EM shielding

Electromagnetic shielding uses conducting materials that are placed between two circuits to either

- reflect EM energy away from the receiving circuits or
- attenuate the energy of the EM wave as it travels from source to receiver.

The effectiveness of a particular shield is defined in dB as

$$S = 20 \log_{10}\left(\frac{V_{ns}}{V_{sh}}\right) = A + R$$

V_{ns} ~ interfering voltage without shield

V_{sh} ~ interfering voltage with shield

Shielding effectiveness due to absorption (A)

In a conductor the amplitude of the electromagnetic wave decreases exponentially at a rate characterized by the attenuation constant.

$$E = E_o\, e^{-x/d}$$

The component of shielding effectiveness provided by attenuation is called the absorptive loss (A) and is measured by comparing the field with no shield to that with the shield.

$$A = 20 \log_{10}\left(\frac{E_o}{E_o e^{-t/d}}\right) = 8.69\frac{t}{d}$$

δ is "skin depth." It is a function of the material properties and frequency.

$$d = \sqrt{\frac{2}{wms}}$$

Here is the conductivity for several metals.

Silver	6.2×10^7 S/m
Copper	5.8×10^7
Aluminum	3.7×10^7
Brass (typ.)	1.6×10^7

Consider the absorptive loss for an aluminum sheet 1.5 mm thick and an aluminum coating 50 µm at several different frequencies.

Frequency	δ	A_{sheet}	$A_{coating}$
60 Hz	11 mm	1.19 dB	0.04 dB
1 kHz	2.6 mm	5.01	0.17
1 MHz	83 µm	157	5.2
100 MHz	8.3 µm	1570	52

In practice attenuation values in excess of 100 dB are not attainable

Shielding effectiveness due to reflections

Shielding effectiveness is not due solely to absorption—EM energy can also be reflected.

We can calculate the amount reflected if we know the shield's impedance.

$$Z_m = \sqrt{\frac{wm}{s}}$$

For aluminum

f	Z_m
60 Hz	3.58 µΩ
1 kHz	14.61 µΩ
1 MHz	461.9 µΩ
100 MHz	4.62 mΩ

The shielding effectiveness due to reflection can be calculated via the formula below.

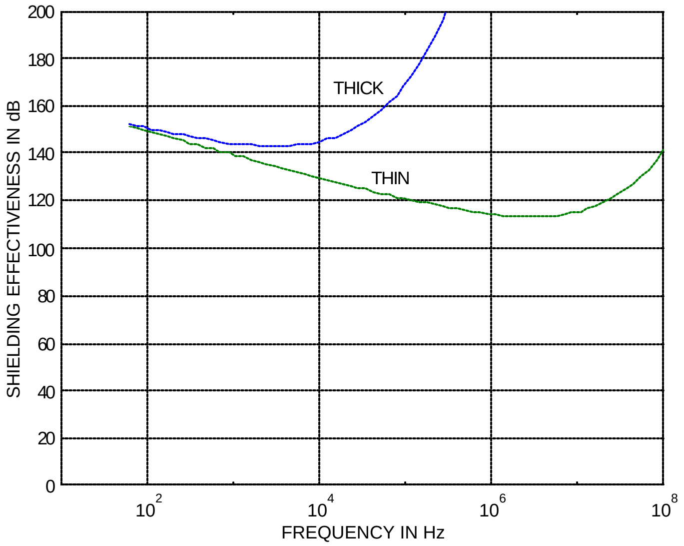
$$R = 20\log_{10}\left(\frac{Z_w}{4Z_m}\right), \qquad \text{where } Z_w = \sqrt{\frac{m_o}{e_o}} \cong 377\ \Omega$$

The total shielding effectiveness can be found by summing the effectiveness due to absorption and reflection.

$$S = A + R$$

At low frequencies, the absorptive loss is small because the absorption increases with the number of wavelengths required to transverse the shield. Reflection peaks at low frequencies because Z_m is small.

Since the attenuation shielding is small at low frequencies, just where the shielding due to reflections is large, their combination can result is an effective shield for all frequencies.



Example

Consider an interfering signal at 10 GHz. Suppose we wish to provide 100 dB of shielding effectiveness. What thickness of copper shielding would be required? Recall the impedance of free space, Z_w, is 377 Ω.

Shield discontinuities

The analysis above is for a continuous shield. Real shields are often not continuous--they have gaps, intentional or not.

For a given hole, a cutoff frequency can be defined.

$$f_c = \frac{15000}{\ell}$$

Where the frequency is in MHz, and the largest linear dimension of the hole is in cm.

