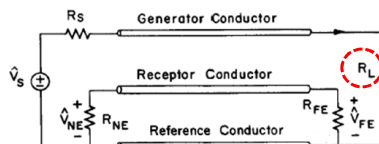
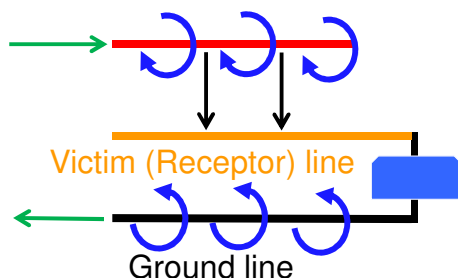


Techniques to Reduce Crosstalk

In previous classes we discussed the problem of crosstalk:

- a voltage and a current on the generator circuit will cause electric and magnetic fields to interact with a neighboring circuit (receptor) and induce noise or interference voltages at the terminations of the receptor circuit (V_{NE} and V_{FE}).
- These induced voltages may be of sufficient magnitude (or spectral content) to cause interference with terminating devices represented by R_{NE} and R_{FE} .

Disturbing (generator) line



$$\hat{V}_{NE} = j\omega(M_{NE}^{IND} + M_{NE}^{CAP}) + M_{NE}^{CI}$$

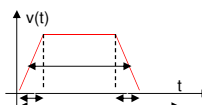
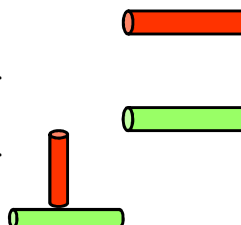
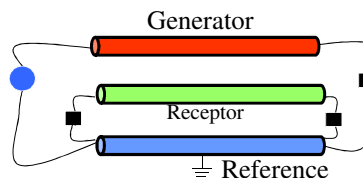
$$\hat{V}_{FE} = j\omega(M_{FE}^{IND} + M_{FE}^{CAP}) + M_{FE}^{CI}$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Techniques to Reduce Crosstalk (9.7&9.8)

The objective is to present ways to reduce the crosstalk in a three-conductor line. Suppose the near- or far-end crosstalk in the previous three-conductor line exceeds desired levels, causing interference with the terminations at the ends of the receptor circuit. Obvious ways to reduce that crosstalk:

- move the generator and receptor conductors farther apart
- route the generator's conductor perpendicular to the receptor's
- slow (increase) the pulse rise/fall times of the source to reduce the high frequency spectral content and hence the crosstalk.

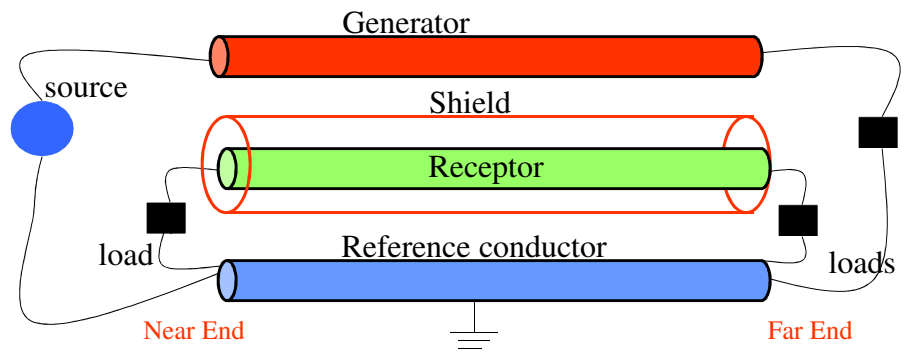
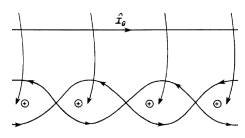


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Techniques to Reduce Crosstalk (Cont.)

For wire-type lines, two common methods to reduce the crosstalk: replace the generator and/or receptor wire with

- shielded wires (9.7) or
- twisted wire pairs (9.8)



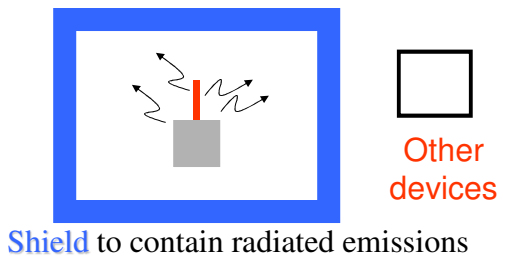
Before discussing these two techniques, let us introduce the concept of “**Shielding**”.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

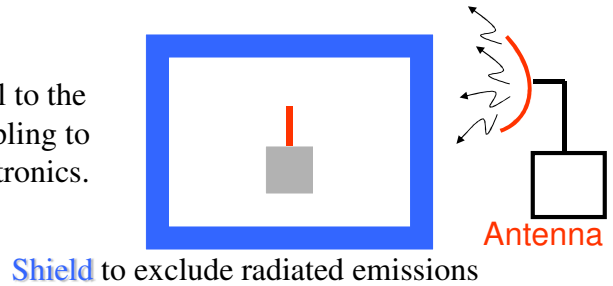
Shielding (Chapter 10)

Shield: A metallic enclosure that completely encloses an electronic product or a portion of that product.

- A shield serves as a barrier to the transmission of EM fields:
 - to prevent emissions by the product outside the boundaries of the product.



- to prevent radiated emissions external to the product from coupling to the product’s electronics.

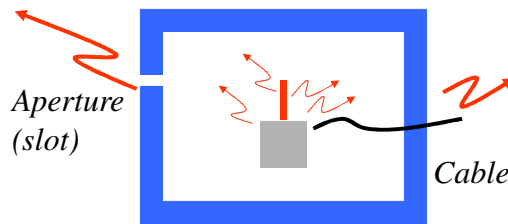
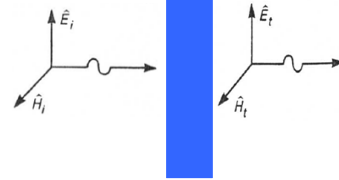


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding (Cont.)

