level.

The basic criterion that any locally generated interference level should be less than the QMAN level is used for the interference evaluations of spurious emissions, transmitter broadband noise, transmitter intermodulation, and harmonics. Similarly, receiver performance shall not be reduced more than 3 dB as a result of cross modulation, receiver intermodulation, desensitization, or spurious responses in the receiver caused by undesired local signals. For each receiver interference the allowable interfering power limit at the receiver input terminals is estimated from measurement data; for example, the cross modulation limitation of the R-1051 receiver is about −10 dBm the power level of the receiver input for a frequency 2-1/2% from the tuned frequency of the receiver. Desensitization and receiver intermodulation products occur at approximately the same power levels as those at which cross modulation occurs.

When the receiving subsystem frequency coincides with a local transmitter frequency, there might be a problem from the possibility of receiving multicoupler or receiver damage. Adequate protection measures should be employed to prevent these damages.

The discussions of this section are based on the assumption that the external noise exceeds the receiver internal noise. If the assumption is not true, then an antenna deficiency does not exist. Nevertheless, the receiver noise is still used as an interference criterion.

4.7 ATTENUATION MODELING AND ANTENNA COUPLING

TRED considers the selectivity and the insertion loss of filter devices. It also considers the possibility of receiving multicoupler damage due to overload, but it does not consider mismatch losses.

As mentioned previously, TRED uses direct threats to establish the minimum allowable antenna coupling value. This is quite different from the approach used in the SEMCA, IPM, and COSAM programs. These programs calculate the value of antenna coupling and predict the power levels of direct threats and indirect threats.

4.8 PRINTOUTS

Since TRED, in its present form, is a manual design procedure, it can be used to calculate the required antenna deficiency, the required antenna coupling, and the interference power levels of various direct and indirect threats at the input to the receiver.

5.0 CO-SITE ANALYSIS MODEL (COSAM)

5.1 GENERAL DESCRIPTION

COSAM has been developed by ECAC and IIT Research Institute. It is a computer program for the evaluation of the EMC potential of a single site which employs a large number of transmitting and receiving equipments. It is used to evaluate interactions between communication equipments in a statistical manner. The development of COSAM was divided into three stages: single channel uhf AM voice transmitting/receiving systems were considered first, then the vhf FM systems, and finally hf SSB systems.

The uhf AM, vhf FM, hf SSB portions of COSAM were validated in 1971, 1973, and 1975, respectively. Measurements were made of numerous interactions at the US Army Electronic Proving Grounds; results were compared with predictions made by the COSAM Program. For the uhf AM portion, it was found that 92% of all the cases resulted in differences between measured SINAD values (S_M) and associated mean values ($\bar{S}_P$) of less than 10 dB. For the vhf FM portion, the result was 90%, and finally 82% for the hf SSB portion. Figure 5-1 shows the cumulative probability distribution of $|S_M - \bar{S}_P|$ for three portions of the COSAM program. The term SINAD represents the signal-plus-noise-plus-interference-to-noise-plus-interference ratio, or (S + I + N)/(I + N), in dB, at the output of the receiver.

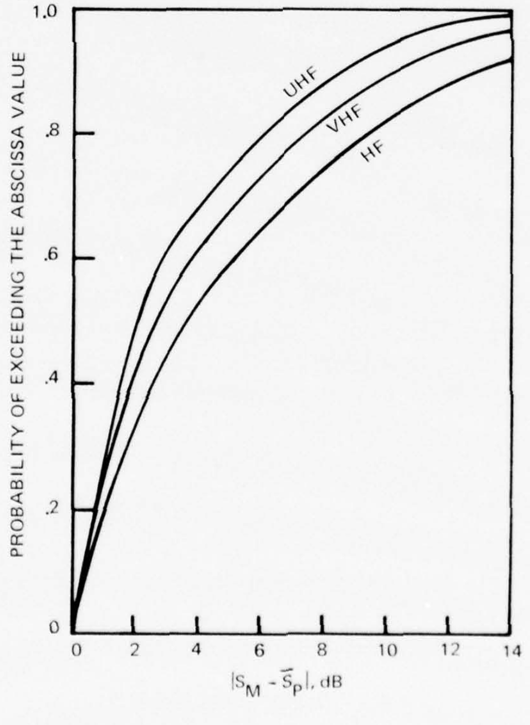


Figure 5-1. Validation of COSAM: cumulative probability distribution of $|S_M - S_P|$.

The 2–30-MHz band represents a difficult analytical problem. The hf band encompasses more than three octaves, whereas the uhf and vhf portions of COSAM consider equipments whose tuning ranges involve approximately one octave. Figure 5-1 indicates that the hf SSB portion of COSAM is the least accurate one among the three portions, despite the fact that additional efforts have been made. Since 1972, a three-phase hf development program has been instituted. Phase I was the development of a coupling model which would provide a statistical estimate of path losses between collocated, properly matched hf antennas. Phase II was the development of an antenna coupler selectivity model which would provide a statistical estimate of off-frequency rejection characteristics of various impedance-matching networks, when used with a variety of hf transmitters, receivers, and antennas. This phase resulted in the development of the Transmitter/Receiver, Antenna, Coupler Evaluation (TRACE) model. The third phase was the generation of hf transmitter and receiver parameter values which can be used in COSAM models. The process implied a capability to model performance of equipments for which no measured data are available, on the basis of similarities with equipment for which measured data are available. On the basis of the results of the validation of the hf portion of COSAM, ECAC recommended that the following areas should be investigated:

Determination of coupler, transmitter, receiver, and antenna characteristics contributing to mismatch losses when frequency separations exceed one octave.

