SIGNAL REFLECTIONS IN A SHIELDED ENCLOSURE

Introduction

Shielded enclosures are currently used for Electro-Magnetic Interference (EMI) and TEMPEST testing. A shielded enclosure is typically a room with metal conducting walls, ceiling, and floor, causing high attenuation of signals passing through the walls. Because a shielded enclosure is an RF quiet environment, measurements of radiated EM fields from a piece of equipment are conveniently made without outside interference. However, because of the nearly perfect conducting property of the walls of the enclosure, signal reflections occur. In this paper, the errors which occur when making these measurements, and a method to eliminate these errors are discussed.

Physical Layout

The shielded enclosure can be considered to be a large cavity with perfectly reflecting walls. The case considered is for a receiving antenna and a transmitting antenna (the equipment under test) separated by some small distance. Both antennas are considered very small and isotropic.

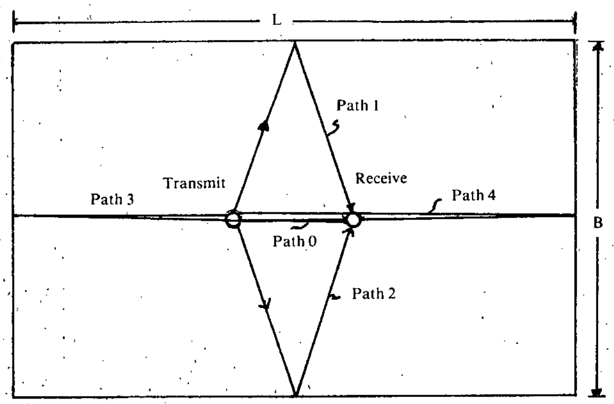

Figure 1. Shielded Enclosure Layout

Figure 1 shows the layout, as seen from the ceiling, of the various "first order" signal paths. Path ϕ is the direct path, assumed to be the desired path. Paths 1 and 2 are reflection paths from the side walls. Paths 3 and 4 are reflection paths from the end walls. Path 5 (not shown) is the combined reflection path from the floor and ceiling. Note all these paths involve only one reflection from the walls. There are, of course, many more possible paths. However, these additional paths will be at least twice as long than these "first order" paths, and will, therefore, have less effect. The antennas are considered to be vertically polarized electric field antennas (such as monopole antennas), and of the same relative size.

Received Electric Field Strength

It is well known that in the far field the magnitude of the received electric field varies inversely with distance. Because the wavelengths of interest (frequency = 1 MHz to 1 GHz), and the antenna separation distances to be considered (about 1 meter) are of the same order of magnitude, the complete field expression is used. For the electric field,

$$E = E_T\left\{\frac{1}{r} - \frac{j}{\beta r^2} - \frac{1}{\beta^2 r^3}\right\} \exp(-j\beta r)$$

Where

E = Transverse Electric Field at Distance r

$E_T = 30I\,\beta h$, volts

$\beta = 2\pi/\lambda$

λ = wavelength

A sinusoidally time varying signal is assumed, and the time factor of exp (jwt) has been omitted. Since we are interested more in the amount of additive and subtractive interference caused by the reflections than in the value of the absolute received signal strength, the phases of all the reflected signals are referenced to the direct path. In order to compute E for each path, we write

$$\frac{E_n}{E_T} = \{Z + jX\} \cdot \{R + jI\}$$

Where E_n = field over path n

$R = \cos\beta r$

$I = \sin\beta r$

$Z = \frac{1}{r} - \frac{1}{\beta^2 r^3}$

The complex multiplication can be performed so that

$$\frac{E_n}{E_T} = \{Z \cdot R - X \cdot I\} + j\{X \cdot R + Z \cdot I\}$$

OR

$$\frac{E_n}{E_T} = (R_T)_n + j(I_T)_n$$

$$\frac{E_{total}}{E_T} = \sum_n \left(\frac{E_n}{E_T}\right) = \sum_n (R_T)_n + j\sum_n (I_T)_n$$

We are interested in the magnitude error caused by the presence of the reflections, so we normalize the total field to the field due to path θ only.