Shielding Effectiveness:

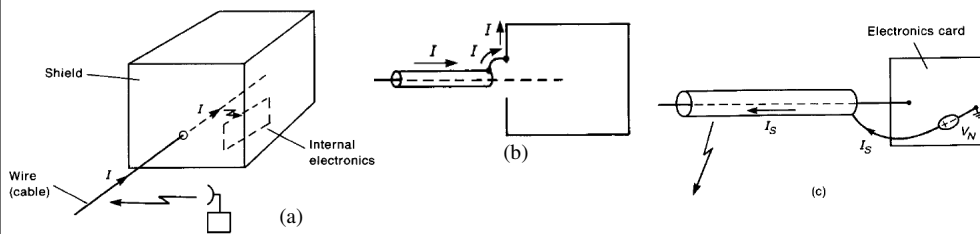
It is the ratio of the magnitude of the electric or magnetic field that is incident on the barrier to the magnitude of the electric or magnetic field that is transmitted through the barrier.



- The shield must completely enclose the electronics and have no penetrations such as holes, seams, slots or cables.
- Any penetrations unless properly treated reduce the effectiveness of the shield.
- We should provide filtering of cables at its entry/exit point.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding (Cont.)



Practical considerations that seriously degrade shielding effectiveness:

- (a) penetration of an enclosure by a cable allowing direct entry (or exit) of external (internal) fields;
- (b) pigtail termination of a cable shield at the entry point to a shielded enclosure;
- (c) termination of a cable shield to a noisy point, causing the shield to radiate.

To reduce the radiated emissions of the Cable, the shield must be attached to a zero-potential point (ideal ground).

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding effectiveness: Far Field Coupling

Assumes that the shield is in the far field of the source of the incident field. (Later we'll discuss near field sources coupling.)

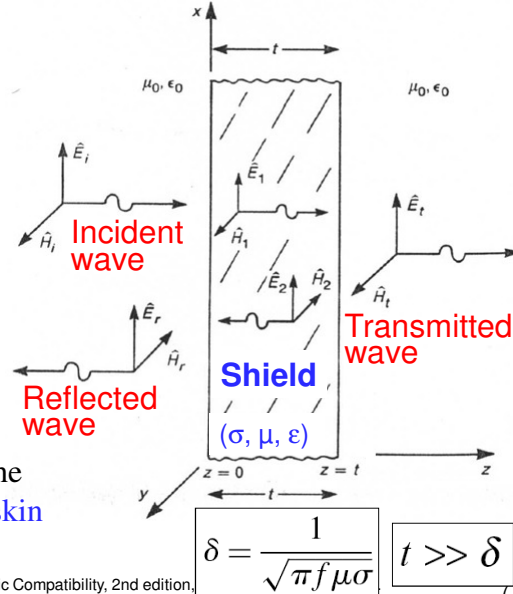
If incident field is a uniform plane wave and media on each side are identical, the shielding effectiveness (SE) is defined as:

$$SE = 20 \log_{10} \left| \frac{\vec{E}_i}{\vec{E}_t} \right|$$

$$SE = 20 \log_{10} \left| \frac{\vec{H}_i}{\vec{H}_t} \right|$$

We assume that the thickness of the shield (t) is much larger than the skin depth (δ) of the shield's material:

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition.



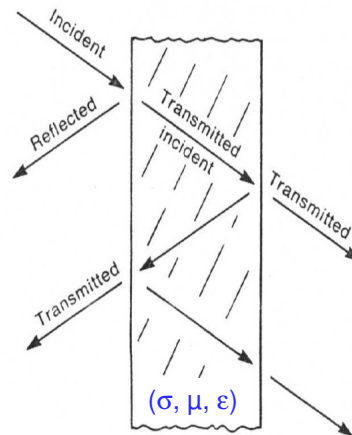
Shielding effectiveness (Cont.)

Exact expression for SE can be derived based on:

1. Solving Maxwell's equations
2. Applying Boundary conditions

The expression for the shielding effectiveness includes the effect of :

- ✓ reflection loss (R),
- ✓ absorption loss (A), and
- ✓ multiple reflections (M):



$$SE_{dB} = R_{dB} + A_{dB} + M_{dB}$$

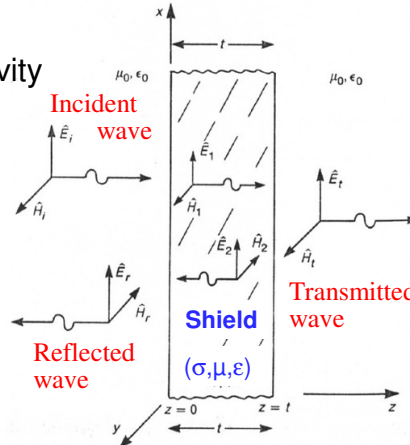
Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Far Field Coupling: Theory

- Consider a conducting shield of thickness t , conductivity σ , permittivity $\epsilon = \epsilon_r \epsilon_0$, and permeability $\mu = \mu_r \mu_0$.
- The medium on either side of the shield is free space with

$$\beta_0 = \omega \sqrt{\mu_0 \epsilon_0} \quad \eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$$

- Assume a uniform plane wave is incident on the left surface.
- Forward- and backward-traveling waves are generated in the left medium and in the shield.
- Only a forward-traveling wave is assumed in the medium to the right of the shield.



