On the Application of Computational Electromagnetic Techniques to the Design of Chambers for EMC Compliance Testing

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Semi-anechoic and fully anechoic chambers are important and cost-effective tools for meeting emissions and immunity requirements.

Introduction

The limits for Radio Frequency (RF) emissions from electronic products are referenced to measurements performed on an ideal Open Area Test Site (OATS); a perfectly-conducting infinite ground-plane. The ability of a semi-anechoic chamber to simulate an OATS is determined by comparing its site attenuation to the site attenuation calculated for an ideal OATS. If its measured site-attenuation is within 4 dB of the calculated site-attenuation, a semianechoic chamber is generally considered equivalent to an ideal OATS for performing emission measurements.

Unlike emission tests, immunity measurements are frequently referenced to free space. Hence, a fully anechoic chamber is commonly used to determine the immunity of electronic products. The performance of these chambers is determined by measuring the field uniformity over a test surface located in the area normally occupied by the equipment under test (EUT). If the fields vary less than 6 dB over a 1.5 meter by 1.5 meter surface, the chamber is typically considered equivalent to free space.

To design chambers that meet one of the above requirements, manufacturers vary the chamber dimensions and select the size and type of absorber placed on the ceiling, walls and, if necessary, on the floor The different types of absorber include carbon-loaded pyramids and wedges ferrite tiles and waffles, and combinations of pyramids and ferrites.

We describe two different, but mutually compatible, electromagnetic analysis techniques which can be applied to the design of semi-anechoic or fully anechoic chambers for EMC compliance testing/research. The first of these, referred to as the "absorber model", involves a method which allows one to replace a doubly periodic absorbing structure such as urethane pyramids or ferrite waffles by layered 'effective' material properties. Using this method, it is possible to obtain the plane wave reflection loss of a sheet of the material. This is extremely helpful in the efficient evaluation and optimization of absorber designs. The second method, referred to as the "chamber model", uses the layered 'effective' material properties in a full three dimensional solution of Maxwell's Equations. This allows one to obtain the chamber performance by mathematical modeling, as opposed to trial and error construction on a full-sized prototype. The computational technique used is fully self-consistent total field solution for

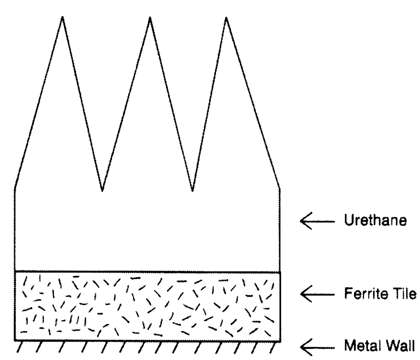


***FIGURE 1:** An example of pyramidal absorber-ferrite tile hybrid. σ is the angle of incidence for the plane wave.*

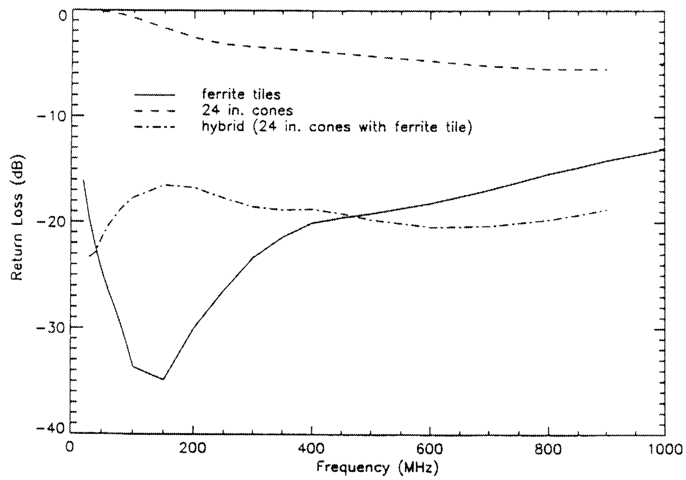


FIGURE 2: *Normal incidence return loss for 24-inch pyramids, ferrite tiles, and a pyramid-ferrite tile hybrid.*

