COMPUTER AIDED EMC ANALYSIS FOR ELECTRONIC SYSTEMS

INTRODUCTION

The development of energy transfer functions, circuit models and modeling techniques, and computer programs has created an advancement in the basic approach of performing the electromagnetic compatibility (EMC) function during system acquisition. Large-scale computer programs, together with the related modeling activity, permit any electronic system—from aircraft to hospital electronic suites—to be meaningfully analyzed in the developmental stages such that project-specific requirements can be generated for the system's EMC performance characteristics in a timely manner.

Since this analytic approach is now being included in selected Air Force procurements, contractors may soon have to develop their capability to incorporate computer aided analysis techniques within their existing EMC engineering activity. Benefits in cost, design flexibility, and quantification of system compatibility margins can be achieved which, heretofore, had not been practical. The results of computer analyses on several complex systems have been verified by, for instance, TRW, comparing predicted compatibility with measured results on integrated systems. The predictions fall within the end-to-end accuracy goal of ±10 DB, with only approximately 1% of the cases being underpredicted.

The development of the system approach to achieving EMC; applications of EMC computer aided analysis to a large system acquisition; basic analysis methods and recommendations for acquiring or improving analysis capability are discussed below.

APPROACHES TO INTRASYSTEM EMC

The approaches applied to achieve intrasystem EMC fall into three general categories: the problem-solving approach, the specification approach and the systems approach. The problem-solving approach is a high-risk approach which involves minimum attention to EMC requirements and instead relies upon fixing any incompatibilities which arise during integration and checkout. The "fixes" usually wind up being costly and less than satisfactory, since the effectiveness of the system is often reduced.

The specification approach is one which relies on compliance to a sub-system EMI specification, e.g. MIL-STD-461. By meeting the majority of requirements of this specification, compatible operation is more likely than with the problem approach, since interference levels have been reduced across the spectrum and equipment susceptibilities are decreased respectively.

The trend toward the system approach is demonstrated by current Air Force studies to develop an intrasystem analysis program. The Air Force is encouraging the use of this approach in recent and upcoming major system RFP's, relying on existing computer programs to serve in an interim capacity until the final program is developed. One of these interim programs, SEMCAP*, will be used to illustrate the manner in which the computer program guides and supports the EMC activity on a major system project. This program is a tool for the EMC engineer and also provides management with continual visibility of the EMC status of the system.

GETTING STARTED

The utilization of large-scale computers in a total systems approach requires a skilled engineering effort. Approximately 10 man-months of effort can be associated with an initial analysis on a large system and less than $1,000.00 of computer time. Subsequent analyses and updates require less effort. The primary engineering effort is associated with modelin the system. This requires EMC engineers who have been trained in the system modeling task. It is possible that companies which typically maintain a large EMC staff and deal with design as well as test will elect to train and establish their own analysis capability. Others may choose to use the services of an outside organization specializing in EMC computer analysis to supplement their capability. While standardization of computer programs for this effort is off in the future, the application of this approach to existing and near-term programs is already upon us.

Training

Training EMC engineers to use the computer programs is best established with a brief classroom program which combines indoctrination into fundamental concepts coupled with an on-the-job course preferably applied to an on-going project. In this manner, skills are transferred gradually with trainers and trainees comprising an analysis team working real problems.

Timeshare systems

Timeshare programs are an excellent means of introducing computer analysis methods to a prospective large scale program user, or to provide small companies or consultants with an otherwise unobtainable analysis capability. The timeshare programs enable the user to use outside computer facilities at a minimum cost with his only investment being the purchase or rental of a remote terminal which uses normal telephone lines to communicate with the outside computer. The timeshare systems typically will solve individual analysis problems associated with the EMC activities on a project. They are particularly useful in calculating coupling between elements of a system, greatly expanding the technical capabilities of the EMC engineer. They cannot, however, handle the overall system problem possible in the batch processing mode where many interference sources are transferred and summed in a receptor. In addition to inserting data into existing programs, the timeshare system also permits the engineer to program his own problems using a straight-forward, easily-learned computer language such as BASIC.

COMPUTER ANALYSIS AND SYSTEM MODELING

Philosophical concept

In any electronic system there are two general sources of electromagnetic energy: that which results from the passage of functional information-bearing signals (referred to herein as "functional energy"); and energy which serves no useful purpose and whose absence would improve, or at least not harm, the system's operation (referred to herein as "extraneous energy"). The term energy if used here loosely, and is meant only to denote the presence of some form of work-producing entitv

To assure intrasystem compatibility, it is desirable to take into account *all* of the effects of the electromagnetic environment on *all* possible responding entities within the system.