- In the shield:

$$\hat{\gamma} = \sqrt{j\omega\mu(\sigma + j\omega\epsilon)} = \alpha + j\beta$$

$$\hat{\eta} = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}} = \eta / \theta_\eta$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Far Field Coupling: Theory

The fields in the three different regions are given by:

1. Incident Fields:

$$\vec{E}_i = \hat{E}_i e^{-j\beta_0 z} \vec{a}_x$$

$$\vec{H}_i = \frac{\hat{E}_i}{\eta_0} e^{-j\beta_0 z} \vec{a}_y$$

2. Reflected Fields:

$$\vec{E}_r = \hat{E}_r e^{j\beta_0 z} \vec{a}_x$$

$$\vec{H}_r = -\frac{\hat{E}_r}{\eta_0} e^{j\beta_0 z} \vec{a}_y$$

3. Fields inside the shield:

$$\vec{E}_1 = \hat{E}_1 e^{-\hat{\gamma} z} \vec{a}_x \quad \vec{E}_2 = \hat{E}_2 e^{\hat{\gamma} z} \vec{a}_x$$

$$\vec{H}_1 = \frac{\hat{E}_1}{\hat{\eta}} e^{-\hat{\gamma} z} \vec{a}_y \quad \vec{H}_2 = -\frac{\hat{E}_2}{\hat{\eta}} e^{\hat{\gamma} z} \vec{a}_y$$

4. Transmitted Fields:

$$\vec{E}_t = \hat{E}_t e^{-j\beta_0 z} \vec{a}_x$$

$$\vec{H}_t = \frac{\hat{E}_t}{\eta_0} e^{-j\beta_0 z} \vec{a}_y$$

E_i is known and find the **Four unknowns**: (E_r , E_1 , E_2 & E_t) by applying the boundary conditions.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Far Field Coupling: Theory (Cont.)

Four unknowns:

$$\vec{E}_r, \vec{E}_1, \vec{E}_2 \text{ \& } \vec{E}_t$$

Boundary Conditions:

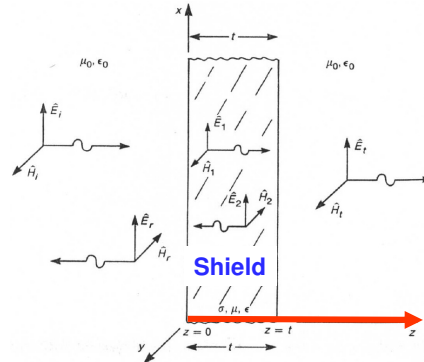
Continuity of the tangential E and H components on the left and right surfaces of the shield yields:

$$\vec{E}_i|_{z=0} + \vec{E}_r|_{z=0} = \vec{E}_1|_{z=0} + \vec{E}_2|_{z=0}$$

$$\vec{E}_1|_{z=t} + \vec{E}_2|_{z=t} = \vec{E}_t|_{z=t}$$

$$\vec{H}_i|_{z=0} + \vec{H}_r|_{z=0} = \vec{H}_1|_{z=0} + \vec{H}_2|_{z=0}$$

$$\vec{H}_1|_{z=t} + \vec{H}_2|_{z=t} = \vec{H}_t|_{z=t}$$



Then substitute from the four sets of equations from the previous slide to yield four equations in four unknowns.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Far Field Coupling: Theory (Cont.)

Solving the resulting four equations,

the ratio of incident to transmitted fields is:

$$\frac{\hat{E}_i}{\hat{E}_t} = \frac{(\eta_0 + \hat{\eta})^2}{4\eta_0\hat{\eta}} \left[1 - \left(\frac{\eta_0 - \hat{\eta}}{\eta_0 + \hat{\eta}} \right)^2 e^{-2t/\delta} e^{-j2\beta t} \right] e^{t/\delta} e^{j\beta t} e^{-j\beta_0 t} \quad \text{where } \alpha = 1/\delta$$

The middle term in the bracket represents the effect of multiple reflection in the shield at the two surfaces

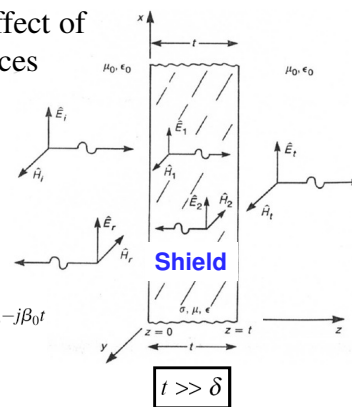
Special Case (Approximate Solution):

For a good conducting shield and for $t \gg \delta$, we can simplify the expression to

$$\frac{\hat{E}_i}{\hat{E}_t} = \frac{(\eta_0 + \hat{\eta})^2}{4\eta_0\hat{\eta}} \left[1 - \left(\frac{\eta_0 - \hat{\eta}}{\eta_0 + \hat{\eta}} \right)^2 e^{-2t/\delta} e^{-j2\beta t} \right] e^{t/\delta} e^{j\beta t} e^{-j\beta_0 t}$$

$\cong 1$ $\ll 1$
1st order approximation

$$= \frac{(\eta_0 + \hat{\eta})^2}{4\eta_0\hat{\eta}} e^{t/\delta} e^{j\beta t} e^{-j\beta_0 t}$$



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding effectiveness (Cont.)

