Some Remarks on Shielding

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(using slides from a talk by Mike Thuot)

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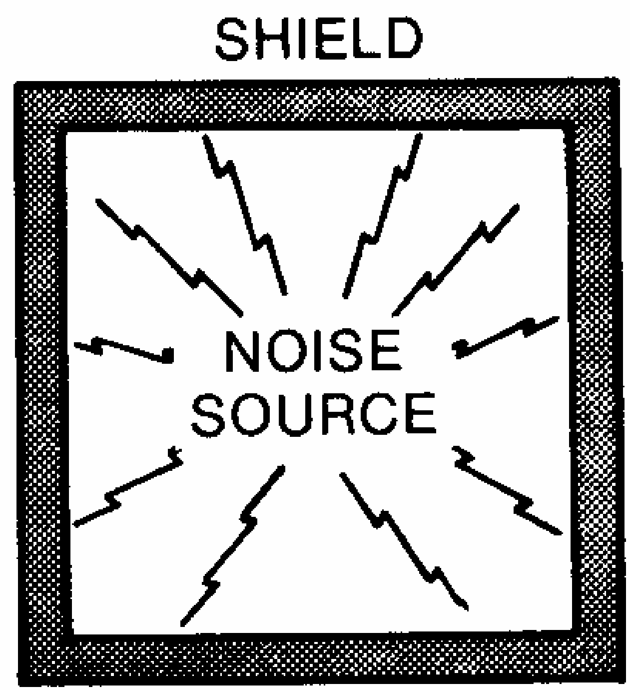
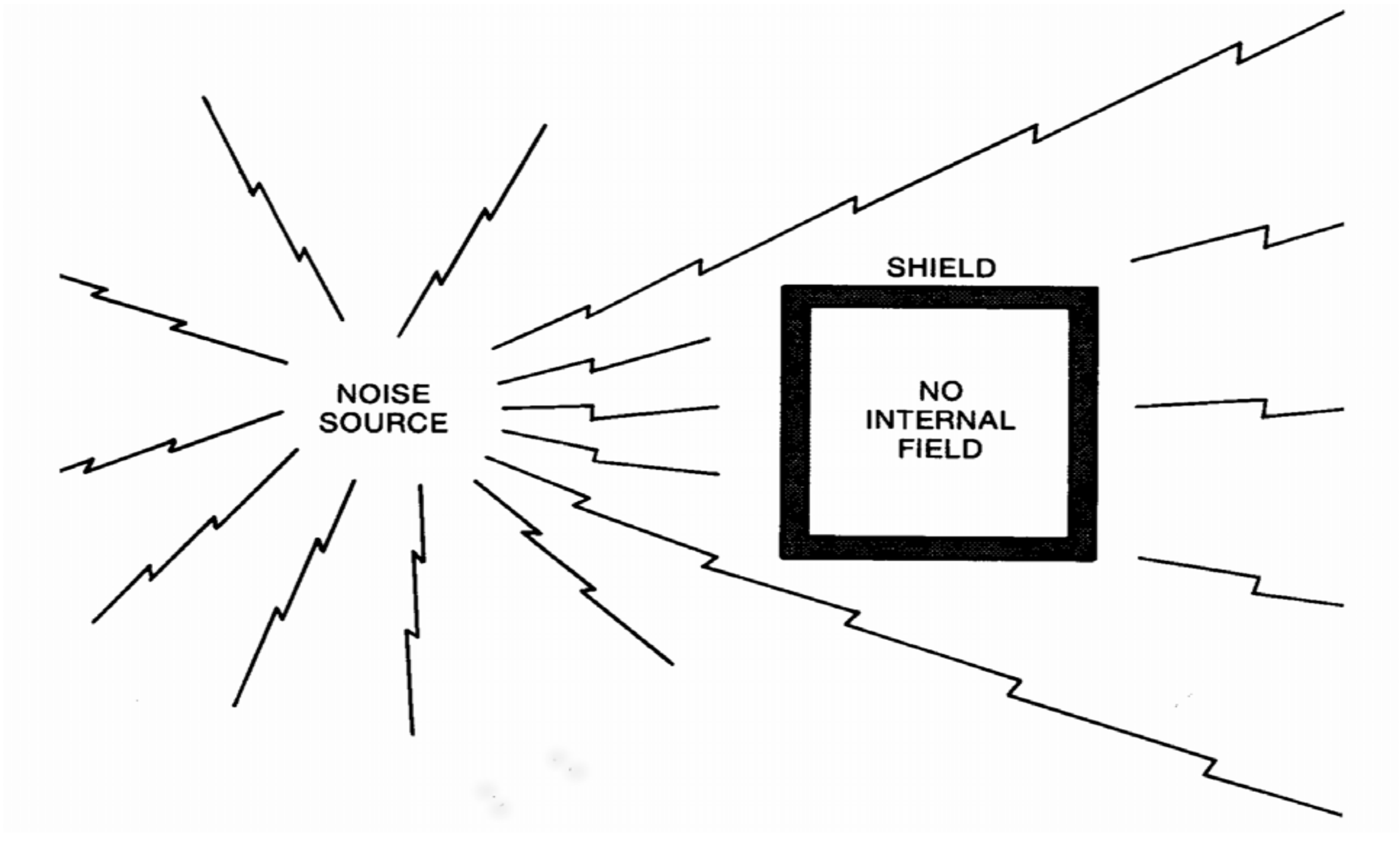
A shield may be used to confine the radiated field from a noise source.

Shields are metallic partitions used to control the propagation of electric and magnetic fields.

