Shielding for EMC

Good topological planning during the design phase is absolutely essential to ensure electromagnetic compatibility (EMC) in electronic equipment and installations. Topology may be likened to a geometric hierarchy of EM zones, ranging from an utterly unprotected environment to a completely "clean" one, such as a computer room or a rack in which all sensitive electronic circuitry has been enclosed within a tight metallic shield. Barriers installed between zones prevent unwanted disturbances from passing into protected areas, whether they be electromagnetic fields generated by intentional or unintentional radio transmitters, transients induced on power lines, electrostatic discharges, or other EM threats (see Figure).

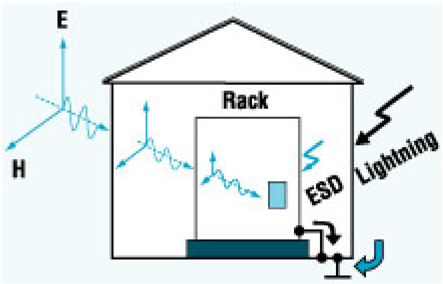
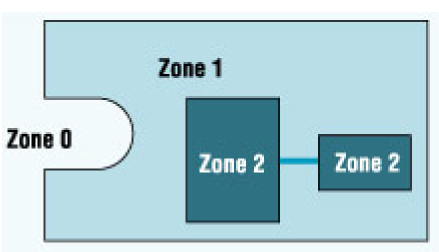


Figure 1. Shields are used to prevent unwanted EH-fields and other electromagnetic disturbances from entering a protected electromagnetic zone.

The Topological Approach

The EM topology approach requires the identification of the various electromagnetic zones created by an apparatus or installation, each of which must be separated by a geometrical or physical barrier (see Figure 2a). A geometrical barrier is essentially an open area in which existing electromagnetic fields will decay to an acceptable level; similarly, between two conductive elements, it may also be a distance that represents a capacitive coupling small enough to neglect the coupling path for transient disturbances. A physical barrier, in contrast, typically takes the form of a metallic shield that will either keep electromagnetic fields from penetrating into electronic circuitry or, conversely, keep radiated emissions produced by electronic circuitry from polluting the environment. Such shields can also protect against electrostatic discharges, as well as currents in the grounding system–provided, that is, that they are connected to ground/earth in such a way that any disturbances are shunted away from the sensitive electronics to be protected, as in Figure 1. Because shielding and grounding go hand in hand, it is vital that the latter be taken into account when the electromagnetic topology is configured (see Figure 2b). A few specific guidelines may be helpful here:



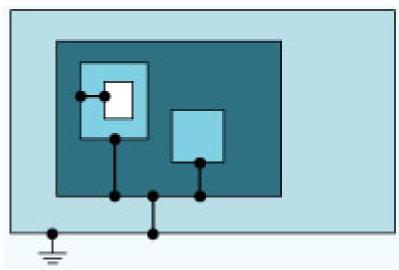


Figure 2a. Electromagnetic topology can be seen as a series of zones separated

Figure 2b. An inner screen shoud be connected with a by ground reference to the surrounding screen. Screens

geometrical or physical barriers	between zones that are not adjacent should not be connected.

• If EMI filters or transient-suppression components are used as a barrier to prevent conducted disturbances originating in one zone from propagating into another, they should always be placed at the border of the protected zone.
• A shielded cable must be carefully grounded in order to do its job effectively.
• Whenever a metallic screen separates two zones, all other barriers should be located as close as possible to that screen.
• A power-line filter with a shielded enclosure must be mounted in direct contact with the screen in order to provide adequate attenuation.

Screened rooms, metallic racks, and conductive chassis all constitute barriers designed to separate a "clean" electromagnetic zone from a more polluted one. Inner zones are often thought of as the cleaner ones, used to protect sensitive electronic circuitry, but the opposite may also be the case, as when a screened cover is employed to prevent emissions from a circuit with very high internal clock frequencies. Similarly, a frequency converter mounted in a rack may require a separate enclosure combined with filters to prevent interference that might disturb other apparatus in the rack.