Assuming that the barrier is constructed from a “good conductor” so that the intrinsic impedance of the conductor $\hat{\eta}$ is much less than that of free space η_0 , we can derive a simplified exact expression:

$$\left| \frac{\hat{E}_i}{\hat{E}_t} \right| = \left| \frac{(\eta_0 + \hat{\eta})^2}{4\eta_0\hat{\eta}} \right| e^{t/\delta} \cong \left| \frac{\eta_0}{4\hat{\eta}} \right| e^{t/\delta}$$

2nd order approximation

To express shielding effectiveness (SE) in dB, take the logarithm of the above result:

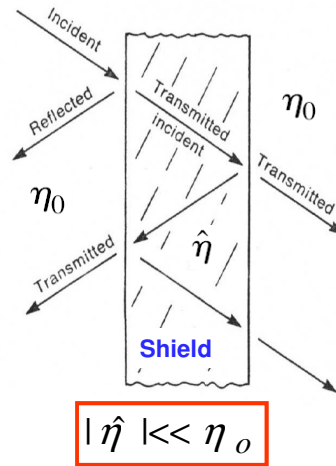
$$SE_{dB} \cong \underbrace{20 \log_{10} \left| \frac{\eta_0}{4\hat{\eta}} \right|}_{R_{dB}} + \underbrace{20 \log_{10} e^{t/\delta}}_{A_{dB}}$$

where R_{dB} is the reflection loss,
& A_{dB} is the absorption loss.

Note: In the above expression, we ignore the multiple reflection effect.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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Shielding effectiveness (Cont.)

Multiple reflections

The loss due to multiple reflections in the shield is not included in the previous simplified exact solution expression due to the assumption that the shield is a good conductor.

$$SE_{dB} \cong \underbrace{20 \log_{10} \left| \frac{\eta_0}{4\hat{\eta}} \right|}_{R_{dB}} + \underbrace{20 \log_{10} e^{t/\delta}}_{A_{dB}} + M_{dB}$$

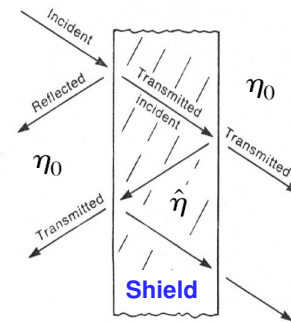
Where the multiple reflections loss coefficient M_{dB} is added and is given by the middle term of the expression for E_i/E_t (see slide #12).

$$M_{dB} = 20 \log_{10} \left| 1 - \left(\frac{\eta_0 - \hat{\eta}}{\eta_0 + \hat{\eta}} \right)^2 e^{-2t/\delta} e^{-j2\beta t} \right| \cong 20 \log_{10} |1 - e^{-2t/\delta} e^{-j2t/\delta}|$$

with $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$, $\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$ & $\hat{\eta} = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}} = \eta/\theta_n$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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Shielding effectiveness (Cont.)

The expressions for total loss (or *SE*) terms can be further simplified to:

$$SE_{dB} = R_{dB} + A_{dB} + M_{dB}$$

Where:

- **Reflection loss:**

$$R_{dB} = 20 \log_{10} \left(\frac{1}{4} \sqrt{\frac{\sigma}{\omega \mu_r \epsilon_0}} \right)$$

- **Absorption loss:**

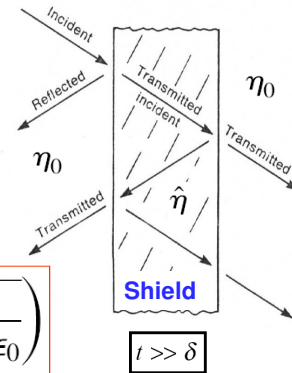
$$A_{dB} = 20 \log_{10} e^{t/\delta}$$

$$= 131.4 t \sqrt{f \mu_r \sigma_r} \quad (t \text{ in meters})$$

with : $\sigma_r = \sigma / \sigma_{cu}$, $\sigma_{cu} = 5.8 \times 10^7$ S/m

- **Multiple reflections loss:**

$$M_{dB} = 20 \log_{10} |1 - e^{-2t/\delta} e^{-j2t/\delta}|$$



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

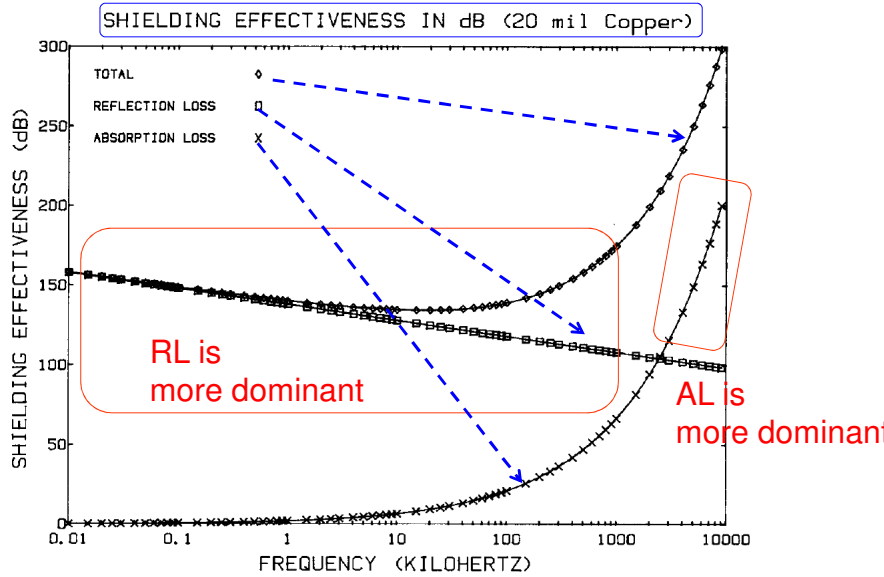
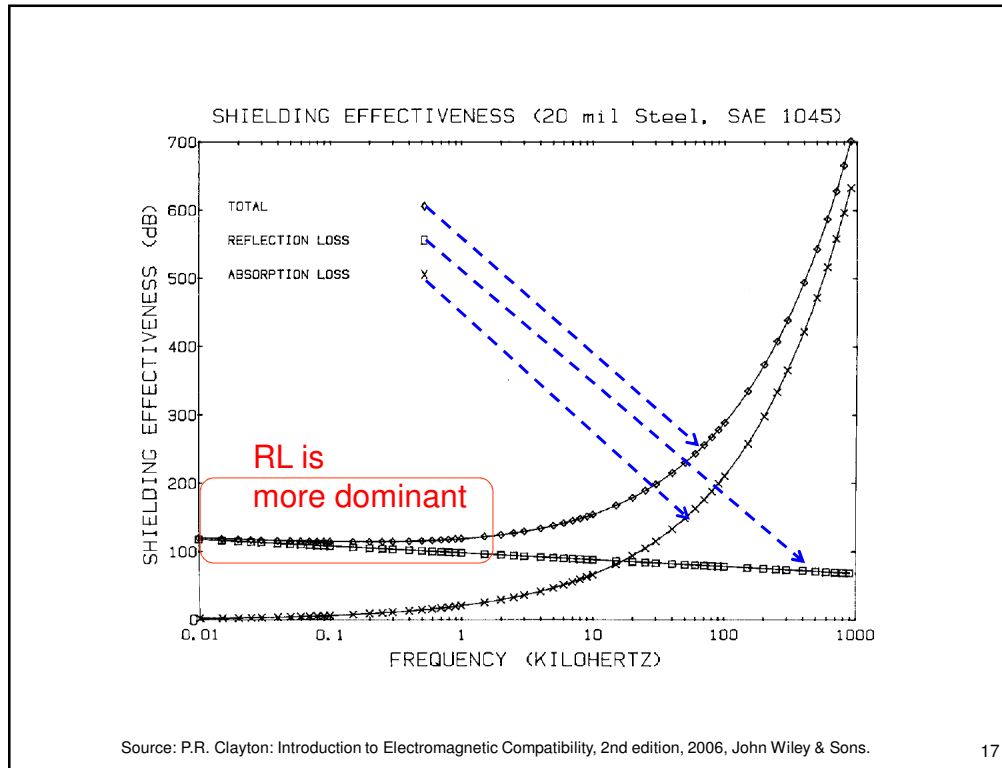