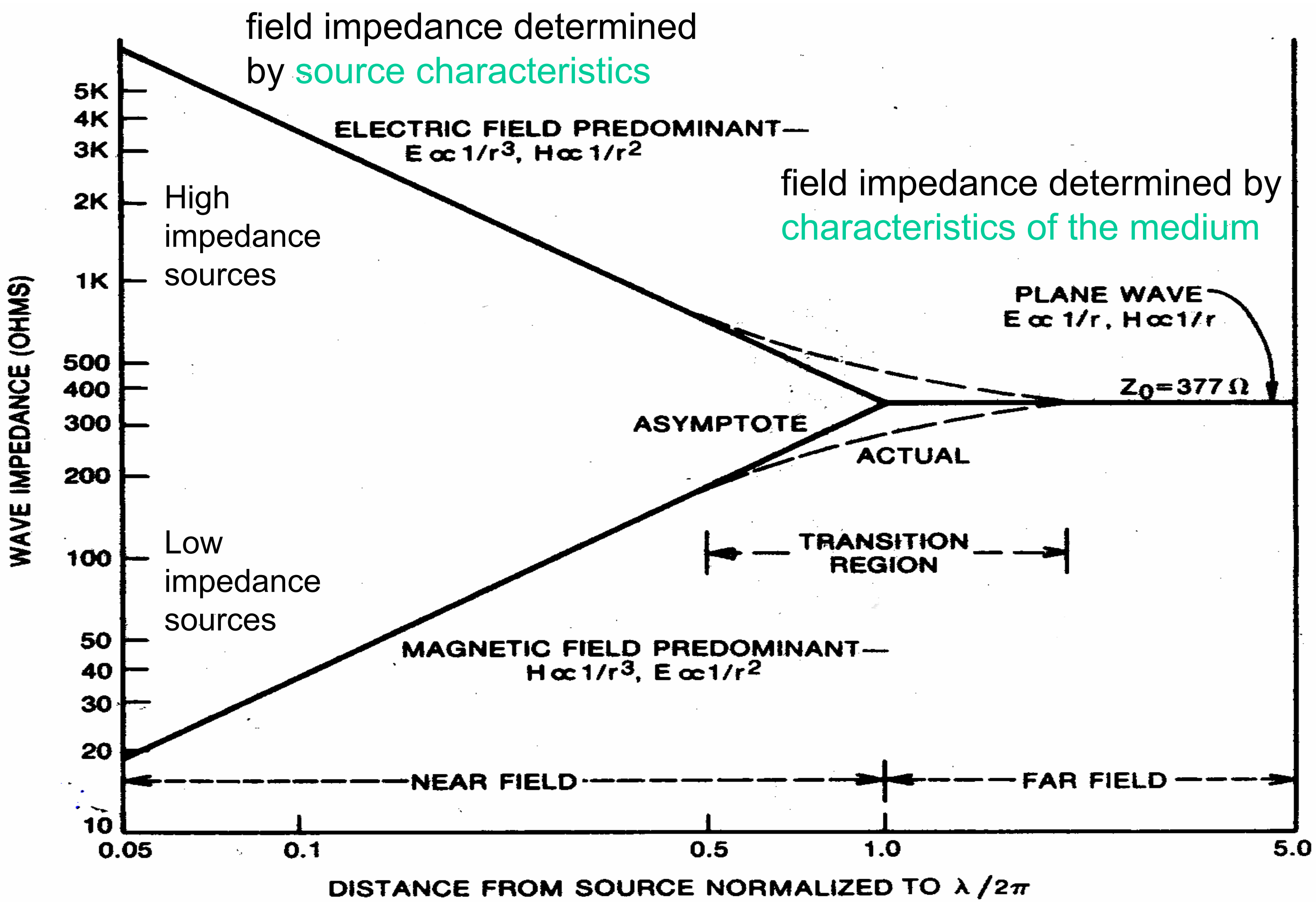
NO EXTERNAL FIELD



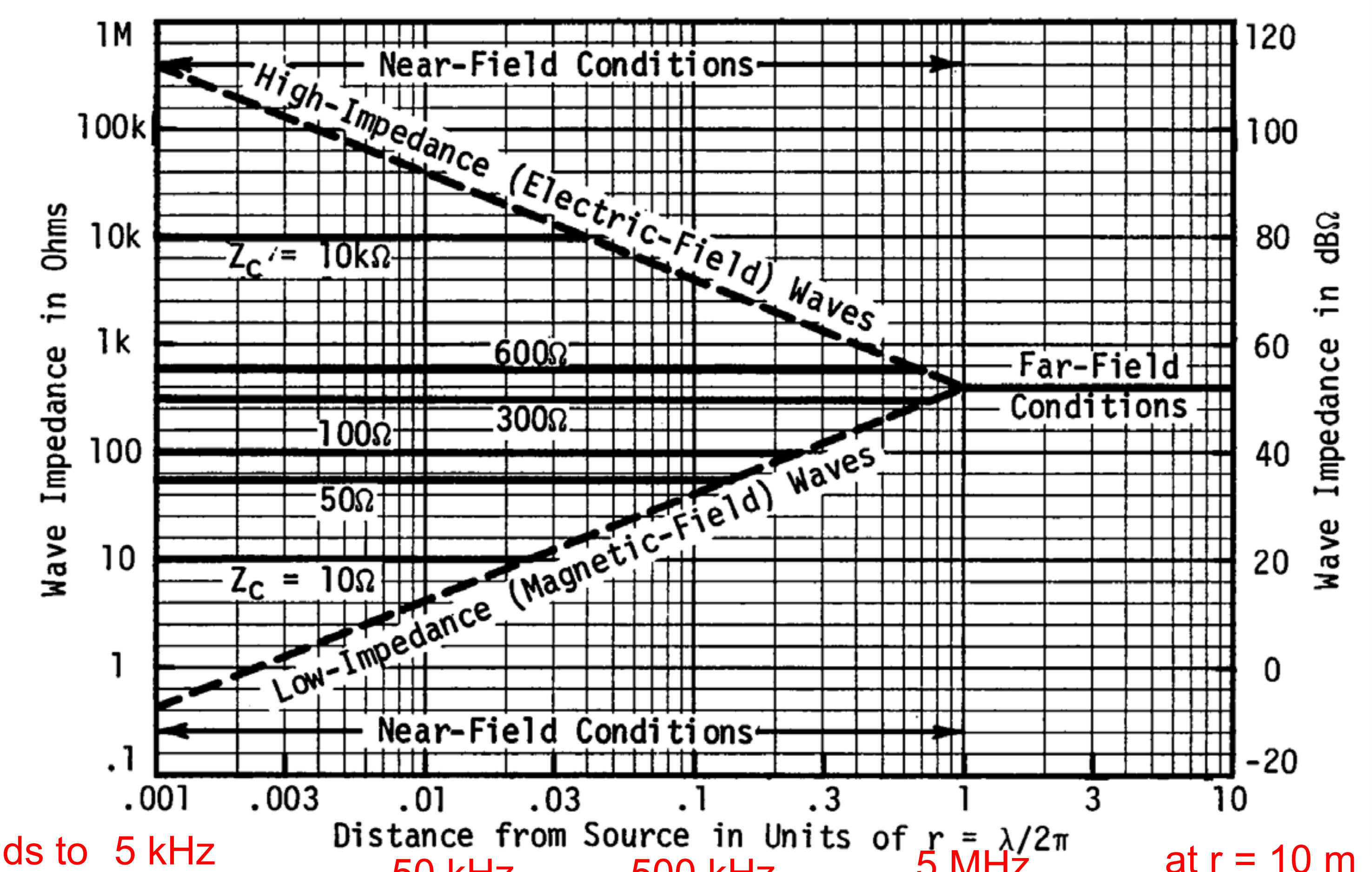
Or, a shield may be used to exclude radiated noise by reflecting and/or absorbing the energy. This is the interesting situation in the FLASH injector rack area.
I was asked: “How good a shield is 0.4 mm Cu sheet?”
Well, that depends ...