Shielding Effects

The shielded room and the screened enclosure both exemplify Faraday's principle. To gain some insight into this physical effect without having to resort to field theory, let's take the example of a thin, conductive, spherical shell placed in an electric field (see Figure 3a). According to Faraday, we can expect the field inside the sphere to be almost zero. Why? Not because the shell has absorbed the field, but because the E-field has caused electrical charges of different polarity along the screen. These charges will, in turn, generate an electrical field that will tend to cancel the original field inside the shell. Because electrons can move easily along any conductive surface, the thickness of the shield is not in itself a significant factor.

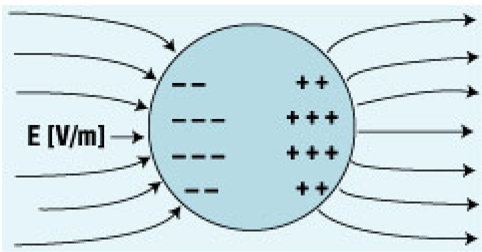


Figure 3a. Faraday's cage. A metallic spherical shell of good conductivity will eliminate the internal electrical field because induced charges tend to generate a second electrical field that cancels the original one.

When it comes to magnetic fields, Faraday's effect has no relevance, since there is no such thing as a magnetic charge. Magnetic-field attenuation can, however, be achieved by means of a screen made of a magnetic material combining high permeability ($\mu >> 1$) with sufficient thickness to attract the material's magnetic field by providing a low-reluctance path (see Figure 3b). Alternatively, as Figure 3c shows, a thin shield made of a conductive material with low permeability can also provide effective shielding for magnetic fields because an alternating magnetic field will induce so-called eddy currents in the screen (assuming, that is, that the shield has adequate conductivity). These eddy currents will themselves create an alternating magnetic field of the opposite orientation inside the shell. The effect will increase as frequency increases, resulting in high shielding effectiveness at high frequencies.

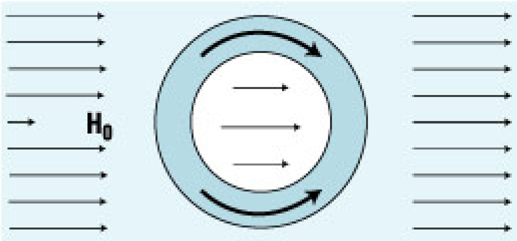


Figure 3b. A spherical shell of magnetic material with good permeability will reduce the field inside because the field tends to remain in the magnetic layer as it offers a low-reluctance path.

Low-frequency magnetic fields are more difficult to shield against. However, whereas absorption shielding typically calls for the installation of thick shields constructed of fairly expensive magnetic materials, shields based on the induced-current principle may be reasonably effective at power-line frequencies. Consequently, aluminum screens are commonly used to protect against 50- and 60-Hz magnetic fields generated by transformers and other sources.

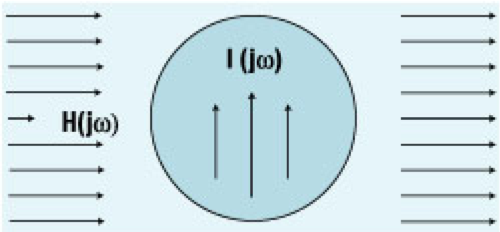
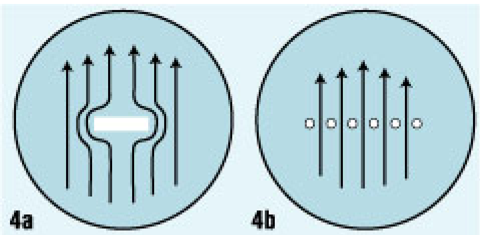


Figure 3c. A thin metallic shell of good conductivity will reduce an alternating magnetic field (ac) inside because the currents induced by the field tend to generate a field of opposite direction from the original.

Any apertures or breaks in a shield will limit its effectiveness. Since the theory behind magnetic-field shielding via induced currents presumes that such currents will flow as long as there are no obstacles in their path, it is essential that any and all apertures be arranged in such a way as to minimize their effect on the currents (see Figures 4a and 4b). Note, too, that apertures have HF resonances, so an (induced) HF current flowing on the screen can cause the aperture to act as a transmitting antenna.