FIGURE 10.8 Shielding effectiveness of a 20 mil thickness of copper.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.



Example: Problem 10.2.3

Compute the electric field reflection coefficient (Γ) for an air-steel interface at 30 MHz, 100 MHz, and 1 GHz.

Compute the electric field transmission co-efficient (T) for an air-steel interface at 30 MHz, 100 MHz, and 1 GHz.

$$\Gamma = \frac{\hat{\eta} - \eta_o}{\hat{\eta} + \eta_o}, \quad T = \frac{2\hat{\eta}}{\hat{\eta} + \eta_o}$$

$$\hat{\eta} = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}} = \eta / \theta_\eta$$

$$\eta_o = 120 \pi \Omega$$

For steel, use $\sigma = 5.8 \times 10^6$ S/m, $\mu = 1000 \mu_o$ H/m

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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E vs H Attenuation

For no shield case:

$$\frac{\hat{E}_1}{\hat{E}_i} \approx \frac{2\hat{\eta}}{\eta_0 + \hat{\eta}} \quad \& \quad \frac{\hat{H}_1}{\hat{H}_i} = \frac{2\eta_0}{\eta_0 + \hat{\eta}} \rightarrow E_1 \approx 0 \text{ when } \hat{\eta} \ll \eta_0$$

For shield, ignoring attenuation loss.

$$\frac{\hat{E}_t}{\hat{E}_i} = \frac{4\eta_0\hat{\eta}}{(\eta_0 + \hat{\eta})^2} \quad \frac{\hat{H}_t}{\hat{H}_i} = \frac{4\eta_0\hat{\eta}}{(\eta_0 + \hat{\eta})^2}$$

Important difference:

- **E-Field transmission** The majority of the electric field that is incident on each interface is reflected → the primary transmission of the electric field occurs at the right interface.
- **H-Field transmission:** the primary transmission of the magnetic field occurs at the left interface,
 - The attenuation of H as it passes through the boundary is more important than is the attenuation of E.
 - This points out that “thick” boundaries have more effect on shielding against magnetic fields than electric fields

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons. 19

Shielding: Where are we?

Shielding Effectiveness:

$$SE = 20 \log_{10} \left| \frac{\vec{E}_i}{\vec{E}_t} \right|$$

$SE_{dB} = R_{dB} + A_{dB} + M_{dB}$

1. Far Field Sources
 - *Plane wave*
2. Near Field Sources
 - *Electric dipole*
 - *Magnetic dipole*

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons. 20

10.2.4 Compute the reflection loss and absorption loss for a 20 mil steel (SAE 1045) barrier at 30 MHz, 100 MHz, and 1 GHz, assuming a far-field source. [53.23 dB, 3656.6 dB, 48 dB, 6676.0 dB, 38 dB, 21,111 dB]

For steel, use $\sigma = 5.8 \times 10^6 \text{ S/m}$, $\sigma_r = 0.1$, $\mu_r = 1000$

$$R_{\text{dB}} = 20 \log_{10} \left(\frac{1}{4} \sqrt{\frac{\sigma}{\omega \mu_r \epsilon_0}} \right)$$

$$A_{\text{dB}} = 20 \log_{10} e^{t/\delta}$$

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

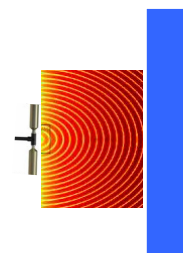
$$M_{\text{dB}} = 20 \log_{10} |1 - e^{-2t/\delta} e^{-j2t/\delta}|$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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Shielding effectiveness: Near Field Sources

- After considering the shielding effectiveness of a shield when it is located in the far field of the source, we will consider **sources located near the shield**.
- Analysis techniques depend on source type:
 - electric dipole or
 - magnetic dipole



