Module 15: Shielding

15.0 Introduction

A shield is a conducting partition or barrier that is used to inhibit the propagation of electromagnetic fields from one region of space to another. Shields are generally used in one of two ways:

1. Shields may be used to contain EM fields. Sources of EM interference may be enclosed by shields to protect systems outside the shield.

2. Susceptible systems or circuits may be enclosed by shields used to keep EM fields out of a particular region.

- Shielding noise sources is generally more efficient than shielding receptors, but this is not always possible, as is the case with intentional radiators.

- Shielding is of little value if fields are allowed to couple out of, or into the shielded region.

- Power and signal cables must be filtered if they penetrate shielded enclosures.

15.1 Near and far fields

Characteristics of an EM field are dependent on

1. behavior of the source

2. medium in which the source is embedded, and through which EM waves propagate

3. distance from the source to the observation point.

- Close to the source, field properties are heavily influenced by the characteristics of the source.

- Far from the source field properties depend on the medium through which EM waves propagate.

Because of this, the space surrounding a source of EM energy is broken into two regions

1. Near (induction) zone – region from the surface of the source region to about $\lambda/2\pi$ from the source.

2. Far (radiation) zone – region from $\lambda/2\pi$ from the source to infinity.

The ratio E_t/H_t is the wave impedance Z_w.

- In the far zone $E_t/H_t \rightarrow$ approaches the intrinsic impedance of the medium in which the EM waves are propagating.

- In the near zone, the ratio E_t/H_t depends on characteristics of the source and the distance from the source to the point of observation.

  i. Near a high current, low voltage source, the magnetic field tends to dominate ($E_t/H_t < 377\,\Omega$ in free space).

  ii. Near a low current, high voltage source, the electric field tends to dominate ($E_t/H_t > 377\,\Omega$ in free space).

15.2 Shielding effectiveness

Shielding effectiveness is determined by the reduction in magnetic/electric field strength caused by the shield (usually expressed in dB).

- For electric fields

$$\text{shielding effectiveness} = S = 20\log_{10}\frac{E_0}{E_1} \text{ dB}$$

where

E_0 = magnitude of electric field incident on the shield
E_1 = magnitude of electric field transmitted through the shield at the point where it emerges from the shield.

- For magnetic fields

$$S = 20 \log_{10} \frac{H_0}{H_1} \quad dB$$

where

H_0 = magnitude of magnetic field incident on the shield
H_1 = magnitude of transmitted magnetic field at the point where it emerges from the shield.

Shielding effectiveness depends on many factors
- properties of the shield material
- number and type of discontinuities such as holes or seams
- geometry of the shield
- frequency of incident EM fields
- direction and polarization of incident fields

Consider a shield consisting of a plane sheet of conducting material. An EM wave which is incident on this shield is partially reflected at the surface. The remainder of the wave attenuates as it propagates through the shield material.

The total shielding effectiveness of a material is given by

$$S = A + R + B \quad dB$$

Here

A = absorption loss due to attenuation of EM waves in shield material

R = reflection loss due to the portion of the EM wave reflected from the surface of the shield

B = correction factor due to multiple reflections which occur in thin shields

The multiple reflection factor B may be neglected if the absorption factor is high.