Determination of what intermodulation orders should be considered when hf transmitters and receivers are collocated.

5.2 MODELING PHILOSOPHY

The COSAM program uses a Monte Carlo simulation technique (1000 samples) to obtain a probability distribution of SINAD which represents the ratio of (S + I + N)/(I + N) in dB at the output of each receiver specified in the analysis. The procedure used to obtain the SINAD distribution is described below.

Three variables are involved. P_d is the desired signal power, P_n is the ambient noise power level, and P_i is the sum of five effective input on-frequency interference power levels (ΣP_{ino}). P_d, P_n, and P_i are random variables. The probability distributions of P_d and P_n are not computed by COSAM. Instead, P_d and P_n are assumed to be Gaussian random variables. However, COSAM determines the probability distribution of P_i.

P_i is the sum of P_{ino}. P_{ino} is the effective input on-frequency interference power level due to a single interaction. There are five interaction types which are calculated by COSAM for each receiver versus the transmitters specified in the analysis. These interaction types are adjacent signal, receiver intermodulation, transmitter intermodulation, receiver spurious response, and transmitter spurious emission. COSAM provides equations to calculate each of the five interactions, the value of P_{ino}.

The parameter $[S/(I + N)]_{ino}$ is calculated by using the equation

$$[S/(I + N)]_{ino} = 10 \log_{10} [P_d/(P_n + \Sigma P_{ino})] .$$

This parameter is defined as the effective input on-frequency signal-to-interference-plus-noise ratio resulting from any of, or the combined effects of, the five types of interactions predicted by COSAM.

Receiver detector transfer function equations are then used to convert $[S/(I+N)]_{ino}$, the input ratio, into $[S/(I+N)]_o$, the output ratio. The detector transfer function depends on the modulation types of the desired signal and undesired signal.

Finally, the value of $[S/(I+N)]_o$ can be easily transformed to SINAD as follows:

$$\mathrm{SINAD} = 10 \log_{10} \left[1 + 10^{0.1[S/(I+N)]_o}\right] \quad \mathrm{dB}$$

In brief, one receiver is selected and an interaction table is examined to determine which transmitters are potentially significant. Then, for each interaction, the appropriate P_i, P_d, and other parameter distributions are selected and a single value is chosen from each by means of a random number generator.

A single value of P_{ino} is computed from these values, the next interaction is considered by use of the same points, as applicable, and so on. This process is termed a "run." Then, for the same receiver, 1000 runs are performed, eventually resulting in a predicted SINAD output distribution. Each receiver is considered in the same manner.

Next, the receiver modeling of COSAM is considered. The receiver model of COSAM is determined by the equations which calculate P_{ino} and the detector transfer function equations. The equations for the calculation of P_{ino} will be presented in section 5.5. In order to account for certain nonlinearities in the receiver, specific power break-points have been specified in the adjacent signal and receiver intermodulation equations. For each equation, if the interfering power level exceeds the break-point, one constant is used; if it does not, another constant is used. As to receiver modeling, ECAC has developed two techniques; namely, receiver waveform simulation and time domain simulation of digital receivers. The results of these simulation programs have been applied to COSAM.

5.3 FLEXIBILITY

COSAM is developed mainly for interference evaluation. COSAM has the option of using the program-supplied antenna coupling model or not.

5.4 DATA BASE

The data base of COSAM includes:

Nominal equipment data extracted from various sources.

Mean values and associated standard deviations, where applicable, of the various parameters. These parameters are used to calculate the effects of five interactions. The parameter values are generated from spectrum signatures or from similar equipments for which measured data are available. If a parameter is considered as a random variable, usually it is assumed that the random variable has a Gaussian distribution.

Rules for describing frequency synthesis procedures which are obtained from technical manuals. These rules are used to evaluate frequency relationships which determine the probable existence of transmitter spurious emissions and receiver spurious responses.

COSAM does not consider modulation spectra. COSAM has an adequate number of equipments which have data stored in the data base.

5.5 NOISES AND INTERFERENCES

As mentioned in section 5.2, there are five interaction types considered by COSAM. The model of each interaction is described below. Adjacent signal interference includes cross modulation, desensitization, saturation, and the effects of transmitter noise.

The equation for the mean value of the effective input on-frequency interference power level from an adjacent signal is:

$$P_{ino} = P_i - \beta_{eff} + (1 - M)(P_d - R_s - 5) \; ,$$

where

P_i = input undesired power in dBm
β_{eff} = effective off-frequency rejection (due to Δf) in dB
P_d = input desired power in dBm
M = a value of the slope $\Delta P_i/\Delta P_d$ = 1.0 for $P_i < P_{ib}$
> 1.0 for $P_i > P_{ib}$
R_s = receiver sensitivity in dBm
P_{ib} = a specified interfering power break-point

Values for β_{eff}, M, P_{ib}, and R_s are obtained from equipment spectrum signature measured data. However, it is questionable that the indirect threat (transmitter noise) and the direct threats (cross modulation, etc) should be represented by a single equation.

