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-461A. 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. A major factor in this appoach is reliance upon "good EMC engineering practices" which have worked for that particular contractor on previous programs. This approach, while of less risk than the problem approach, can be very costly and affords little visibility into system performance prior to system test.

The system approach is much more cost-effective in that concentration is on the achievement of intrasystem EMC while optimizing the engineering program and requirements accordingly. This approach represents the current trend and the one which could be standardized eventually in all procurements.

However, analysis of the complex electromagnetic interactions in a large system is difficult without the use of computers. Many EMC organizations which advocate the system approach rely upon existing DoD EMC specifications and modify them to the extent that their depth of analysis permits. The resultant approach lies somewhere between the specification approach and the system approach. This approach often works, but with a high degree of risk and additional cost. The system approach should be a fully integrated, computer-aided approach which follows the system acquisition process from the outset, enabling EMC to interact with the design in a quantitative manner and which can generate subsystem EMC requirements unique to the system being procured.

The trend toward the system approach is demonstrated by current Air Force studies to develop an intrasystem analysis program, due to be completed in 1974. In the interim, 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.

The computer program provides for the following:

- EMC analysis during system acquisition and operation.
- Tailoring of specifications (e.g., MIL-STD-461) to system performance criteria.
- Analysis of waivers requests based on equipment test data.
- System critical test point selection.
- Tracking of the intrasystem electromagnetic environment.
- Analysis of external electromagnetic effects.

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. At first glance, it might appear unwise to develop a capability prior to standardization. However, the following factors should be considered:

- While it is true that each computer program will have its idiosyncrasies, the fundamental approach will be similar and will require EMC engineers trained in reducing complex systems into meaningful circuit models.
- Standardization on a specific computer program is unlikely; rather, the performance standards for the computer program will be established allowing flexibility in the computer software.
- The benefits to companies following the system approach are considerable in terms of maintaining competitive posture, cost-effectiveness and related technical and management flexibility at reduced risk.

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.

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*Specification and ElectroMagnetic Compatibility Analysis Program

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 entity.

Functional energy can be modeled, since a data base for such a description exists in the form of specification requirements, proposal inputs, system performance documents, design review data packages (containing descriptions of the signals, wiring geometry, wiring types, impedances, response thresholds, bandwidths, etc.), and unit and subsystem test reports. Extraneous energy is usually not modeled, since it is due to secondary, non-design effects, and the data needed to characterize this energy generally does not become available until the start of hardware development. It is, therefore, necessary to control the extraneous environment to a level that is acceptable to all responding devices or circuits, and to control the response of a system to the existing total electromagnetic environment. This approach offers closed-loop EMI intrasystem control of that energy, and the response to that energy is either accounted for via modeling (functional energy and response), or by specification limits generated by the computer and imposed upon extraneous emitters and receptors.

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.

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. This kind of flexibility is an advancement over previous approaches in which waivers were granted largely upon the basis of cost and schedule impact since it was difficult to assess the impact upon compatibility. As the computer program prints out the compatibility margins for each modeled receptor, it is a simple matter to identify those receptors which should be a part of the system test due to their marginal characteristics. Even the earliest test plan can therefore be relatively specific in defining test points and as subsequent runs are made, the test points can be culled to the minimum required for system test. The cost of a system test is minimized since fewer circuits require monitoring.

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

It is not uncommon for a large weapon system to remain in the inventory for as long as a decade or more. In such cases, the configuration of the system often undergoes many changes. For instance the basic mission of a tactical aircraft might be changed from a tactical to reconnaissance mission whereby the basic avionics would be supplemented with reconnaissance equipment.

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.

Quick reaction capability is considerably enhanced through the application of the file, in that it is possible to assess many alternate configurations of equipment prior to the time that the equipment is actually integrated, and in an extremely short time.