Computer Program

This computer program performs an EMC analysis between modeled generation circuits and modeled receptor circuits for various means of interference transfer. The circuits to be modeled as interference generators are analyzed to determine those parameters to be inserted into the computer generator model bank. This model bank contains a number of generator types. The parameters are inserted for the generator circuits, the transfer functions, and the receptor circuits. The computer calculates the spectrum of the generator circuits and transfers the energy via the applicable transfer functions to the receptor terminals.

The received spectrum is limited by the receptor bandwidth and integrated over the complete frequency range from 10 Hz to 100 GHz. The integral then represents the voltage available at the receptor terminals. This received voltage is compared to the threshold of the particular circuits to determine compatibility status. In addition, the computer stores the voltage received from a particular generator and proceeds through the complete generator list until the contribution of each generator is determined. These contributions are summed to determine if the receptor is compatible with the sum of all generating sources modeled.

*SEMCAP - Specification and Electromagnetic Compatibility Analysis Program developed by TRW Systems

System Model

The computer program utilizes transfer functions that describe the voltage received at the receptor terminals in terms of the generator interference output. These outputs are individually described by E-field, H-field, current, and voltage of the source. Figure 1 represents the system model used by the computer. A generator terminal feeds wiring, and interference is transferred via capacitive coupling (i.e., voltage coupling, C) and mutual inductance (i.e., inductive coupling, I), and common impedance coupling, A. In addition, the electric and magnetic fields generated by the generator wiring and antenna (if an antenna exists) are coupled into the receptor wiring by electric and magnetic fields. If the receptor contains an antenna, the generator and receptor antennas are coupled along with the generator wire and receptor antenna. The coupling path, from the generator antenna to the receptor wiring and from the generator wiring to a receptor antenna includes the attenuation caused by the passage of these fields through the skin of the vehicle. The computer program processes the interference transferred and bandwidth limited for each of the transfer paths of each generator modeled and compares the preprogrammed threshold level to the sum of the interference received from all generating sources.

As subsystem test data becomes available, it is placed into the computer program and replaces the assumed extraneous levels previously defined by the subsystem specification limits. Subsystem test data which exceeds the applicable limits may undergo waiver analysis since the impact of granting the waiver on the system can be readily determined. If the particular subsystem requesting the waiver does produce a problem in the system, it may still be possible to grant a waiver and modify the design elsewhere, depending upon the economics involved.

The final computer runs comprise the intrasystem EMC signature and are maintained on file for future utilization in configuration changes or definition of new subsystem requirements.

EMC activities during system modification

In the case where the new equipment is available off-the-shelf, the procedure would be to model the new system and interface it with the existing file in the location and geometric layout which is being proposed. Compatibility problems would then be determined by the computer and the solutions inferred through examination of the printout and determination of the coupling mechanisms. In the event of a problem, the solution might possibly be to modify the location or the integration design.

In the case where the new subsystem is to be developed, it would be possible to extract the tactical aircraft "Intrasystem EMC Signature File" and develop the requirements for the proposed new system. These requirements would, of course, be those required to achieve compatibility upon integration.

EMC MANAGEMENT IN A MAJOR WEAPON SYSTEM ACQUISITION

Conceptual Phase EMC ACTIVITY

Organized EMC activity during the conceptual phase of a large program is often quite limited. The application of the system approach in this phase, on the other hand, can permit design tradeoffs that could affect the design configuration of the system. When questions arise, the data from prior system acquisitions which have employed a system approach, can be surveyed to determine the EMC characteristics of similar systems. Additionally, the required subsystem types can be collected to synthesize a similar system. In the conceptual phase of a scientific or reconnaissance spacecraft, for instance, it could be of interest to determine what the total electromagnetic environment might be at a certain point from the spacecraft to determine the possible location of sensitive experiments or receivers, which in turn could affect the physical configuration of the spacecraft.

