Correlation Between Measured and Simulated Parameters of a Proposed Transfer Standard

Jim Nadolny
AMP Incorporated

ABSTRACT

Total radiated power of a device can be measured using a mode stirred chamber (MSC). The technique is briefly outlined with emphasis on the peak and average error associated with this technique. A transfer standard, advocated by the IEEE EMCS P482 Working Group, is used as a noise source for a cable radiation study which measured and simulated the total radiated power from a cable-like noise source. Two techniques, the Finite Difference Time Domain (FDTD) and the Method of Moments (MOM) were used to predict the total radiated power. This work represents an initial step in relating system level emission requirements to component level electrical parameters such as transfer impedance.

INTRODUCTION

Numerous electromagnetic simulation software packages are available. In an effort to compare these packages a standard electromagnetic compatibility (EMC) problem was selected. The problem was found to be geometrically simple and have aspects which were analytically well developed. Yet, it represents a practical EMC type problem. The device considered in the problem consists of a commercially available 7 mm airline with a small hole drilled in the wall. Attached to the airline are two sections of RG402 semi-rigid which connect the airline to SMA feed-through connectors. The transmission line structure is mounted inside a mode stirred chamber (MSC) and can be powered by an external source. Figure 1 shows the overall test set up, Figure 2 the detail of the airline and aperture dimensions. This airline with aperture has been adopted by the IEEE EMCS P482 working group as a transfer standard or shielding artifact which is intended to be used as a standard device with known properties for comparison of measurement techniques. The problem is representative of a broad class of EMC problems which have a low amplitude noise source which drives common mode currents down cabling.

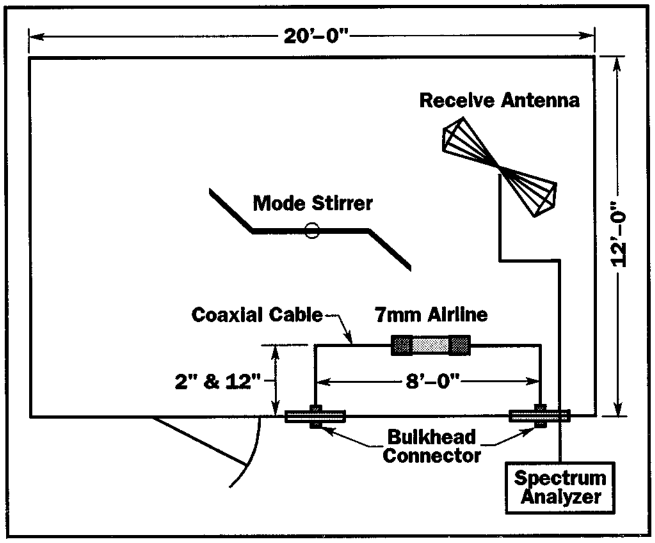

Figure 1. Test set-up. Top view of the mode stirred chamber. 10 ft high, 12 ft wide, 20 ft long.

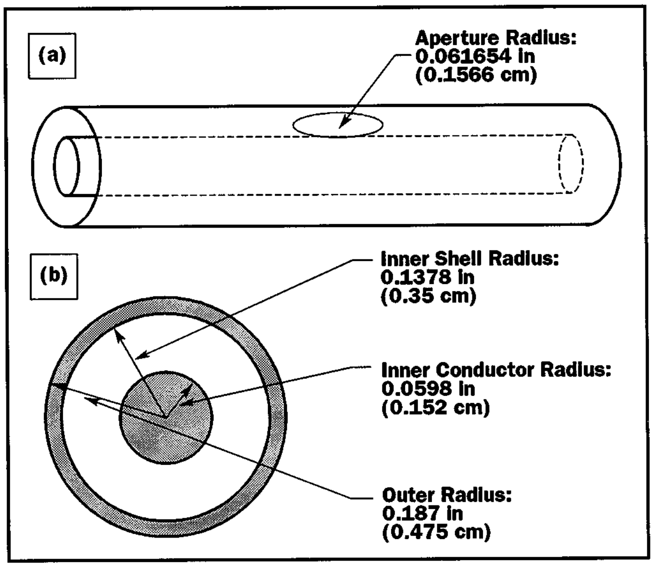

Figure 2. Detailed airline dimensions.

