Improved Shielding through Multiple Layers

A composite shield provides a large impedance change at each interface, and hence, maximum reflection.

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INTRODUCTION

In 1990 the authors presented test data showing that composite materials containing alternate layers of conductive and ferromagnetic materials are effective shields against electromagnetic fields in the medium frequency range.[1] The results indicated that the attenuation of three layers is greater than the sum of the attenuations due to each layer separately, and greater than that of two layers containing the same total thickness of each metal.

It was shown that this improvement, presumably due to the multilayer construction, is roughly equivalent to that predicted by the wave-theory analysis of Schelkunoff.[2] However, the Schelkunoff formulae have been found inexact in certain other test conditions, and the absence of an intuitive explanation of the phenomenon casts doubt on the generality of the above conclusions. The purpose of this article is to suggest a mechanism consistent with the test results previously obtained.

SHIELDING MECHANISMS

Three separate phenomena contribute to the effectiveness of any shield.

- **Conductive Reflection.** Eddy currents are induced in a conductor penetrated by a time-varying magnetic field. These currents produce a magnetic field of their own in the opposite direction to the imposed field, and thereby reduce the total field beyond the shield.
- **Magnetic Reflection.** Magnetic flux lines produced by the transmitting antenna are diverted by ferromagnetic shields to paths which do not link the receiving antenna.
- **Conductive Energy Absorption.** Eddy currents give rise to resistive heating in a conductor and thereby reduce the energy of the imposed field. (This energy is responsible for the "skin effect" phenomenon, by which the amplitude of a field is exponentially attenuated as it penetrates below the surface of a thick conductor.

EFFECT OF MULTIPLE LAYERS

The near-field test apparatus employed in the experiments of Reference 1 contains circular coaxial transmitting and receiving coils. The shield was placed at a distance of 3.5 cm from the transmitting coil, and 0.5 cm from the receiving coil. (The results, indicating improved shielding associated with multilayer construction, are similar to those obtained by others employing different geometries.)

MAGNETIC SHIELDING

Since the conductive energy absorption or attenuation due to energy loss within the metal is not dependent upon any conditions outside the metal except the frequency of the wave attenuated, an explanation is needed for the conductive and magnetic reflection phenomena, the reflections of energy caused by the interfaces between air and metal, and between the copper and ferromagnetic layers of the composite.

MULTILAYER SHIELDING

When a three-layer composite material composed of copper and permalloy (42% nickel) layers is exposed to a magnetic field, reflections occur at four interfaces: air-copper, copper-alloy, alloy-copper, and copper-air. A monometallic shield, on the other hand, occurs at two interfaces: air-metal and metal-air.

Reflection phenomena are commonly analyzed in terms of the change of impedance at an interface, such as the junction between a 50-ohm cable and a 75-ohm cable. The equivalent of the cable impedance in a shielding context is the impedance of the wave in a given medium.

It is well known that the impedance of a plane wave in air, (the ratio of the electric field vector, E, to the magnetic field vector, H), is 377 ohms resistive. However, the near-field of a coil antenna is very far from a plane wave and exhibits a very much lower wave impedance. This impedance was approximated by Schelkunoff as $Z_w = j\omega\mu_0 r$, where ω is the angular frequency of the wave, μ_0 is the permeability of free space, and r is the distance between the antenna and the point at which wave impedance is to be measured. This relatively low impedance, which implies that the magnetic field is large compared to the electric field, is the reason that such fields are commonly called "magnetic" fields, as opposed to the "electric" field of a dipole antenna.

In a metal, on the other hand, the wave is nearly always approximately a plane wave and its impedance is given by $Z_{metal} = (1 + j)\rho/\delta$, where ρ is the resistivity of the metal, and δ is the penetration depth in the metal. $\delta = k\sqrt{\rho / \mu f}$ where μ is the magnetic permeability of the metal and f is the frequency of the wave.

Table 1 shows the wave impedance in air, copper and the 42%-nickel alloy for some typical frequencies and conditions. At

FREQUENCY	3 kHz	10 kHz	30 kHz	100 kHz
Z_{air}	j0.83	j2.8	j8.3	j28
R_{42}	4.9	9.0	15.6	28
R_{Cu}	0.015	0.027	0.047	0.085

TABLE 1. *Wave Impedances in Different Media (milliohms; in metals, $Z = (1 + j)R$).*

all frequencies, the 42% nickel alloy has an impedance approximately 300 times larger than that of copper. On the other hand, the alloy's impedance can be fairly comparable to that of the arriving magnetic wave. The fact that the impedances of all metals are very low compared to 377 ohms explains the excellent shielding against plane waves afforded by relatively thin sheets of metal.

We now see the advantage of a composite shield: it provides a large change of impedance at each of the four interfaces, and hence, maximum reflection. When the components are tested separately, reflection takes place at the two surfaces of the copper sheet, but little reflection occurs at the surfaces of the alloy. The three-layer composite then provides the same shielding due to energy loss as does its component parts, but greatly increases attenuation at the two surfaces of the ferromagnetic layer. (This explanation is also in agreement with the observed fact that an alloy-copper-alloy shield is usually less effective than copper-alloy-copper.)

CONCLUSION

Although the exact analysis is very complex and the best equations for predicting shielding effectiveness are not agreed upon by all researchers, it seems reasonable to conclude that the observed

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THE FIELD SITE SOURCE ...
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the radiation from the EUT. In the near field the radiation is very sensitive to the physical configuration of the cables and peripherals of the EUT. What are the chances of two independent labs having *exactly* the same physical set-up?

Another factor affecting comparison of measurements between sites is randomness. One example concerns a power supply. A master clock (250 kHz) internally synchronized two board-level clocks (125 kHz). Due to the method by which the circuit was implemented, either board-level clock would sync to the first or second pulse of the master clock at start-up. There was a 50-percent chance of the board level clocks starting up out of phase. After many re-starts, a consistent 4 dB variation was observed due to phasing of the clocks. Essentially, the measured conducted emissions were binary random variables. In asynchronous digital systems with no synchronizing, emissions can vary more dramatically.

SUMMARY

A standard field site source is the hardware equivalent of a test specification: a standard to ensure repeatability. A highly stable and repeatable field source is ideal for performance verification of radiated emissions measurements at one site or between sites. For laboratories serious about quality control, a standard field site source is an essential tool.

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impinging on a metallized filament encounters multiple thin layers of metal often separated by dielectric filaments. Double layers of shielding materials separated by a dielectric layer have shown to provide greater shielding than a single layer of the same material with equal total thickness.*

Given the natural variation in air permeability of fabrics, which depends on pore size and fabric thickness, and the predicted sensitivity of the shielding effectiveness of metallized fabrics to those same parameters, sizable sample-to sample variation in shielding effectiveness is to be expected. This should be borne in mind when evaluating product performance reproducibility.

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*In-house measurements of metallized fabrics.

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effectiveness of copper-alloy-copper shields is due to increased reflection at the boundaries between the metal layers.

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