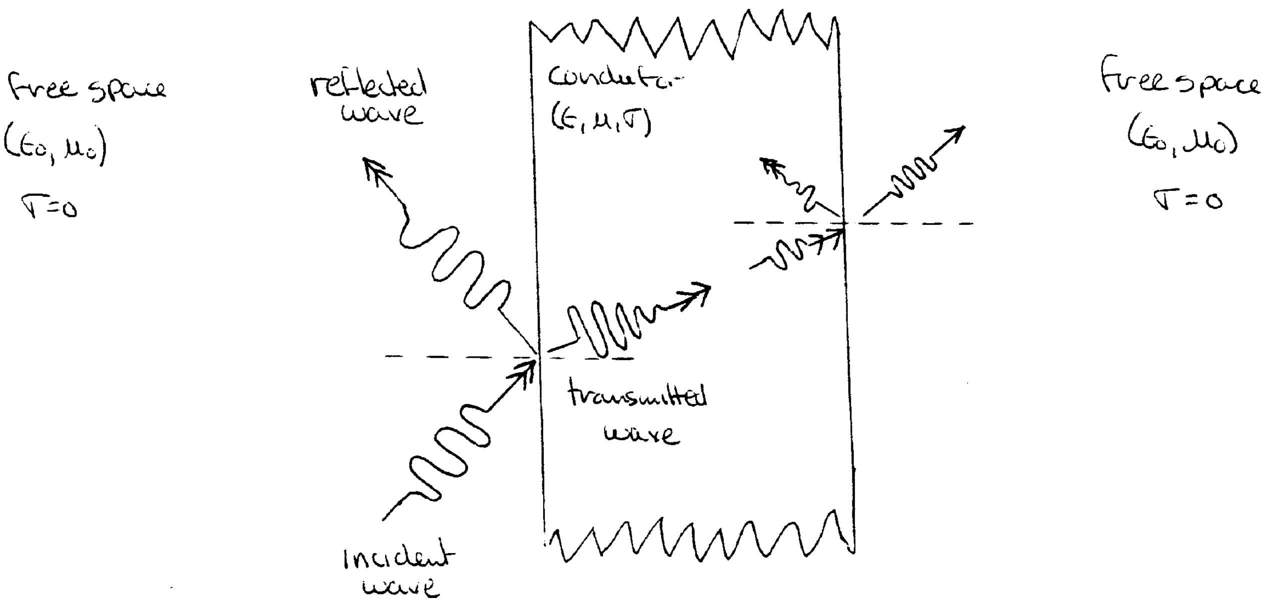

Figure 1. Planar conducting shield.

• absorption loss

As an EM wave propagates through the lossy shield material, the wave attenuates (the wave amplitude decreases). This attenuation is due to ohmic losses. The EM wave interacts with the shield material in such a way that some of the energy carried by the wave is converted to heat. As a result

$$E(t) = E_o e^{-t/\delta}$$

$$H(t) = H_o e^{-t/\delta}$$

where E(t) and H(t) are electric and magnetic field amplitudes (respectively) at a distance "t" from the surface of the shield, E_o and H_o are the incident electric and magnetic field amplitudes at $t=0$ and δ is the skin depth

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \cdot$$

Frequency	Copper (in.)	Aluminum (in.)	Steel (in.)
60 Hz	0.335	0.429	0.034
1 KHz	0.082	0.105	0.008
1 MHz	0.003	0.003	0.0003
10 MHz	0.0008	0.001	0.0001
100 MHz	0.00026	0.0003	0.00008
1000 MHz	0.00008	0.0001	0.00004

Figure 2. skin depths for various frequencies and materials

• <u>reflection loss</u>

Consider a plane wave which is normally incident from a region of free space onto a planar conductive region. Assume that the interface between the regions lies in the $z=0$ plane.

