BASIC SHIELDING THEORY

WHAT A SHIELD DOES

A shield reduces the EM field strength. It has no effect on the frequency or wavelength and any changes in field impedance are important to EMI control only if there are two or more shields. When a shield contains EM energy the field strength outside the shield will be markedly reduced by the shield; and conversely when the shield excludes EM energy it markedly reduces the field strength inside the shield.

Shielding is measured and specified in terms of the reduction in field strength caused by the shield. Thus, when a shield is evaluated, two measurements are required; the field strength with the field strength without the shield. The shielding achieved is the change in field strength. The unit of shielding is the decibel (dB) which is defined as:

$$\text{db} = 20 \log \frac{E_1}{E_2} \quad \text{For a change in volts/meter}$$

$$\text{Or dB} = 20 \log \frac{H_1}{H_2} \quad \text{For a change in ampers/meter}$$

$$\text{Or dB} = 10 \log \frac{P_1}{P_2} \quad \text{For a change in watts/m}^2$$

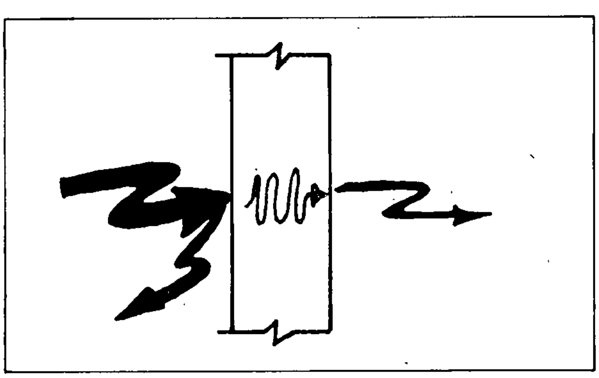
HOW A SHIELD WORKS

A shield contains (or excludes) electromagnetic energy by reflecting or absorbing the energy as shown schematically in Figure 1. Whenever EM energy passes from one medium into another, a portion is reflected. Note that the reflection occurs at the interface. The energy not reflected at the air-to-shield interface goes into the shield. Whenever EM energy passes thru a conductive material, some of it is absorbed due to I^2R losses from induced currents. Absorption occurs in the shield. The total shielding (s) possible from a material is the amount the field strength is reduced due to reflection (R) plus the amount the field strength is reduced by absorption (A):–

$$S = R + A$$

(This formula disregards secondary interface reflections which can be done whenever $A > 10$ dB).

FIGURE 1



ABSORPTION

The amount of EM energy absorbed by a shield depends on:
–Impinging field's frequency only.
–Shielding material's thickness, conductivity, and permeability.

Absorption is computed from:

$$A = 3.34\, t \sqrt{FG\mu}$$

Where:

A = Absorption in dB.
t = Thickness of shield in .001 inches.
F = Frequency in MH_Z
G = Conductivity relative to copper.
μ = Relative magnetic permeability

To show the practical implications of this, the amount of shielding due to absorption only for 1/32" thick copper, aluminum, and steel are shown in Figure 2. The 1/32" thickness was used because mechanical considerations seldom allow the use of a thinner shield. Thus above a few megahertz any metal shield thick enough to be mechanically suitable will also be electrically suitable. Note that the amount of shielding due to reflection hasn't even been considered.

Shields that are thicker than 1/8" are generally mechanically unsuitable because of weight, difficulty in forming, etc. Figure 3 clearly shows that additional absorption is gained by using 1/8" thick metals but below 1 MHz copper or aluminum may not be thick enough to provide enough absorption. The amount of shielding due to reflection must be added to get the full picture.