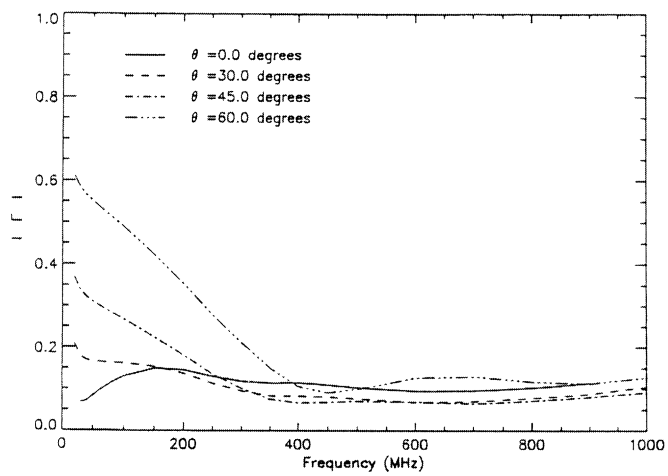


FIGURE 3: *Reflection coefficient magnitude for the 24-inch pryamid-ferrite tile hybrid for various angles of incidence,* θ.

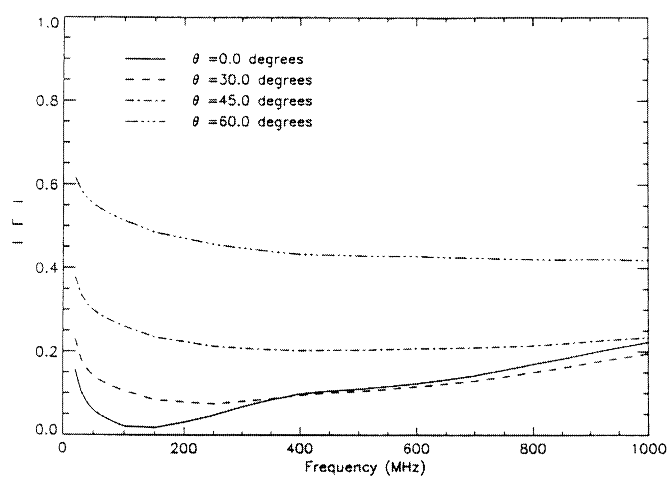


FIGURE 4: *Reflection coefficient magnitudes for the ferrite tile hybrid for various angles of incidence,* θ.

the electric and magnetic fields inside the chambers, as opposed to ray tracing with images techniques. A further benefit of the full three-dimensional model is the ability to calculate the actual performance of the chamber when testing products.

The Absorber Model

The conventional type of absorber used in both semi-anechoic and fully anechoic chambers is the urethane pyramid or wedge shown in Figure 1.

It is generally known that this type of absorber works very well at high frequencies. By good performance, we mean that only a small amount of electromagnetic energy is reflected from the absorber, with most of the energy dissipated as heat in the absorbing material. If we define the reflection coefficient of the absorber, Γ, as

$$IF = E_{ref}/E_{inc}$$

where Eref is the reflected field and Einc is the incident field, then the smaller the magnitude of IF, the better the absorber. Alternatively, absorber performance is given as the return loss, R_1 , which is related to the reflection coefficient, Γ, by

$$R_1 = 20\log10(\mid \Gamma \mid).$$

Generally, these quantities are measured or computed for a plane wave normally incident on an idealized plane sheet containing an (infinite) array of pyramids.

The good response of the absorber at high frequencies can be explained by the interaction of a plane wave with the pyramid structure. When the wavelength of the electromagnetic wave is small relative to the absorber dimensions, then the wave 'sees' the, structure of the pyramid. Geometric optics then shows that the wave will make several reflections with the tapered sides of the pyramids, losing energy with each reflection, before reaching the metal wall behind the absorber. If the absorber material is sufficiently lossy, then the transmitted wave from each reflection is mostly absorbed in the pyramid. Similar reductions occur for the remaining (transmitted) wave which is then reflected from the metal wall. The overall reflection coefficient is then very low, since very little energy is left to re-emerge from the pyramids.

In order to apply the same arguments at low frequencies (or long wavelengths), the length of the pyramidal taper must be correspondingly increased. This leads to very large pyramids, which use excessive amounts of space in chambers. For example, at 30 MHz the pyramids would need to be 30 feet long to be analyzed using geometrical optics. Fortunately, typical materials have skin depths which allow the wave to penetrate the absorber and be dissipated at these frequencies. From an intuitive standpoint, it is clear that the low frequency waves do not 'see' the fine structure of the pyramids, but instead 'see' an effective average material property which is a function of penetration into the structure. Full numerical models for the low frequency response of the pyramidal absorber have been applied to successfully estimate the reflection coefficient for this case. These include finite element methods, the method of moments and finite difference techniques (references [1]-[4]). These techniques are capable of high accuracy from low frequency to high frequencies extending to the geometric optics range, but are computationally very intensive and time consuming.