The expression for spurious response calculations is

$$P_{ino} = (1-q)\, R_s + q\,(P_o - \beta_{sr}) \; ,$$

where

P_{ino} = effective on-tune interference power in dBm
P_i = input undesired power in dBm
R_s = receiver sensitivity in dBm
β_{sr} = effective spurious response rejection in dB
q = a positive integer which represents the harmonic of the spurious frequency

Equations are used in COSAM to determine the various receiver IF and local oscillator (LO) frequencies as a function of tuned frequency. The spurious response frequency is then calculated as a function of the IF and LO frequencies.

The expression to compute the spurious emission power at the receiver takes the form

$$P_{ino} = P_t - \beta_{se} - \beta(C_t) - C_{tr} - 1 \; ,$$

where

P_{ino} = effective on-tune interference power in dBm
P_t = transmitter power in dBm

β_{se} = effective spurious emission rejection in dB

$\beta(C_t)$ = off-frequency rejection due to the transmitter coupler in dB

C_{tr} = coupling loss between transmitter and receiver due to antenna gains and path loss in dB

The value of 1 dB represents the insertion loss of the receiver coupler.

The transmitter intermodulation power is given by the equations:

$$P_{im} = mP_v + n(P_i - \beta_{vi}) - K_{m,n} - \beta vr$$

and

$$P_{ino} = P_{im} - \beta(C_v) - C_{tr} - 1 \ ,$$

where

P_{im} = power level of the IM product at the transmitter at frequency f_{im} in dBm

P_v = output power level of the victim transmitter signal at f_v in dBm

P_i = received power level of the interfering transmitter signal at f_i in dBm

β_{vi} = off-frequency rejection, a function of frequency difference between f_v and f_i and the victim transmitter output selectivity, in dB

$K_{m,n}$ = transmitter conversion loss term for the m+n order case

β_{vr} = off-frequency rejection, a function of the difference between f_v and f_r where $f_r \simeq f_{im}$, and f_r is the tuned frequency of a victim receiver, in dB

m,n = integers

f_{im} = $mf_v - nf_i$

Values for $K_{2,1}$, $K_{3,2}$, and $K_{4,3}$ have been computed from spectrum signatures.

The receiver intermodulation power is:

$$P_{ino} = m(P_v - \beta_{vr}) + n(P_i - \beta_{ir}) - K_{m,n} \text{ (or } K'_{m,n}) \ .$$

where

P_{ino} = power of the intermodulation product produced in the receiver in dBm

m,n = integers

P_v, P_i = power level of undesired signals in dBm

β_{vr}, β_{ir} = off-frequency rejection, a function of the difference between undesired frequencies and receiver tuned frequency (f_r), where $f_r \simeq f_{im}$, in dB

fr = $mf_v - nf_i$

$K'_{m,n}$ = receiver rf amplifier conversion loss. $K'_{m,n}$ is used if P_v and P_i are greater than P_{ibk} (interfering power break-point)

$K_{m,n}$ = first mixer conversion loss. $K_{m,n}$ is used if either P_v or P_i is not greater than P_{ibk}.

Values of $K_{1,1}$, $K_{2,1}$, $K_{3,2}$, and $K_{4,3}$ for the firxt mixer, and $K'_{1,1}$, $K'_{2,1}$, $K'_{3,2}$ and $K'_{4,3}$ for the rf amplifier, as well as β curves, have been computed from spectrum signature data. Note that in the computation of P_{ino}, parameters P_d, P_i, P_t, P_v, R_s, β_{eff}, β_{sr}, β_{se}, β_{vi}, β_{vr}, β_{ir}, C_{tr}, $K_{m,n}$, and $K'_{m,n}$ are considered as Gaussian random variables.

COSAM does not treat passive device generated intermodulation, rusty bolt, shipboard man-made noises, and receiver burnout.

5.6 INTERFERENCE THRESHOLD CRITERIA

The COSAM model computes the statistical distribution (ie, histogram) of SINAD. The user has to set a SINAD threshold value which is based on an articulation score measure. The COSAM model then computes the probability of exceeding this threshold value. This gives a numerical score upon which the seriousness of degradation to a system is determined. A threshold value of SINAD which gives an articulation score of 0.7 is commonly used. For example, a SINAD of 10 dB is used in the hf SSB portion of COSAM.

5.7 ATTENUATION MODELING AND ANTENNA COUPLING

COSAM considers the selectivity, insertion loss, and mismatch loss (by using the TRACE program) of filter devices. Various algorithms are provided for the calculation of antenna coupling loss.

The COSAM program has two options for describing attenuation of filter devices. The first assumes that the off-frequency rejection loss, $\beta(C)$, due to antenna couplers is that of N cascaded single-pole Butterworth bandpass filters. The second permits the user to input any set of rejection values describing losses between transmitters and associated antennas as well as receivers and associated antennas.

In general, hf antennas are not matched to the transmitter (or receiver) and transmission line over much of the hf band. The presence of a coupler or matching network will improve the match at the tuned frequency and will contribute to the rejection characteristics at frequencies distant from the tuned frequency.

The TRACE program, developed by ECAC, provides a statistical distribution of the rejection characteristics of any transmitter (or receiver) and antenna combination, including the effects of associated couplers and transmission lines. In many antenna applications, uncertainties exist in the lengths of the transmitter-to-coupler and the coupler-to-antenna lines. The statistical distribution of the rejection characteristics is generated in TRACE by allowing the line lengths to vary over specified ranges, turning the coupler and calculating the various losses at the frequencies of interest. The results of TRACE can be used by the COSAM program.

