GENTEX CORPORATION

A Smarter Vision®

Looking Out For You

Shielding Tutorial

Gentex EME Lab

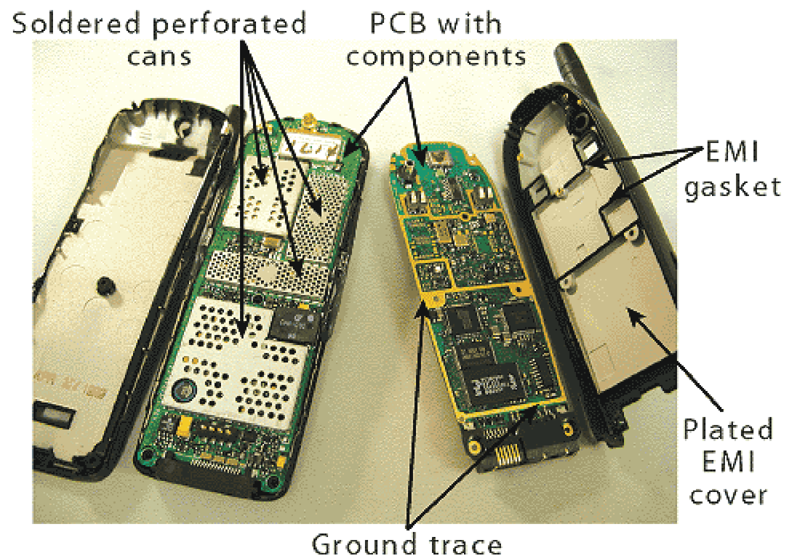
Shielding Course Outline:

I. Why do we need shields?
II. Introduction to the Basic Shield Design Process
    A. Apertures
    B. Materials
III. Corrosion
IV. Summations and Conclusions
V. Demonstrations
    A. Measuring Shielding effectiveness of various materials in a Near-Field Magnetic Field
    B. Aperture Measurement Program
VI. Questions
VII. References

The Question: Why do we need Shields?

Why do we need shields?

- Immunity
  - Prevent external energy from interfering with sensitive circuits
- Emissions
  - Prevent noisy circuits and devices from interfering with neighboring devices
- Self Compatibility
  - Prevent a device from interfering with itself

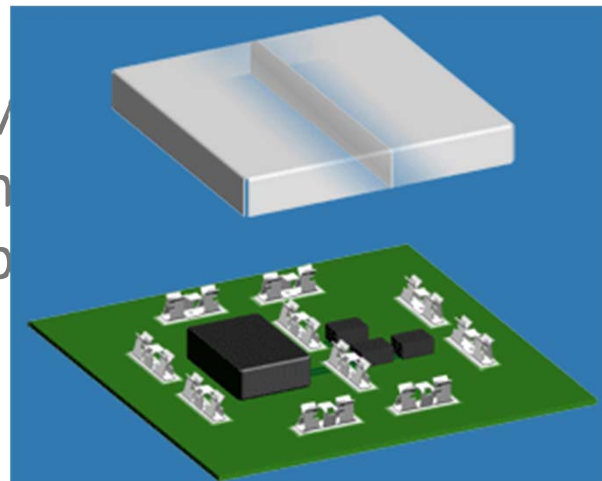


1. Traditional PCB shielding methods include soldered perforated cans and plated covers with EMI gaskets.

Shields: Definition and Misconception

Definition: A Shield is a conductive barrier enveloping an electrical circuit to prevent time varying Electromagnetic fields from coupling or radiating from the circuit.

Misconception: M … s an almost unshakable axiom … hat a conductive surrounding will p … ding protection in all cases.

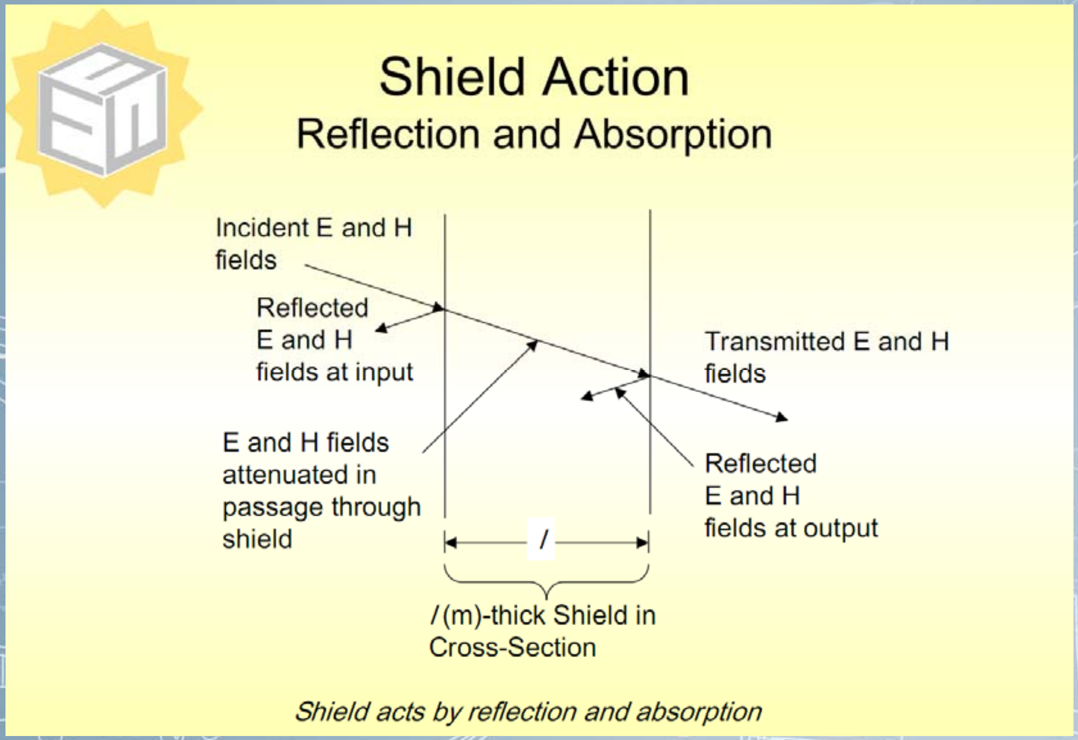


While shields can be very effective, designers will get the most performance when some key issues are kept in mind.

