APERTURE SHIELDING EFFECTIVENESS

Experimental data on the electromagnetic shielding effects of circular apertures is presented.

J. G. Sketoe, McDonnell Douglas Corporation, St. Louis, MO

INTRODUCTION

Enclosure apertures are the well-known and long-standing Achilles' heel of shielding effectiveness. Analytical techniques for bulk shielding effectiveness are well-documented in the literature, one source being the AFSC Design Handbook 1-4.[1] Similarly, the same literature covers aperture leakage for waveguide below cutoff apertures (pipes) and apertures covered by mesh or other conductive material. The discussions of these two areas include both the analyses and the collaborating experimental values, although frequently not within the same document.

What is not covered are transition aperture sizes of 0.01 to 0.5 wavelengths. Apertures with diameter sizes larger than 0.5 wavelength have zero dB shielding, and sizes smaller than 0.01 wavelength have significant (over 60 dB) shielding. The transition region between these points has been relatively neglected.

Bouwkamp provides an excellent theoretical treatment of plane wave diffraction through circular apertures in terms of transmissibility.[2] The purpose of this paper is to present experimental data on the electromagnetic shielding effects of circular apertures, with numerical values given in dB of shielding effectiveness. The apertures tested were ¼, ½, 11⁄16, 13⁄16, 1, 3, 5, and 7 inches in diameter. The frequencies covered were 200 MHz to 18 GHz. The measurements were made using mode-tuned resonant cavity techniques. A total of 533 data points were recorded, normalized, and plotted to generate a statistically sound and convenient data set.

Shielding effectiveness is normally plotted versus frequency for a specific size aperture, with different plots being produced for different size apertures. However, this writer's intent is to present the data in a format that can be readily interpolated for various size apertures. RF leakage is proportional to aperture size relative to frequency, and the most apparent aperture parameter that can be readily related to frequency is the diameter in wavelengths. A frequency may be specified by giving the aperture diameter in wavelengths ($0.08467 \cdot D_{in} \cdot f_{GHz}$), and the shield effectiveness measured at that frequency. The data is plotted in Figure 1. Bouwkamp chose to size the aperture by using the circumference in wavelengths as the independent variable, k. His k = 2 and k = 10 breakpoints represent diameters of d = 0.64 and d = 3.18, respectively.

DATA RESULTS

Several observations can be made from the data as plotted in Figure 1. First, the variance of shielding effectiveness is readily apparent by the 25-30 dB swings between adjacent