FIGURE 2

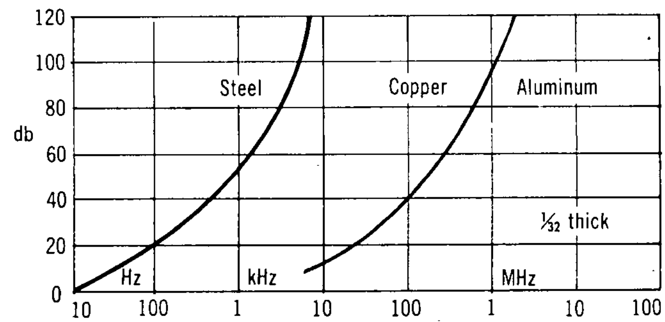
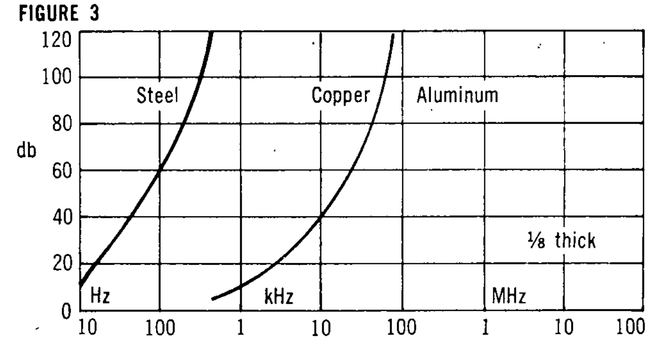


FIGURE 3



REFLECTION

Unfortunately the reflection of EM energy by a shield is not as easy to compute or explain as absorption. Often EE shielding theoreticians and mechanical designers of enclosures that must shield, have a bad case of "communications gap" here. We hope this explanation will close this gap to some extent.
Some electromagnetic energy is reflected at the surface of the shield.
It is reflected because the shield does not accept all the energy that arrives at the shield. The energy that doesn't go into the shield has to go somewhere and the only place it can go is back away from the shield.
Impedance of the electromagnetic field as it arrives at the shield determines how much of it will be reflected as shown by:

$$R = 20 \log \frac{Zw}{4Zs} \qquad (2)$$

Where:

R = Reflection in dB.
Zw = Impedance of the wave at the shield.
Zs = Impedance of shield which in all practical shield problems.
<<ZZw

A high wave impedance field will have more reflection than a low impedance field.

Wave impedance has already been defined as the ratio of electric field intensity to magnetic field intensity (Zw = E), thus if a source is designed to generate an EM field with a high electric component and a weak magnetic component at the source, it would be called an "Electric Field."

A rod antenna connected to a high voltage RF generator would be such a source (Figure 4). The heavy field lines show schematically that the E field is more intense than the thin magnetic field at the source. A loop antenna connected to a generator with a high RF current output (Figure 5) would generate an intense magnetic field (heavy field lines) and a weak electric field (thin gray field lines). It would be called a "Low Impedance Field" or a "Magnetic Field."

FIGURE 4

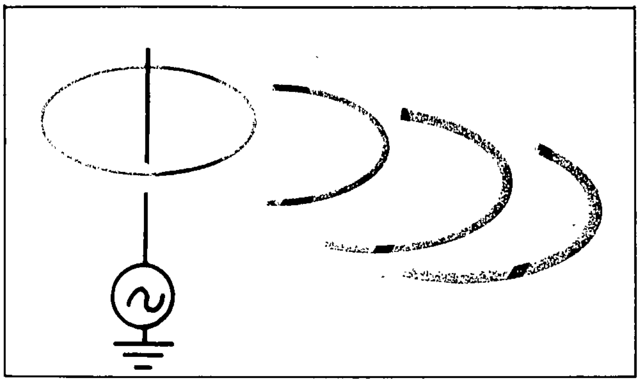
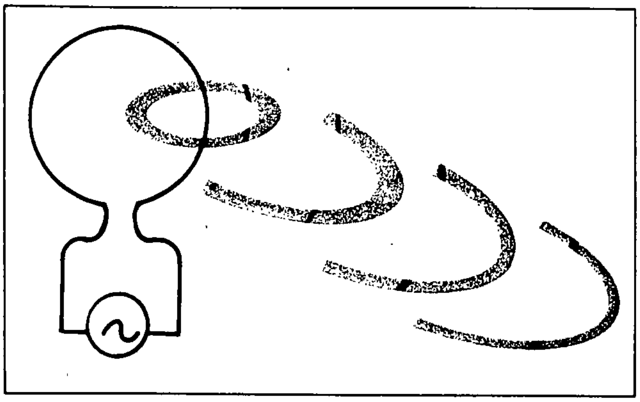


FIGURE 5



Three very important basic electromagnetic field principles should now be introduced.