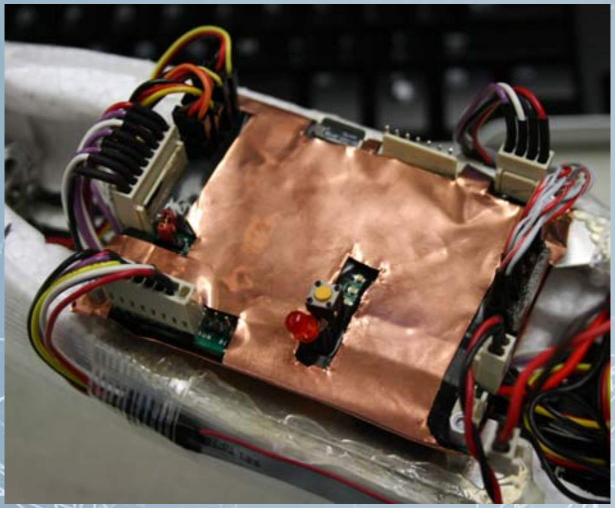
What makes a good shield?

- It depends….
  - Frequency of interference
  - Type of interference:
    - Magnetic-Field
    - Electric-Field
  - Location of Field:
    - Near-Field
    - Far-Field
  - Number of openings and size of openings (Apertures)
  - Type of shielding material (Conductivity/Permeability)
  - Thickness of shielding material
  - Available mating surface (printed circuit board)

Introduction to the Basic Shield Design Process



Aperture Considerations



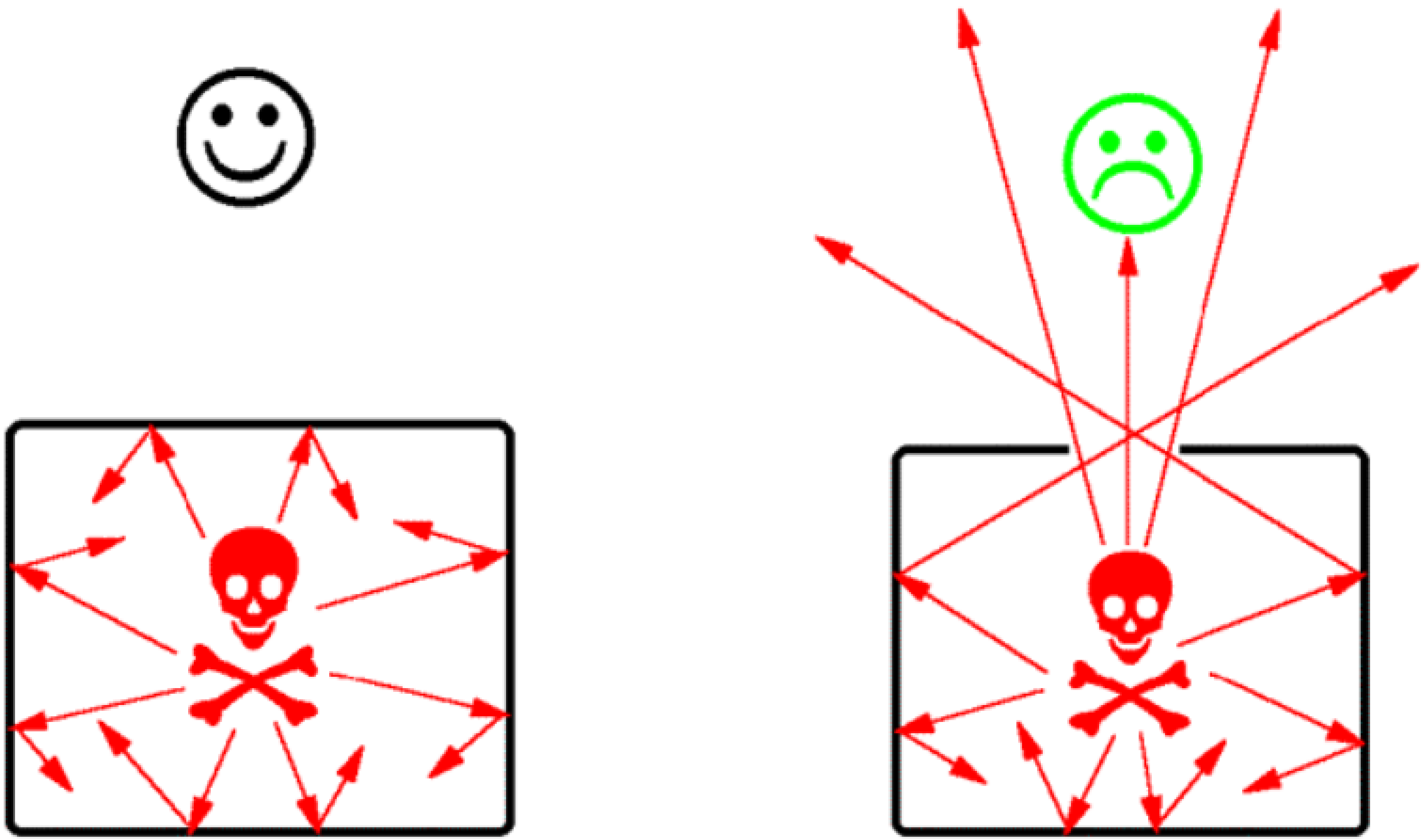
Aperture Design:

Most shielding effectiveness is governed by apertures

1

2

3



Aperture Design:

1) The main item determining the leakage from a slot is the maximum linear dimension (not <u>area</u>) of the opening.
2) Remember to take into account the highest frequency harmonic present.
3) Multiple apertures farther reduces the shielding effectiveness. The amount of reduction depends on:
    a) The spacing between the apertures
    b) The frequency
    c) The number of apertures