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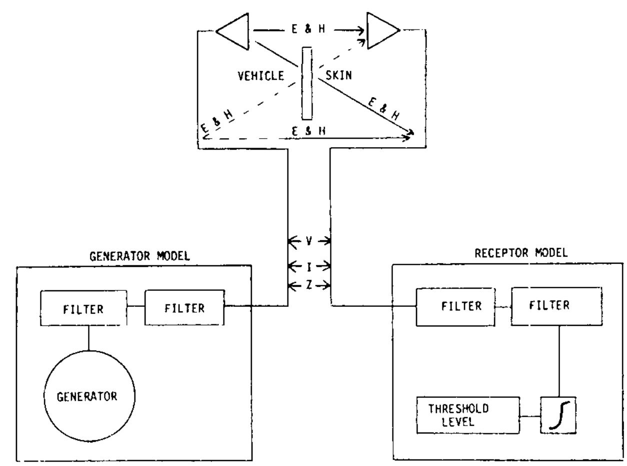

Figure 1: General System Model

Definition Phase EMC activity

The above tradeoff activities will also continue during the definition phase or may not even be initiated until then, depending upon the system being procured. During the definition phase, the technological advances resulting from the conceptual phase are translated into detailed system and element performance and design requirements. This phase is primarily concerned with identifying cost, schedule and performance objectives, and the EMC activities that take place include:

- A continuation of the design tradeoff process.
- A total interaction with the system design.
- The definition of the required system EMC critical circuit margins.
- The development of the subsystem/equipment EMC specifications including limits.
- The preparation of a detailed EMC Program Plan.
- The preparation of a preliminary system EMC Technical Control Plan.
- The preparation of a preliminary EMC Test Plan.

Utilization of the computer program by an integrating contractor permits considerable interaction with the design process. This is an extremely attractive feature in that it allows departure from standard EMC design practice and permits considerably more flexibility. The preliminary EMC design criteria are used as a baseline and modified through interaction with the system design utilizing the compatibility analysis routine. As a design progresses, more functional information is available and the analyses that are performed are consequently more definitive. Subsystem/equipment specification limits can be generated at any point in time for purposes of tailoring the applicable, military standard. However, this activity generally is performed after the design appears to be reasonably firm.

Acquisition Phase EMC activity

The fundamental purpose of the acquisition phase is to acquire and test the system elements required to satisfy the system specification. The EMC activities during this design and development phase consist of:

- Continued analysis activity required to support the system design.
- The finalization of the EMC system test plan.
- System and subsystem design review.
- The review of subsystem test programs and waiver processing.
- The update of system compatibility analysis using subsystem test data.
- Definition of critical circuit margins.
- System verification test.

The primary procuring agency management roles involving EMC which take place during this phase are the design reviews, waiver processing, system test planning review, and monitoring of system EMC verification. With the computer program, it becomes a simple matter to perform a compatibility analysis run at any point in time during the program. The results of the analysis are, as a minimum, made available prior to preliminary and critical design reviews.

Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP)*

IEMCAP is a link between equipment and subsystem EMC performance and total system EMC characteristics. It provides the means for tailoring EMC requirements to the specific system, whether it be ground based, airborne, or a space/missile system. This is accomplished in IEMCAP by detailed modeling of the system elements and the various mechanisms of electromagnetic transfer among them to perform the following tasks:

- Provide a data base which can be continually maintained and updated to follow system design changes.
- Generate EMC specification limits tailored to the specific system.
- Evaluate the impact of granting waivers to the tailored specifications.
- Survey a system for incompatibilities.
- Assess the effect of design changes on system EMC.
- Provide comparative analysis results on which to base EMC trade-off decisions.

The system model for IEMCAP employs the standard EMC approach of identifying all ports in the system having potential for undesired signal coupling. These ports are divided into arrays of emitter ports and of receptor ports having identifiable coupling paths. A simplified diagram of this approach is given in Figure 2 where each element of an array of N_s emitters is considered to have a coupling path to one or more elements of an array of I_R receptors. In this simplified diagram only three coupling paths are shown, illustrating the general idea that more than one emitter can couple to a given receptor and further illustrating that a given emitter can couple to more than one receptor.

All emitters in a system are characterized by emission spectra and all receptors are characterized by susceptibility spectra. All ports and coupling media are asumed to have linear characteristics. Emissions from the various emitter ports are assumed to be statistically independent so that signals from several emitters impinging at a receptor port combine on an RMS or power basis.

IEMCAP determines, by analysis, whether signals from one or more emitters entering a receptor port cause interference with the required operation of that receptor. Electromagnetic interference (EMC) is assessed in the program by computation of an "EMI Margin" for each receptor port. This EMI Margin is just the ratio of power received at a receptor port to that receptor's susceptibility. Actually, the program computes the margin in decibels; the more positive the number in decibels the greater is the potential for interference.