PROPERTIES OF MODE STIRRED CHAMBERS

The MSC has been the subject of numerous studies and is extensively used for shielding effectiveness measurements. A rotating vane distributes the radiated energy inside the chamber resulting in a relatively constant time averaged power density at all points in the chamber. The major restriction of the MSC is that it only exhibits the property of time averaged unity power gain at frequencies above 4 or 5 times the first cavity resonant frequency. This property of time averaged unity gain for any transmit antenna can be used to measure the total radiated power from any radiating source. The property of time averaged uniform power density is attractive from a measurement repeatability standpoint since the transmit and receive antennas do not have to be in exactly the same location. For the measurements performed in this study the antenna factors are not required. Their contributions are included as part of the chamber calibration process.

MEASUREMENT OF THE MSC TRANSFER FUNCTION

IEC 46A Sec 183 details a technique for measuring the chamber insertion loss, which is the ratio of output power to input power expressed in dB. The chamber transfer function is simply the ratio of the time averaged received power to the time averaged transmitted power, or the reciprocal of the chamber insertion loss. Time averaged, as used in this context, refers to the process of summing the measured quantity for each vane position and dividing the result by the number of vane positions. The received power is not corrected for receive antenna factors. Only cable losses are corrected for. This process treats the MSC, the transmit antenna and the receive antenna as a linear two-port device with a unique insertion loss. The transmitted power is measured with a calibrated dual directional coupler system and is computed as the forward power minus the reflected power. To verify the assumption of the MSC/antenna system having a unique insertion loss, five different source antennas were used to measure the MSC transfer function. They were a 4-inch diameter loop, a 10-inch diameter loop, a log periodic, a 10-inch monopole and a log spiral antenna. The amount of variation between the different transfer functions can be considered to be within the error margin associated with the technique. A 12th order polynomial curve fit was applied to the data to smoothen the curve for ease of use. The five different transfer functions are plotted in Figure 3, the average of these five curves in Figure 4, which represents the composite transfer function of the MSC.

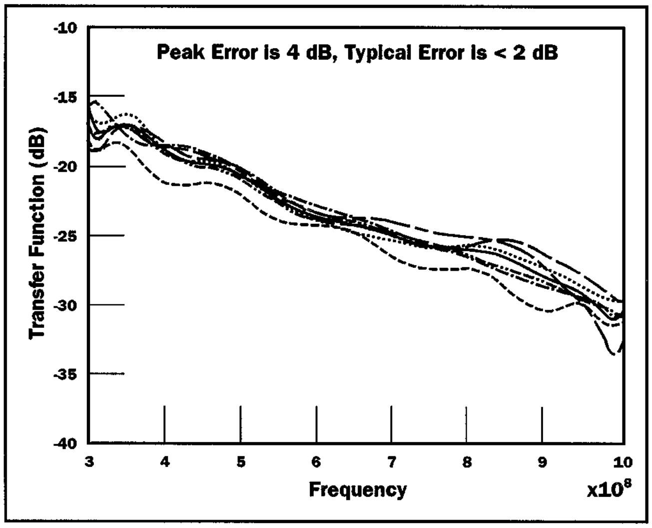

Figure 3. Chamber transfer functions using five different transmit antennas.