Figures 4a and 4b. Apertures may prevent induced currents from promoting shielding effectiveness. They can also act as transmitters for certain HF frequencies related to their resonance frequency

Closed screening is one kind of electromagnetic barrier.Another kind may consist of a sort of open generalized screening representing the attenuation of the electromagnetic coupling between two zones. For example, a vertical metallic plane positioned in the path of a horizontally propagating electromagnetic field will provide a generalized screening effect for electronics located in the "shadow" on the other side. Yet another example is the ground plane on a printed circuit board or on the ground floor in a computer room. Both will reduce the coupling of an environmental electromagnetic field into any cables and/or strips placed close to them, creating a protective zone extending some distance above the plane or floor. This generalized screening may yield an attenuation of up to about 30 dB per 10 dB shielding effectiveness for electronic circuitry mounted on a printed circuit board or for a computer system with cables placed close to the computer room floor. The reason for this is that the E-field tends to "hit" a conductive ground plane at right angles, rendering it impossible for the field to induce an electric potential along cables running parallel to the screen. Likewise, because an H-field located near a metallic surface tends to have its predominant field component parallel to the surface, it will be unable to induce currents into a cable loop placed close to the shield. Keeping cabling as close as possible to a reference ground plane is therefore a very effective means of achieving a generalized screen.

Shielding in Practice

In order to be effective, a shield must be as tight as possible. The presence of intentional–and, inevitably, unintentional–apertures (e.g., everything from doors, windows, ventilation holes, and inlets for panel instrumentation to seam gaps and cable throughputs) will lower the shielding effectiveness of a screen. Figures 5a and 5b illustrate how a magnetic and an electric field, respectively, will pass through a hole and induce interfering currents or voltages on an underlying cable; as the figures show, disturbances will be induced in the cable whenever an H-field surrounds it or an E-field falls along it.

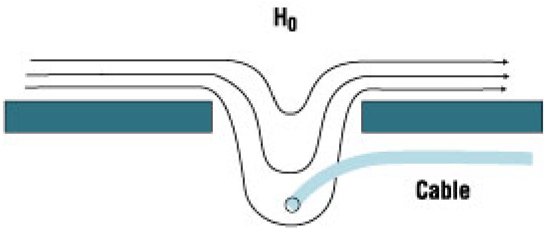


Figure 5a. An H-field, which is predominantly tangential close to a metallic screen, may penetrate through an opening and introduce an induced current into an underlying cable.

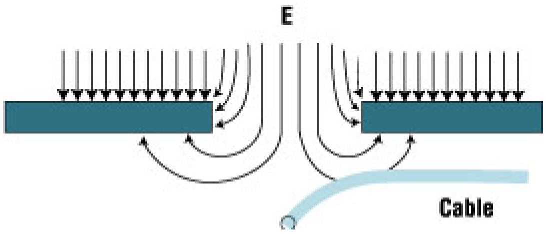


Figure 5b. An E-field, which will hit a metallic screen at right angles, may penetrate through an opening and enable an induced voltage to run along an underlying cable.

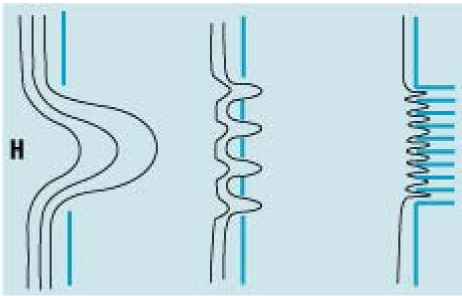


Figure 6. Multiple small openings are preferable to a single large one. Note that multiple

waveguides may be very effective in stopping fields at frequencies well below their cutoff frequency.

As Figure 6 makes clear, multiple small apertures will provide better protection than a single large one. A window with multiple waveguides (i.e., a "honeycomb" window) can be an effective tool for preventing EM fields where the cutoff frequency of those fields is considerably higher than the frequency span of the electromagnetic field. In such cases, the field will not be able to penetrate very long if the diameter is small compared to the wavelength. The remaining shielding effectiveness at a distance d [m] behind a hole of diameter D [m] can, for frequencies with a wavelength λ>>D, be approximately calculated as:

20 dB at d/D $\approx$1

40 dB at d/D $\approx$2

60 dB at d/D $\approx$5

It is best not to allow any opening larger than about λ/30. For effective screening of electromagnetic fields with frequencies up to 1 GHz, apertures should be no bigger than 1 cm. A good illustration of the importance of aperture size is seen in the difference between the attenuation provided by a shielded room constructed of a homogenous material (e.g., with walls of 6 mm aluminum), at about 100 dB, and that given by a simple mesh-shielded enclosure such as a "chicken net," with openings measuring about 0.5 mm diam, at about 40 dB for EM fields up to 1 GHz.