Then we can sum the fields for all paths:

$$|e| = \frac{|E_{total}|}{|E_0|} = \frac{\sqrt{\left(\sum_n R_t\right)^2 + \left(\sum_n I_t\right)^2}}{\sqrt{(R_t)_\theta + (I_t)_0}}$$

Where E_0 is the magnitude of the direct path field.

A shielded enclosure was modeled on a computer, using the above equations for the 5 "first order" paths. The enclosure size was 12 × 20 × 8 feet. The resulting normalized signal strength vs. frequency is shown in Figure 2 for an antenna separation distance of 1 meter. If there were no reflections, the received signal strength would be 0 dB. Note that the received signal strength varies dramatically across the frequency range, with the variations being almost 30 dB.

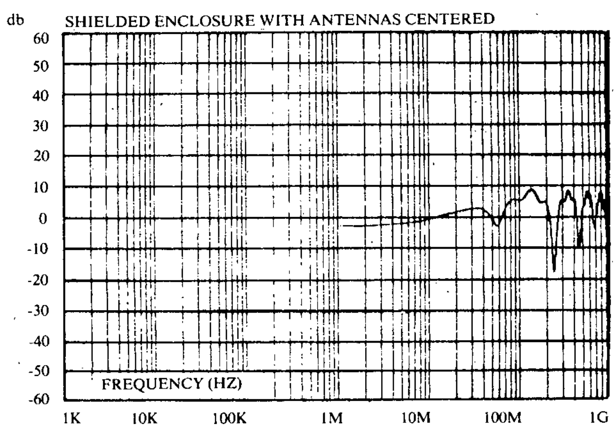

Figure 2. Received Signal Strength With Antennas Centered in a Shielded Enclosure.

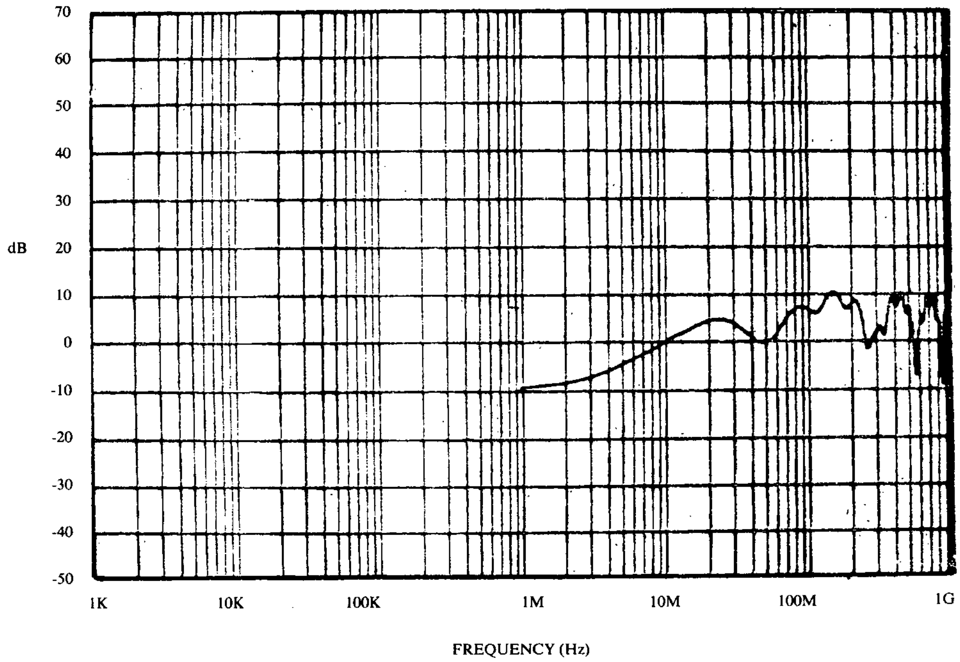

Figure 3. Received Signal Strength With Antennas Centered in a Shielded Enclosure (Separation Increased to 1.5 Meters).