As a wave propagates through a material, the impedance of the wave, Z = E/H, approaches the intrinsic impedance of the material. In vacuum Z = 377 Ω.



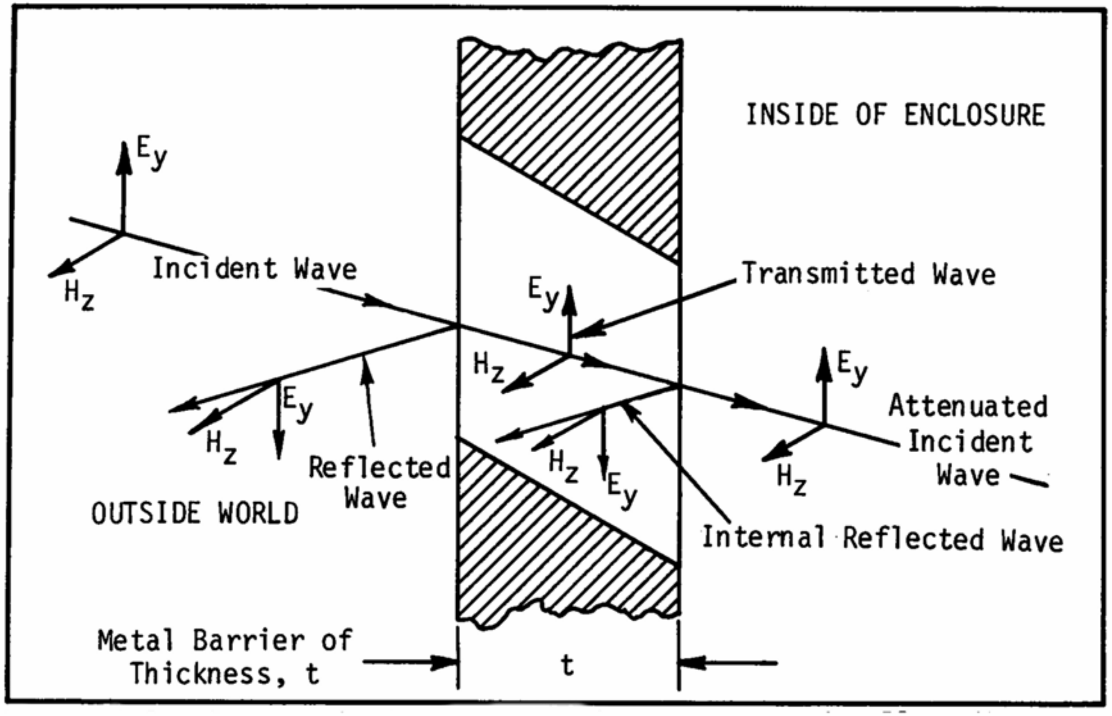
In the near field, the electric and magnetic fields must be considered separately since the ratio E/H is not constant.



corresponds to 5 kHz 50 kHz 500 kHz 5 MHz at r = 10 m

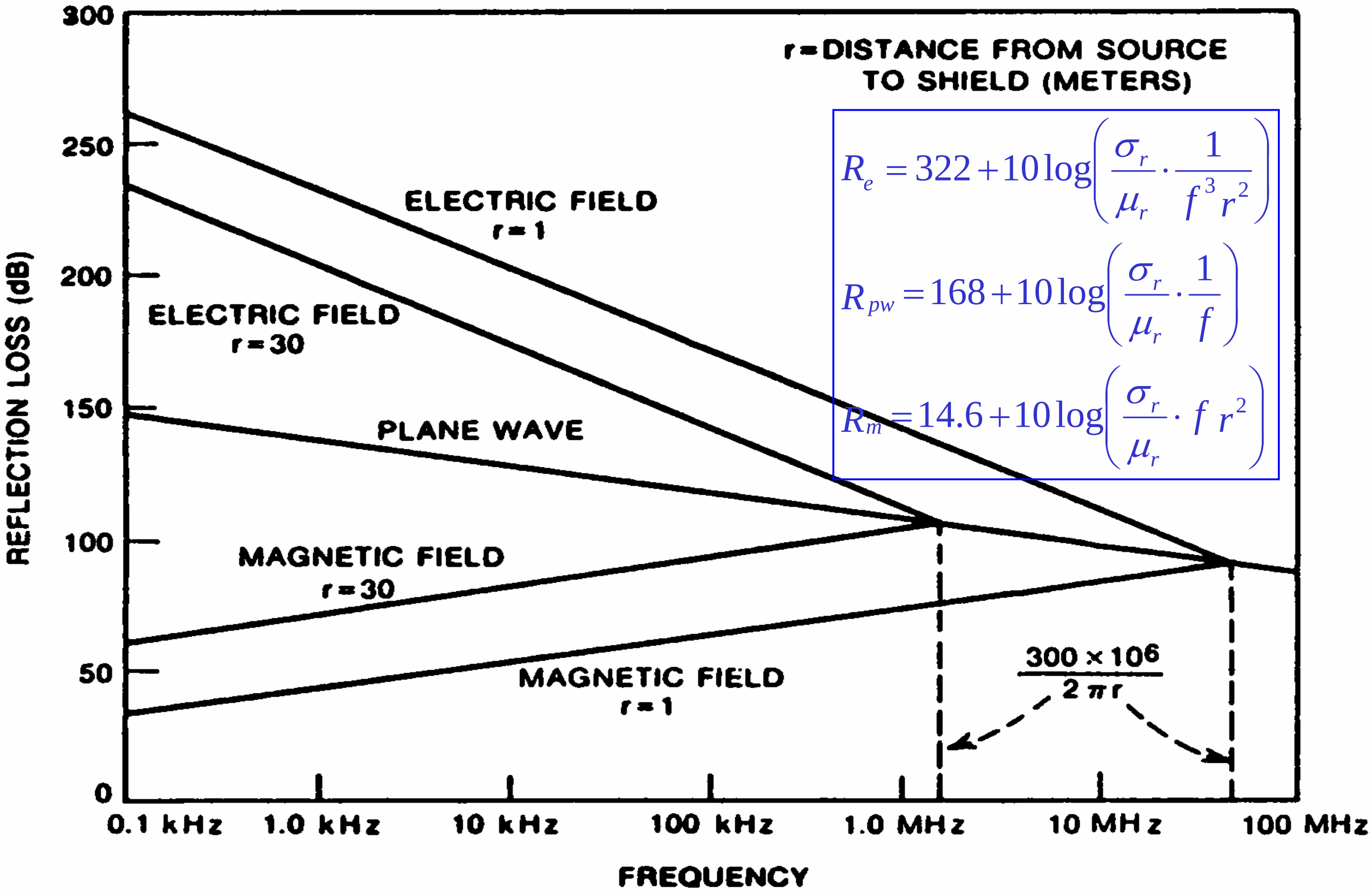
Shielding effectiveness is a measure of the reduction in magnetic and/or electric field strength caused by a shield.