Recently, a method for determining the effective average material properties as a function of depth into the structure has been developed and applied to pyramidal absorbers (references [5]-[8]). Using these averages, it is possible to compute the plane wave reflection coefficient for low frequencies in a much less computationally intensive way. This model runs on a personal computer and can compute the reflection coefficient at multiple frequencies in a matter of seconds. The model results have been compared to the results of the full numerical solutions mentioned above, as well as to measurements, with very good agreement. This model can be used to efficiently design optimal absorber for EMC applications. Typical results that illustrate the performance of a new hybrid absorber (urethane pyramid, dielectric layers and ferrite tiles) designed using this model are shown below.

Typical Absorber Performance

The first example of this new technique is a comparison of the return losses of a normally incident plane wave on 24-inch urethane pyramids, ferrite tiles, and the pyramid-ferrite tile hybrid, shown in Figure 2. This comparison shows that the hybrid outperforms the pyramid at all frequencies shown, while outperforming the ferrite tile above approximately 500 MHz. It should be noted that these results are for off-the-shelf materials. Optimal return loss could be obtained by systematically varying the bulk material properties and dimensions of the absorbers to obtain the best impedance match over the frequency range of interest. Figures 3 and 4 show the reflection coefficients for the hybrid and the ferrite tile, respectively. The hybrid outperforms the ferrite tile for off-normal incidence, which is important for many chamber applications.

Absorber Material Property Optimization

The new technique has been used to optimize both the geometry and material properties (or loading) for pyramid absorber used in an existing EMC chamber (see references [5] and [8]). Figure 5 shows a comparison of the reflection coefficients for 4-foot and 6-foot pyramids with their standard loadings along with 6-foot pyramids with the 4-foot pyramid's standard loading. The larger pyramid with the smaller pyramid's loading performs better from 30-200 MHz. In Figure 6, a comparison of the reflection coefficients for 6-foot pyramids with different lengths of the tapered section of the pyramid is shown, with material properties very similar to the 4-foot pyramid's. Also shown is the reflection coefficient for the standard material (l = 1.80 in). Clearly, these optimizations have improved the wideband low frequency performance of pyramidal absorbers.

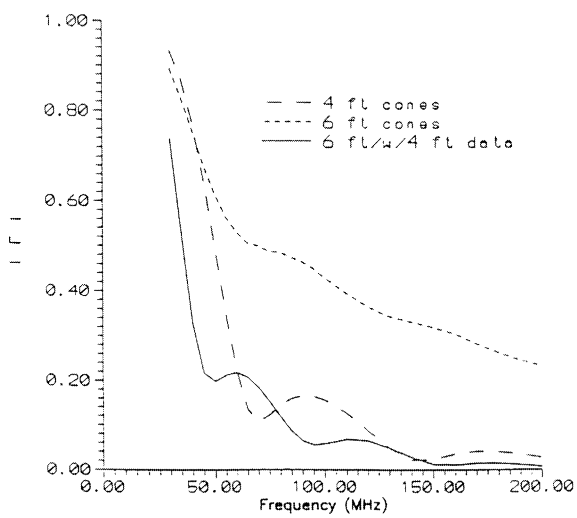


FIGURE 5: *Normal incidence reflection coefficient magnitudes for 4-foot, 6-foot, and optimized 6-foot pyramid absorbers.*

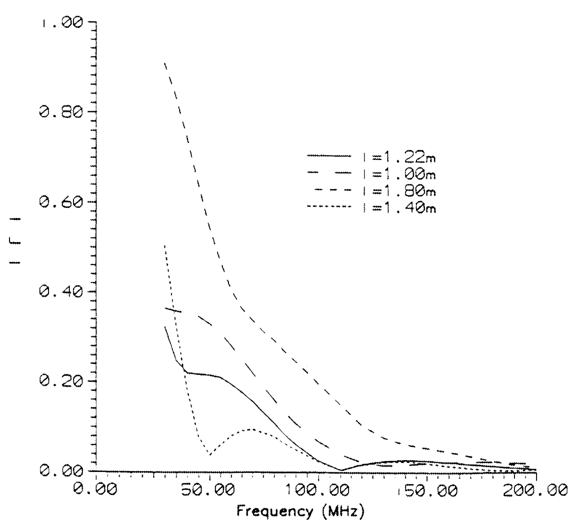
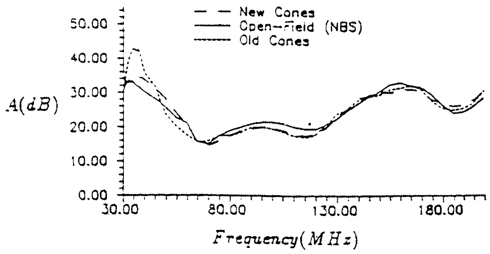
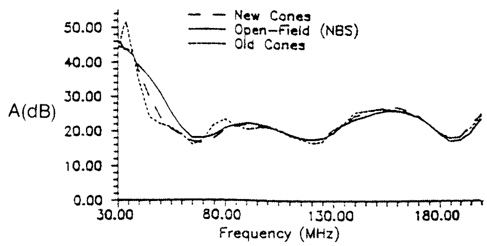