COSAM calculates the antenna coupling loss by one of two methods depending upon the co-site installation. If a ground or ship installation is being analyzed, one method is used. If, on the other hand, the installation is an aircraft, a second method must be used. The method for the ship installation is described below:

For the uhf AM portion of COSAM, the statistical expression for the calculation of antenna coupling loss is

$$C_p = -G(1) - G(2) - 44 - 50 \sin^2\theta + 20\,(1 + \sin^2\theta)\,\log_{10}(df) \quad .$$

where

C_p = *mean* coupling loss between antennas 1 and 2 in dB
$G(1), G(2)$ = gains in dB of antennas 1 and 2, respectively
d = distance between antennas in feet
f = frequency of transmitted signal in MHz
θ = vertical angle between antenna positions in degrees

The statistical distribution of antenna coupling loss is assumed to be Gaussian and a value of standard deviation is supplied.

For the vhf FM portion of COSAM, the expression C_p is:

$$C_p = -G(1) - G(2) - 37 - 60 \sin^2 \theta + 20 (1 + \sin^2 \theta) \log_{10}(df) + 14 P (1 - \sin\theta)^2 ,$$

where P is polarization factor — 1 for cross polarization, 0 otherwise. Again, antenna coupling loss is assumed to be a Gaussian random variable and a value of standard deviation is supplied by the program.

There are various expressions of C_p for the hf portion of COSAM; the models are listed as follows:

CONFIGURATION	MODEL
Whip-to-whip	$C_p = -2G_{WHIP} + MAX \left[L_{FS}, L_{GW}\right] + \sin^2\theta \left[-50 + 20 \log fd\right]$
Whip-to-dipole	$C_p = -G_{WHIP} - G_{DIPOLE} + MAX \left[L_{FS}, L_{GW}\right] + \sin^2\theta \left[-50 + 20 \log fd\right] + 14 \left[1 - \sin\theta\right]^2$
Dipole-to-dipole (equal heights)	
parallel orientation	$C_p = -2G_{DIPOLE} + MAX \left[L_{FS}, L_{GW}\right]$
perpendicular orientation	$C_p = -2G_{DIPOLE} + MAX \left[L_{FS}, L_{GW}\right] + 14$
end-to-end orientation	$C_p = -2G_{DIPOLE} + MAX \left[L_{FS}, L_{GW}\right] + 20 \log fd - 50$
45° orientation	$C_p = -2G_{DIPOLE} + MAX \left[L_{FS}, L_{GW}\right] + 3$

where $MAX \left[L_{FS}, L_{GW}\right]$ is the larger of the two losses calculated by

$$L_{FS} = -37 + 20 \log fd$$

and

$$L_{GW} = -14 - 15 \log h_1' h_2' + 40 \log d \text{ (ft)}.$$

h_1', h_2' are "effective" heights, given by

$$h' = \sqrt{h_0^2 + h^2},$$

where

h is the structural height (relative to the feed point) in feet, and

h_o is the minimum effective height in feet.

The formulas for h_o apply to the type terrain considered in the test.

$\log h_o = 1.5 \log f + 3.45$ if $1 \leq f \leq 20$ MHz

$= -1.3 \log f + 3.2$ if $f > 20$ MHz for vertical polarization

$h_o = 0$ if $f > 1$ MHz for horizontal polarization

C_p = mean coupling loss between the two antennas in dB

G_{WHIP} = gain of a whip antenna in dB

G_{DIPOLE} = gain of a dipole antenna in dB

d = distance between antennas, in feet

f = frequency of the transmitted signal, in MHz

θ = vertical angle between antenna positions in degrees

5.8 PRINTOUTS

COSAM provides three numerical scores; namely, the upper performance score (UPS), the system performance score (SPS), and the relative performance score (RPS). UPS is the probability of providing adequate performance if no interference is present. UPS is calculated by an analytical expression. SPS is the probability of adequate performance in the presence of interference. SPS is obtained by the application of Monte Carlo simulation. RPS is the ratio of SPS to UPS. The criteria for adequate performance are determined by the user when he sets the threshold values of (S+N)/N and (S+I+N)/(I+N).

After the computation of each receiver's degrading scores, a printout is given summarizing the results of the interference analysis. The average P_{ino} values for each interference situation are provided. A plot of the SINAD distribution is also printed.

6.0 OTHER LESS APPLICABLE TECHNIQUES

6.1 IEMCAP

IEMCAP was developed by McDonnell Aircraft Company for Rome Air Development Center. It is a computerized analysis program for the implementation of EMC at all stages of an Air Force System's life cycle ranging from conceptual studies of new systems to field modification of old systems. IEMCAP provides four analysis capabilities; namely, specification generation, waiver analysis, design change evaluation, and tradeoff analysis. The program performs the following tasks:

It generates EMC specifications to supplement or replace MIL-STD-461 or MIL-I-6181.

It assesses the impact of these specifications.

It determines the effect of design changes and evaluates the feasibility of new concepts.

It provides information on design parameters that assist the EMC and design engineers in establishing a compatible system design and in making tradeoff decisions.

The program is applicable to ground, aircraft, and space/missile systems. It seems that IEMCAP may be able to analyze a shipboard EMC situation as well by using the mode of a ground system.