If a hole in a shielded room is to be used to allow a length of plastic tubing to pass through (as for a water or an air inlet), a mechanical waveguide may be used as a filter for electromagnetic waves with frequencies well below its cutoff. Such a cutoff filter may take the form of a circular or rectangular tube (see Figure 7). Note, however, that the attenuation will decrease with frequency and become zero at the cutoff.

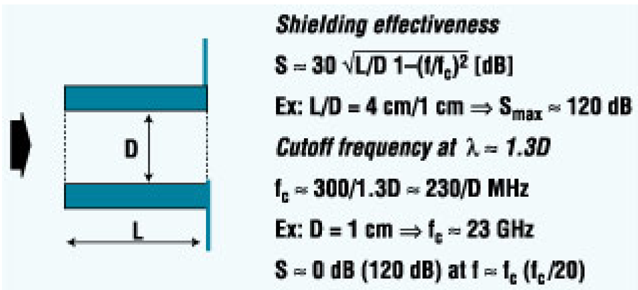


Figure 7. Typical characteristics of a circular waveguide below its cutoff frequency.

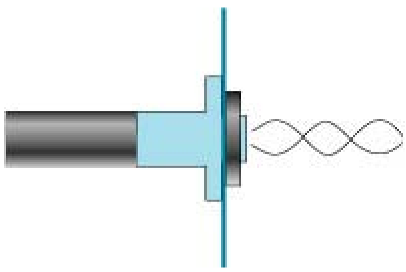
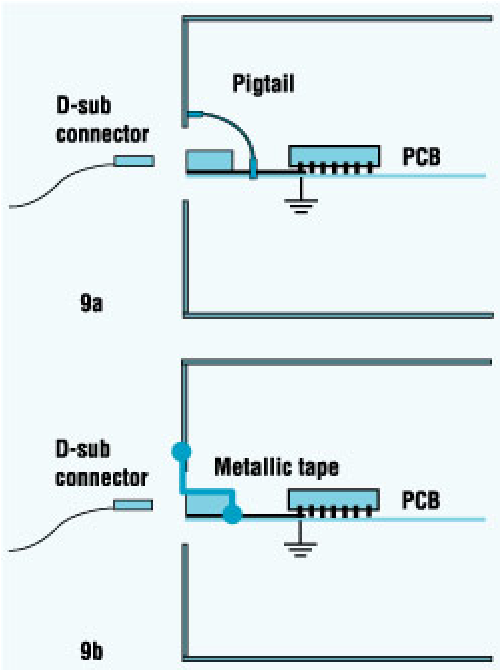


Figure 8. A cable shield should be fitted to the enclosure wall as tightly as possible.

Establishing proper protection requires an awareness of the EM topology and efficient use of appropriate barriers. The topology must not be compromised by holes cut into the barrier to permit cable screens or separate grounding cables to pass through, as such holes will allow ground currents to slip into the protected zone. All screenings should be grounded at the barrier to prevent the introduction of unwanted disturbances. The grounding, like the shielding, should be as tight as possible. Shielded connectors with full peripheral coverage (i.e., 360°) afford the best protection (see Figure 8), but simpler arrangements may suffice depending on the particular threat posed. When a shielded connector must be grounded to a chassis, for example, tight metallic tape may provide much greater shielding effectiveness than a simple pigtail connection (see Figures 9a and 9b). A capacitor connected between the signal line and the screen, or a feed-through capacitor mounted in the screen itself, can be employed to shunt away HF disturbances superimposed on the signal line. If a number of cables are to be connected to a shielded apparatus, a feed-through plate with efficient connectors and filters should be used.