The incident wave is partially reflected from a metal barrier at each interface, with a reflection coefficient that depends on a ratio of wave impedance to metal impedance. Inside the metal, the wave is attenuated at a rate of ~9 dB per skin depth.



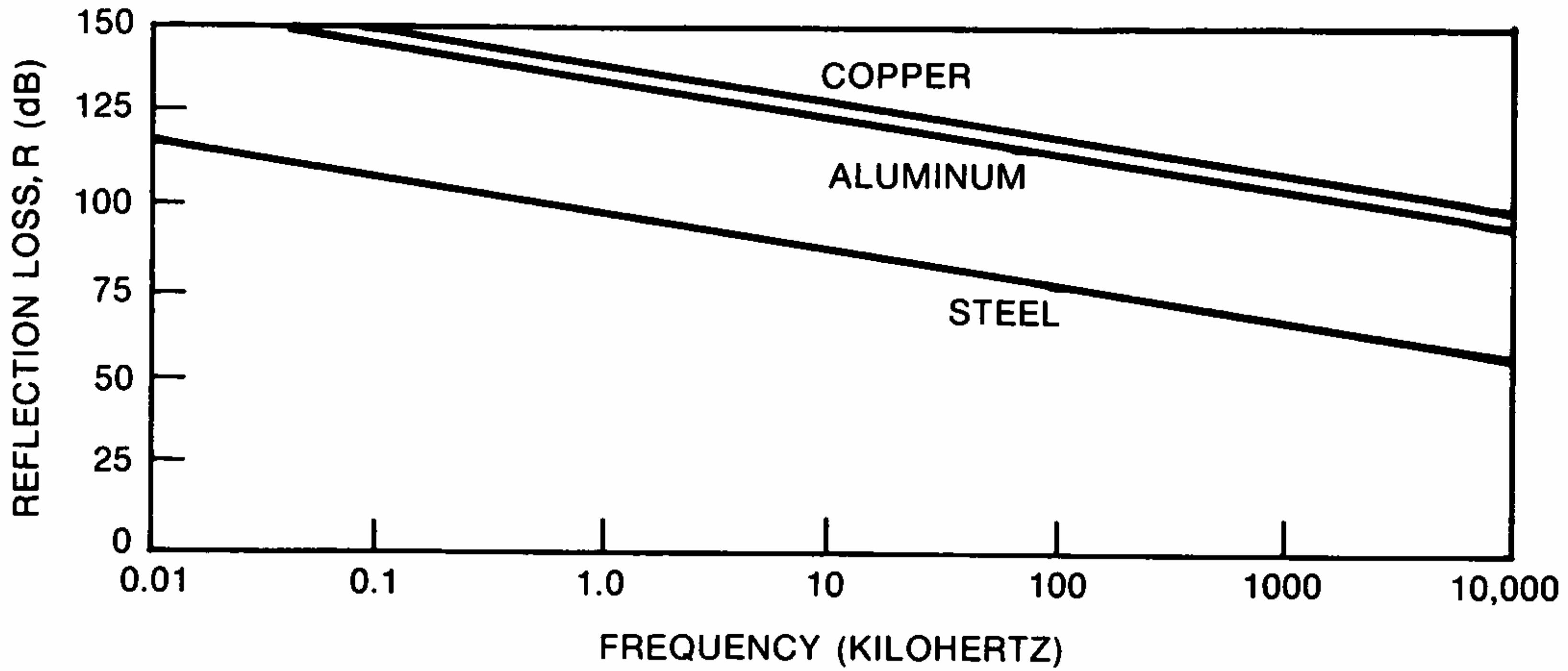
The reflection loss is dependent on the type of field, frequency and the wave impedance

In copper, reflection loss for E fields is >> than for H fields in the near field