The main features and limitations of IEMCAP are listed below:

It uses a worst-case deterministic approach.

A receiver is modeled as a linear device which is represented by a susceptibility curve. The nonlinear effects of the receiver, such as receiver intermodulation and cross modulation, are not considered in the program. It also does not consider transmitter intermodulation.

The receiver detector model is based on the assumption that the summation of all interferences can be represented by a Gaussian noise. The transfer function of the detector relates the signal-to-noise ratio (SNR) of the input to the detector and the SNR of the output of the detector, where noise is assumed to be Gaussian.

The interference threshold criterion is determined by standard receiver sensitivity and the detector transfer function which gives an acceptable SNR for a specified modulation type of desired signal.

IEMCAP considers the modulation spectra of fundamental frequency and harmonics of transmitters.

Coupling models consist of cable-to-cable coupling, direct coupling (common impedance), antenna-to-antenna coupling, cable-to-antenna coupling, field-to-cable coupling, and case-to-case coupling. A user must use the program-supplied coupling models. For example, there is no option for the user to use his antenna-to-antenna coupling data.

Only one filter can be simulated between the transmitter (or receiver) and the associated antenna.

IEMCAP does not consider mismatch loss and transmission line loss.

For use in conjunction with IEMCAP there will be a series of supplemental models that will provide additional analysis for aircraft stores, electroexplosive devices and subsystems, lightning, magnetospheric substorms, and static electricity.

Nonlinear and EM/near-fields analysis models — which will characterize the input/output relation to nonlinear circuits, EM/near-field interactions, and antenna and aperture coupling — are being developed for off-line use.

The program is being validated. The results of the validation will be available within 8 months.

6.2 COSIM-1

The COSIM-1 program was developed by IIT Research Institute to identify the potential interference problems between transmitter-receiver pairs. For each transmitter-receiver pair, COSIM-1 examines the transmitter fundamental and up through the twelfth harmonic emission. Interference is said to result whenever a transmitted signal has been found to exceed the interference threshold for a receiver in the system. The interference threshold is determined by the sum of receiver sensitivity and the margin M, which is an input parameter specified for each receiver.

A primary assumption of COSIM-1 is that the receivers are linear. Receiver response is taken to be proportional to the magnitude of the signal; ie, nonlinear effects such as overloading, saturation, and intermodulation are not considered. Other important EMC-related parameters not considered by COSIM-1 are transmitter broadband noise, transmitter intermodulation, and spurious emissions. Rapid analysis is considered to be one of the prime objectives of the COSIM-1 program. Unfortunately, it results in an oversimplified evaluation of the potential interference in a given electromagnetic environment.

6.3 ISCAP

ISCAP was developed by Sachs/Freeman Associates and has been used for solving wire-to-wire coupling problems, among other things. It was designed for general intrasystem compatibility analysis which includes:

MIL-STD-469, check of radar design characteristics

MIL-STD-188B, check of communication equipment design parameters

Spectrum overlap and interference potential from transmitter fundamental, harmonic, and spurious emissions

Interference potential through receiver spurious, intermodulation, and cross modulation responses

Interference potential due to receiver local oscillator radiation

Interference potential due to radiation from cables, cases, and antennas coupling into nondesign receptors.

7.0 SUMMARY OF COMPARISON

7.1 TABLES OF COMPARISON

Tables 7-1 through 7-7 compare SEMCA, IPM, TRED, and COSAM with respect to the aspects of modeling philosophy, flexibility, data base, noises and interferences, interference threshold criteria, attenuation modeling and antenna coupling, and printouts. The comparisons are based on the discussions presented in sections 2.0 through 5.0.

7.2 SUMMARY AND CONTENTS

The main features and limitations of SEMCA, IPM, TRED, and COSAM are summarized in tables 7-8 through 7-11. These tables are also based on the discussions presented in sections 2.0 through 5.0.

TABLE 7-1. PROGRAM PHILOSOPHY.

	Deterministic or Statistical Approach	Receiver Modeling
SEMCA	● Incomplete statistical approach ● Consider only mean value and σ but not PDF	● Detailed model of each receiver functional block
IPM	● Deterministic approach	● Use sensitivity, rf selectivity, and IF selectivity of receiver ● Also use data of RX, IM, and spurious response
TRED	● Deterministic approach	● Use receiver sensitivity and measured data of cross modulation, desensitization, etc
COSAM	● Statistical approach ● Use Monte Carlo simulation to get histograms of $(S + N)/N$ and $(S + I + N)/(I + N)$	● Mathematical models of adjacent signal effects, spurious responses, and intermodulations ● Summation of interference power levels

TABLE 7-2. PROGRAM FLEXIBILITY.

SEMCA	● Three interference evaluation modes ● Four subproblems (Cull 3, Cull 4, frequency selection, coupler main) ● Choice of whether detector processing be done ● Option of using program-supplied models or not ● Option of printouts
IPM	● Three Interference evaluation modes ● Four subproblems (interference evaluation, RX; power spectral density; field strength; and rusty bolt) ● Option of using program-supplied antenna coupling model
TRED	● TRED follows a step-by-step development of problems with visibility of possible solutions and can be used to examine parts of problems ● A computer program is yet to be developed
COSAM	● Mainly for interference evaluation

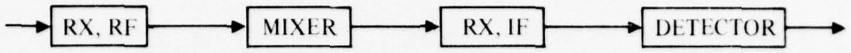
TABLE 7-3. DATA BASE.