1. All alternating **electric fields** gradually lose some of their intensity in generating a complementary **magnetic field.** Figure 4 shows this schematically by gradually reducing the width of the gray electric field lines while the green magnetic field lines increase proportionately.
2. All alternating magnetic fields gradually lose some of their intensity in generating a complementary **electric field.** Figure 5 shows this schematically by gradually reducing the green magnetic field and increasing the gray electric field lines.
3. At a distance of approximately one wavelength from either source, both fields will have the same "normal" impedance. In Figure 4 and 5 this is indicated by showing both fields from both sources with equal width field lines at a distance equivalent to one wavelength.

How much difference source impedance can make in the reflection portion of shielding is shown in Figure 6. It shows the reflection for EM fields from electric and magnetic sources 12 inches from the shield and for the same three metals used to show absorption in Figures 2 and 3. Thickness need not be shown because reflection occurs at the air-to-metal interface and is not effected by thickness provided the shield is at least a few mils thick. Reflection for plane wave field is shown for reference only since special antenna techniques would be required to generate a plane wave at the frequencies shown, only 12" from the source. Note that the H fields and E fields lines converge to the plane wave line as distance approaches one wavelength (see scale at top of curve).

FIGURE 6

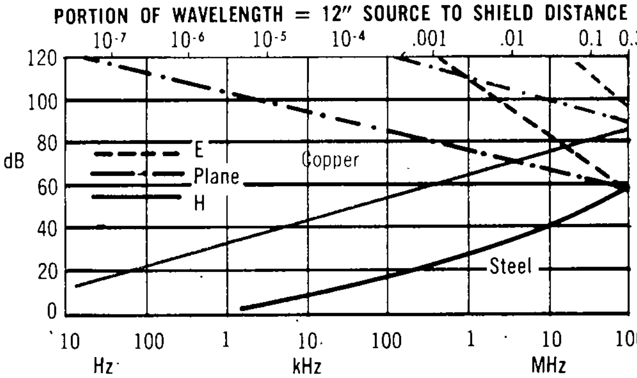
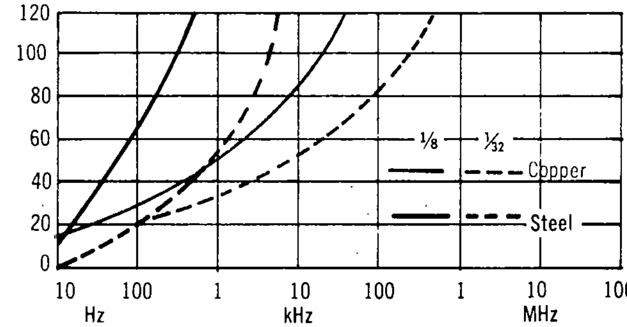


FIGURE 7



This curve also shows why low frequency E field shielding is seldom a problem; the reflection is much, much more than would ever be needed. Not so for the H field, its reflection becomes less and less at lower frequencies.

Attenuation plus Reflection—Figure 7 shows total shielding, attenuation plus reflection, of magnetic fields with a source-to-shield distance of 12" for copper, aluminum and iron; both 1/32" and 1/8" thick. Total shielding for all **plane wave** and **electric** fields is more than 120 dB for all three metals, both thickness and all frequencies . . . they couldn't even be shown on this curve.

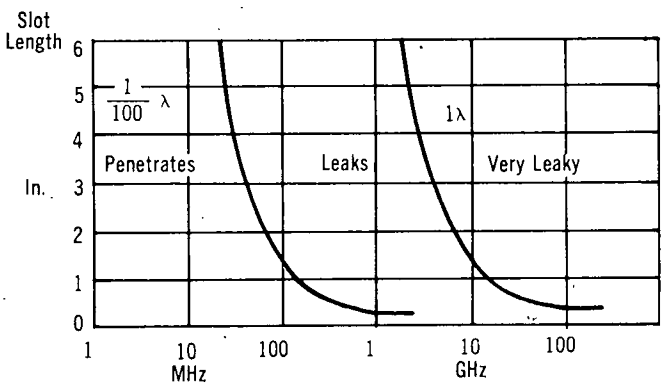
For low frequency magnetic field shielding, reflection is so small that total shielding can be increased mainly by increasing the EM energy absorbed by the shield which is:

$$A = 3.34t \qquad FG$$

Thus low frequency magnetic shielding is increased by:
–Increasing t, the shield thickness.
–Increasing G, the shield conductivity.
–Increasing *u*, the shield permeability.