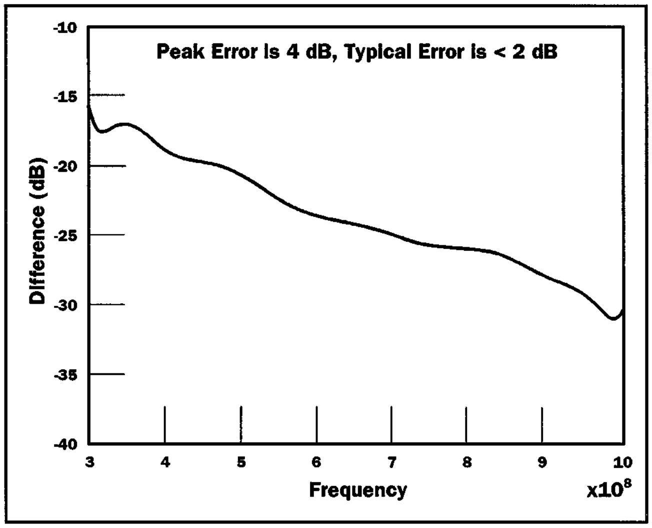

Figure 4. Composite transfer function.

Subtracting the averaged transfer function from each of the five smoothed transfer functions yields the average error. It is shown in Figure 5. Subtracting the averaged transfer function from the five raw transfer functions yields a measure of the peak error. The result is shown in Figure 6. An understanding of the error associated with the measured transfer functions is crucial since this error determines the precision of the measured values of total radiated power. Figures 5 and 6 show that the peak error associated with the MSC transfer function is ± 4 dB while the average error is ± 2 dB.

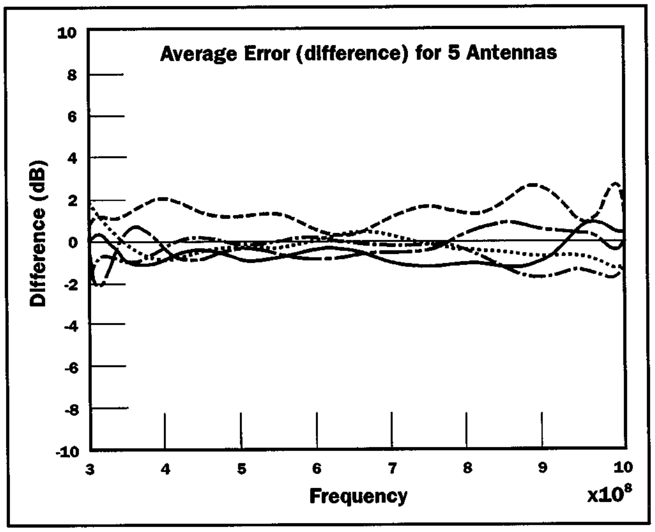

Figure 5. Average transfer function error.

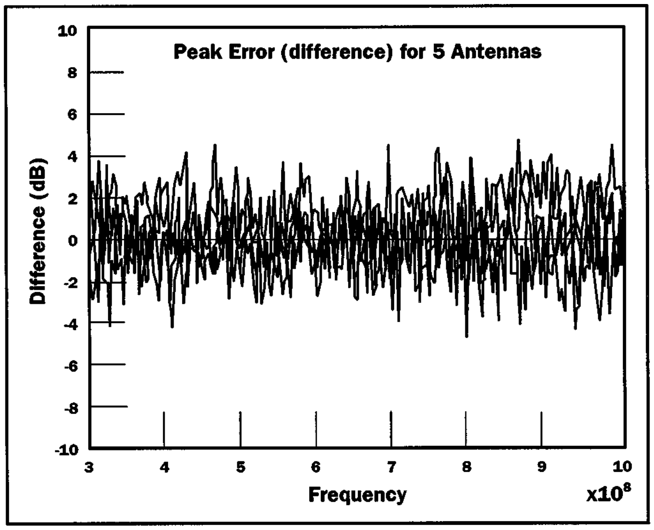

Figure 6. Peak transfer function error.