	Item	SEMCA	IPM	TRED	COSAM
Sources of Data	Limited ship-field measurement	✓			
	Spectrum signature data or laboratory measurement	✓	✓	✓	✓
	Synthesis from partial or comparable data	✓	✓		✓
	Nominal characteristic given in manuals or specifications		✓		
	Analog model	✓			
	Modulation spectra		✓		
	Complexity and difficulty of preparing data	complex	complex difficult	relatively simple	complex
	Number of equipments which have data stored in the data base	many	DD 963 equipments	limited	some

TABLE 7-4. NOISES AND INTERFERENCES.

Item		SEMCA	IPM	TRED	COSAM
System Indirect Threats	TX broadband noise	model or data considered as "noise"	data	data	considered as direct threat
	TX harmonics	data	data	data	included in spurious missions
	TX spurious emissions	data considered occasionally	model (freq) data (PWR)	data	model
	TX intermodulation	model or data	data may cause direct threat	data	model
	Passive device generated IM	none	data	none	none
Environmental Indirect Threats	Ambient noise (atmospheric)	model or data	none	model	model
	Rusty bolt	none	model impractical	none	none
	Shipboard man-made noise	none	none	none	none
TX Fundamental Causes Direct Threats	RX internal noise (noise figure)	data	data	data	data
	RX cross modulation	data or model not sure	none	data	model
	RX desensitization, saturation, or overload	data	model questionable	data if required	model
	RX spurious response	data or model not sure	model (freq) data (PWR)	data if required	model
	RX intermodulation	model or data	data	data if required	model
	RX burnout	none	none	data	none

TABLE 7-5. INTERFERENCE THRESHOLD CRITERIA.



	Input to Rf Stage	IF Output or Input to Detector	Detector Output
SEMCA	Power cull criterion is receiver noise-15 dB Adjustable by user	Related to sensitivity S/N and S(N + I) for BER of 2.5×10^{-3}	S/N and S/(N + I) Articulation index (AI) of 0.7, 0.4
IPM	Saturation level is sensitivity +70 dB User sets IM level	User sets S/I for AS of 0.5 ($\simeq$0.42 of AI) and BER of 1×10^{-2} or sets S/I = 0 dB When S not specified assume S = sensitivity Interference ≤ sensitivity	
TRED	Interference ≤ receiver noise QMAN ≤ receiver noise		
COSAM			User sets threshold values of S/N and S/(N + Σ I)

TABLE 7-6. ATTENUATION MODELING AND ANTENNA COUPLING.

	Item	SEMCA	IPM	TRED	COSAM
Filter Devices	selectivity	√	√	√	√
	insertion loss	√	√	√	√
	mismatch loss	√			√
	transmission line loss	optional			√
	Antenna Coupling	SCAPS model ground wave line of sight on-board coupling	far field near field user's data	establish a required antenna coupling value	various algorithms

TABLE 7-7. PRINTOUTS.

SEMCA	• Printout of desired signal and interference power summary at various receiver stages • Major noise (receiver noise, ambient noise, or transmitter broadband noise) • Articulation index or BER for each interference • Receiver performance is graded as acceptable, marginal, or unacceptable, according to each AI or BER • Detector input SNR margin for acceptable performance • Degradation due to cross modulation and desensitization • Frequency assignment • Coupler rejection characteristics, Smith Charts of antenna impedance data or TX/RX impedance data
IPM	• Interference summary • Interference identification (IF interference, rf saturation, and RX intermodulation) • Power spectral density at various RX stages • Field strength at a specified location • Interference identification due to rusty bolt
TRED	• Manually calculated to meet user's needs
COSAM	• Upper performance scope (UPS). Prob $\left[(S + N)/N > \text{threshold}\right]$ • System Performance score (SPS). Prob $\left[(S + I + N)/(I + N) > \text{threshold}\right]$ • Relative performance score (RPS). SPS/UPS • Average power level of each interference • Histogram of $(S + I + N)/(I + N)$

TABLE 7-8. SUMMARY AND COMMENTS — SEMCA.

Main features	Limitations
• Detailed receiver modeling • Flexible (freq assignment, math models, and printouts) • Consider most of the important noises and interferences. Either models or data are used • Receiver noise, ambient noise, and transmitter broadband noise are considered as noise • Interference means the undesired signal whose frequency is exactly the same as the receiver tuned frequency. Cross modulation and desensitization are not called interferences and are considered separately • Threshold value is related to AI and BER • Noises and each interference give an AI or BER • To have an acceptable system, each AI and BER must be acceptable • Consider mismatch loss and transmission line loss • Consider AGC effects	• Incomplete statistical approach • Use analog model to get data • Insufficient spurious emission data • Does not consider the effects of passive device generated IM, rusty bolt, and man-made noise • Antenna coupling algorithm is questionable • The program-supplied antenna coupling algorithm must be used. No option for using user-supplied data or model • Program is not user interactive

TABLE 7-9. SUMMARY AND COMMENTS — IPM

Main features	Limitations
• Deterministic approach • Calculate field strength at a specified location • Consider modulation spectral • Emphasis on the manual treatment of spectrum by user • Has some spurious emission and spurious response algorithms	• Incomplete receiver modeling (does not consider cross modulation, fixed RX. Saturation level is not adequate) • Does not consider atmospheric noise and man-made noise • Rusty bolt program is impracticable • Frequency must be in MHz • Data base has DD 963 equipments only. It is complicated to establish data base for a new equipment. • Program is not user interactive. • Does not consider mismatch loss

TABLE 7-10. SUMMARY AND COMMENTS – TRED.