The program performs the interference analyses by exercising various programmed formulas corresponding to mathematical models of emitters, of receptors, of the signal transfer mechanisms between emitters and receptors and of the system. IEMCAP is divided into two sections and the flow through them is illustrated in Figure 3.

Early in the development of the IEMCAP system approach, it was concluded that the program could not be designed to be a substitute for the strategies of the competent EMC engineer for all system situations and still achieve the cost-saving objectives that prompted its development. The program was accordingly designed to maximize the benefits obtainable from computerized specification generation on new systems and equipments whose flow is shown in Figure 4. As shown, the strategy employed by the engineer for this new system using IEMCAP is to initially relax the non-required spectrum requirements of the baseline MIL-STD-461 by a considerable amount in the program input. Then he performs a computer run to see how the system holds up under these "noisy" conditions. Interference occurring in this initial run will cause automatic adjustments, resulting in a set of interference limits that, hopefully, are an improvement over the stringent MIL-SPEC requirements. Instances of large interference will be evident in the program output and these are then amenable to the application of engineering judgement in their treatment during the next run through the program.

To successfully implement this program the EMC engineer must work closely with, and have the confidence of the project systems engineers. If the EMC engineer just runs IEMCAP and gives the final adjusted specification numbers to the design groups, generally, the specifications will not be optimum for cost.

* IEMCAP was developed for the Air Force by McDonnell Aircraft Company (MCAIR) under Contract Number F30602-72-C-0277.

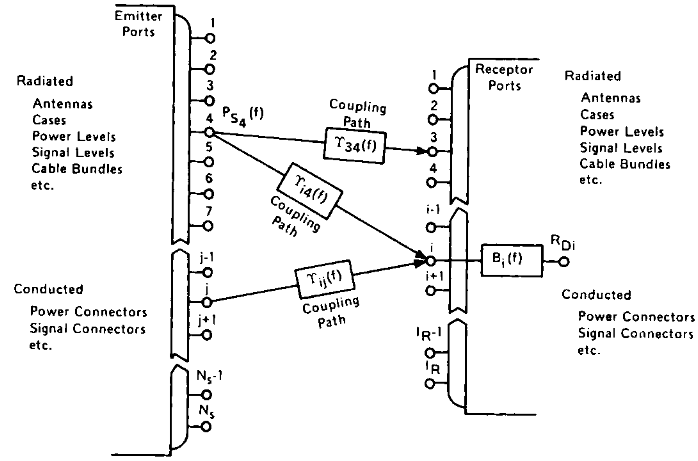

Figure 2
System Approach Identifies Arrays of Emitter and Receptor Ports with Coupling Paths

The system design engineer must be involved in the trade-offs made during specification generation. For example, it may be easier to adjust a receptor than an emitter, to increase the transfer loss by moving a wire from one bundle to another, to add a discrimination capability to software, to add blanking, to reassign frequencies, to "live" with the EMI, etc.

The basis for all calculations performed by each of the functions of IEMCAP is the linear relationship for power coupled from an emitter, through a transfer medium, and received by a receptor. The general communication theory equation relating power spectral density at the detector of a receptor to power spectral density present at an emitter's output port is expressed as follows:

$$\text{o.p.s.d.} = \eta_{Sj}(f)\ T_{ij}(f)\ \beta_i(f)$$

where

o.p.s.d. =output power spectral density (in watts/Hz) received by receptor i (at its detector) from emitter j,

$\eta_{Sj}(f)$ =output power spectral density (in watts/Hz) at the terminals of source j (including cw power as delta functions),

$T_{ij}(f)$ =power transfer function of the coupling medium between source j and receptor i,

$\beta_i(f)$ =receptor response function relating power at the detector to power at the input terminals.

IEMCAP calculates an integrated EMI margin which is an overall figure of merit representing the ratio of the power received by the receptor to susceptibility over the entire frequency range. The program computes the margin per bandwidth at all spectrum sample frequencies (both emitter and receptor). For broadband emissions, the received signal is the power contained in one receptor bandwidth. This level is compared to the power required to produce a response in the receptor at the sample frequency. This ratio per bandwidth is integrated over the range of frequencies to obtain the broadband component of the integrated margin.