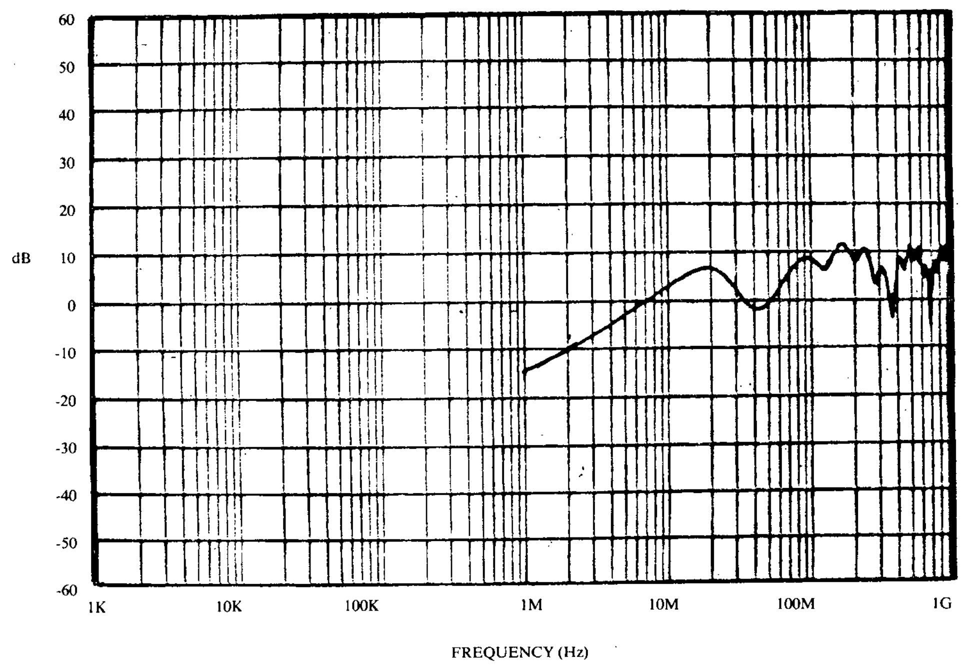

Figure 4. Received Signal Strength With Antennas Centered in a Shielded Enclosure (Separation Increased to 2 Meters).

The distance between the antennas was then increased to 1.5 meters. Figure 3 shows the received signal strength plot for this distance. The change in distance has changed the frequencies where the dips and peaks occur, along with the amplitudes. Figure 4 shows the same test except the distance between the antennas is now 2 meters. The received signal has changed dramatically from Figure 2 and represents an uncertainty of 15 dB.

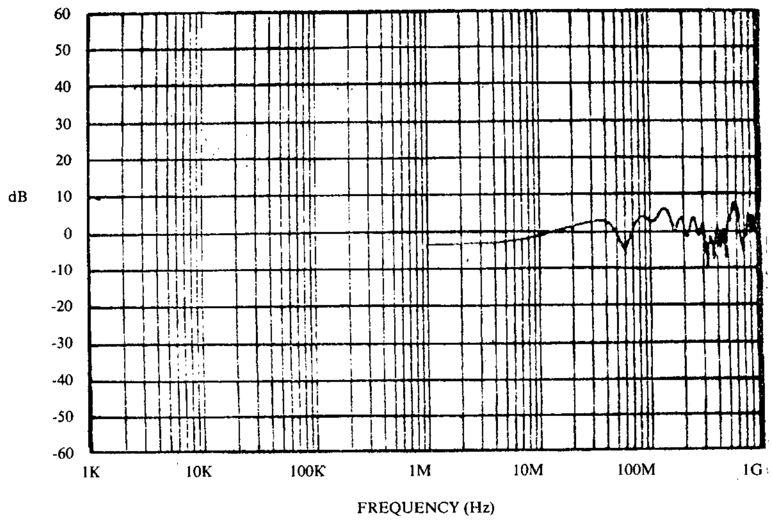

Figure 5. Received Signal Strength With Antennas Placed One Half Meter Toward Side Wall in a Shielded Enclosure.