Main features	Limitations
• Deterministic approach • Evaluate each noise or interference separately • Use RX noise and quasi-minimum atmospheric noise as threshold criteria • Flexible • Use empirical data • Calculate the required antenna coupling value	• Incomplete receiver modeling • A computer program is yet to be developed • Limited empirical data • Does not consider the effects of passive device generated IM, man-made noise, and rusty bolt • Does not consider mismatch loss

TABLE 7-11. SUMMARY AND COMMENTS – COSAM.

Main features	Limitations
• Statistical approach • Threshold value may be related to AI and BER • Summation of interference powers generated by all transmitters • Noises and interferences are modeled mathematically • Consider mismatch loss by the application of an off-line program called TRACE	• Consider transmitter broadband noise as a direct threat • Not applicable to a receiver which has undesired signals with different modulation type • Only uhf AM, vhf FM, and hf SSB systems have been considered • Antenna coupling algorithm is questionable • Does not consider the effects of passive generated IM, rusty bolt, and man-made noise • Program is not user interactive • Need a confidence interval for the System Performance Score

8.0 PRELIMINARY EVALUATION

8.1 INTRODUCTION

This section presents a preliminary evaluation of the existing system interaction analysis techniques. The final evaluation will be reported subsequently to the sample problem exercise and empirical investigations scheduled for completion at the end of the 1976 transition quarter.

The evaluation concentrates on the development of a system interaction analysis capability for communications. To analyze a proposed system design means not only to predict the preliminary system performance but also to identify any possible deficiencies in the design. On the basis of the results of the analysis, a designer can either find feasible solutions to the problems identified or make tradeoff decisions. It is hoped that the design goal of acceptable system performance can be reached through the iterative utilization of the computerized analysis program and the engineering judgment of the designer.

Once a system interaction analysis program has been developed, in addition to the design of a new ship, it can be used for other purposes such as:

Development of equipment specifications

System proofing for ship class design and acceptance test

Modification of existing systems during ship modernization

Development of general frequency management guidance

This evaluation will be made in terms of modeling philosophy, flexibility, data base, noises and interferences, interference threshold criteria, antenna modeling and attenuation modeling, and printouts.

8.2 MODELING PHILOSOPHY

There are three steps in the process of designing an acceptable new system: the prediction of preliminary system performance, the identification of system deficiencies, and the elimination of these deficiencies. Usually these design steps are repeated many times before a final design can be reached. Thus, time and cost are important factors to be considered in the development of a system interaction analysis program.

The statistical system modeling approach requires a great deal of computer time, especially when Monte Carlo simulation is performed. On the other hand, the worst-case deterministic approach is rapid and cost-effective.

A detailed receiver modeling is not necessary during the process of designing a new communication system. The receiver modeling approach used by TRED is rapid and cost-effective.

However, when an acceptable preliminary design is obtained, there is a need to evaluate the design more thoroughly. The purpose of this evaluation is to predict the final system performance. In this system performance prediction program, the statistical system modeling approach and the detailed receiver modeling should be used. The final system performance will be expressed in terms of articulation index for voice communication and bit error rate for digital communication systems. An approach similar to SEMCA is suitable for this purpose. The SEMCA type approach would also be useful for the other four purposes listed in section 8.1.

8.3 FLEXIBILITY

During the system design stage, a highly flexible analysis program is needed by means of which the user can interface with the computer to predict interferences, to identify deficiencies, and to make tradeoff decisions.

An *analysis program* is envisioned which is comprised essentially of a loosely connected library of subprograms or routines programmed on any large-scale digital computer accessible from a time-share terminal. The subprogram I/O formats would be designed so that the output of one program is acceptable as input to another, thus allowing the user to select the appropriate subprograms to build an overall computer program to handle end-to-end mutual interference problems.

Additionally, the subprograms could be utilized as stand-alone models to allow the user to isolate any particular aspect of a larger problem. The flexibility and time savings afforded by this approach make it particularly useful in parametric studies; that is, observing the reaction of a selected parameter as a function of controlled changes in one or more variables, with the remaining variables held fixed. For example, the program would be easily configured by the user to perform analyses of the type accomplished in the TRED studies of hf communications.

A *performance prediction program* is required mainly for the final system evaluation. It is not necessary that it be interactive, but it may have various input-output options.

8.4 DATA BASE

The data base of the proposed computer programs can be obtained from those of the existing computer programs such as SEMCA, IPM, and COSAM and that of TRED. However, the accuracy of the data is important, and the data need validation. The validation of the data should be determined by other continuing efforts.

8.5 NOISES AND INTERFERENCES

Topside-generated intermodulations (rusty bolt) and passive device generated intermodulations are two very important sources of interferences. Unfortunately, the state of the art does not permit the simulation of these two effects on a digital computer satisfactorily.

Empirical investigations currently carried out at NELC will give insight to the problem of intermodulations, including passive device generated intermodulations, transmitter intermodulations, and receiver intermodulations. The results were scheduled to be reported at the end of the 1976 transition quarter.