For narrowband emissions, the power received is independent of the receptor bandwidth, and the integral becomes a summation. The narrowband signal can be represented by one dalta function in the center of the receptor bandwidth. The narrowband spectra are limits in that no single delta function can exceed the specified level. If a measuring instrument is connected to this port and tuned across the band, the program assumes that the instrument reads exactly this specification level everywhere. This is equivalent to having one delta function per instrument bandwidth across the band with amplitudes at the spectrum level. These narrowband levels are assumed to vary linearly from sample point to sample point for the summation. The integrated margin is the sum of the broadband and narrowband components.

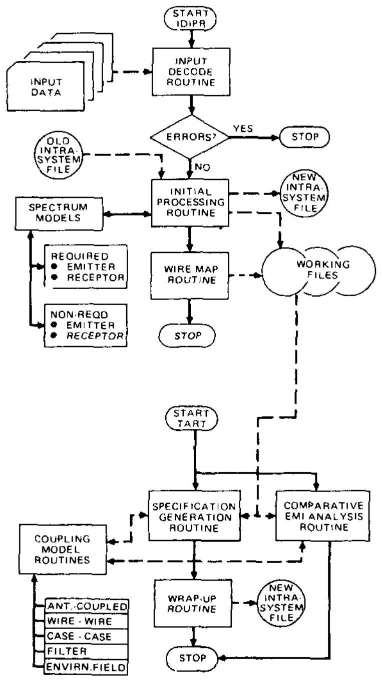

Figure 3
IEMCAP Functional Flow

The integrated EMI margin provides the interactive mechanism by which the engineer is enabled to optimize the program EMI specification limits. The engineer will probably exercise the program two or more times in an effort to optimize safety margins and adjustment limits toward values that drive the integrated margin figures for the system receptors toward values that are optimum in the sense that spectra are neither too stringently controlled nor too relaxed. This interactive approach is desirable in the interest of maximizing system economy and conserving system weight as these are influenced by EMI controls.

To illustrate the interactive approach, it will be supposed that the integrated margin for some receptor is a rather large positive number in dB. The engineer will accordingly want to apply corrections to his input data to drive this number, on the next pass through the program, to some moderately negative value in dB. This could be accomplished by applying corrections to all spectra, i.e., increasing the safety margin. However, the greatest economy should result if the corrections are limited to only those particularly offensive interferers or especially susceptible receptors. These are identifiable in the program printout of the interval-by-interval EMI margins. The engineer can thus decide upon selective corrections to be made aimed at curing the actual offenders without penalizing (over-specifying) the remaining portions of spectra. A specific example of such a selective corrective measure would be a decision to shield a wire or, possibly, to relocate a wire.

It is clear from the discussion thus far that a "good" integrated margin is probably one whose value in dB is moderately negative. Neither large negative numbers nor large positive numbers are desirable since these represent, respectively, excessive (therefore uneconomical) interference control and unacceptably high interference. It should be understood that a moderately positive integrated margin may sometimes be unavoidable; a particular situation might involve unresolved interference from required signals or spectra adjusted to their practical limit that will either have to be lived with or else will require other control measures, such as blanking, to remove the interference.

Individuals interested in obtaining more information on IEMCAP should contact: Mr. James C. Brodock, Rome Air Development Center, RBCT, Griffiss AFB, N.Y. 13441, Phone: (315) 330-3490.

This information was provided by William G. Duf of Atlantic Research Corporation. Much of the material was obtained from Intrasystem Electromagnetic Compatibility Analysis Program, prepared by J. L. Bogdanor, M. D. Siegel, et. al., McDonnell Aircraft Corporation.

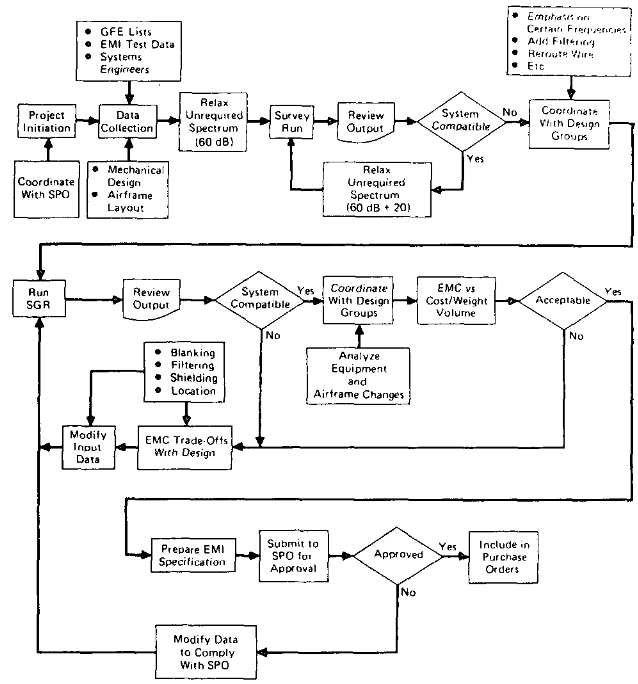

Figure 4
IEMCAP Typical Task Flow
(Initial Specification Generation)