Near field/far field criterion: *electric dipole wave impedance*

Consider an elemental (Hertzian) electric dipole: ↑

Far fields:

At sufficiently distant (at least three times the wavelength) points from the source, field resembled plane waves

- The far-field components are orthogonal.
- The ratio of these two fields is the intrinsic impedance of the medium: $E_{\theta}/H_{\phi} = \eta_0$
- Field components vary as the inverse of the distance: $1/r$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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Shielding effectiveness: Near Field Sources

Near field (Hertzian electric dipole):

- The wave impedance is defined as:

$$\hat{Z}_w = \frac{\hat{E}_\theta}{\hat{H}_\phi}$$

- And, the field components in this case vary with distance as: $1/r$, $1/r^2$, and $1/r^3$ (see chapter 7)

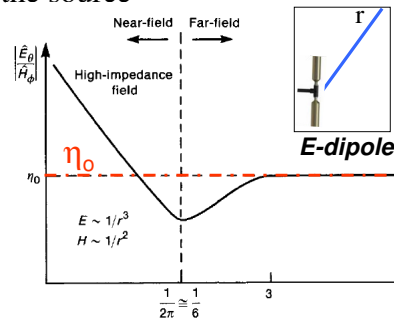
$$\therefore \hat{Z}_w = \eta_0 \frac{j/\beta_0 r + 1/(\beta_0 r)^2 - j/(\beta_0 r)^3}{j/\beta_0 r + 1/(\beta_0 r)^2} \cong \eta_0 \left(-j \frac{1}{\beta_0 r} \right)$$

$\beta_0 = \omega \sqrt{\mu_0 \epsilon_0}$ & r = the distance from the source

- Plot Z_w vs distance

- The wave impedance is greater than the intrinsic impedance of the medium.
- The Electric Dipole represents a **High Impedance** source.
- The magnitude of the wave impedance:

$$|\hat{Z}_w|_e = 60 \frac{\lambda_0}{r}$$



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding effectiveness: Near Field Sources

Near field: (magnetic dipole)

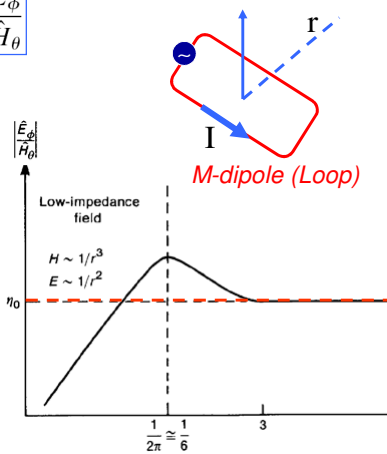
- the wave impedance (chapter 7):

$$\hat{Z}_w = \frac{\hat{E}_\phi}{\hat{H}_\theta}$$

$$\therefore \hat{Z}_w = -\eta_0 \frac{j/\beta_0 r + 1/(\beta_0 r)^2}{j/\beta_0 r + 1/(\beta_0 r)^2 - j/(\beta_0 r)^3} \cong -j\eta_0\beta_0 r$$

- Plot Z_w vs distance

- In the near field, the wave impedance is less than the intrinsic impedance of the medium.
- The Magnetic Dipole represents a **low Impedance** source.
- The magnitude of the wave impedance:

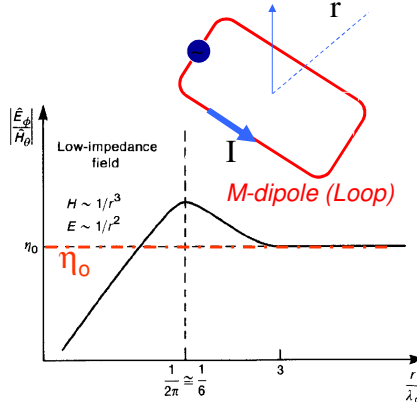
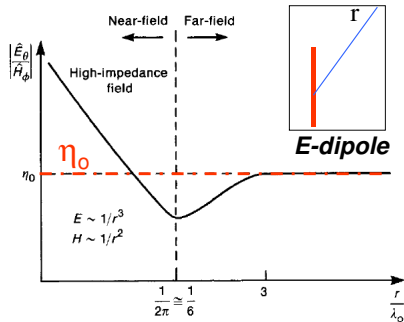


$$|\hat{Z}_w|_m = 2369 \frac{r}{\lambda_0}$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding effectiveness: Near Field Sources

Near field



In the near field, the wave impedance for the two elementary sources can be simplified (reduced) to:

Electric dipole

$$|\hat{Z}_w|_e = 60 \frac{\lambda_0}{r}$$

Magnetic dipole

$$|\hat{Z}_w|_m = 2369 \frac{r}{\lambda_0}$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Shielding effectiveness: Near Field Sources

- We will make use of the previous far field analysis to drive expressions for the near field sources *SE*

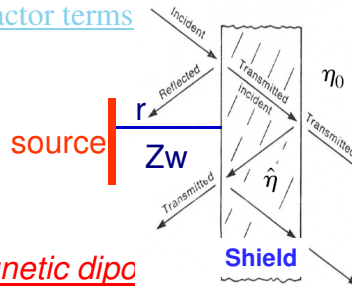
- The **absorption loss** term is unaffected by type of source

$$A_{dB} = 20 \log_{10} e^{t/\delta} \quad \delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

- **Reflection losses** are calculated by substituting the wave impedance for intrinsic impedance in the previous loss factor terms

$$R_{dB} = 20 \log_{10} \left| \frac{(\hat{Z}_w + \hat{\eta})^2}{4\hat{Z}_w \hat{\eta}} \right| \cong 20 \log_{10} \left| \frac{\hat{Z}_w}{4\hat{\eta}} \right|$$

Electric dipole



Where for: Electric dipole

$$R_{e,dB} = 322 + 10 \log_{10} \left(\frac{\sigma_r}{\mu_r f^3 r^2} \right)$$

Magnetic dipole

$$R_{m,dB} = 14.57 + 10 \log_{10} \left(\frac{f r^2 \sigma_r}{\mu_r} \right)$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

Example: Problem 10.3.2

Compute the reflection loss and absorption loss for a 20-mil steel (SAE1045) barrier at 10 kHz, 100 kHz, and 1 MHz for a **near-field electric source** that is a distance of 5 cm from the shield.