MEASURED PARAMETERS OF THE TRANSFER STANDARD

To measure the total radiated power emitted by the airline with aperture and semi-rigid coaxial cable, the structure was driven with a signal generator. Since the radiated levels were quite low, a 1 watt amplifier was used to increase the signal strength. The forward and reflected power were measured with the dual directional coupler. The output of the coaxial radiating structure was terminated with a 50 Ω load. Radiated power levels were recorded at each vane position using the log periodic receive antenna. They were added up and the sum divided by the number of mode tuned positions. This power level was then normalized to 0 dB, referenced to 1 mW (dBm) input and the composite transfer function was applied.

The common mode current on the outside of the semi-rigid coaxial cable was also measured. It has a high standing wave ratio (SWR) and is quite position dependant. For repeatability, it was measured with the probe placed directly over the aperture. This placement of the probe was found to have relatively little effect, < 2 dB, on the radiated power spectrum. From this, it was concluded that the addition of the measurement probe did not alter the current profile by more than about 2 dB. Again, with these types of measurements it is crucial that the measurement uncertainties be bounded for correlation to simulated quantities. The measured current at several frequencies of interest is shown in Table 1, the total radiated power in Figure 7.

Table 1. Measured current profile. The unit dBµA indicated a dB value referenced to 1 µA.

Frequency MHz	Current dBµA
370	−22
494	−19
597	−17
838	−14
955	−13

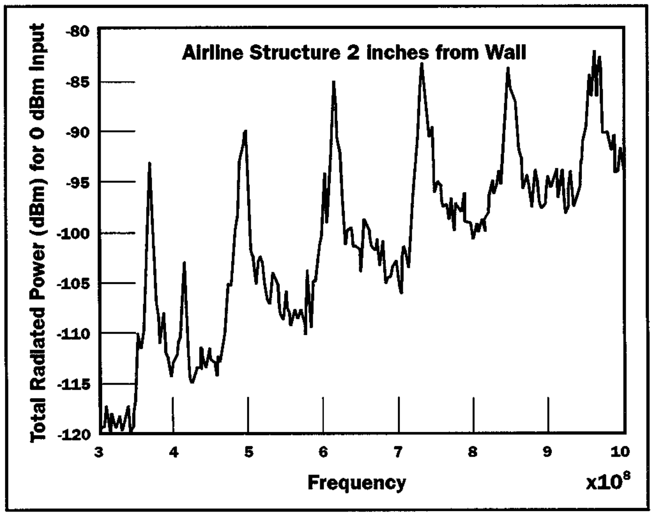

Figure 7. Measured radiated power from airline.

MODELING OF THE TRANSFER STANDARD

The circular aperture in a coaxial structure has been analyzed and measured previously.[3] Using the previously derived formulas with the appropriate constants, aperture diameter, conductivity, etc., the transfer impedance was calculated and is shown, plotted versus frequency in Figure 8. For reference, the equation for a thin walled, coaxial structure with a small aperture is:

$$Z_{tr} = \frac{t}{\delta}\,\frac{R_0(1 + j)}{\sin h\left(\frac{t}{\delta}(1 + j)\right)} + j2\pi fM \text{ (in } \Omega\text{)}$$

where

$\delta = 1/\sqrt{\pi f \mu \sigma}$ = skin depth
$R_0 = 1/2\pi b\sigma t$ = DC resistance per meter
t = annular wall thickness
b = inner shield radius
a = hole radius
$M = 2\mu_0 N a^3\, 10^{-0.8t/a}/\pi^2 b^2$ = mutual inductance
N = number of apertures.

The transfer impedance is viewed as a longitudinal voltage source which drives a common mode current on the exterior of the semi-rigid coaxial cable. The coaxial cable is then the dominant radiating structure as is typical of most EMC problems.