EMC DESIGN SYNTHESIS USING PROGRAMMABLE CALCULATORS AND MINICOMPUTERS

SUMMARY

Computer-Aided EMC programs today are oriented toward prediction and/or analysis. This applies from the small HP-65 and SR-52 calculator programs to the very large Air Force computer programs. Many EMC programs are slanted toward computing S/(N+I) ratios or equivalent output given the input data. In some instances, *default data* are used when user inputed information is missing. The programs may have some design value by trying out many combinations of selected input trial designs and recomputing S/(N+I) ratios for each. In this case, the user could select the desired design corresponding to the greatest S/(N+I) ratio or a target I/N ratio. The practical aspects of design, however, would be severely limited, since the number of practical user trial designs is limited. Furthermore, the user may not even know how to select a reasonable combination of sub-system grounding, cabling, shielding, filtering, etc.

A design synthesis approach, on the other hand, outputs one or more good (not necessarily the best) sub-system designs. Called SEMCD* it does not require, for example, that a user know the performance merits of a twisted-shielded pair over a triax, or how each shield should be grounded. This, the SEMCD design synthesis program selects quantitatively by internally computing S/(N+I) ratios corresponding to a number of good options. In essence, the sequential selection process of the internal option SEMCD programs represents the *picked brains* of EMC system engineers. The value of the computer math models and prediction and analysis techniques then is relegated to supportive internal quantitative computations. The user must still input a number of variables such as cable impedances; circuit sensitivities, cut-off frequencies, and skirt slope; length of harnesses between boxes; electromagnetic ambients; etc. In case he does not know some inputs, a number of default situations will be either used or computed. In all cases an absolute and relative listing of good trial designs are displayed or printed out.

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*SEMCD = Synthesis of EMC Design (DWCI)

Some believe that the above SEMCD approach to equipment and subsystem level design constitutes the first hard design systhesis to EMC problems It tends to prevent EMC under or over design. It clearly eliminates such myths as (1) cable shields should be multi-point grounded; (2) shields are not effective unless their thickness is at least one skin depth (preferably 4.6) at the lowest frequency of use; (3) low-frequency coupling is by magnetic (inductive) means and high-frequency coupling is by electric (capacitive) means; etc. The first of these new SEMCD design synthesis programs has been prepared on a Wang-2200 and modified for use on a small computer using BASIC language which may be either owned or time-shared by the designer.

PHILOSOPHY OF DESIGN SYNTHESIS

Design synthesis may be thought of as playing or running a SEMCAP, IEMCAP or other EMC related program backwards or in reverse. EMC design synthesis requires that the functional parts and electromagnetic ambient conditions be inputted by the user and the output will portray one or more optional solutions to circuit and box grounding, cable type, shield use, filter configurations, etc. The concept is best illustrated in the rather simplified executive block diagram shown in Figure 1.

The user inputs multi-box functional, non-EMC, design data (see box #), such as in-band recepter sensitivities, cutoff frequencies, inter-box cable lengths; circuit impedances; vehicle skin thickness; etc.; and EMC design constraints such as grounding condition of both box and internal circuit boards. The user also inputs EM ambients (box #2) such as internal E and/or H fields near box cables; frequencies, bandwidths and distances of all intentional radiator locations outside the sub-system or vehicle skin.

Given the above, unless the user otherwise also inputs, the computer then supplies *non-functional* EMC design data (box #3) for the receptors such as minimum out-of-band rejections and spurious response levels. The computer also selects the simplest inexpensive EMC designs for missing data (box #4). such as adjacent parallel untwisted, unshielded wire pairs, and grounded boxes. These data are starting data and may not be EMC effective. The computer also supplies missing EM ambients (box #5) as default data based on MIL-STD-461A or other selected vehicle/environment types.