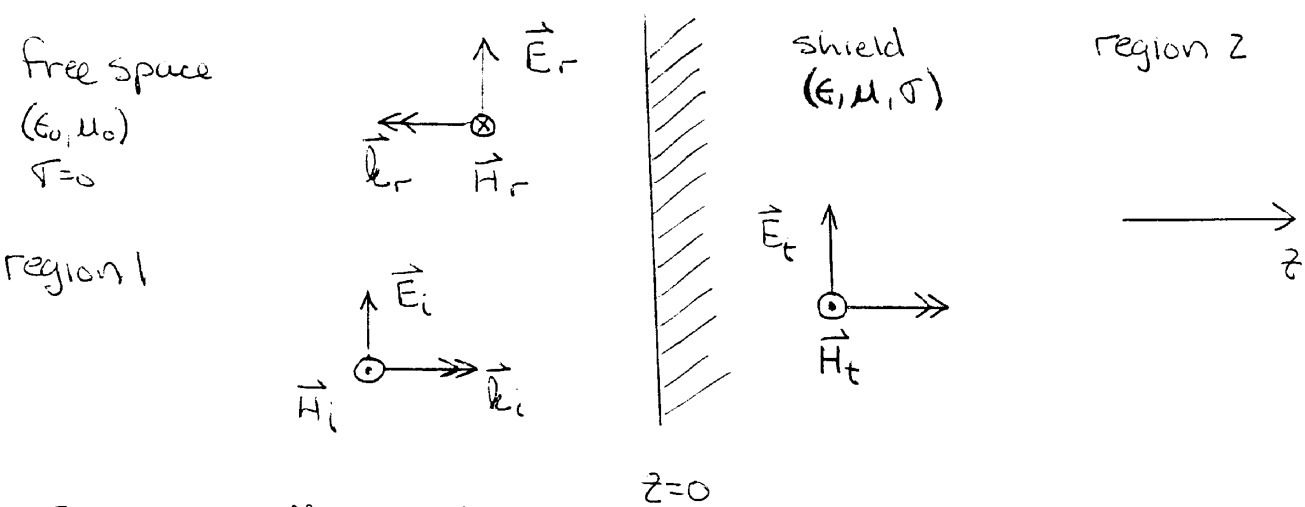

Figure 4. Normally incident plane wave.

Here the incident electric and magnetic fields are given by

$$\vec{E}_i(z) = \hat{x} E_{io} e^{-j\beta_1 z}$$

$$\vec{H}_i(z) = \hat{y} \frac{E_{io}}{\eta_1} e^{-j\beta_1 z}$$

where η_1 is the intrinsic impedance of region 1. The incident wave is partially reflected back into region 1 and partially transmitted into region 2. The reflected wave consists of electric and magnetic fields given by

$$\vec{E}_r(z) = \hat{x} E_{ro} e^{j\beta_1 z}$$

$$\vec{H}_r(z) = -\hat{y} \frac{E_{ro}}{\eta_1} e^{j\beta_1 z} .$$

The transmitted wave consists of electric and magnetic fields given by

$$\vec{E}_t(z) = \hat{x}\, E_{to}\, e^{-j\beta_2 z}$$

$$\vec{H}_t(z) = \hat{y}\, \frac{E_{to}}{\eta_2}\, e^{-j\beta_2 z} .$$

Boundary conditions at the interface between region 1 and region 2 require that the tangential components of electric and magnetic fields be continuous across the interface. Therefore at $z=0$

$$\vec{E}_i(0) + \vec{E}_r(0) = \vec{E}_t(0) \qquad \text{or} \qquad E_{io} + E_{ro} = E_{to}$$

$$\vec{H}_i(0) + \vec{H}_r(0) = \vec{H}_t(0) \qquad \text{or} \qquad \frac{1}{\eta_1}(E_{io} - E_{ro}) = \frac{E_{to}}{\eta_2} .$$

Solving these gives

$$E_{ro} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}\, E_{io}$$

$$E_{to} = \frac{2\eta_2}{\eta_1 + \eta_2}\, E_{io}$$

The ratios E_{ro}/E_{io} and E_{to}/E_{io} are the reflection and transmission coefficient, given by

$$\Gamma = \frac{E_{ro}}{E_{io}} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}$$

and

$$T = \frac{E_{to}}{E_{io}} = \frac{2\eta_2}{\eta_2 + \eta_1} .$$

The magnitude of the electric field transmitted from region 1 to region 2 is given by

$$E_{to} = \frac{2\eta_2}{\eta_1 + \eta_2} E_{io}$$

and the magnitude of the magnetic field transmitted from region 1 to region 2 is given by

$$H_{to} = \frac{E_{to}}{\eta_2} = \frac{2}{\eta_1 + \eta_2} E_{io} = \frac{2\eta_1}{\eta_1 + \eta_2} H_{io} .$$

When a wave passes through a planar shield, such as that shown in Figure 1, it encounter two interfaces, one between free space and the shield and the other between the shield and free space. From the analysis above, the wave transmitted from free space into the shield is given by

$$E_{t1} = \frac{2\eta_s}{\eta_s + \eta_o} E_{io}$$

and

$$H_{t1} = \frac{2\eta_o}{\eta_s+\eta_o} H_{io}$$

where

η_o = wave impedance in free space
η_1 = wave impedance in shield material

Neglecting absorption loss, the wave which is transmitted completely through the shield, and emerges again into free space is given by

$$E_{tf} = \frac{4\eta_o\eta_s}{(\eta_o+\eta_s)^2} E_{io}$$

and

$$H_{tf} = \frac{4\eta_o\eta_s}{(\eta_o+\eta_s)^2} H_{io}.$$

Assuming that $\eta_o \gg \eta_1$ gives

$$E_{tf} = \frac{4\eta_s}{\eta_o} E_{io}$$

and

$$H_{tf} = \frac{4\eta_s}{\eta_o} H_{io}.$$

Neglecting multiple reflections, the reflection loss is given by

$$R = 20 \log_{10} \frac{\eta_0}{4\eta_s} \quad dB .$$

This expression represents reflection loss for a normally incident plane wave. If the wave is not normally incident, reflection loss increases with angle of incidence.