Figures 9a and 9b. A shielded D-sub connector tightly grounded to the chassis by means of metallic tape may afford much better shielding effectiveness than a simple pigtail connection.

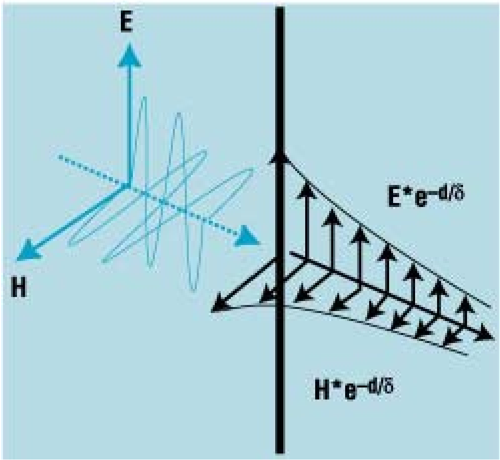


Figure 10. The absorption loss in a screen decreases exponentially and is reduced by 1/e at a distance d equal to the penetration depth

Shielding Theory

Shielding theory is based on two fundamental mechanisms, reflection loss and absorption loss. Figures 10 and 12 illustrate the principle involved in placing a metallic barrier in the path of an electromagnetic plane wave propagating with orthogonal E and H vectors. The E- and H-field components are related by the wave impedance, which is defined by the ratio of the tangential field components, so that

Z = E / H

In free space, the wave impedance is

$$Z_0 = \sqrt{\mu_0/\varepsilon_0} = 120\pi = 377[\Omega]$$

where,

μ0 = 4π 107/ε0 = 109/36π

A metallic screen, however, has much lower impedance:

$$[Z_s] = \sqrt{\omega\mu/\sigma[\Omega]}$$

μ = μrμ0 is the permeability;

= r 0 is the dielectric constant;

σ is the conductivity [1/Ωm or "mhos/m"]; and

ω= 2πf = 2πc0/λ,

where

f is the frequency [Hz];

c0 = 3 • 108 is the speed of light [m/s];

and λ= c0/f = 300/fMHz is the wavelength [m]

This implies an impedance mismatch for the wave, which therefore causes reflections. The remaining field is transmitted through the barrier after partial absorption by the metal. The electric-field component is reflected predominantly when it has to pass into a medium with lower impedance (at the first surface), while the magnetic component is reflected when it must pass into a medium with higher impedance (the second surface). Between the two surfaces there will be multiple reflections, which may be overlooked if the absorption loss in the barrier is at least 10 dB.

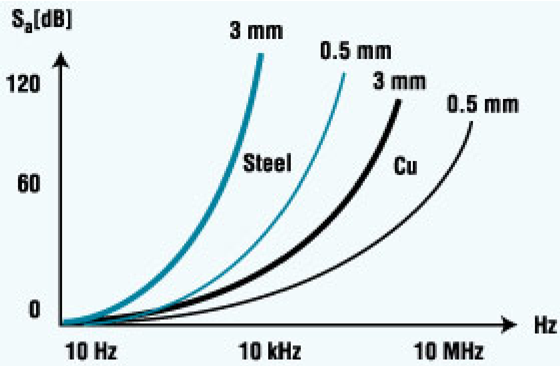


Figure 11. Absorption loss for an EH-wave as a function of frequency for a steel and a copper shield, respectively, of 0.5 and 3 mm thickness.

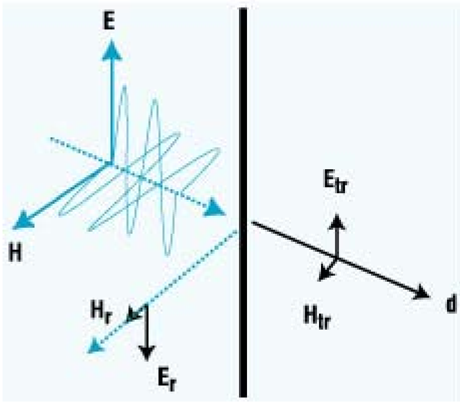


Figure 12. The reflection loss for an EH wave will depend on the ration of the free space impedance Z0 to the impedance in the screen Zs.