ECAC is addressing the shipboard man-made noise problem during the 1976 transition quarter. A decision concerning whether the man-made noise should be included in the analysis program will be made at the end of the ECAC effort.

For the analysis of the aircraft EMC, IEMCAP treats the interferences which are the results of cable-to-cable coupling and equipment case-to-case coupling. However, at the present time, it is assumed that these interferences will not be significant in the case for the shipboard EMC analysis.

8.6 INTERFERENCE THRESHOLD CRITERIA

Since no detailed receiver modeling is necessary for a system interaction analysis program which is used during the system design stage, an interference threshold criterion should be set at the input to the receiver. A threshold criterion which is related to receiver sensitivity should be used.

However, for the system performance evaluation, interference threshold criteria may be set at the detector output or input. The threshold criteria depend on the modulation types of the desired signal and the undesired signals. This enables system performance to be expressed in terms of articulation index or bit error rate.

In order to predict system performance, SEMCA and TRED consider the power level of each interference type separately; COSAM adds the power level of various interference types; IPM and IEMCAP use the power spectra density curve and calculate the interference power for a specified frequency range.

Although the calculation of the interference power by the integration of the power spectral density function over a specified frequency range is mathematically sound, it does not identify the type of interferences. During the system design stage the design engineer needs this information. With the interferences identified, he is able to eliminate deficiencies or to make tradeoff decisions.

As to the calculation of signal-to-interference-plus-noise ratio in dB, the sum of various interference power levels can usually be approximated by the largest interference power level. Thus, in practice, the approach of considering each interference separately is preferred. Additionally, the approach will be more rapid and cost-effective.

8.7 ATTENUATION MODELING AND ANTENNA COUPLING

Some of the antenna-to-antenna coupling algorithms used in SEMCA, IPM, and COSAM are not adequate. Antenna modeling algorithms developed under Task I and Task II of the ITEMA project can be run off-line. These state-of-the-art antenna modeling techniques consider the interactions among various antennas and many different obstacles and objects of various geometrical shapes and sizes which exist aboard ships. The results of these newly developed antenna modeling algorithms will be used as the input data to the proposed system interaction analysis program.

The attenuation modeling needs further study. It includes the selectivity of filter devices, mismatched losses, insertion losses, and the effects of cable lengths.

It is common practice to publish selectivity characteristics of filter devices of the receive system with data measured with both generator and load impedance of 50 ohms at all frequencies. However, in the receive system the 50-ohm impedance is provided at the desired signal or receive frequency, not at the direct threat frequency (ie, transmitter frequency). In fact, the protection against the threat is derived from the departure of impedance at the transmit frequency from 50 ohms. Therefore, in the receive system, source and load impedances of the various equipments ahead of the receiver are not 50 ohms at a direct threat frequency. The actual degree of protection against the direct threat can be significantly greater or less than the published values. Similarly, when indirect threats are considered, the actual selectivity characteristic of the filter devices of the transmit system can be significantly different from the published values.

When a standard spectrum signature is measured (eg, MIL-STD-449D/spectrum signature), it is made with the transmitter feeding rated fundamental frequency output power into a 50-ohm dummy load. Since the transmitter source impedance varies with departure from the fundamental frequency, such measurements are accurate only as an indication of power delivered to a 50-ohm load. At frequencies far removed from the fundamental frequency, such as harmonics, the mismatch between source and load impedance is very significant. In fact, the transmitting system will not provide a 50-ohm load to the transmitter at all frequencies. The magnitude of the mismatch is a function of cable length. In many cases the cable lengths are not expected to be known precisely.

8.8 PRINTOUTS

The printouts of the system interaction analysis program should predict interference power levels at the input to the receiver and the preliminary system performance.

The printouts of the system performance evaluation program should predict the final system performance in terms of articulation index or bit error rate.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The existing electromagnetic system interaction computer programs — namely, SEMCA, IPM, and COSAM — are suitable for the interference prediction of a final system design. Their main features and limitations are summarized in tables 7-8, 7-9, and 7-11, respectively.

TRED is a manual design procedure for the design of shipboard communication systems. Its main features and limitations are summarized in table 7-10.

9.2 RECOMMENDATIONS

A rapid and cost-effective system interaction analysis program is needed during the design stage of shipboard communication systems. A program is envisioned which has the following features:

1. The program is rapid and cost-effective.
2. The program is based on the design philosophy used by TRED.
3. The program uses a deterministic approach and does not need detailed receiver modeling.
4. The program is user-computer interactive and accessible from a time-share terminal of a main-frame digital computer.
5. The data base of the program can be obtained from those of the existing computer programs such as SEMCA, IPM, COSAM, and that of TRED. The data need validation.
6. The program considers all important noises and interferences which can be simulated satisfactorily on a digital computer.
7. The program sets the interference threshold criteria at the input to the receiver. The interference threshold criteria are related to the receiver internal noise.
8. State-of-the-art attenuation modeling and antenna coupling algorithms should be used. The algorithms may be run off-line, if necessary.
9. The printouts of the program should indicate any possible deficiencies of the system and predict interference power levels at the input to the receiver.

When an acceptable preliminary system design is achieved, the outputs of the program can be used as a part of the input data to a system performance evaluation program. The system performance evaluation program will require a statistical approach and detailed receiver modeling. System performance can be expressed in terms of articulation index or bit error rate.

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