For steel, use $\sigma = 5.8 \times 10^6$ S/m, $\sigma_r = 0.1$, $\mu_r = 1000$

$$R_{e,dB} = 322 + 10 \log_{10} \left(\frac{\sigma_r}{\mu_r f^3 r^2} \right)$$

$$A_{dB} = 20 \log_{10} e^{t/\delta}$$

$$= 131.4t \sqrt{f \mu_r \sigma_r} \quad (t \text{ in meters})$$

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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Near Field Sources: Reflection losses

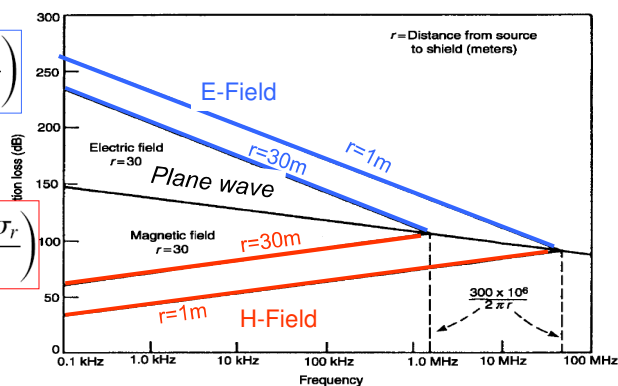
Effect of distance and frequency



➤ The reflection losses are given by

$$R_{e,dB} = 322 + 10 \log_{10} \left(\frac{\sigma_r}{\mu_r f^3 r^2} \right)$$

$$R_{m,dB} = 14.57 + 10 \log_{10} \left(\frac{f r^2 \sigma_r}{\mu_r} \right)$$



- The reflection losses for electric and magnetic field sources are shown for a **copper shield** and various distances from the source to the shield.
- The reflection loss for a plane-wave source is shown to illustrate the asymptotic convergence as the source-to shield distance is increased.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

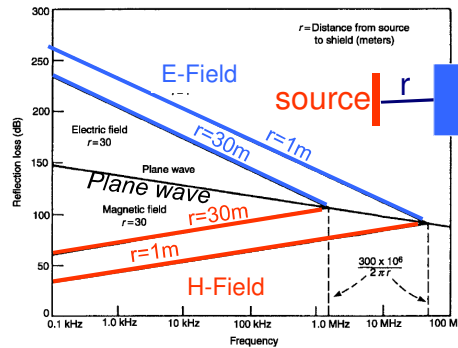
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Near Field Sources: Reflection losses

Observations

Electric dipole

$$R_{e,dB} = 322 + 10 \log_{10} \left(\frac{\sigma_r}{\mu_r f^3 r^2} \right)$$



- Observe in this figure that the reflection loss for near-field electric sources is considerably **higher** than for a uniform plane-wave source.
- It also increases with decreasing distance between source and shield.

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

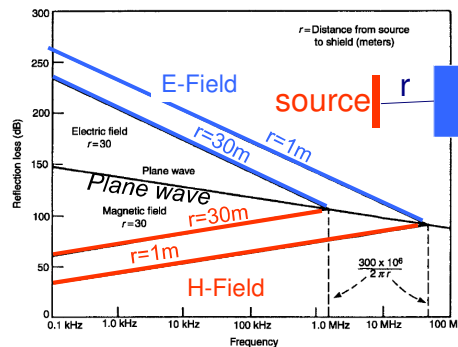


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Near Field Sources: Reflection losses

Magnetic dipole

$$R_{m,dB} = 14.57 + 10 \log_{10} \left(\frac{f r^2 \sigma_r}{\mu_r} \right)$$



- Observe that the reflection loss decreases for decreasing frequencies, and is **less than** for the plane-wave reflection loss. Consequently, reflection loss is usually negligible for lower frequencies.
- The absorption loss is small for low frequencies, so that other techniques must be used for **shielding against low-frequency, near-field magnetic sources**. (To be discussed next)

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.



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Low Frequency Magnetic Field Shielding

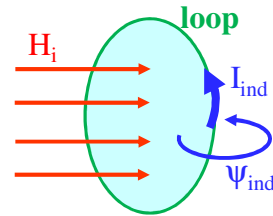
- **Absorption loss** is the dominant shielding mechanism for **near field magnetic source** at all frequencies
- **Two basic methods for shielding** low frequency magnetic sources.



Both represent situations where shielding can be effective in the reduction of the effect of low-frequency magnetic fields.

1. Generation of Opposing Flux Technique:

- A conductor loop such as a wire is placed such that the **incident magnetic field H_i** penetrates the surface bounded by **the loop**, thereby inducing, according to Faraday's law, a **current I_{ind}** in the loop, and associated **magnetic flux Ψ_{ind}** .
- This induced magnetic flux Ψ_{ind} is opposing the original incident magnetic field, and so the net magnetic field in the vicinity of the loop is reduced.

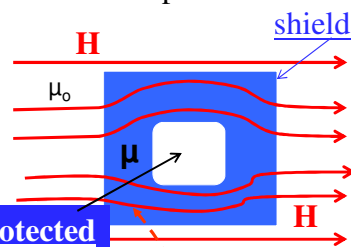


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons. 31

Low Frequency Magnetic Field Shielding (Cont.)