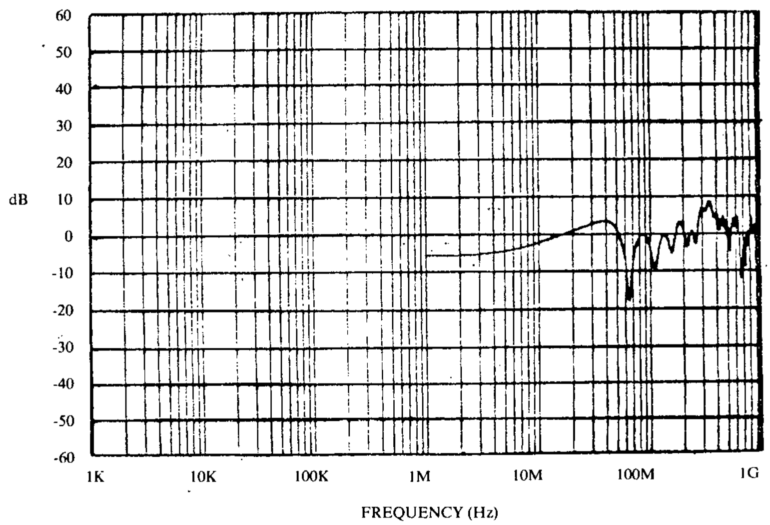

Figure 6. Received Signal Strength With Antennas Placed One Meter Toward Side Wall in a Shielded Enclosure.

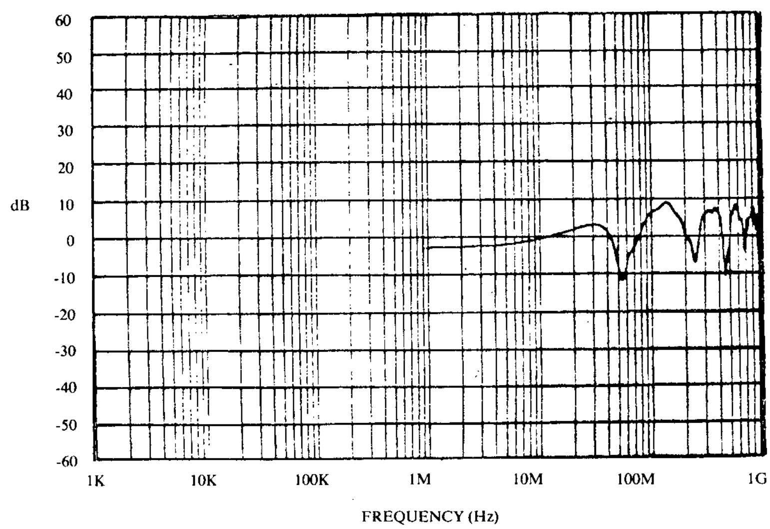

Figure 7. Received Signal Strength With Antennas Centered Then Moved Toward End Wall By 1 Meter.

The antennas were again separated by 1 meter and then moved to one side (off-center) by .5 meter and 1 meter. Figures 5 and 6 show the results of these conditions. Again, the received signal strength plot has changed dramatically from Figure 2. Figure 7 shows the results when the antennas were centered and then moved toward one end by 1 meter. This condition is the closest yet to Figure 2 (antennas centered). However, the amplitudes have changed somewhat.

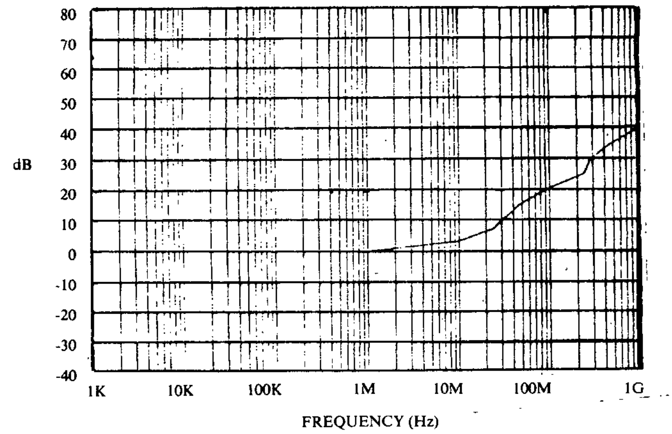

Figure 8. Reflected Signal Attenuation of Two Foot Thick Material.