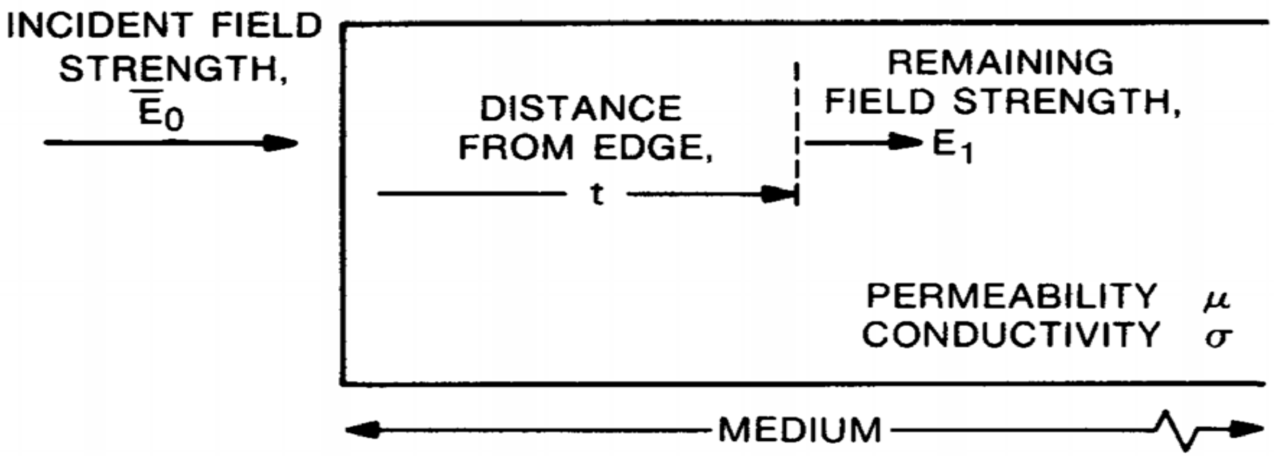
Far field (plane wave) reflection loss is greatest at low frequencies and for high conductivity materials.

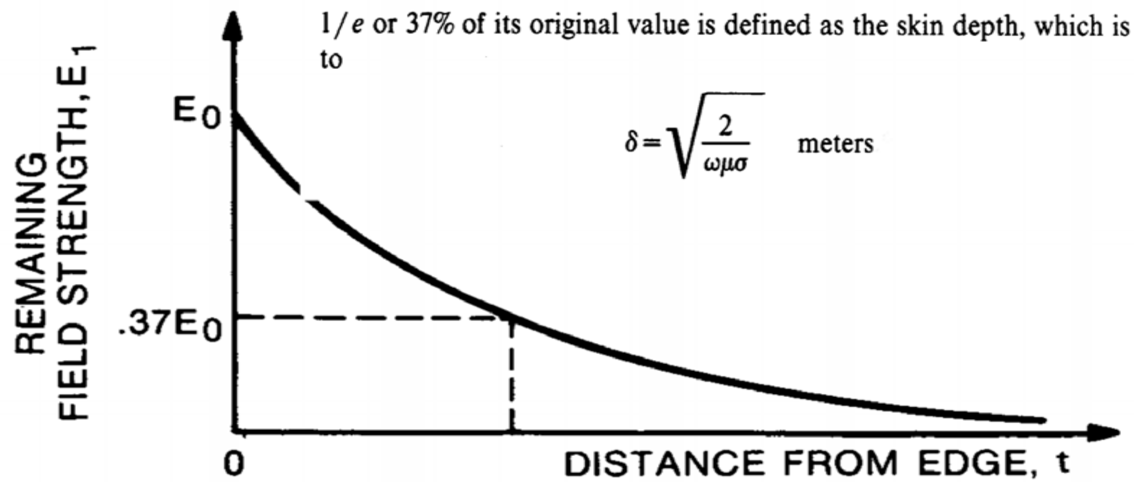
Shield impedance is minimized by using materials with high conductivity and low permeability, so steel has much less reflection loss than copper



An EM wave passing through an absorbing medium is attenuated exponentially.

Decay is the result of ohmic losses by induced currents





$1/e$ or 37% of its original value is defined as the skin depth, which is equal to

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \quad \text{meters}$$

Skin depth in a material depends on the frequency, the conductivity and the permeability.

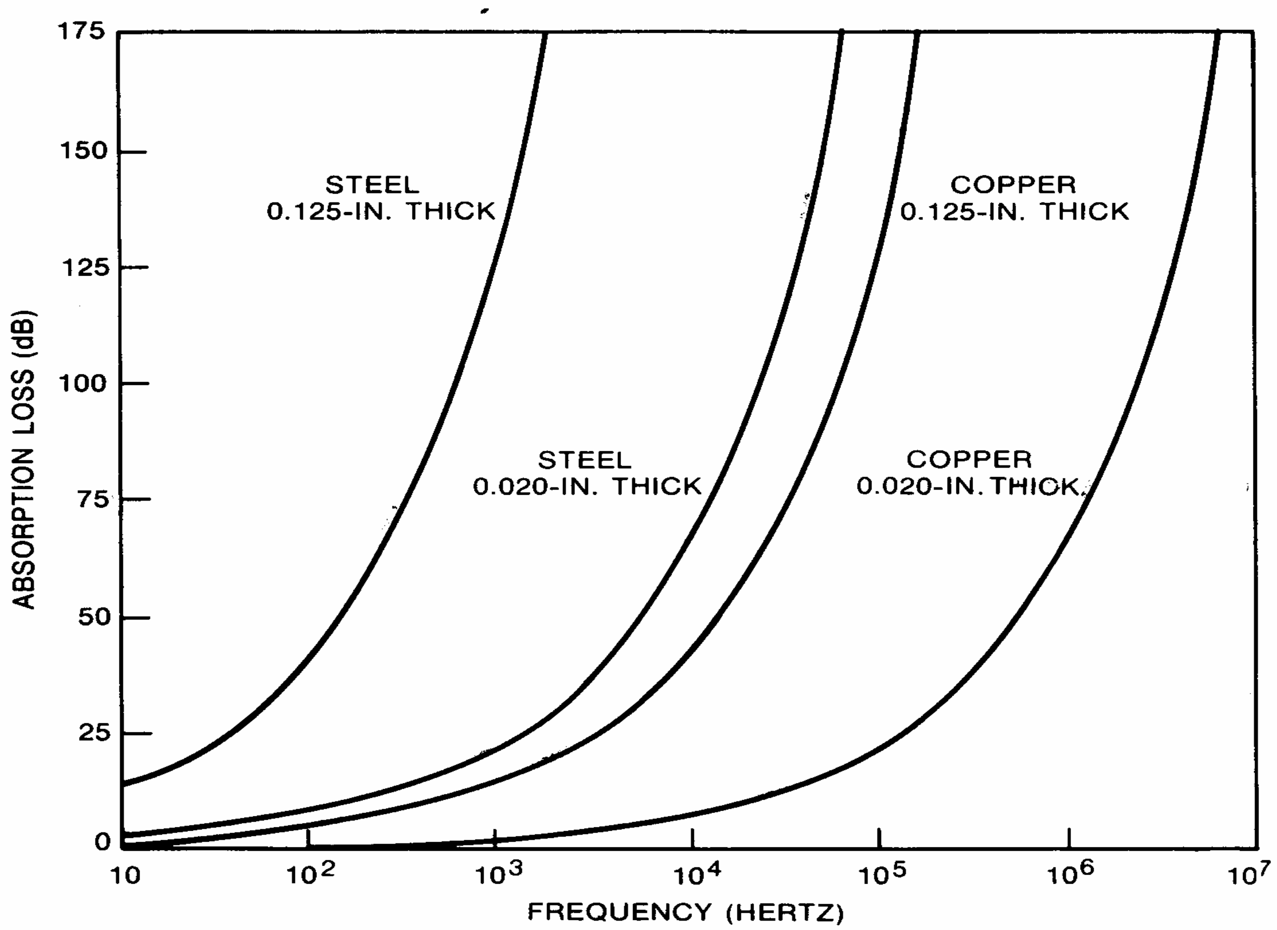
Skin depth is the surface thickness of a metal at any frequency for which 1-1/e or 63.2% of the current is flowing. Two skin depths = 86.5% and three skin depths = 95% of the total current flow.
99% of a current flows on a conductor's surface within 4.6 skin depths

