COMPUTER AIDED EMC ANALYSIS FOR ELECTRONIC SYSTEMS

SEMCAP—VERSION 8

INTRODUCTION

SEMCAP (Specification and Electromagnetic Compatibility Analysis Program) is a large scale computer program for intrasystem EMC analysis, and has been in use since 1968, when it was developed as a spacecraft oriented intrasystem analysis program for NASA's Manned Space Center (later Johnson Space Center) in Houston, Texas. Numerous articles* have been written about the subject of intrasystem compatibility and about the original version of SEMCAP. Basically, this program performs an EMC analysis between modeled interference generators and modeled interference receptors for various interference transfer functions. The generators and receptors are modeled in terms of their electrical and physical parameters. The system's physical characteristics are also modeled so that transfer functions can be computed. The computer calculates the spectrum of the generator circuits and transfers the energy via the transfer function to the receptor terminals. The received spectrum is limited by the receptor bandwidth and integrated over the complete frequency range from 10 Hz to 10 GHz (or higher, at the user's option). 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. The purpose of this article is to acquaint the EMC community with the latest version of SEMCAP (Version 8), which has considerably more capabilities than earlier versions.

BACKGROUND

Through years of usage, many improvements and added capabilities have been incorporated into SEMCAP in order to make it more responsive to the needs of the user and to new engineering problems which had not been foreseen when it was first developed. By mid-1969, a number of improvements had been made in the area of reducing the work required to input data and to read the computer printout. One of the first of these was to use a wire list which could be called up by each circuit, rather than having the user describe the wire parameters for each circuit. Another of the early, and very important improvements, was to add a check routine which allowed the program to run through its input data reading routines regardless of most types of input errors, and then to abort the run if any errors were detected, but only after it had printed out the identifications and locations of the errors, thereby facilitating corrections by the user. Over the years, this feature has been extended to check for inconsistencies in input data (e.g., the sum of the wire segment lengths may not exceed the end to end wire length) and for out-of-tolerance inputs (e.g., source and load capacitance must be less than 1000 μf). The purpose of the latter is to minimize "decimal point" errors. The user has the option to override the error abort if he wants to use data which is outside the fixed tolerance limits of SEMCAP. Another early improvement was the development of special computer data sheets which reduced the number of user errors in entering data for the keypunching of computer cards.

By 1972, Version 6 (V6) of SEMCAP was operational and in use on the B1 Bomber program. Because of the greater complexity of the wiring geometry of an airplane versus most spacecraft, improvements were necessary to facilitate the handling of the input data. Therefore, the major improvements of V6 were to increase the number of wiring harness map elements from 72 to 120, and to divide the single geometry matrix into four distinct matrices. These were as follows:

- A close coupling matrix which contains the separation distances and group shielding factors for wires which share parallel (or roughly parallel) paths separated by a few millimeters to a number of centimeters. It is used to define different separation distances for different classes of circuits, and had a maximum capacity of 1600 elements (40 generator classes versus 40 receptor classes). Of course, it could be used as a one element matrix if the user wished to use only a common separation distance for all wires.
- A field coupling matrix which contains the separation distances for wires and antennas which are separated by larger distances. It was also a 40 $\times$ 40 matrix.
- A shielding matrix which contains bulkhead shielding factors for wires and antennas that are separated by structural shielding. It is also used to describe the effects of shading and of sidelobe and backlobe radiation from anetnnas. This was also a 40 $\times$ 40 matrix.
- A common resistance matrix which contains four subclasses of common resistance factors. The most important of these is that relating to use of common returns for more than one circuit. This was a 20 $\times$ 20 matrix.

Other improvements in V6 were: (1) added capability to input complex filter functions described by frequency-attenuation points, (2) an output flag identifying which generators were steady-state and which were transients, and (3) an output summary of margins of all receptors.

By late 1972, Version 7 (V7) was operational, and by 1974, Version 7.4 was in use. The additional features of this version are new printout options, frequency versus amplitude printer plot outputs of noise spectrums and transfer functions, and a blocking option which inhibits computation of coupling between circuits which are not on at the same time, or which are otherwise known to be secure from each other. Minor improvements in data handling, data checking, and printout formats were also made during this time. The V7 programs have been used on many military and scientific satellites and by a number of organizations including TRW, JPL, Rockwell International, ERNO, and Hawker-Siddely.

The results of the continual work done on SEMCAP have led to statistically predictable error distributions, shown in Figure 1.

*Articles by A.K. Thomas, W.R. Johnson, and J.A. Spagon in the 1968 IEEE Symposium Record, and in the 1969 IEEE Symposium Records, and by J.A. Spagon in the 1976 IEEE Symposium Records, and in previous issues of ITEM.