- <u>multiple reflections</u>

For thin shields, or shields made of materials with low absorption loss, waves may reflect several times inside the shield. This may have an effect on overall shielding effectiveness. For shields that are sufficiently thick and/or highly lossy, this effect is neglected.

15.3 Apertures

In practice, most shields are not solid, but rather may incorporate openings such as

- access covers
- doors
- holes for cables, ventilation, or switches
- joints and seams

Overall shielding effectiveness tends to depend more on type and numbers of apertures, than material characteristics.

Leakage from a shield discontinuity depends on

1. maximum linear dimension of the aperture
2. wave impedance
3. frequency of the source.

When an **EM wave** is incident on a conducting shield, currents are excited on the surface of the shield. These currents flow over the surface of the shield. A slot or aperature which interrupts this flow of current will act as an antenna. Fields will be excited across the gap which may radiate into **or** out of a region protected by the shield

- Generally, the more the path of currents flowing on the shield is interrupted, the greater the amount of radiation from the aperature. A long thin slot may radiate more than many tiny aperatures.

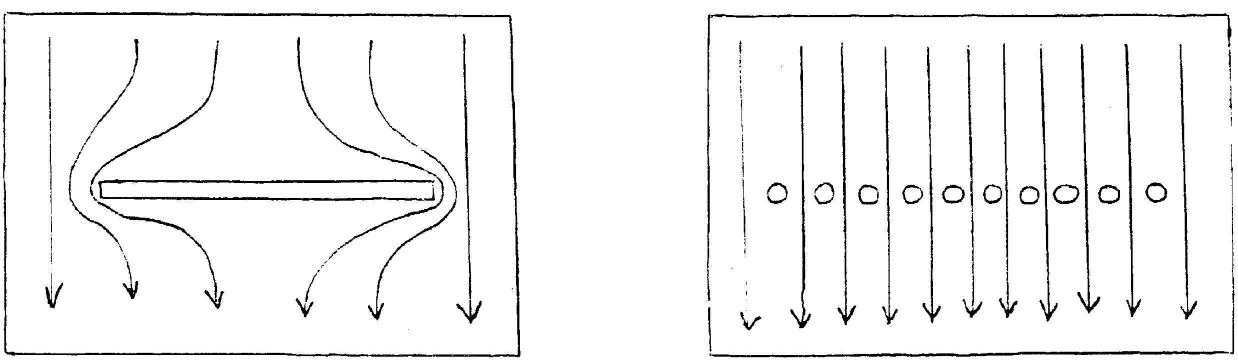

Figure Effect of aperatures on shield currents

- A large number of small holes will impact shielding effectiveness less than one large hole of the same total area.

- Like antennas, slots which are $\lambda/2$ long tend to radiate well.

- It is best to avoid openings in a shield which are more than 1/20 of a wavelength long.

- Material on both sides of a seam should be conductive. Good electrical contact should be provided at intervals small enough to provide the desired shielding effectiveness.

Attenuation can be obtained from a hole if it is shaped to form a wave guide. Closed-pipe waveguides have a certain cutoff frequency, ω_c, below which no EM waves will propagate. As long as the frequency of the incident field is below cutoff, and if the hole is sufficiently long, no EM energy will pass through.

The cutoff frequency of a waveguide with rectangular cross-section is

$$(f_c)_{mn} = \frac{v}{2}\sqrt{(m/a)^2 + (n/b)^2}$$

where m,n are modal indices and a,b are waveguide height and width. The cutoff frequency of a closed-pipe waveguide with circular cross-section is

$$(f_c)_{n\ell} = \frac{v\,p'_{n\ell}}{2\pi a}$$

where "a" is the radius of the waveguide, and $p'_{n\ell}$ is the ℓ^{th} root of

$$J'_n(p'_{n\ell}) = 0 .$$

References

Ott, H., "Noise Reduction Techniques in Electronic Systems," John Wiley & Sons, second edition, 1988.