Aperture Equations:

$$SE_{dB} = 20Log_{10}(\lambda/(2L)), \text{ where } L< \lambda/2$$

Where:

SE_{dB} = shielding effectiveness

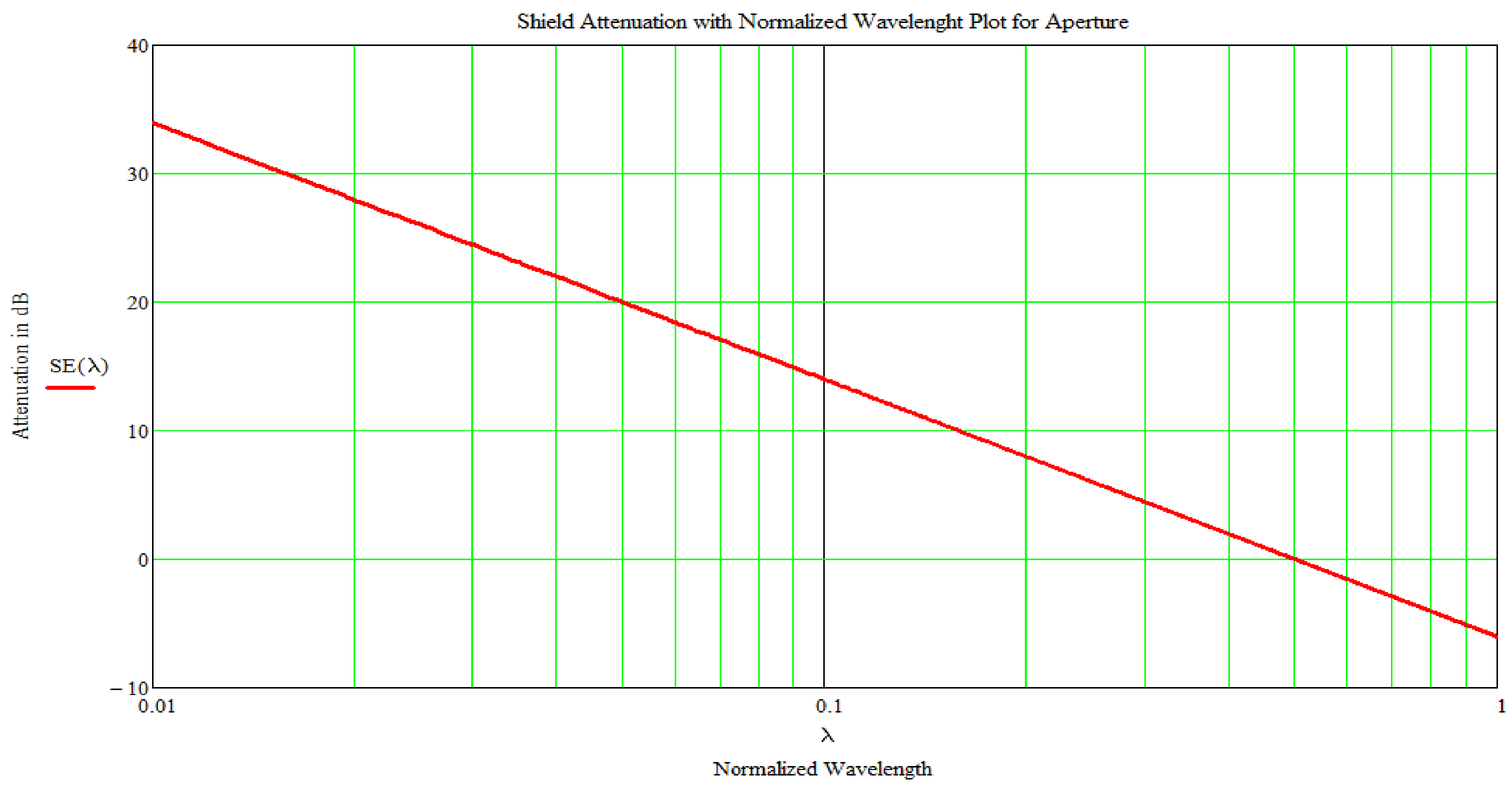
λ = wavelength

L = aperture length, longest dimension

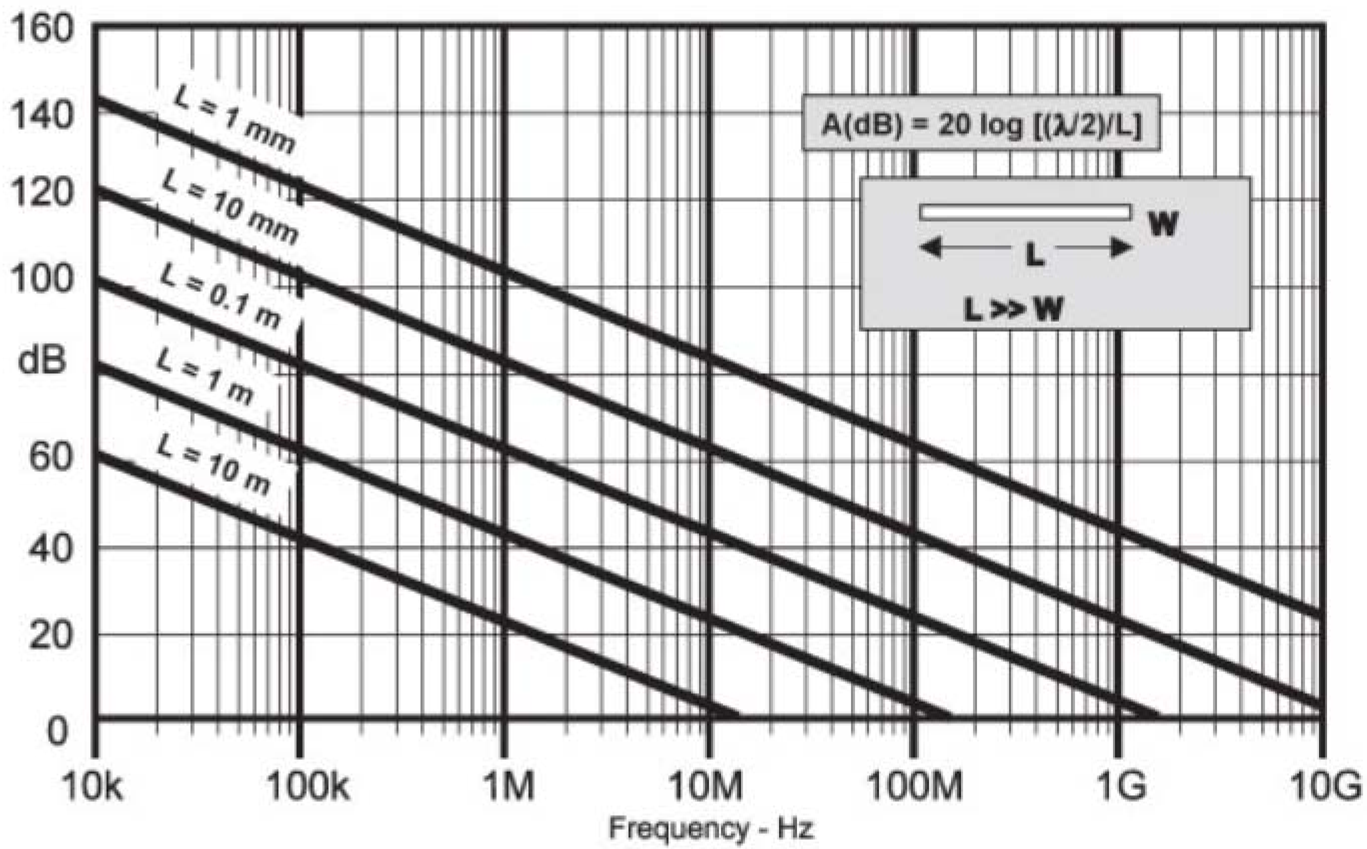
- This is applicable for slots with a dimension equal or less than $\lambda/2$ wavelength.
- The equation illustrates:
  - The **shielding effectiveness is 0 dB when the slot is $\lambda/2$** long and
  - Increases 20 dB/decade as the length L is decreased.
  - Reducing the slot length by ½ increases the shielding by 6 dB.

Effect of Aperture Length on Shield Attenuation:

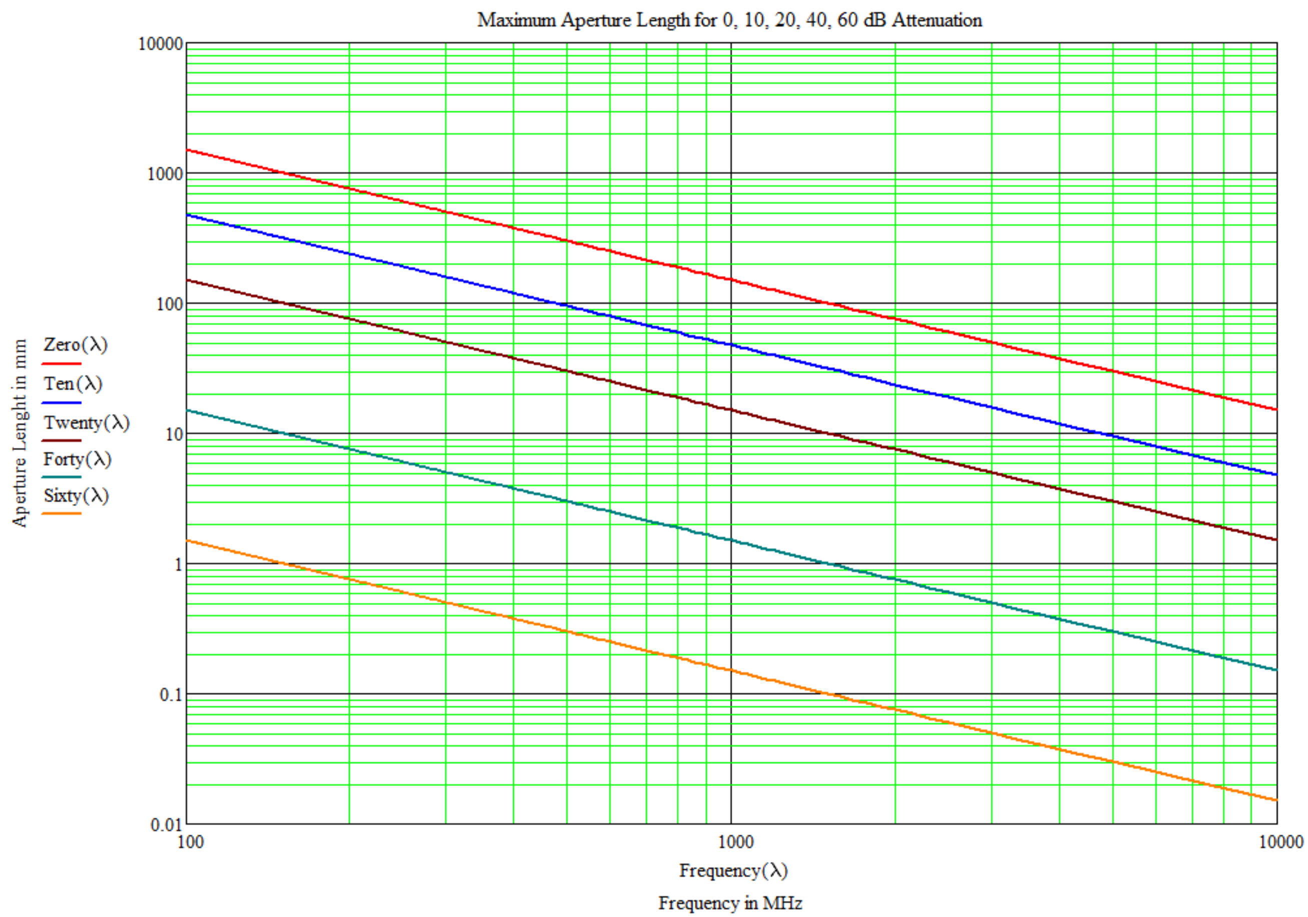
$$SE_{dB} = 20Log_{10}(\lambda/(2L)), \text{ where } L< \lambda/2$$