From the above, the computer calculates the resulting S/(N+I) ratio (box #6) at each receptor from all input EM ambients. For those receptors having inadequate S/(N+I) ratios (box #9 and no decision, diamond #7), the computer selects one or more EMC hardening elements or techniques (box #8) in accordance with the logic and sequencing of the selection process. Here is where the *picked brains* of the EMC engineer have been defined. For example, twisted-wire pair is selected over braided coax provided functional information is below 10 MHz where the VSWR of twisted wire is satisfactory. Another example is to use cable shields as *spare tires* only. Where a conflict in design at both ends of a cable exists, either the tighter requirement will be imposed or an isolator or absorbing ferrite material is selected in accordance with the sequencing process.

After selecting each EMC hardening element or technique (box #8), the new S/(N+I) is computed (box #6) until a *yes* decision is reached (diamond #7). Because there usually exists more than one adequate EMC design combination, the program is cycled (diamond #10 and box #11) to synthesize a second and third such combination. The final EMC design conditions are displayed on a CRT or printed out (box #12) in either decending order of S/(N+I) ratios or preferred mixes of EMC components and techniques.

DESIGN CONFIGURATION LAYOUT

The design configuration to be synthesized in SEMCD is shown in Figure 2 for a two-box sub-system or equipment. The figure also identifies the coded input data and coded synthesized output conditions. The codes and their meaning have been deleted from this article because of space limitations.

CONCLUSIONS

The first of a long new series of design synthesis programs in BASIC language known as SEMCD, has been prepared by DWCI which permit quantitative design using criteria and math models for coupling, grounding, shielding, cabling, isolators, absorbers, and filters. The programs are prepared for running on minicomputers or time-share terminals. Less complex versions are available for the HP-9815A, HP-9830, and Wang 2200 desk top calculators. The purpose of these programs is to facilitate EMC design to minimize both under and overdesign, and to eliminate myths and rules of thumb in EMC design.

Admittedly, the above SEMCD programs are in an embrionic stage as of the end of 1975 since little EMC precedent for them exists. They are presently limited to the multi-box design of equipments and sub-system levels. In time, both the number and complexity of the SEMCD programs will be increased. At the present time and at the risk of generalizing, however, their cost is less than one per cent of the much larger computer analysis and system modeling programs in use. And, most importantly, the above SEMCD programs permit EMC design synthesis to which the much larger programs are not particularly responsive. Thus, the future should augur well for this new EMC approach.

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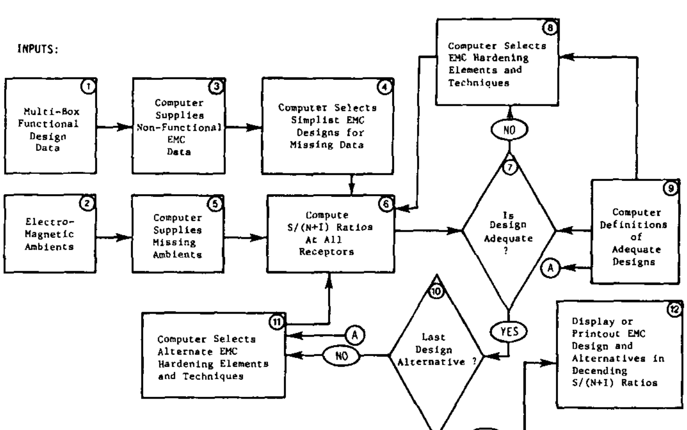

Figure 1 - Simplified Philosophy of EMC Design Synthesis in SEMCD

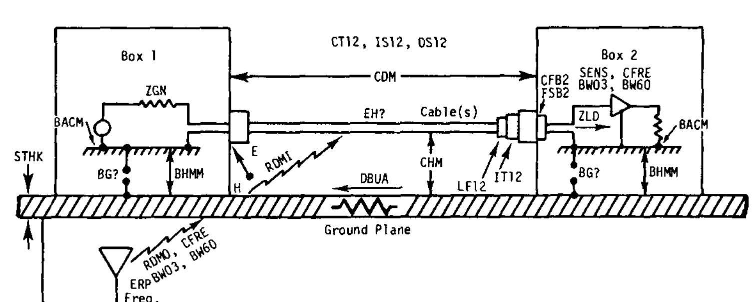

Figure 2 - SEMCD Two-Box Equipment/ Sub-System EMC Design Synthesis Configuration