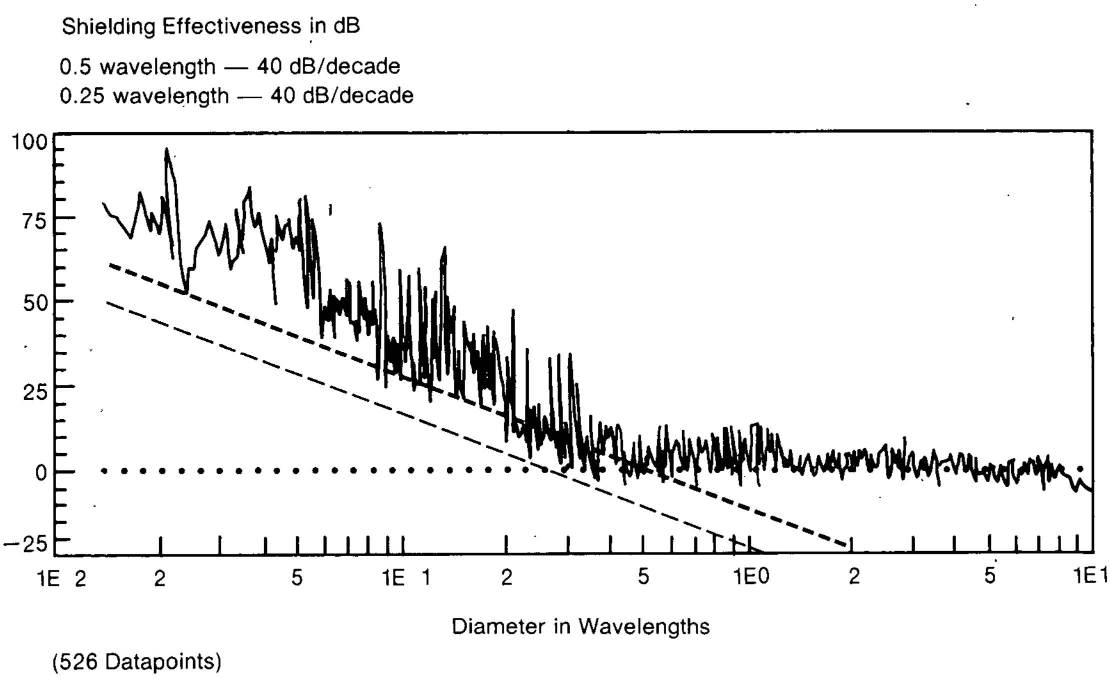

Figure 1. Shielding Effectiveness Circular Apertures.

measurements within the transition region. This is characteristic of shielding effectiveness measurements; however, repeated measurements at exactly the same frequency are typically within 6 dB. If the transition region is used, the EMC engineer must account for this inconsistency.

The second observation is the shielding effectiveness outside the transition region. Below 0.5 wavelengths the shielding rapidly approaches test equipment limitations of 80 dB. Above 0.5 wavelengths the shielding effectiveness, as expected, approaches zero dB with very little variance. Bouwkamp's treatment indicates a monotonic increase in transmission coefficient to 1.0 at 1.8 wavelength circumference or about 0.6 wavelength diameter. At this point the transmissibility begins a damped oscillatory motion decaying to 1.0. This motion correlates well with the decreasing volatility of the experimental data above 0.5 wavelength diameter.

Thirdly, two rules-of-thumb can be generated by drawing one 40 dB/decade line through the 0 dB – 0.5 wavelength point and another through the 0 dB – 0.25 wavelength point as depicted in Figure 1. The first line, 0 dB – 0.5, provides an approximation to the actual shielding. The second line, through the quarterwave – 0 dB point, provides a lower bound of shielding effectiveness of open apertures from ¼ inch to 7 inches. Extrapolation beyond 7 inches should be done with caution at least until the validity is spot-checked.

The measurements reported herein were conducted using a mode-tuned reverberation chamber. NBS Tech Note 1092[3] has an excellent coverage of the reverberation chamber technique of measuring shielding effectiveness. This method is widely accepted as a conservative shielding effectiveness measurement technique. Consequently, the values given herein are worst case, and in a specific application at least that much shielding is a reasonable expectation. Also there are many, many measurements in the database (532 total — 6 were above 10 wavelengths).

Therefore the data are statistically sound. The data points are denser in the more germane 0.05 to 1.0 wavelength range; however, they are sufficiently dense elsewhere to retain their statistical validity.

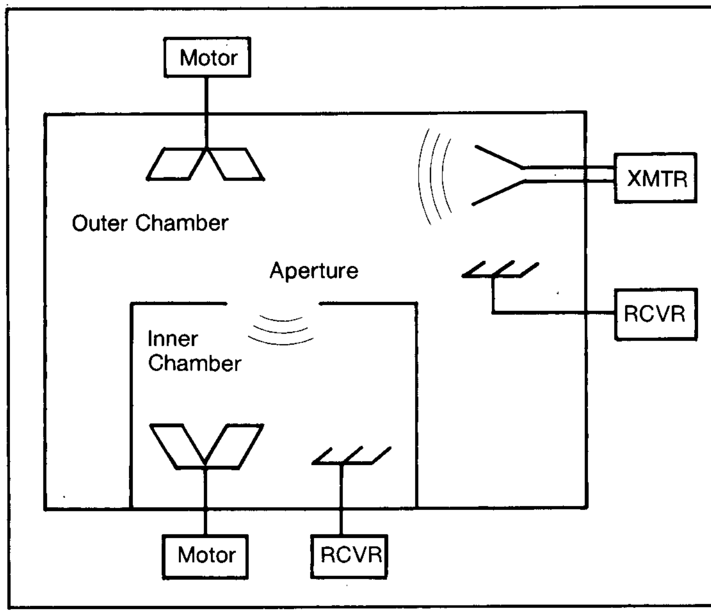

Figure 2. Aperture Shielding Test.