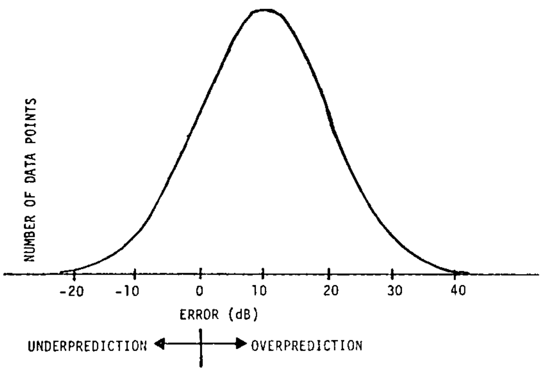

Figure 1. SEMCAP Error Distribution Curve

NOTES:
(1) ERROR (dB) = 20 LOG $\frac{\text{VOLTS PREDICTED}}{\text{VOLTS MEASURED}}$
(2) MEAN ERROR (μ) $\approx$ 9 dB
(3) STANDARD DEVIATION (σ) = 10 dB
(4) μ and σ are based on a sample of 81 data points.
(5) Each data point is an actual voltage measurement made during spacecraft system level EMC tests on circuits for which SEMCAP predicted voltages were in excess of allowable conducted noise levels.

DEVELOPMENT OF VERSION 8

In the course of using SEMCAP for large problems, the need arose to solve smaller problems on a quick turnaround basis, so SEMCAP-T was developed. The favorable response to this on-line-terminal version of SEMCAP lead to the development of a remote terminal version of the batch SEMCAP, and eventually to Version 8 (V8) During the conceptual stages of the V8 development, an opportunity was seen to make additional improvements to the program. In brief, these data improvements are as follows:

- Free form data input
- Data entry by cards or by timeshare terminal
- Data storage on permanent disk files or tape
- The limit of 240 generators and 240 receptors has been removed
- The number of harness segment lengths and map elements has been increased from 120 to 240
- Larger geometry matrices can be accommodated
- New diagnostic messages have been added for more thorough data checking
- Mnemonics, instead of model numbers, are used for model types
- Some improvements have been made in some transfer functions
- The storage for subsystem and circuit names has been increased from 24 to 40 characters
- There will be a decrease in the amount of core storage and CPU time in some cases
- Faster job turnaround can be expected when using remote batch job submission

In order to facilitate the use of V8 for problems originally defined for V7, a conversion program has been written (CNV78) to convert V7 data decks to V8 deck or disk files with almost no manual intervention. This conversion program has been used successfully on two major spacecraft analyses (HEAO and DSCS II) originally defined for V7.

PRESENT CAPABILITIES OF SEMCAP VERSION 8

SEMCAP was developed to perform EMC analyses of spacecraft, where the major problems are in the area of wire-to-wire coupling in complex cable harnesses. Antenna to antenna radiation on most satellites does not represent a serious analysis problem because, unlike an airplane, there are few antennas on most satellites, and these usually operate in the GHz frequency range. Therefore, the emphasis was placed on what happens inside the spacecraft. Consequently, SEMCAP models are virtually unconstrained by the complexity of cable harnesses regardless of the number of different wires or types of wires used, the number of harness segments, unequal spacing of wires in the harness, different heights above ground, different pigtail lengths, etc. A unique feature of SEMCAP is that the model may simultaneously define a large number of different separation distances between wires in the same harness, or between wires in different harnesses. The metric system is used throughout. In addition to handling the effects of shielded wires, SEMCAP simultaneously can deal with the effects of group shields, bulkhead shielding, various values of ground return resistances, various values of common return paths, etc.

However, because it is recognized that not all problems deal with wire-to-wire coupling, a flexible method was developed for modeling antenna to antenna, antenna to wire, and field to wire coupling. This method requires definition of the field rather than definition of typical antenna parameters. In fact, the antenna coupling capability of SEMCAP has been used very little because of the nature of the analytical problems to which it has been addressed. On the other hand, coupling from external fields originating from arc discharges and EMP has been analyzed using the E and H-field models. A feature of this flexibility is that any number of various internal and external fields can be modeled simultaneously, in either the time or frequency domains, and a large number of different structural shielding characteristics can be modeled simultaneously, with the shielding factors being either constant or variable as a function of frequency.

Another unique feature of SEMCAP is that it generates its own frequency base using as many points as necessary to define the spectrums, and has a standard frequency base of 1801 points which are logarithmically spaced to give 1% resolution. On the other hand, if the user wishes to select frequencies as in frequency amplitude pairs, he is virtually unlimited as to the number he may use.