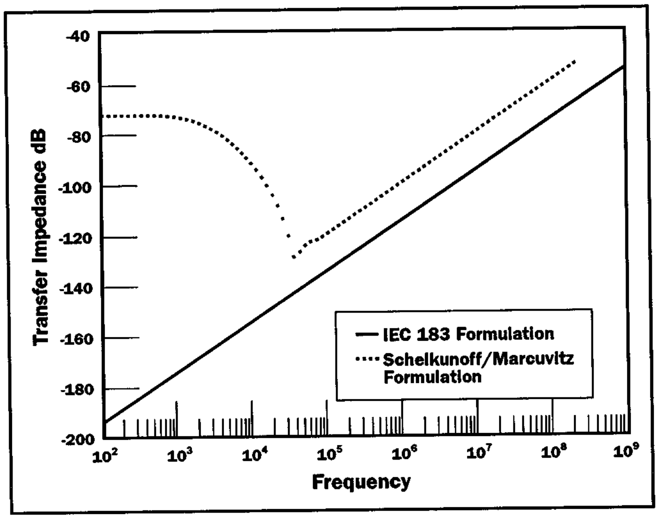

Figure 8. Transfer impedance of airline with aperture.

For the computer simulation of this problem two different techniques were selected. The first of them was the Finite Difference Time Domain (FDTD) approach with absorbing boundary conditions (ABCs) and/or shorting planes to truncate the problem domain to a manageable size. The second was the Method of Moments (MOM) to model the entire wire radiator above a ground plane.

The FDTD technique was a full three dimensional, two port simulation. A 7.8 inch section of the original cable was modeled with ABCs used to match the two ports of the cable and absorb the radiation from the cable. A perfectly conducting plane was used to model the MSC wall 2 inches away. The cable was excited inside near the matched origin with the dominant TEM modal field distribution. Two simulations were run, one with shorting planes at the cable origin and terminus to model the standing wave pattern in the current distribution and one without the shorting planes.

The method used to compute the total radiated power from the structure was to calculate the Poynting vector at the airline aperture, which was modeled with two grid cells in the axial and four cells in the azimuthal direction as shown in Figure 9. This was found to be effective in predicting the average power level as shown in Figure 10 but was not accurate enough to predict the peaks due to cable resonance in the radiated spectra shown in Figure 7. The reason for this lack of fine detail is centered on the necessity to truncate the original cable length of 8 ft 3 inch to a 7.8 inch because of computer memory limitations. Since the peaks in the radiated spectra occur at the cable resonances, they are highly influenced by the cable length. Hence, the much shorter cable was insufficient for modeling them. Figure 10 shows the results of the FDTD analysis for the two cases with and without the shorting planes at the cable ends. Due to the short cable length, the presence of the shorting planes perturbed the radiated power only slightly, whereas the actual measured data showed clearly identifiable peaks.

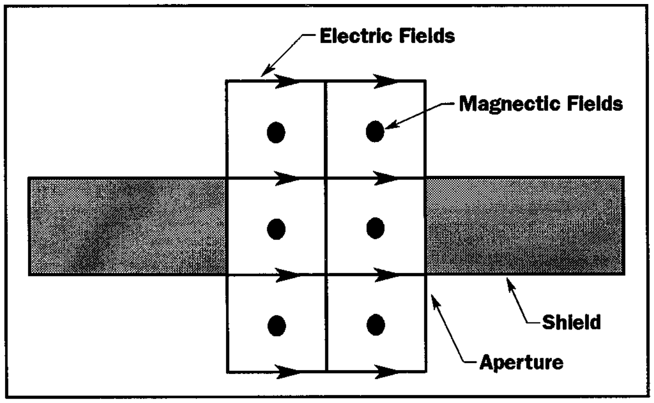

Figure 9. FDTD mesh in region of aperture.