FIGURE 6: *Normal incidence reflection coefficient magnitudes for 6-foot pyramids for different lengths of the tapered section, l.*



a) Vertical Polarization



b) Horizontal Polarization

FIGURE 7: Site attenuatuions for a chamber before and after pyramid optimization compared to NIST OATS measured site-attenuation.

The pyramids shown in Figure 6 were used to rebuild an existing EMC chamber (references [5] and [8]). Figure 7 shows a comparison of the site-attenuation of this chamber before and after the new pyramids were installed. Also shown in this figure is the measured site attenuation of the NIST OATS. With these new pyramids the measured site-attenuation was within 4 dB of the NIST OATS measured site-attenuation.

Pyramid-Dielectric-Ferrite Hybrid Absorber

A hybrid absorber (urethane pyramid, dielectric layer, ferrite tile) has been designed and the return loss is shown in Figure 8. The figure shows very good wideband performance. Notice that the minimum of the return loss for the hybrid is about 700 MHz as compared to the ferrite tile's minimum at approximately 150 MHz. With this new type of hybrid it is possible to place the minimum at a strategically useful frequency, such as one which causes overall performance problems for a particular chamber size.

Figure 9 illustrates the hybrid's off-normal incidence reflection coefficients. Here too, improved off-normal incidence performance compared to the ferrite tile alone, as shown in Figure 4, is seen.

Chamber Models

To accurately characterize the performance of a chamber, it is necessary to consider more than the plane wave reflection coefficients of the absorber. Particularly for smaller chambers used for EMC testing, the fields incident on the absorber are not plane wave in nature. Thus, once an absorber design has been settled upon, it is imperative to evaluate its performance in the actual chamber configuration in which it is to be applied.

This can be accomplished by building the chamber and measuring its performance. This is a costly undertaking, and, if the chamber does not meet its specified performance figures of merit, a trial and error series of fixes may have to be undertaken. A second approach is to develop a theoretical model of the chamber configuration including the absorber and the test antennas, etc. A major stumbling block to this second approach is the difficulty in modeling the geometry of the absorber on the walls of the chamber, even when one was only interested in the low frequency behavior of the chamber. The development of the methodology for determining the effective averaged material properties [7] has removed this stumbling block.

The computational technique chosen to analyze chamber performance is based upon a fully three-dimensional self-consistent solution of Maxwell's Curl Equations using a variant of the program EMA3D (C) [9]. This allows for the inclusion of the spatial variation and the frequency dependences of the effective averages of the dielectric permittivities and magnetic permittivities of different absorber materials, as well as models of the transmit and receive antennas using the Thin Wire