Skin Depth of Copper.

f	δ
60 Hz	8.5 mm
1 kHz	2.09 mm
10 kHz	0.66 mm
100 kHz	0.21 mm
1 MHz	2.6 mils
10 MHz	0.82 mils
100 MHz	0.26 mils
1 GHz	0.0823 mils

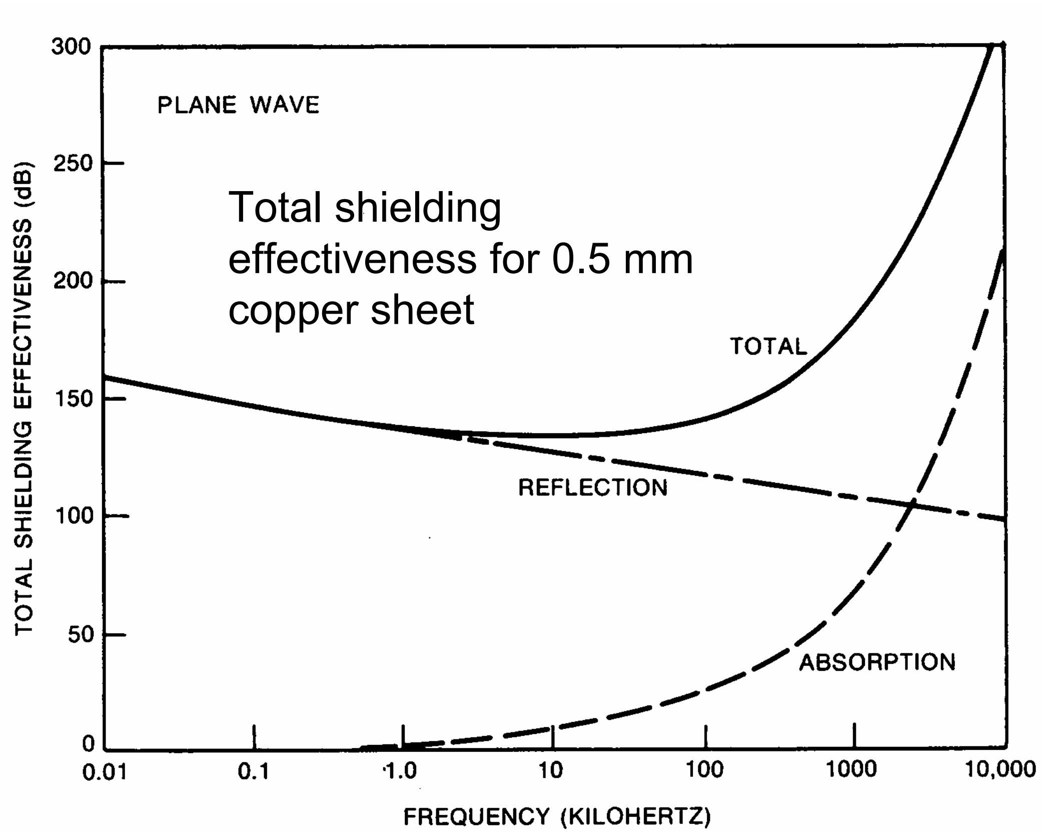
Absorption loss increases with frequency and shield thickness.

Steel offers more absorption loss than copper of the same thickness
A thin sheet of copper provides ~0 absorption loss below 1 kHz