The absorption loss of a plane wave passing through a metallic shield at a distance d (see Figure 11) may be calculated as follows:

$$S_a = 11d\sqrt{f\mu_r \mu_0 \sigma} \rightarrow S_A \sim 9(d/\delta)\ [dB]$$

where δ is the skin depth–that is, the penetration depth at which the strength of the field will have decayed to 1/e:

$$\delta = \sqrt{2/\omega\mu_r\mu_0\sigma[m]}$$

This results in A1 (μr = 1; σ= 38•106)

δ= 12 mm at 50 Hz, and

δ= 0.1 mm at 1 MHz.

The absorption loss SA increases with frequency and is typically >100 dB above 1 MHz. The reflection loss, meanwhile, is

$$S_r \approx Z_0/4Z_s = Z_0/4\sqrt{\omega \mu_r \mu_0/\sigma}$$
$$\rightarrow S_R \sim 168 + 10\log(\sigma/\mu_r f)\,[dB]$$

The reflection loss decreases with frequency and is normally about 100 dB at 1 MHz; the total loss (if multiple reflections in the shield are neglected) is S = SaSr = SA[dB] + SR[dB].

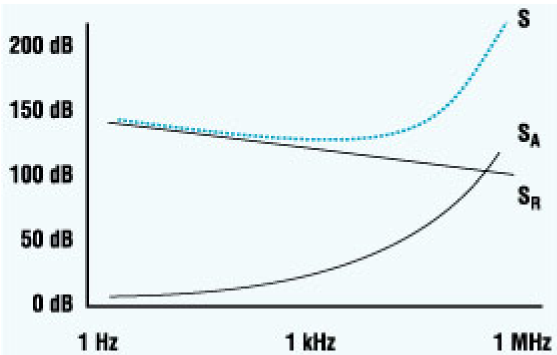


Figure 13. The total loss is the sum of the absorption and the reflection losses (multiple reflections neglected).

Figure 13 shows that the shielding effectiveness for a plane wave is typically no less than 100 dB in the MHz region. For a large metal screen of thickness t, the total loss can thus be calculated as:

S = SaSr ≈0.35 • (λ/2πμrδ) • $et/^{\delta}$ (t > δ)

S = SaSr ≈(t/¶) • (λ/2πμrδ) (t < δ)

A thin spherical shield, in contrast, will produce a loss of:

S = SaSr ≈(t/δ) • (2r/3μrδ) (t > δ)

(where r = equivalent radius and t = thickness)

In the case of a multiple-laminated shield, the total reflection and absorption losses may be seen as, respectively, the sum of reflection losses at each surface and the sum of attenuation losses in each layer.

Near-Field Conditions

Plane-wave conditions assume that the field is fully developed (E/H = Z0 = 377 Ω), which is the case if the distance from the radiation source is great enough. This is called the far-field region. The amplitude of the E-field and H-field, respectively, decreases in the far-field region as 1/r– that is, the E- and H-field is reduced 20 dB (10 dB) if the distance r is increased 10 times (3.3 times).

In the near-field region, by contrast, the ratio between E and H is complex and varies with the distance from the source. A high-impedance source antenna (e.g., a dipole antenna) will produce a near field dominated by E (E/H >> Z0), while a low-impedance antenna (e.g., a current loop) will yield a near field dominated by H (E/H << Z0). At a distance of $\lambda/2\pi$, the wave impedance will approach Z0 and the field will start to decrease linearly with distance when r $\approx \lambda/2$.

In the near field, the shielding effectiveness must be regarded separately for the electric and the magnetic fields.

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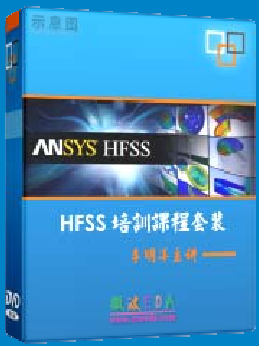

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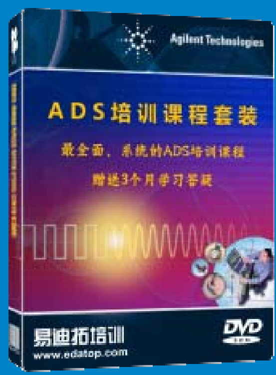

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