MEASUREMENT TECHNIQUES

The mode-tuned chamber shielding effectiveness measurement technique uses two chambers with the sample under test (SUT) providing the only RF path between them (Figure 2). The technique depends upon both chambers having numerous modes of excitation at the frequency of measurement. RF power is injected into the outer chamber, and the fan rotated to mix the RF, exciting as many of the modes as possible. Although not readily apparent in Figure 2, the fans are non-symmetric to further enhance the mixing action. At some point of the rotation of the outer chamber's fan, the coupling of RF energy to the monitoring antenna of the outer chamber will be maximized. Similarly, at some (most likely different) point the coupling to the SUT's worst case leakage point will be maximized. The peak field strength at the antenna and the SUT are essentially the same.

Accordingly, the aperture to inner chamber coupling is *tuned* by the inner chamber fan. The inner fan rotates a full 360 degrees for each step of the outer fan. The inner chamber's antenna measures the peak RF field coupled into the inner chamber. For each outer fan step there will be some peak chamber field at some inner fan step. The inner chamber peak will occur at the outer fan position which maximizes RF coupling through the SUT.

The shielding effectiveness of the SUT is calculated as peak outer chamber received power in dBm measured by the outer chamber's receiver antenna (regardless of outer fan position) minus the peak inner chamber received power in dBm (regardless of either outer or inner fan position). This value is the worst case (i.e., the least amount) shielding effectiveness provided by the SUT.

The hundreds of modes that exist within the chamber's bandwidth for each frequency cause the measured values to be extremely volatile. Consequently, very small changes in fan position and frequency were used to keep from skipping a resonance point. For each frequency, each fan steps 50 times in 360 degrees. This results in 50 x 50 = 2500 measurements to obtain a single data point.

Next the frequency was changed by a very small step, and the fans rotated again. The applicable fre-

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quency range to cover the diameters of 0.01 to 10 wavelengths was broken into bands as dictated by equipment constraints and was swept multiple times stopping at the same frequencies each time. Although measured values varied greatly from frequency to frequency, multiple measurements at a single frequency varied less than 6 dB.

The shielding effectiveness is then taken as the average of the multiple measurements at each frequency. This average value is the reported shielding effectiveness at a frequency.

The fan rotation is done with an outer/inner loop logic. For instance, a single outer fan step requires a complete rotation of the inner fan. Most of the data points taken for this report used 50 x 50 steps for a total of 2500 measurements to get a single set of peak outer/inner power level measurements to calculate a single shielding effectiveness value for that frequency. The complete frequency band sweep was repeated four times for most apertures, and the shielding effectiveness calculated values averaged. Thus, a single data point as plotted in Figure 1 represents 25,000 measurements (2 antennas, 2500 fan positions, 5 frequency sweeps, 5 shielding effectiveness calculations, and one averaging operation). ■

REFERENCES

1. AFSC Design Handbook on Electromagnetic Compatibility, DH 1-4, Fourth Ed., 2 March 1984, Hqs, Aeronautical Systems Division, Wright-Patterson AFB, OH.
2. Bouwkamp, Christoffel J., Theoretical and Numerical Treatment of Diffraction Through a Circular Aperture, English version published in "IEEE Transaction on Antennas and Propagation," Vol. AP-18, No. 2, March 1970, pp. 152-176.
3. Crawford, M. L. and G. H. Koepke, NBS Tech Note 1092, "Design Evaluation and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements," U.S. Department of Commerce, National Bureau of Standards.