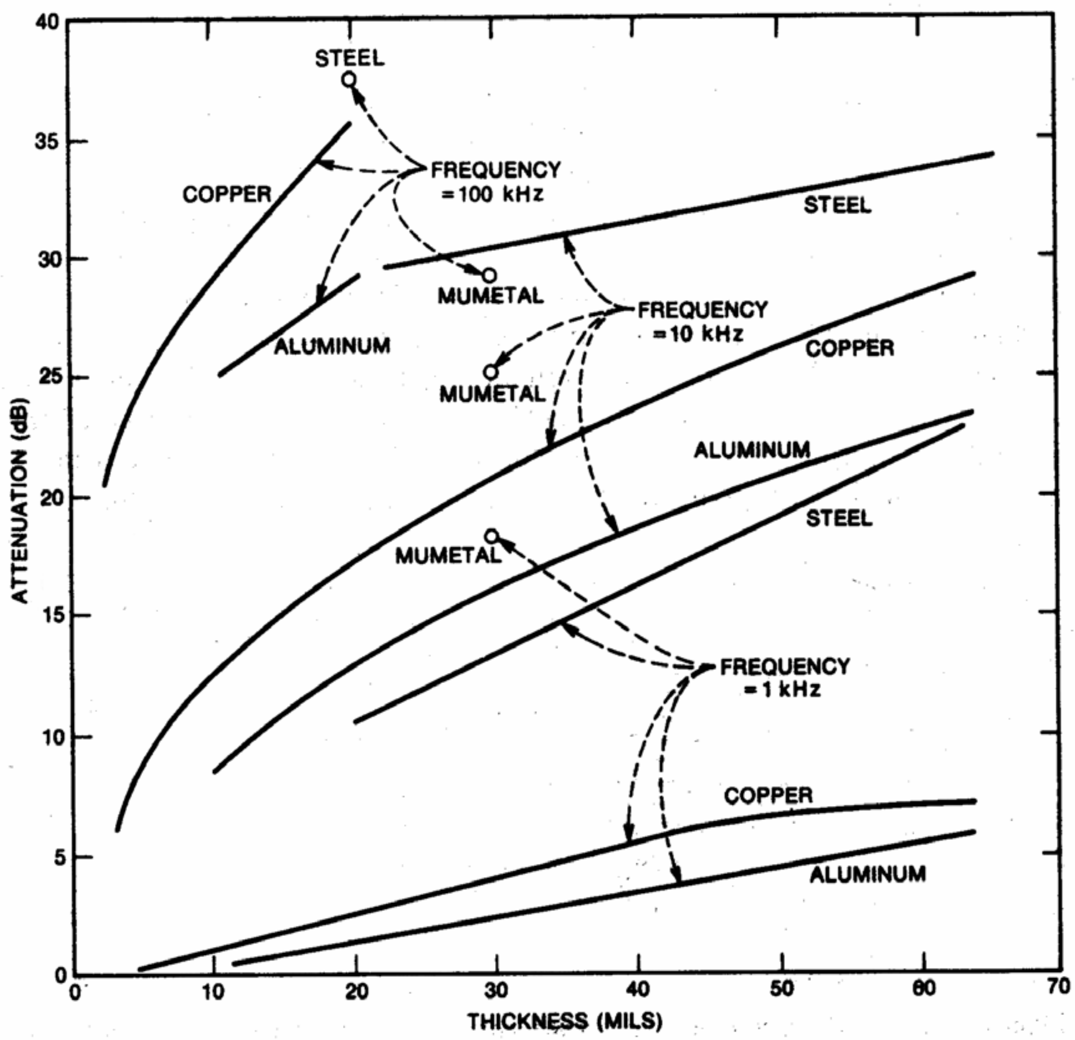


Total shielding effectiveness (total loss) is a combination of absorption and reflection losses.

The reflection loss decreases with frequency since shield impedance increases with frequency. The absorption loss increases with frequency since the skin depth decreases with frequency.



Effectiveness of shield materials to low impedance waves varies widely.



The shielding effectiveness of steel exceeds that of copper at low frequencies with low impedance waves, as long as saturation is avoided.

As frequencies increase above 100 kHz and the wave impedance increases towards 377 ohms copper shields become more effective than steel.

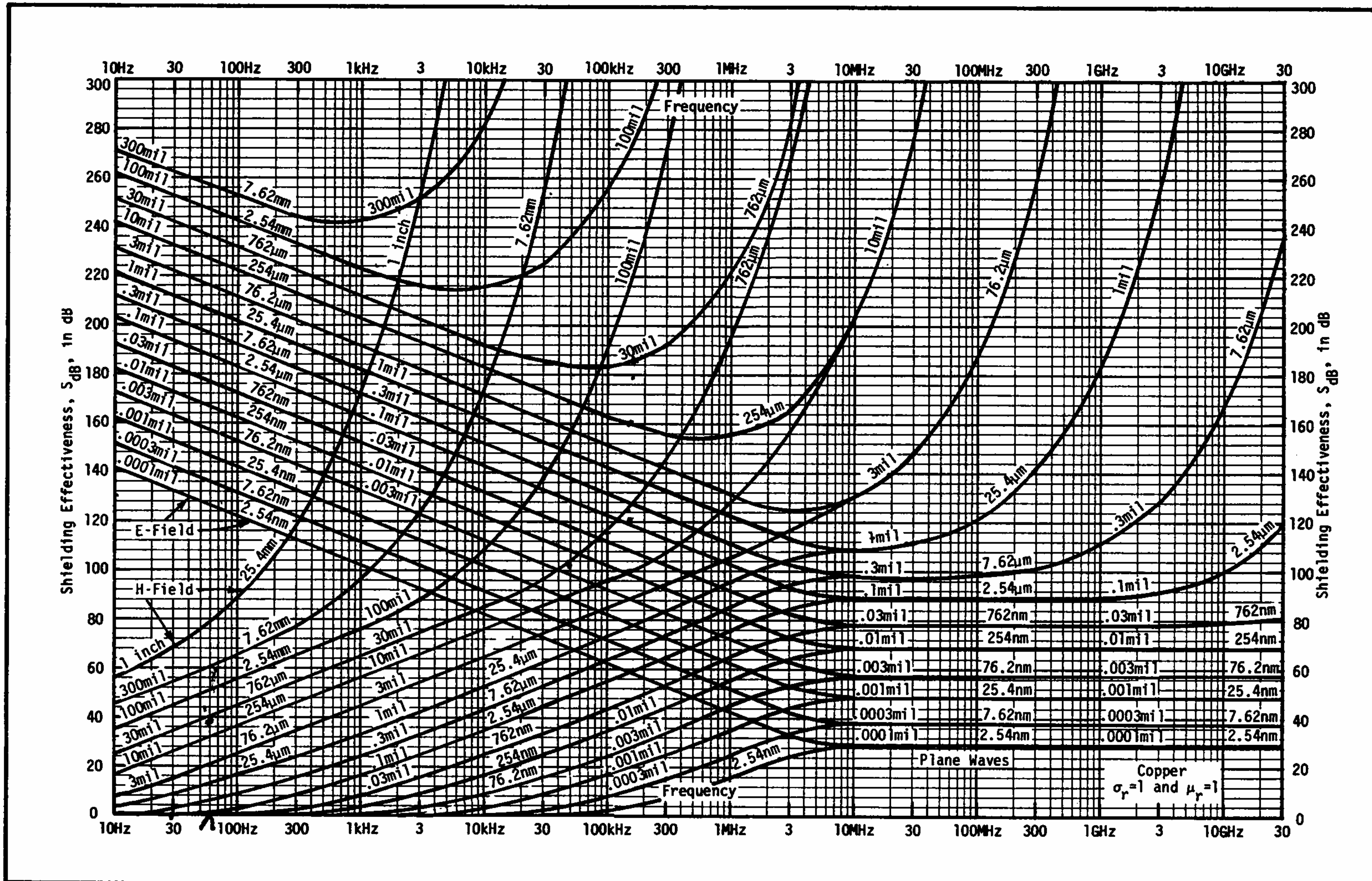


Figure A.3 - Shielding Effectiveness of Copper vs. Frequency for Source-to-Metal Distance of 10m

