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Upper Frequency Measurement Boundary for Evaluation of Shielding Effectiveness in Cylindrical Systems

FOREWORD

Changes in this revision are format/editorial only.

INTRODUCTION

Electrical energy leaks through a shield both by diffusion, as Schelkunoff (Reference 1) has described; and by aperture coupling, as described by Marcuvitz (Reference 2). At low frequencies, diffusion dominates, and at high frequencies, aperture coupling dominates. A convenient way to measure this leakage is Transfer Impedance, Z_t, and Transfer Admittance, Y_t, because they characterize the shield leakage independent of the source (or object) of the interfering signal, and because they are also independent of the number and arrangement of conductors inside the shield and their termination. In other words, Z_t and Y_t are characteristics of the shield alone.

Since sources and receivers of electrical energy cover a frequency range of DC to over 100 GHz, shielding is likely to be needed over that range also. If shielding is required, some means of measuring its Z_t and Y_t are necessary. A number of methods have been proposed (References 3 to 11), most of which are variations of the method of Zorzy and Muehlberger (Reference 12). Most of these methods have been limited to frequencies below 1 GHz, some considerably below. The limitation has in some cases (References 3 and 10) been instituted to simplify the data analysis, although ways around this difficulty have been suggested (References 4 and 8).

Aside from limits of convenience, a transition frequency, f_t, exists, beyond which the variance in measurements of Z_t and Y_t can become large. The existence of this transition frequency has been recognized in military specifications (References 5 and 6), where Z_t measurements are terminated before the transition frequency is reached. In the H revision of MIL-C-38999 (Reference 6), a stirred mode technique (Reference 13) is called out for frequencies over 1 GHz, which generally includes frequencies above the transition frequency. However, stirred mode testing does not evaluate Z_t. Methods which do not evaluate Z_t or Y_t bring into the measurement both the nature of the source (or object) of interference and the nature of the conductor arrangement inside the shield, as well as the method of terminating the conductors. Such measurements are situation specific, i.e., they evaluate the shielding in the configuration of, and under the conditions of, the measurement but are not generally transportable to other conditions and configurations. A non-transportable measurement may be suitable for engineering reference or to evaluate an assembled system, but it is not suitable as an acceptance test on a system component.

1. SCOPE:

This AIR points out that above a frequency called the “transition frequency,” variances associated with the shielding effectiveness measurements can become large. It includes the derivations to demonstrate this. This fact should be taken into account when designing shielding for use above the transition frequency.

2. REFERENCES:

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3. THE EXISTENCE OF A TRANSITION FREQUENCY:

Any system of two or more conductors can form a transmission line. As long as the resistance of the conductors is low (e.g., a metal) and the electrical energy flowing on the line propagates in the TEM mode, the electric and magnetic field vectors are both contained in a plane perpendicular to the conductors, and current flow is along the axis of the conductors.

Now let us consider a two conductor transmission line in which the outer conductor surrounds the inner one. This arrangement is often encountered in Z_t measurements, where the inner conductor is a shield under test, and the outer conductor is used to establish a known field. The conductors of this line can have any shape in cross-section but are restricted to having the same cross-section throughout their entire length.[1] Let us examine current flow on the outer conductor. For simplicity, we will assume that the conductor is a circular cylinder, although the following discussion applies equally well to a conductor of irregular cross-section. As we have said previously, the flow of current on this conductor is axial when the propagating mode is TEM.

Now let us raise the frequency of the propagating energy to the point where the perimeter of the conductor under consideration just equals a wavelength. This situation for a circular cylinder is illustrated in Figure 1.

1. For the purpose of this discussion, a non-uniform conductor can be replaced by a uniform conductor having the largest cross-section of the non-uniform conductor. Also, one of the two conductors could be geometrically complex; e.g., the skin of a vehicle, or the remaining N-1 conductors in an N conductor cable.