2. Flux Diversion Technique:

- Assuming the external medium is free space (μ_0) and the shield is constructed of a **ferromagnetic material** having $\mu \gg \mu_0$.
- The diversion of **magnetic flux** is due to a low-reluctance path due to the high permeability of the shield material.
- The magnetic field will tend to concentrate in the low-reluctance ferromagnetic path, and as such will be diverted from affecting the region interior to the shield.



- Two factors that may degrade the effectiveness of the flux **diversion technique** are:

- The permeability of ferromagnetic materials decreases with increasing frequency.
- The permeability of ferromagnetic materials decreases with increasing magnetic field strength.

$$\mathcal{R} = \frac{L}{\mu s}$$

σ	μ
I	Ψ
R	\mathcal{R}

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons. 32

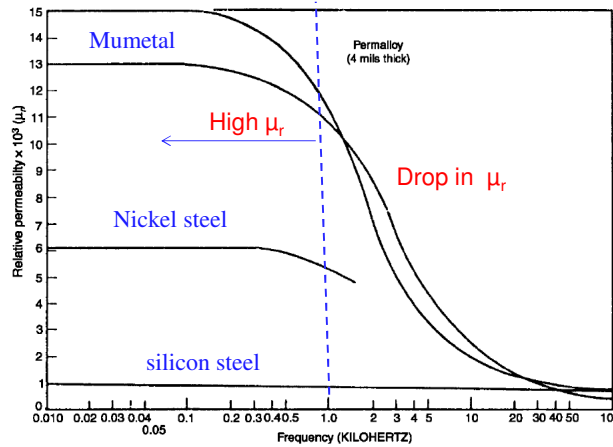
Flux diversion technique (Cont.)

Frequency Dependence of various ferromagnetic materials

- Shielding enclosures of switching power supplies (above 20 kHz) are constructed from steel (cheaper) rather than Mumetal (high permeability at low frequencies)

- For 60Hz interference, Mumetal is used if field strengths are not too large to *saturate the material*

- see the B-H curve, next slide.



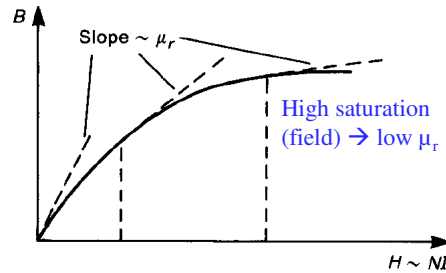
Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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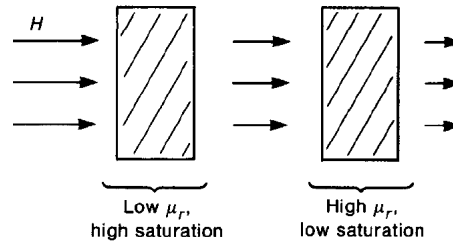
Flux diversion technique (Cont.)

- Slope of the B-H curve is proportional to the permeability of the material:

- Field strength should not be too high to reach saturation and results in a low μ_r



- To minimize potential saturation of the material, use two shields
- The first to reduce incident magnetic field so that it does not saturate the second shield

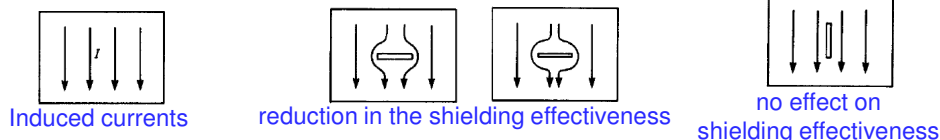
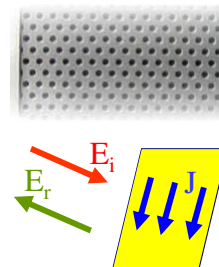


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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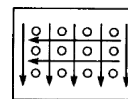
Shielding: Effect of Apertures

- Sometimes openings are required to ventilate the internal electronics for thermal reasons.
- The **incident field** induces a **surface current** which produces **the reflected field**.
- The **reflected field** should be of a polarity such as to cancel the incident field to satisfy the boundary condition.
- Current should be allowed to flow unimpeded
- Slots in the shield: Width of slot does not affect the flow of current.



- Large number of holes are required.

Many small holes provide as much ventilation as does one long slot, but perturb the induced current much less, thereby reducing the degradation caused by the aperture.

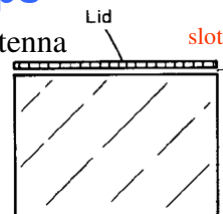


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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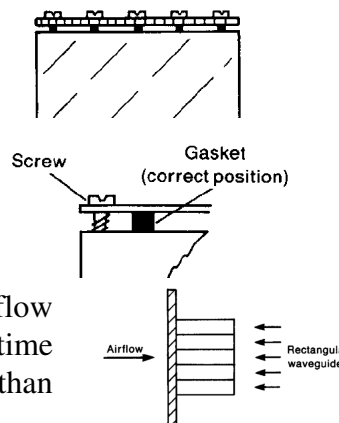
Shielding: Effect of Door Gaps

- A **gap** is produced around the door that acts as a slot antenna
- Gap may be small but radiation potential is quite large
- Length of the gap is more important than its thickness in determining radiated emissions of the gap
- Long gap has similar radiation to a dipole antenna:



To control radiated emissions:

- Screws are placed at intervals to break up the potential slot antennas
- Metallic gaskets are frequently used to close screw gaps
- Gaskets should be placed on the inside to prevent radiation from the screw holes
- Use waveguides below cutoff to allow airflow into a shielded enclosure and at the same time prevent the propagation of frequencies lower than the cutoff frequency into the enclosure.



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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