A more direct approach was also used to simulate the shield current with the FDTD method which relied on the placement of ABCs on the outer transmission line. After computing the current for the 7.8-inch model of the cable with ABC terminations, the current was extrapolated to the [8 ft 3 inch]-cable and doubled to approximate its value in the actual problem. Since

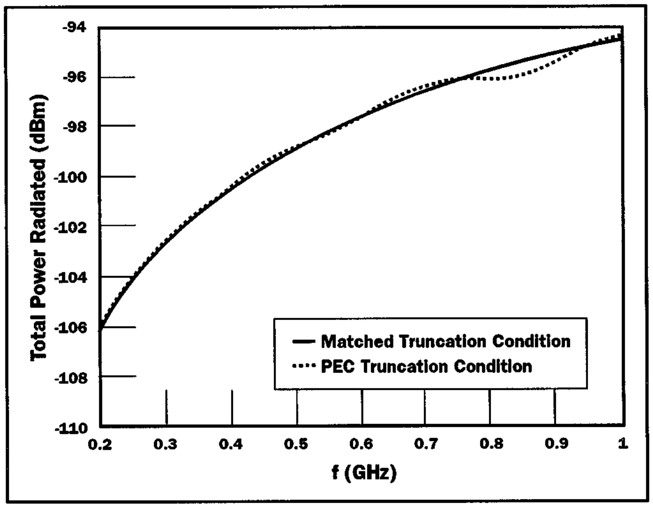

Figure 10. FDTD-simulated radiated power from airline structure.

the actual problem has the outer transmission line short circuited to a ground plane, the simulated current results, extrapolated from the FDTD analysis, had to be doubled as predicted by transmission line theory. The advantage of this procedure is that the 7.8-inch FDTD cable model can be used to approximate the current on the {8 ft 3 inch}-cable. This approach was tested at a single frequency and was found to be accurate within 3 dB at 597 MHz.

The problem was also simulated by MOM using a software package available in commerce. In this approach the {8 ft 3 inch}-long coaxial, radiating structure was divided into 33 wire segments. The current distribution on each segment was modelled as a third order polynomial. The structure was excited with an aperture voltage of unity. Current and total radiated power were scaled to correspond to the measured current values. This approach relies for normalization on a previously measured value of current. The measured values of total radiated power are compared to the simulated values in Table 2.

Table 2. Comparison of measured and calculated values of the total radiated power. Calculations used MOM simulation. P_r = power received.

Frequency MHz	P_r Measured dBm	P_r calculated dBm
370	−93	−104
494	−92	−99.6
560	−107	−107
597	−86	−95
838	−84	−88
880	−95	−93
955	−82	−86

CONCLUSION

A technique to measure the total radiated power from a radiating structure has been presented and the error margin has been experimentally bounded. A typical cable-connector EMC problem has been studied. This problem represents a standard EMC modeling problem commonly found in interconnect systems. Validity of computer programs commonly used to simulate this problem was verified on classic analytic type problems, such as a dipole in free space, etc. However, when applied to a reasonably complex geometry the programs were found to produce errors as much as 10 dB.

This work represents an initial step related to studies in the area of cable connector EMC type problems, which are among the most typical types of problems encountered in practice. Interface standards which attempt to define interconnecting hardware electrical requirements for the purpose of system level EMC compliance would benefit from further development of analytical EMC techniques.

ACKNOWLEDGMENTS

Paul Harms and Raj Mittra at the University of Illinois performed FDTD simulation, problem decomposition and assisted in the interpretation of the results. Be Nguyen measured the radiated power and was instrumental in developing the software for controlling the instrumentation. Special thanks to Jerry Bogar for his endless patience and many fruitful hours in discussion of MSC properties and the use of MOM.

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James Nadolny is a Member of Technical Staff in the Global Technology Group of AMP Incorporated, Harrisburg, Pennsylvania.

Mr. Nadolny holds a Bachelor of Science degree in electrical engineering from the University of Connecticut and a Master of Science degree in electrical engineering from the University of New Mexico. He joined AMP in 1993 after having worked as an EMI design specialist for seven years at Honeywell in Albuquerque, New Mexico. Current research interests focus on electromagnetic modelling for EMC and electromagnetic characterization of connector and cable assemblies.