SEMCAP models for generators are described in either the time or frequency domains. In the time domain, it accepts models for sinewaves, single pulses, pulse trains, and ramp steps. In the frequency domain, there is no practical limit to the number of frequency amplitude pairs that may be used. Voltage sources and current sources are defined independently. E and H-field sources are derived from the voltage and current sources, or may be entered independently, at the user's option. Filters may be used for each source and may be defined in either the frequency domain or by standard parameters such as cutoff frequency, slope, inband insertion loss, etc. Two filters may be cascaded for each source. The use of generator filters is optional, and in practice is used infrequently.

SEMCAP models for receptors are modeled as voltage thresholds combined with a frequency response curve. This allows a reasonably accurate representation of both analog and digital (or bi-level) circuits. The frequency response curve can be defined in the frequency domain or by standard filter parameters. If desired, two filters can be cascaded for each receptor.

Because SEMCAP does not assume compatibility except within a black box, all generators are played against all receptors. As stated previously, there is no actual limit as to the number of generators and the number of receptors, although there are practical limits based on engineering time and computer time. Figure 2 shows the actual amount of CPU time as a function of G-R interactions for a CDC 6600 computer. Each interaction is called a "cell" in the G-R matrix. For example, an analysis of 100 generators and 100 receptors would result in a 10000 cell matrix, and would use between 500 and 600 CPU seconds.

The standard printout of a SEMCAP run shows, in addition to all the input data, a list of all the models, the integrated voltage received and margin for each generator-receptor interaction (including a breakdown by coupling mode, i.e., capacitive, inductive, E-field, H-field), the total voltage received and margin for each receptor versus all generators, and a compatibility matrix of all receptors and generators coded to identify ranges of margins. This last item is useful in providing a "quick look" at the results of an analysis.

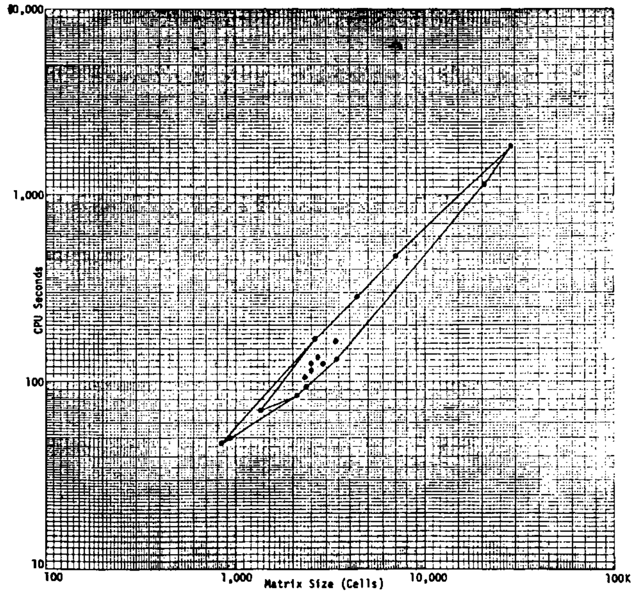

Figure 2. SEMCAP Running Time Matrix Size versus CPU Seconds

CONCLUSION

The developmentof SEMCAP V8 provides an enhanced version of a proven system level EMC analysis program which has been successfully used for many years by a number of well known aerospace organizations.

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(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 a 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 3 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 1_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.

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

All emitters in a system are characterized by emission spectra and all receptors are characterized by susceptibility spectra. All ports and coupling media are assumed 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.

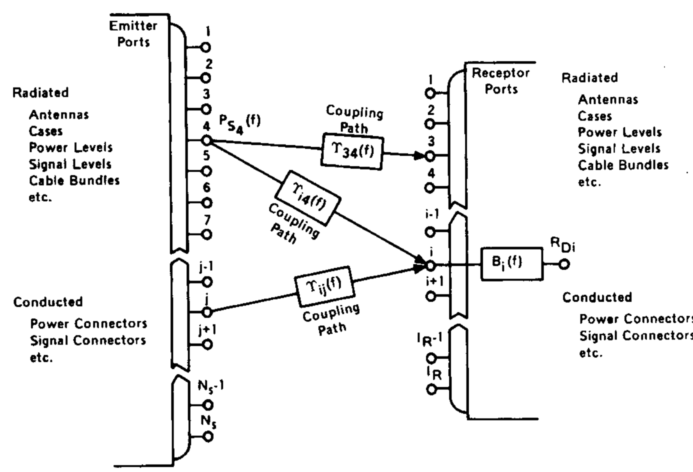

Figure 3
System Approach Identifies Arrays of Emitter and Receptor Ports with Coupling Paths