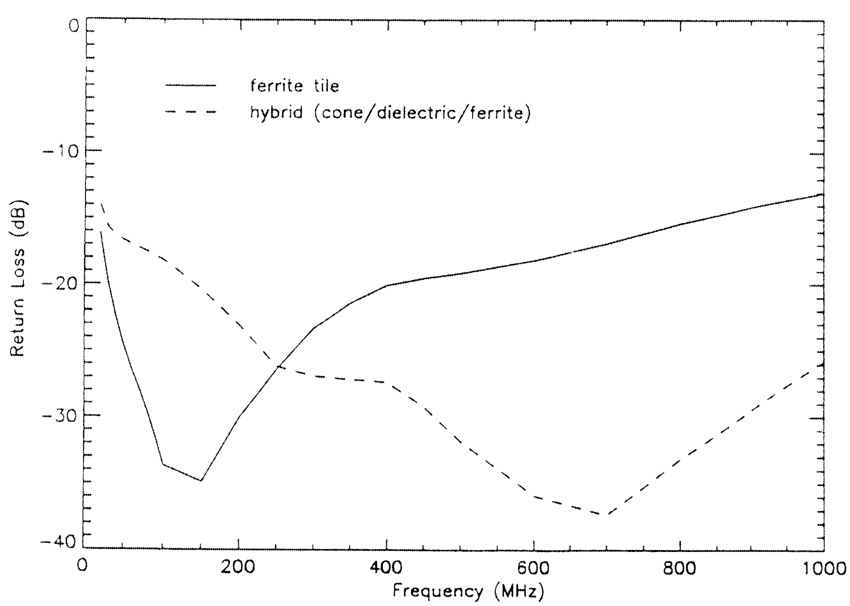


FIGURE 8: Normal incidence return loss of a ferrite tile and a pyramid-dielectric-ferrite tile hybrid.

capabilities available in the program. The computational volume is terminated at the metal walls of the chamber, which are treated as perfectly conducting. Another useful feature of the computational model is the availability of both the electric and magnetic field vectors on a discretized spatial lattice within the chamber. This feature allows for sampling of the field vectors at locations where testing will take place, as well as problem locations on or near the walls.

As examples of the results from the chamber models we show two types of EMC applications, site attenuation and field uniformity. Figure 10 shows the computed site attenuation for a semi-anechoic chamber 29' x 20' x 17' (1 x w x h) compared to an ideal OATS. The absorber material is a ferrite tile waffle which is 1.8 cm thick. Note that these results are for vertical polarization and both transmit and receive antennas at a height of 1 m from the floor. These results indicate that the chamber site-attenuation site-atenuation of an ideal OATS.

Figure 11 shows an example of a slightly different chamber size and use (field uniformity). This chamber is 20' x 16' x 10' and the absorber material is 5 mm thickness ferrite tile on $^{1}/_{2}$" thick dielectric. The absorber-on-dielectric covers the floor, ceiling, and walls of the chamber. In this model, the source is an ideal dipole current element and the field uniformity has been calculated on a 1.5 in x 1.5 in surface 3 in horizontally separated from the ideal dipole. The surface starts 0.8 in above the floor and the fields are sampled at 0.5 in intervals on the surface. Because the source is on the chamber centerline, the problem is bisymmetric and, therefore, only 8 of the 16 test-points on the surface are plotted. The fields are uniform within 6 dB over the test surface and the entire frequency range of interest.

Conclusions

A technique to accurately predict and optimize the low-frequency performance of carbon-loaded urethane pyramids and wedges has been presented. This technique can also be used to optimize the design of various combinations of urethane absorbers and ferrite tiles or waffles. The technique was also incorporated into a computational electromagnetic model that provides a three-dimensional solution of

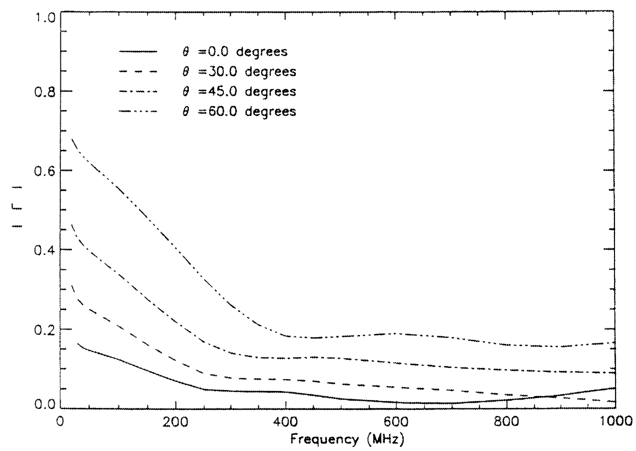


FIGURE 9: *Reflection coefficient magnitudes for the pyramid-dielectricferrite tile hybrid for various angles of incidence, 0.*