EMC MANAGEMENT IN A MAJOR WEAPON SYSTEM ACQUISITION

Conceptual Phase EMC ACTIVITY

Organized EMC ac tivity 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

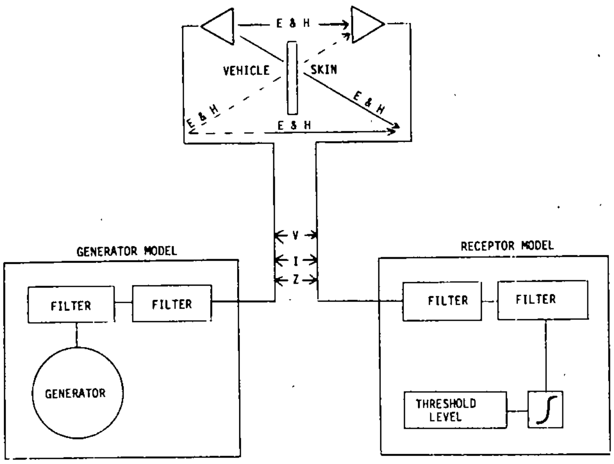

Figure 1: General System Model

location of sensitive experiments or receivers, which in turn could affect the physical configuration of the spacecraft. Tradeoff studies concerning the selection of a power system type could be performed by modeling the interference characteristics of each type considered, and comparing these with the sensitivities of the payloads that are being proposed. While conceptual phase analyses are rather general, they still allow order of magnitude approximations to be made which are adequate to determine design impact.

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.

Figure 2 illustrates the interaction of EMC activities during a typical contract definition phase.

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.

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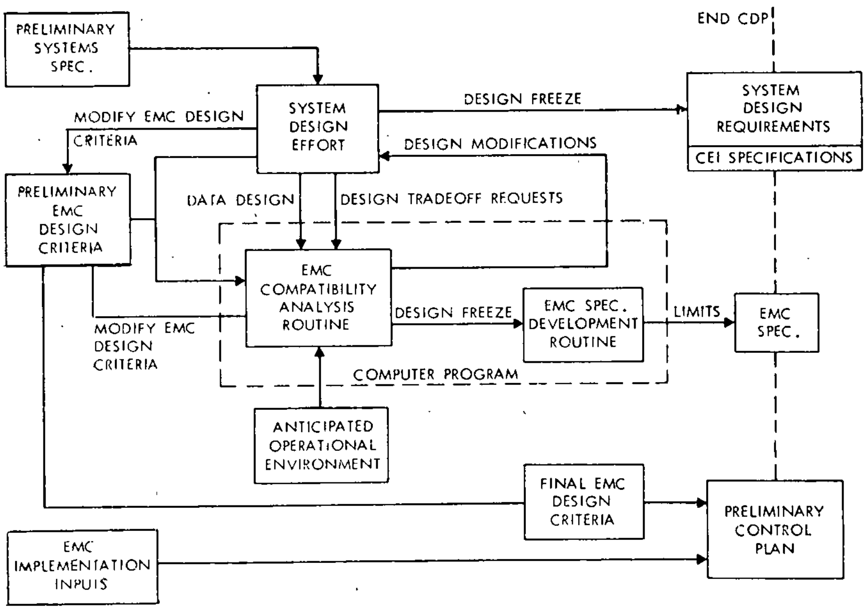

Figure 2: Definition Phase EMC Activity

PREDICTION, ANALYSIS, AND DESIGN CONTROL OF EMI USING HP-65 EMC MAGNETIC PROGRAM CARDS

There has been much ado in recent years about the use of computer aids in EMC analysis of electronic systems. Such capability seems to be further advanced for inter-system prediction and analysis than for intra-system. The former involves emission exit and entry antennas for both potential culprit transmitters and victim receivers. Intro-system prediction and analysis, on the other hand, usually involves either no antennas or antenna(s) for transmitters only. Thus, problems associated with cables and harnesses, grounding and bonding, ground-current loops, common-impedance coupling, shielding, filtering, and the like predominate for intra-system situations.

That computer aids have not seen wide use is understood when it is recognized that they have been geared to the big system or vehicle-level problem involving many emitters, receptors, and coupling paths. Thus, it is not uncommon for six or more months and $50,000 or more to be required before computer aids start yielding answers to the system-level problem. The use of time-share programs and terminals reduces both lead time and cost, but both are still significant. All this leaves the 98+% of the EMC community with little relief since their EMI problems are much less complex, and quick-reaction (response time is measured in hours or days) and small cost are paramount. Consequently, magnetic cards for the HP-65 hand-held computer/calculator, having EMI problem-solving capability, appear to be one solution. Don White Consultants, Inc. offers over 100 EMI problem-solving HP-65 cards for sale and the cards are also used in its national and international EMC training seminars.

COMPUTER & PROGRAM COST

At the time of this writing, the HP-65 computer is available from Hewlett Packard for $795 and from Olympic Sales of Los Angeles for about $698. As mentioned above, EMC magnetic cards are available from Don White Consultants, Inc. for $5 to $20 per card, depending on the program complexity. The magnetic cards have 100 programmable steps each and permit the use of 70 pre-wired functions (sin x, y^x logic decisions, etc.). As such, this is equivalent to more than 1,000 series steps in most minicomputers. Nine storage registers and four working registers support the programming and computations. Thus, the HP-65 is limited to small programs only.