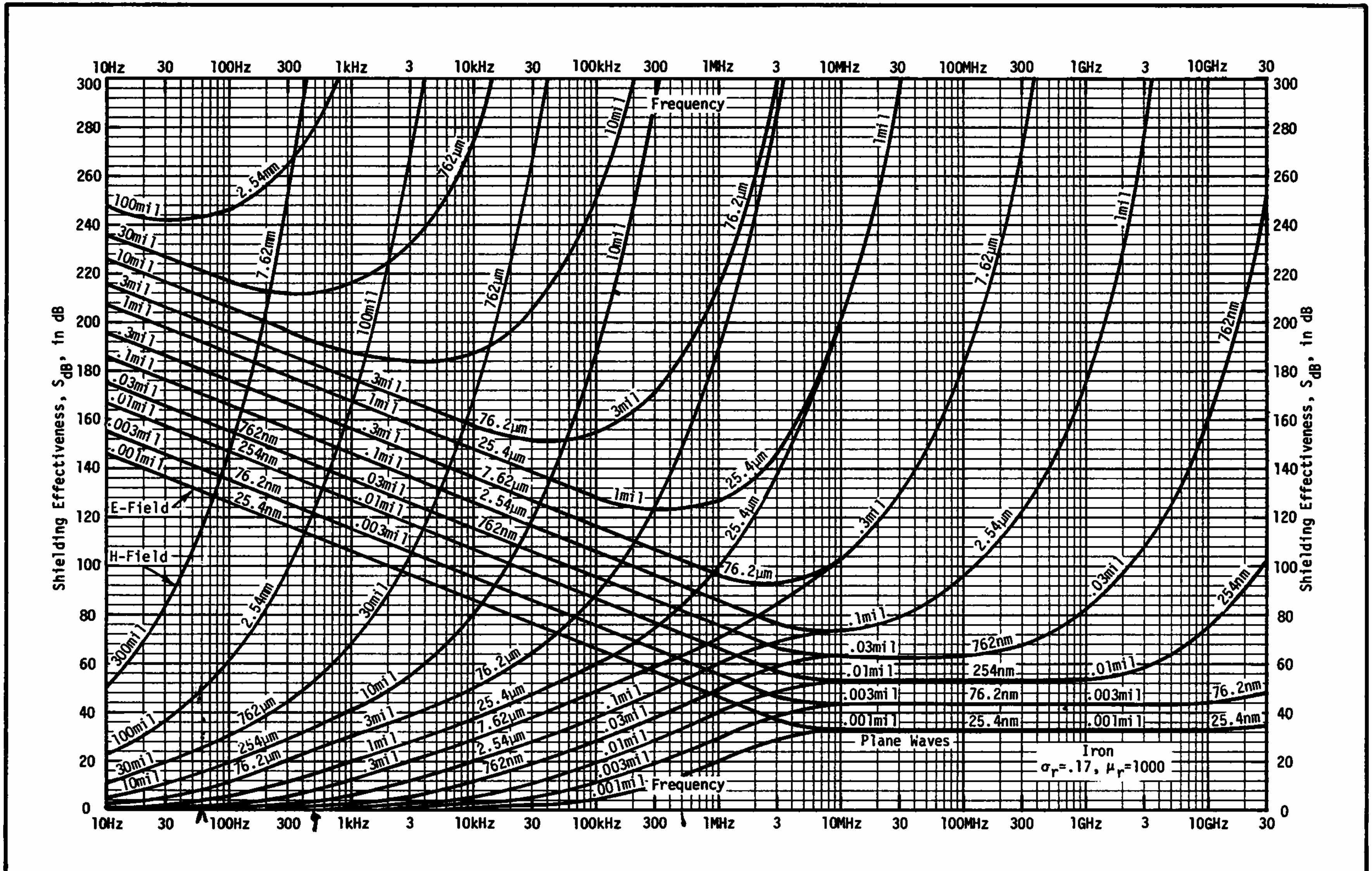


Figure D.3 - Shielding Effectiveness of Iron vs. Frequency for Source-to-Metal Distance of 10m

Qualitative summary of solid shielding materials

(no holes; no seams)

Material	Frequency (kHz)	Absorption loss[a] all fields	Reflection loss		
			Magnetic field[b]	Electric field	Plane wave
Magnetic ($\mu_r = 1000$, $\sigma_r = 0.1$)	<1	Bad–Poor	Bad	Excellent	Excellent
	1–10	Average–Good	Bad–Poor	Excellent	Excellent
	10–100	Excellent	Poor	Excellent	Good
	>100	Excellent	Poor–Average	Good	Average–Good
Non magnetic ($\mu_r = 1$, $\sigma_r = 1$)	<1	Bad	Poor	Excellent	Excellent
	1–10	Bad	Average	Excellent	Excellent
	10–100	Poor	Average	Excellent	Excellent
	>100	Average–Good	Good	Excellent	Excellent

Key	*Attenuation*
Bad	0–10 dB
Poor	10–30 dB
Average	30–60 dB
Good	60–90 dB
Excellent	>90 dB

[a]Absorption Loss for 1/32-in. thick shield.
[b]Magnetic field reflection loss for a source distance of 1 m. (Shielding is less if distance is less than 1 m and more if distance is greater than 1 m.)

Summary of Shielding

- Reflection loss is very large for electric fields and plane waves.
- Reflection loss is normally small for low frequency magnetic fields.
- A shield one skin depth thick provides approximately 9 dB of absorption loss.
- Magnetic fields are harder to shield against than electric fields.
- Use a good conductor to shield against electric fields, plane waves, and high frequency magnetic fields.
- Use a magnetic material to shield against low frequency magnetic fields.

Many illustrations for this talk were taken from:

- Ott, Henry W., Noise Reduction Techniques in Electronic systems, Wiley 1976
- Paul, Clayton R., Introduction to Electromagnetic Compatibility, Wiley 1992
- White, Donald R., Electromagnetic Shielding Materials and Performance, D.W.Consultants 1975