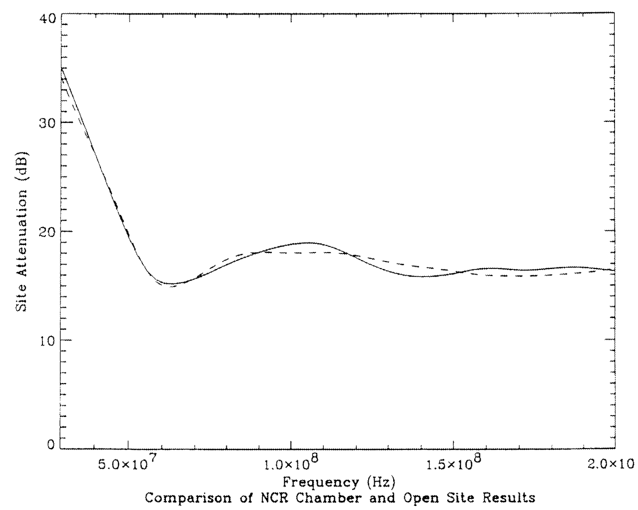


FIGURE 10: *Site attenuation for a 29' x 20' x 17' semi-anechoic chamber (dashed line) compared to an ideal OATS site-attenuation The absorber is a ferrite tile waffle.*

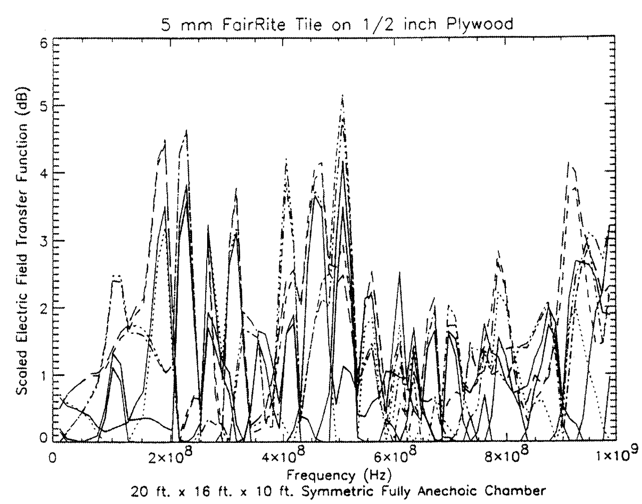


FIGURE 11: *Field uniformity for a 20' x 16' x 10' fully anechoic chamber with ferrite tile on a $^{1}/_{2}$" thick dielectric slab.*

As a final example of results from the chamber modeling, Figure 12 shows the same results for a 23' x 10' x 10' chamber with the same absorber on the walls and ceiling as in Figure 11 but only a 9' x 9' mat of the material on the floor between the ideal dipole and the test surface. These results indicate that the fields are uniform to within 6dB at all but one frequency point at approximately 500 MHz.

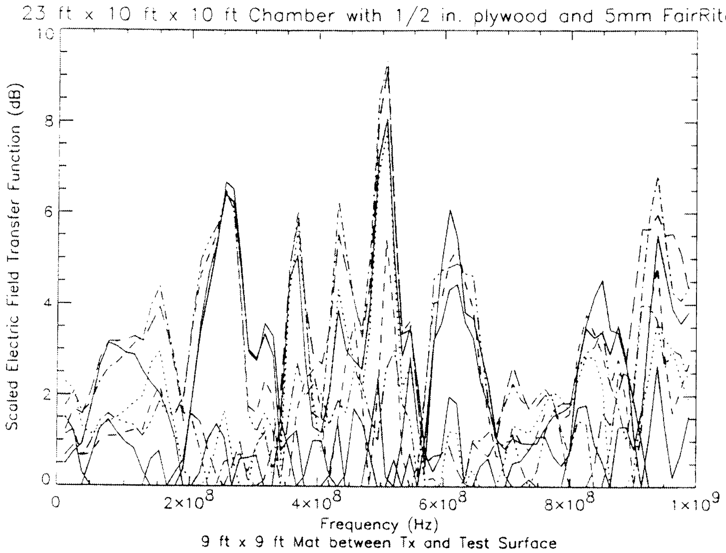


FIGURE 12: *Field uniformity for a 23'x 10'x 10'room with ferrite tile on 1/2" thick dielectric on the walls and ceiling and a 9'x 9'mat of absorber between the transmit antenna and the test surface.*

Maxwell's equations for semi-anechoic or fully-anechoic chambers. This complete chamber model was then used to rapidly optimize the design of chambers used for emissions and immunity testing, without resorting to trial and error design techniques.

Acknowledgment

This research has been funded by Lehman Chambers Program of Paul E. Lehman, Inc., as part of the Ben Franklin Partnership Program of the Commonwealth of Pennsylvania. The effective average material properties methodology for optimizing absorber designs is patented. The patent is held jointly by the University of Colorado, Dr. C.L. Holloway, Dr. E.F. Kuester, and Hugh Gibbons. That research was funded by IBM, Corp.

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