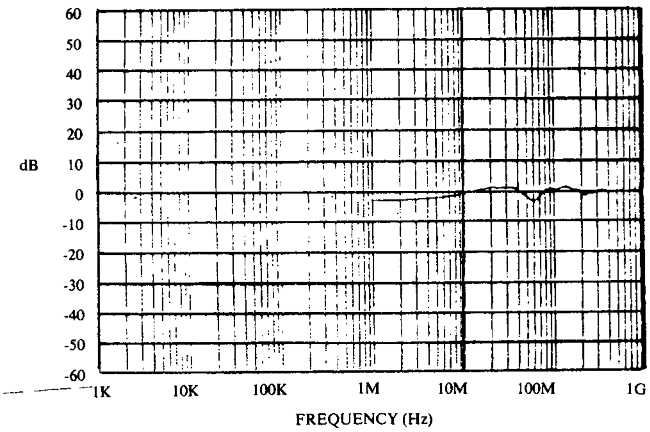

Figure 9. Reflected Signal Strength With Antennas Centered in a Shielded Enclosure With Absorber Material on Walls and Ceiling.

It is apparent from Figures 2 through 7 that not only are there variations in the received signal strength from the desired case, but these results change significantly with positions of the antennas. Before any accurate electric field strength measurements can be made in a shielded enclosure, the "enclosure factor" (similar to the commonly used antenna factor) would have to be considered. The enclosure factor is not a slowly varying value (as a function of frequency) in these cases, and changes significantly with antenna position and separation. It is unlikely any accurate measurement could be performed even with this enclosure factor. Therefore, some other means of handling these variations are needed.

RF Absorber Material

Since the undesirable uncertainties arise from unwanted reflections from the walls and ceilings, we want to attenuate these reflections. Installing RF absorber material on the walls and ceilings should have this desired effect. The floor is not covered with the absorber material to allow movement in the room and access to the ground plane when using monopole antennas. Reflections from the floor are attenuated by placing a loose piece of 2-foot by 2-foot absorber on the floor, centered between the antennas. Because of the size of the shielded enclosure selected (12 × 20 × 8 feet), two-foot thick absorber material is the maximum thickness useable while allowing enough room to work. The absorber material modeled is the pyramid shaped microwave absorber commercially available from a number of companies and used in most anechoic chambers. This absorber material has a very high attenuation characteristic at UHF frequencies and almost no attenuation at HF frequencies. Figure 8 shows the approximate attenuation characteristics of the reflected signal with two foot thick, pyramid-type absorber material.

This attentuation was then included in the calculations of received signal strength. Figure 9 shows that the variations present in Figure 2 have almost completely disappeared. There remains only a slowly varying curve with a peak-to-peak excursion of about 4 dB. The UHF variations have been completely attenuated, and the HF and VHF variations are minor. This curve could be used as an enclosure factor with a much higher degree of confidence than was possible with Figure 2.

The same analysis was performed for various antenna positions and separation distances. The resulting curve did not vary significantly from Figure 9.

This analysis shows that large errors can occur when making electric field measurements in a plain shielded enclosure. The errors magnify themselves when attempts are made to repeat measurements, and the antennas are positioned slightly differently. RF absorber material has been shown to significantly reduce these errors. The cost of pyramid-shaped two-foot thick RF absorber is approximately $17,000 for a 12 × 20 × 8 foot enclosure. Absorber less than two feet thick provides less attenuation for less expense. However, without any absorber, field strength measurements inside a shielded enclosure are subject to severe inaccuracy.

This article was prepared by Bruce R. Archambeault, Sr. Electrical Engineer, Government Systems Groups, Digital Equipment Corporation, Hudson, New Hampshire and published with permission.