Effect of Aperture Length

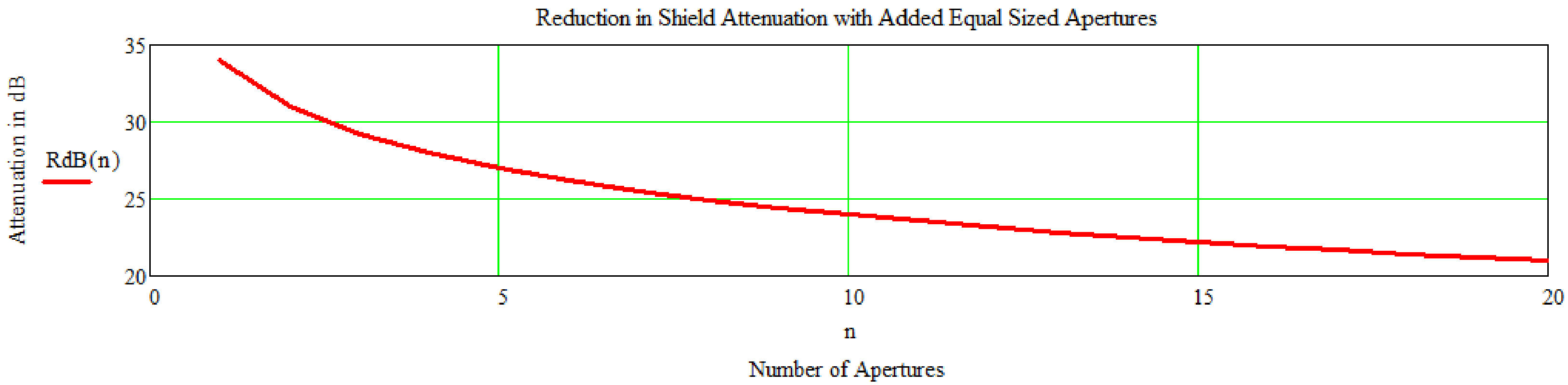


Aperture Length vs. Frequency for Various Attenuations:

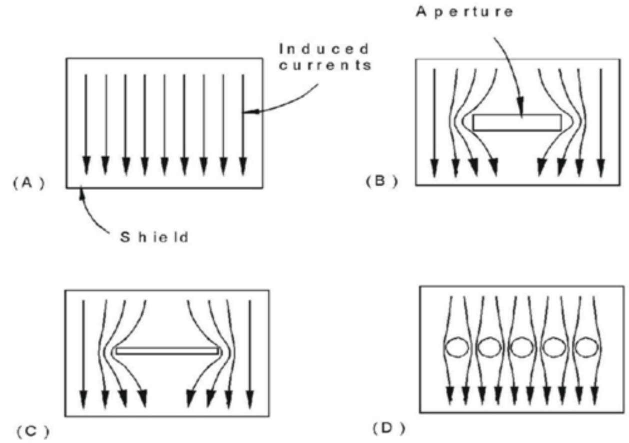


Shield Attenuation with Multiple Apertures and fixed λ and Aperture Length

$$R_{dB} = 20\log_{10}(\lambda/2L) - 20\log_{10}(n^{1/2})$$



Affects of Apertures on Shield Currents



$$S.E. = 20 \log \left(\frac{\lambda}{2L} \right)$$

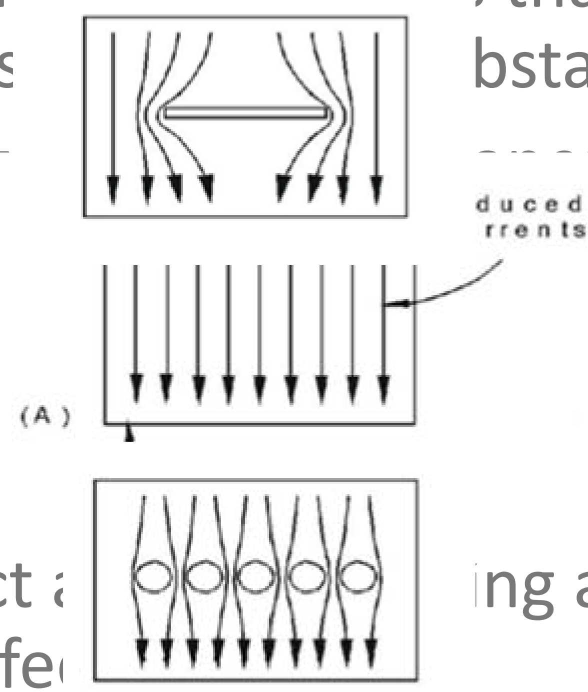
$$S.E. = -10 \log (n)$$

- A slot behaves like an equivalent dipole with orthogonal polarization (Babinet).

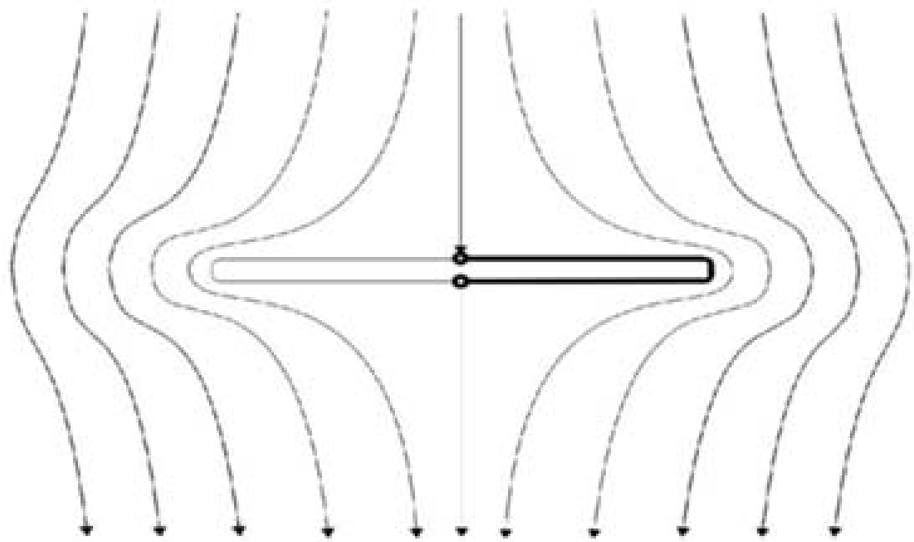
For example, at 1GHz, a slot of 0.6" length or less will still provide a S.E.=20dB