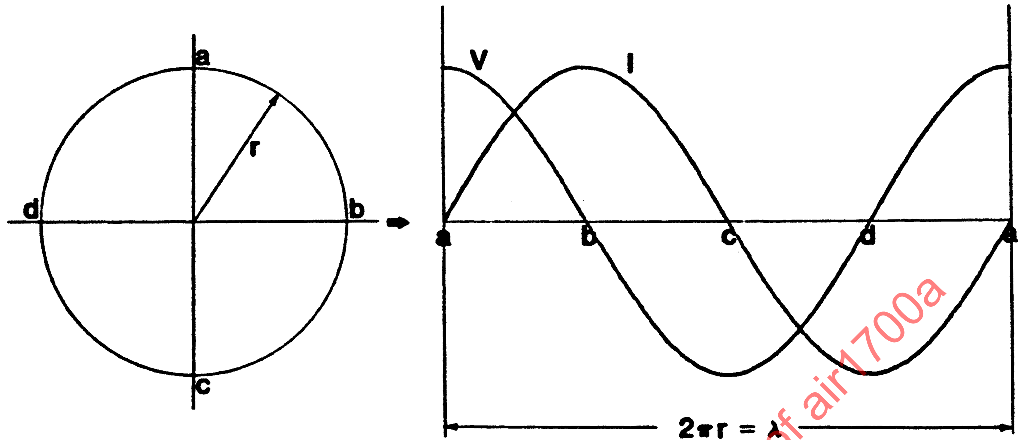

FIGURE 1 - Voltage and Current Distribution on a Cylinder in a Plane Transverse to the Axis of Propagation, When the Perimeter of the Cylinder is One Wavelength Long

3. (Continued):

A standing wave can now exist which appears as a dipole, with a positive voltage at a, and a negative voltage at c. This dipole drives a current back and forth around the circumference of the cylinder from a to c. The vector sum of this current and the axial current is a resultant current flowing at some angle (depending on the relative strengths and phasing of the components) with respect to the Z axis. Since the current flow is no longer axial, the mode or propagation is no longer TEM, and the transmission line is said to have "moded."

The frequency at which this moding becomes possible can be calculated from the relation (Reference 14)

$$f = \frac{\nu}{\lambda} \qquad \text{(Eq. 1)}$$

where f = frequency in Hertz, ν = velocity of propagation in meters/second, and λ = wavelength in meters. The velocity of propagation can be calculated from the relation (Reference 14)

$$\nu = \frac{3 \times 10^8 \text{m/s}}{\sqrt{\mu\varepsilon}} \qquad \text{(Eq. 2)}$$

3. (Continued):

where μ = relative magnetic permeability of the medium surrounding the inner conductor (which is the shield being examined), and ε is the relative dielectric constant. For a cylinder of diameter D, the circumference is equal to a wavelength when

$$\lambda = \pi D \qquad \text{(Eq. 3)}$$

The frequency at which the circumference (or periphery) of the conductor is just equal to a wavelength is technically defined (Reference 15) as the "cut-off frequency." However, the use of the term "Transition Frequency" is preferred, as it is more descriptive of the process of transitioning from a frequency region where the assumption of TEM propagation is generally valid, to a region where the assumption is generally invalid. The transition frequency is designated by f_t and can be found by substituting Equations 2 and 3 into Equation 1:

$$f_t = \frac{3 \times 10^8}{\pi\sqrt{\mu\varepsilon}D}\text{Hz} \qquad \text{(Eq. 4)}$$

or

$$f_t = \frac{0.095}{\sqrt{\mu\varepsilon}D}\text{GHz} \qquad \text{(Eq. 5)}$$

If D is in inches instead of meters,

$$f_t = \frac{3.76}{\sqrt{\mu\varepsilon}D}\text{GHz} \qquad \text{(Eq. 6)}$$

As an example, let us calculate the transition frequency for a cable shield having an outside diameter of 1 inch, and having a jacket with a relative magnetic permeability of 1 and a dielectric constant of 2.6. If this cable is laid on a ground plane (so that the largest characteristic dimension is that of the cable itself), but is otherwise surrounded by air, the effective dielectric constant will be closer to 2. Letting D = 1, μ = 1, and ε = 2 in Equation 6, we find that f_t = 2.66 GHz. If the cable is put inside a tube of 2 inches I.D. (for example, to measure its shielding effectiveness) and assuming ε is still about 2, f_t decreases to 1.33 GHz, because the largest diameter in the system is now the inside diameter of the tube.