Above the cutoff frequency little or no shielding is provided (S can be 0 dB).

Below the cutoff frequency the shielding effectiveness of an infinitely thin shield (that is, no absorption) can be approximated as

$$R = 20\log_{10}\left(\frac{f_c}{f}\right)$$

For holes of finite thickness there is also attenuation.

For a circular hole.

$$A = 32\frac{t}{d}$$

For a rectangular hole

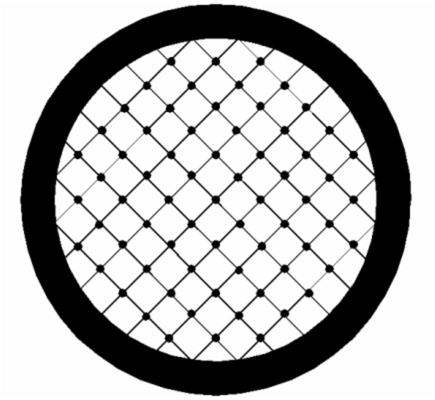
$$A = 27.3\frac{t}{\ell}$$

These formulas are for single holes. For multiple holes, the factor 10 $\log_{10}N$ is subtracted from the single hole shielding effectiveness, S.

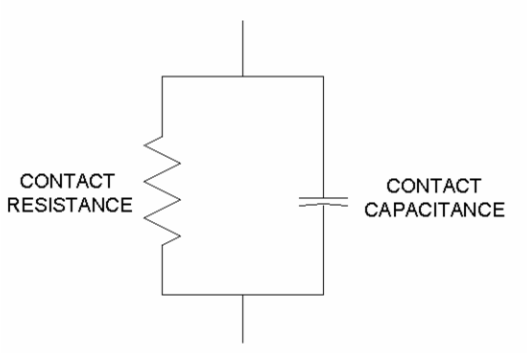
$$S = S_{\text{one aperature}} - 10\log_{10}N$$

Often in electronic enclosures openings must be present for cooling purposes. These opening must be designed so that the shielding integrity is not compromises.

Many times, a wire grid is used.



Enclosures often also include seams. These seams must perform both mechanically and electrically. They must allow the current to flow freely across them. The seam can be characterized via an impedance.



To make an effective seam, current must be allowed to freely flow.

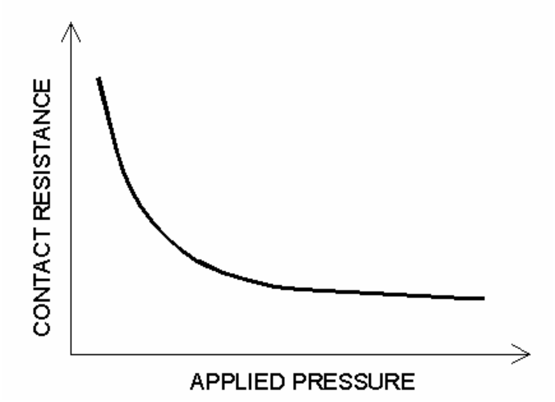
1. The material should have a low surface resistance. Metals such as aluminum that form an oxide layer required a greater contact pressure to perform well.

2. The surface should remain free from poor conducting substances such as paint, grease, or dirt.

3. Dissimilar metals can lead to corrosive effects at their junction. Care needs to be exercised when testing each seam. Be sure to include a variety of environments.

4. Adequate contact pressure, well past the "knee" in the graph below, should be maintained to ensure free flow of surface currents.

A conductive gasket, with sufficient pliancy, can help the performance of critical seams.



Example

Now suppose we need to cut a 1 cm diameter hole in the shield. How thick does the shield need to be now to obtain 100 dB of shielding effectiveness at 10 GHz?

Example

A transducer is attached to a machine to investigate its vibration. We expect to measure signals as small as 100 μV. The transducer is located a distance of 20 ft away from the measuring equipment that will analyze the signal. The 60-Hz magnetic field produced by other machines in the factory and the wiring for the room lighting has a maximum flux density of 10^{-4} Webers/m^2.

i. The accuracy of the vibration measurement can be degraded by an interfering signal as small as 1/10 of the smallest signal voltage expected from the transducer. Calculate the threshold of interference.

ii. Let the transducer be connected by two wires that are spaced 1 inch apart. Compute the amount of 60-Hz voltage induced in the circuit and compare the result to the threshold of interference.

iii. Next place the wires snugly next to each other for a spacing of 0.1 inches and re-compute the induced voltage.

iv. Finally, replace the cable with a twisted pair having 8 twists/inch and compare the resulting induced voltage with the threshold on interference.