Increasing the number of interfaces by having two or more successive shields to increase reflection may be ineffective for very low frequency magnetic field shielding because reflection is so small.

FIGURE 8



SHIELD DISCONTINUITIES

Solid, continuous shields as have been assumed to this point are seldom used in actual applications. Practical shields have discontinuities at covers, doors, panels, ventilating openings and panel hardware. Experience shows that these cracks and openings are often very leaky to EMI. Since any mechanically suitable metal enclosure will give more than enough shielding above 1 MHz (Figure 7), **all EMI leakage above 1 MHz is due to discontinuities.**

EMI Leakage from Discontinuities–The amount of EM energy that will leak from a discontinuity depends mainly on:
–Maximum length (not area) of the opening.
–The wave impedance.
–The wavelength of the EM energy.

Maximum Length rather than width of the opening is important because the voltage will be highest wherever the "detour" for the currents is longest. This is at the center of the slot and voltage increases as the length of the slot increases. The width has almost no effect on "detour" length, and as a consequence has little effect on the voltage. A useful analogy might be an incomplete dam in a river. If it is perpendicular to water flow, it will build up a back pressure and dam thickness is unimportant.

Wave Impedance is important because a low impedance wave will induce high currents, resulting in higher voltages. A high impedance will induce only weak currents.

Wavelength controls how much the "slot antenna" radiates. If the slot happens to be a 1/4 wavelength or longer, it will be a very efficient radiator; if it is less than 1/100 wavelength, it will be a rather inefficient radiator.

Therefore, slots only .001" to .005" wide but 1/100 wavelength or more long can be responsible for large leaks. Figure 8 shows wavelength and 1/100 wavelength vs. frequency for 0-6", slot lengths that can typically occur in normal metal enclosures. Combinations of frequency and slot lengths to the right of the 1/100 wavelength line would tend to be leaky, to the right of the 1 wavelength line they could be very leaky. This shows why discontinuities in shields, even if very narrow but a few inches long will severely reduce the shielding capability of an enclosure above 100 MHz.

THE dB–WHAT IT IS AND MEANS

Since the dB (decibel) is the universally used unit of measure for shielding, it is very important to clearly understand its meaning and to have a "feel" for its magnitude.

A dB compares two values, it is not a measure of one value. This is a basic concept which should be kept firmly in mind. In shielding it measures the **change** in field strength due to a shield not **absolute** field strength.

Often, in casual conversation, dB is used as though it measures actual field intensity . . .

Anyone that has made shielding measurements or has been closely associated with EMI work has acquired a natural feel for what 30 dB or 50 dB or even 100 dB means in a real world, practical way. The descriptions below are an attempt to impart some of this feel to those who have not yet acquired it. These descriptions are not in any way meant to be precise or all-inclusive but merely to help better understand the practical implications of the dB.

0 to 10 dB–This is very little shielding. An enclosure that reduces an EM field by this amount hardly deserves to be called a shield. The effects of the "shield" may be noticeable, but EMI, generally speaking, would not be eliminated.

10 to 30 dB–This would represent the minimum range for meaningful shielding. In mild cases, EMI would be eliminated. Shield design is very simple.

30 to 60 dB–This would be "average" shielding. It will solve all mild and some moderate EMI problems. Attention should be paid to good shield design. Measurement of shielding easy, even possible with ordinary equipment.

60 to 90 dB–This is above average shielding; it is required to solve moderate to severe EMI problems. Shield design is of primary importance in equipment housing design, other considerations become secondary. Measurement of shielding requires special instrumentation.

90 to 120 dB–Generally speaking this is the maximum possible with the best shielding designs. Measurements require instrumentation specifically designed for these measurements, and in some cases measurement is beyond present state-of-the-art.

Over 120 dB–Limit of the state-of-the-art (with some specific exceptions) for instrumentation and shield design.

(The above material has been furnished courtesy of the **Metex Corporation**)