SAMPLE PROGRAM

To illustrate the contents of each HP-65 EMC card set, consider card #1720 package, which covers the reduction in amplitude of a transient or pulse as it is processed through an amplifier or filter. This mathematical process is called "convolution" or complex-frequency multiplication and integration. The card set describes the process in terms of tutorial basics and fundamentals, provides one or more illustrative examples, gives the user keyboard strokes, and documents each step of the stored program.

The envelope of a transient or pulse in Fig. 1 in the time domain is shown in Fig. 2 as a pulse spectrum amplitude density distribution in the frequency domain:

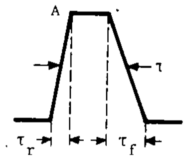

Fig. 1 Time Domain

When Fig. 2 is processed through a filter or amplifier, the resultant frequency domain situation shown in Fig. 3 exists.

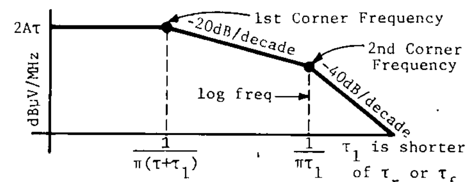

Fig. 2 Frequency Domain

As an example, compute the transient rejection offered by a Hi-Fi preamplifier having a cutoff frequency of 100 kHz and a skirt slope of 6 dB/octave. The amplifier sensitivity is 500 μV (54 dBμV and the transient amplitude coupled to its input line is 10 mV. The transient has a pulse width of 100 nsec and a pulse rise time of 10 nsec. Also what would be the effect if the amplifier skirt slope rolls off at 18 dB/octave.

After loading program card #1720, the user keys in: .01 Volts (STO 1), τ = .1 μsec (STO2), τ_1 = .01 μsec (STO3), f_{co} = .1 MHz (STO 5), and N = 1 (skirt dB/6) (STO 6). Keying user function "A" yields a transient reduction of 21 dB. Keying user function "B" results in a transient amplitude of 59 dBμV or 5 dB above amplifier sensitivity. Thus, a "click" may be heard. By rekeying N=3 (18 dB/octave) (STO6) and again keying "A", the transient level is reduced by 30 dB. Keying "B" shows a level of 50 dBμV or 4 dB below the amplifier sensitivity.

THE OUTLOOK FOR MICROCOMPUTER EMC PROGRAMS

The above example is but one of over 100 HP-65 program cards available from Don White Consultants. While more cards are developed each week, the question remains about the future or outlook of the HP-65 and what subsequent vintages may look like.

The packing density of present day microprocessor "chips" is about 20,000 components per chip. Doubling each year, it has been estimated that the packing density may level off at about 1,000,000 components per chip by about 1980. Thus, it would appear that 1976 versions of the HP-65 may approximate 1000 steps of stored programs and increased register capacity. Ten thousand-step programs in hand-held computers are likely by 1980. Consequently, as long as such microcomputers remain below $1,000, there seems little value to support most time-share programs and terminals except for very large programs. The value of the magnetic program card subroutines will endure since they represent basic math models of the physics and electronics.

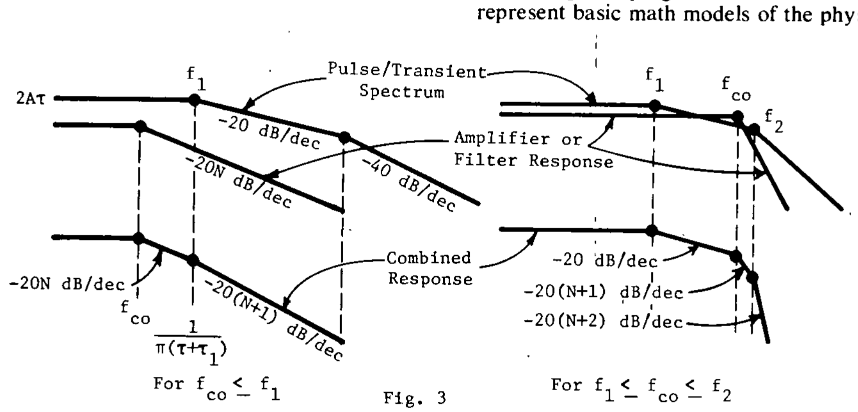

Fig. 3