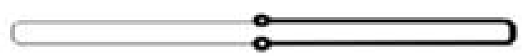
Aperture Design and Babinet's Principle:

1. The theory behind magnetic-field shielding provided by induced cur… …s that currents will flow as long as … bstacle in their path.
2. It is essential … …tures be arranged in s… …nize their effect on the curre…
3. Apertures ha… …an induced HF current flowi… …cause the aperture to act … …ing antenna (Babinet Principle or Effe…



Babinet's Principle: The Potential difference. Length is the issue.



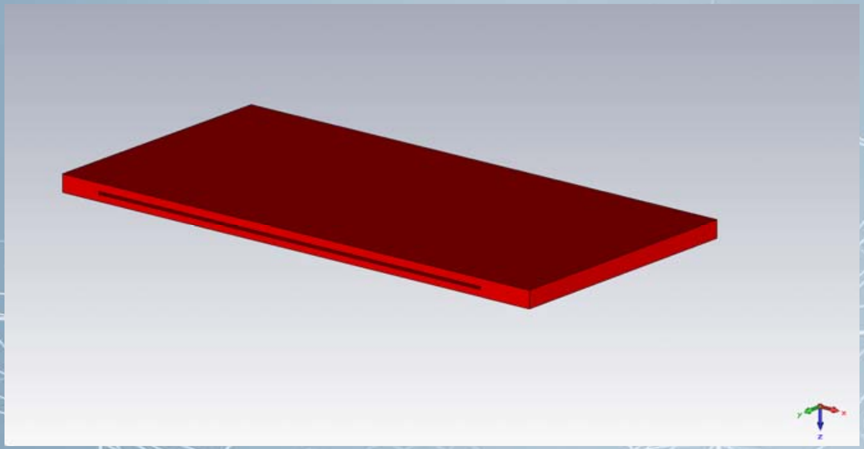


$Z = R + j X_L$

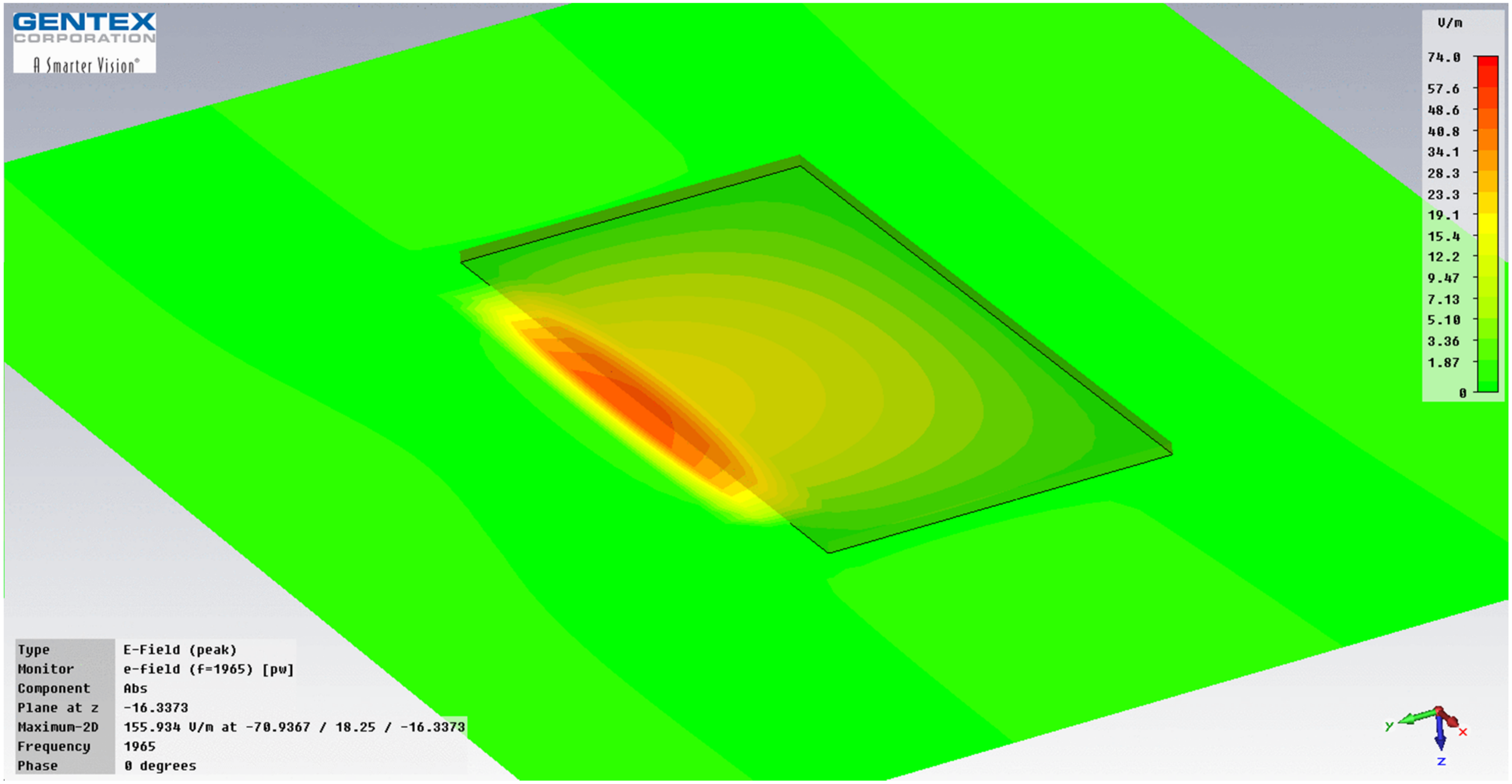
$V = I Z$

E-field ~ V

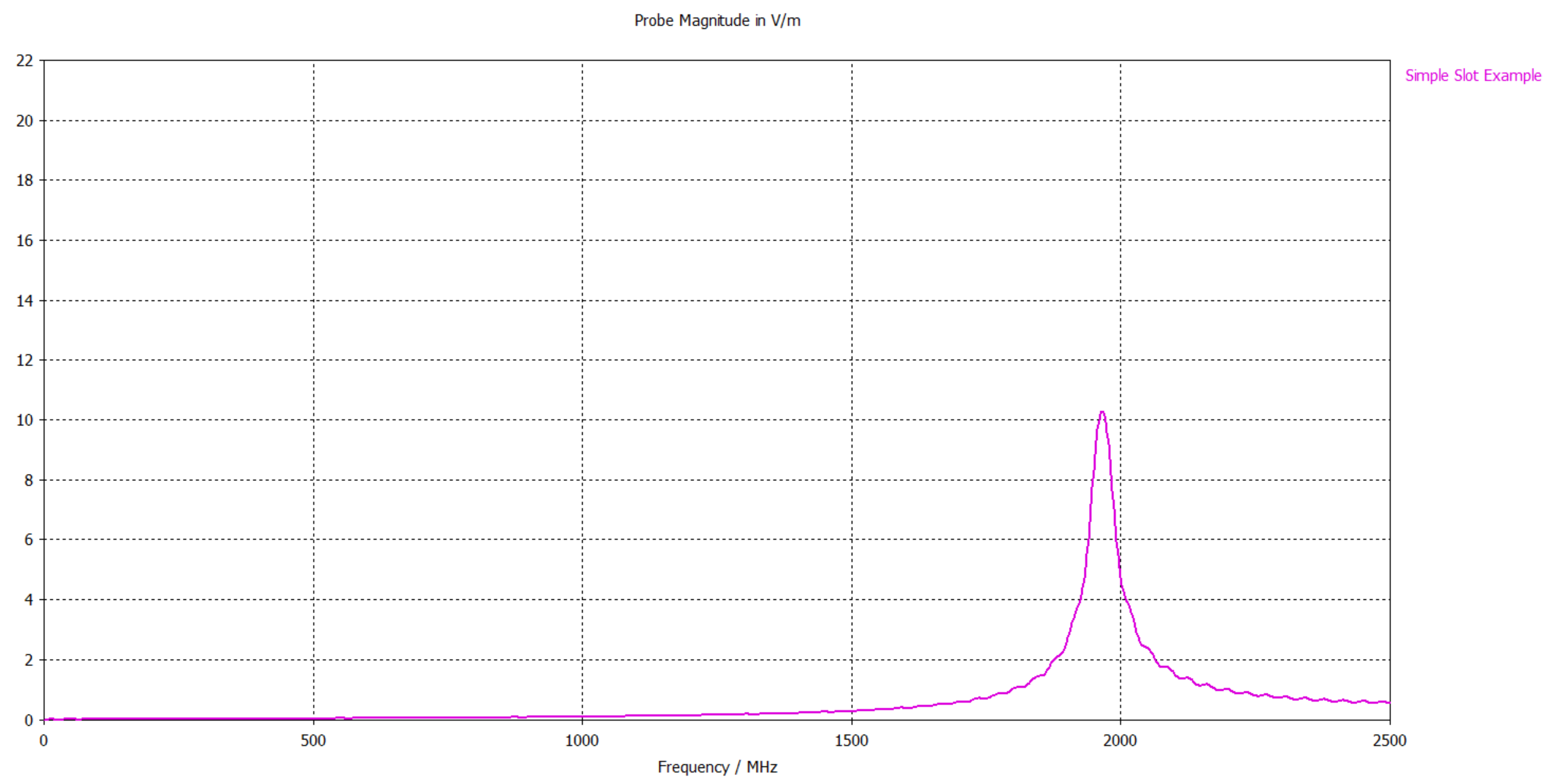
3-D Simulation Results: (Scott Piper)



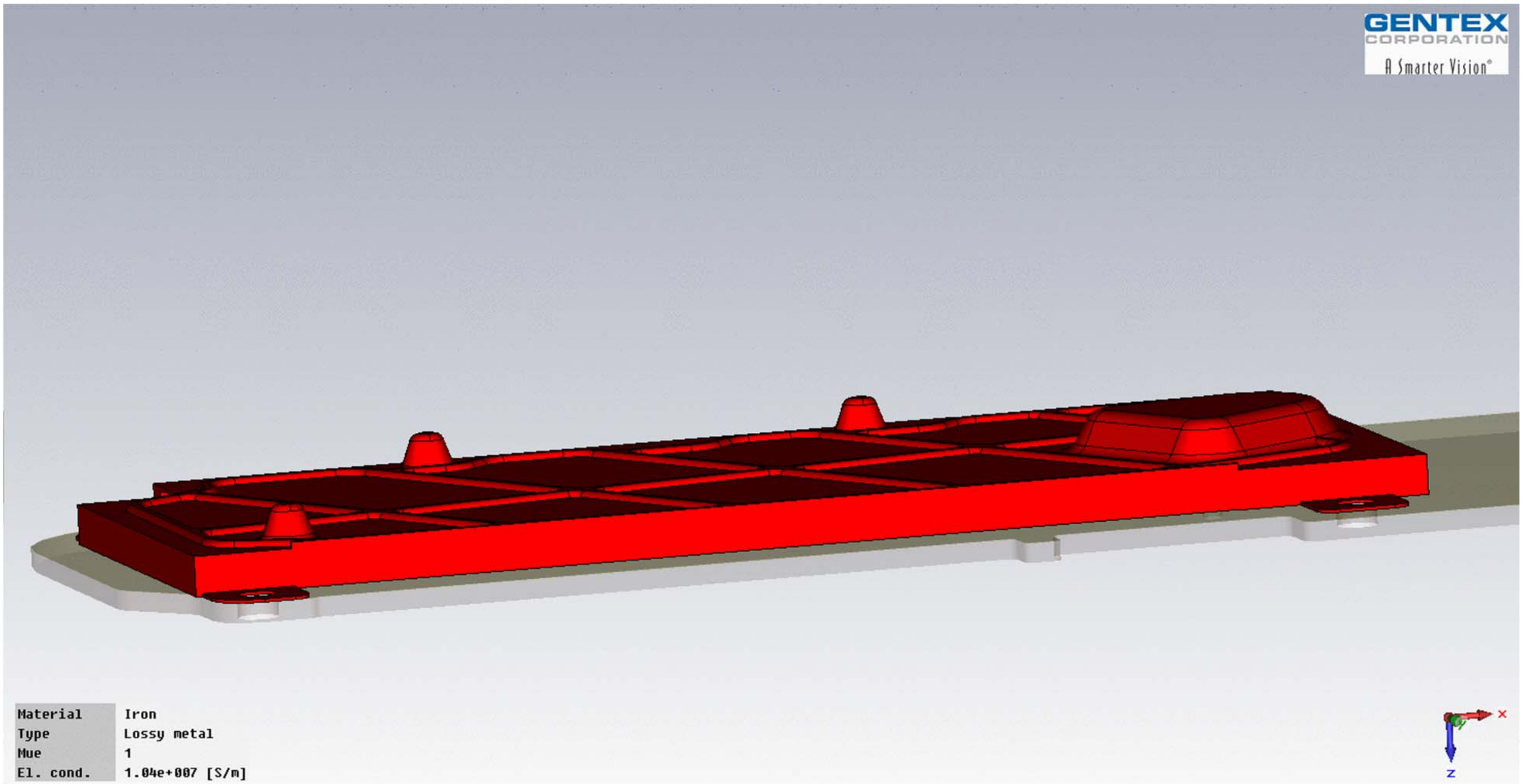
Simple Radiation Pattern



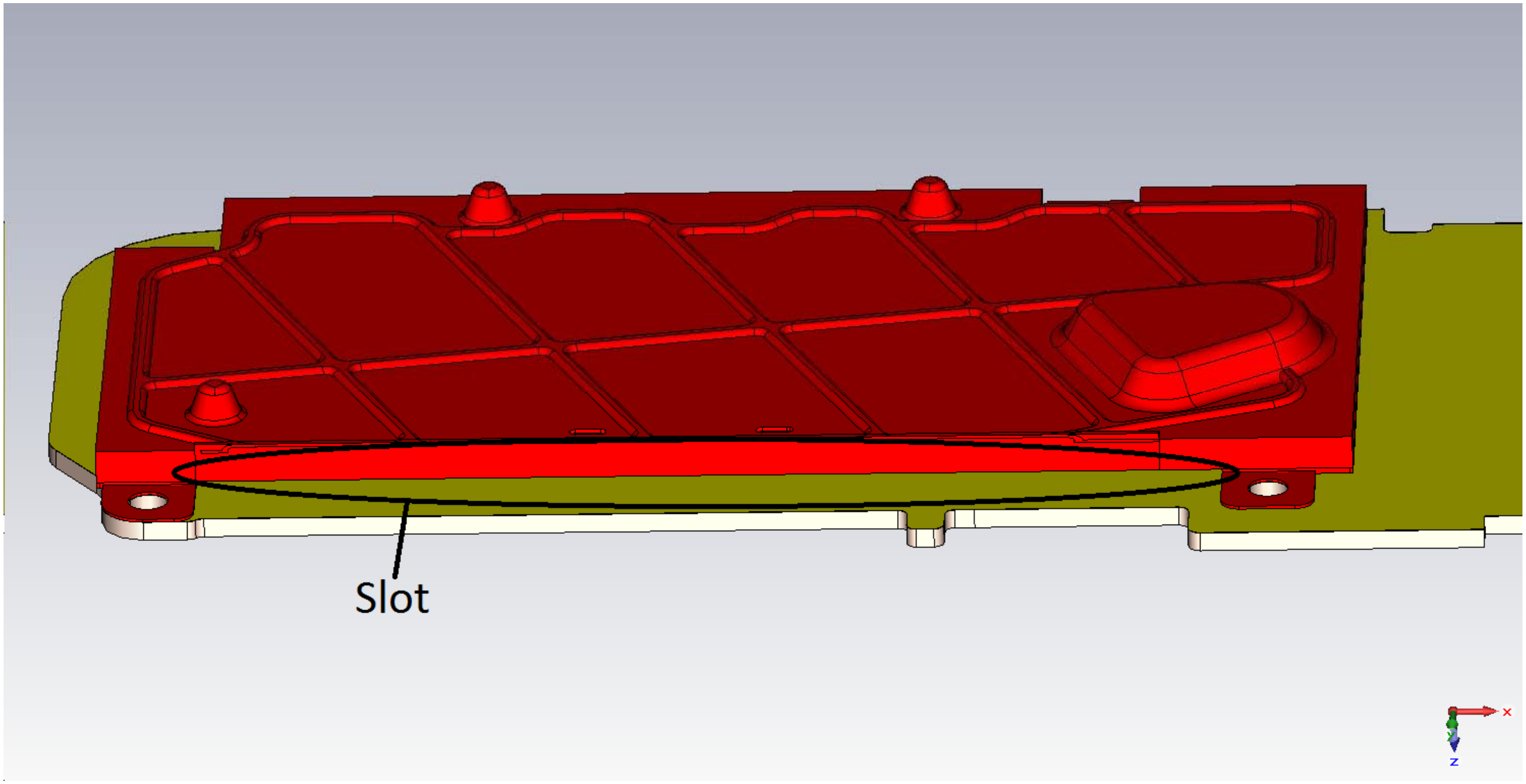
Simple Slot Graph



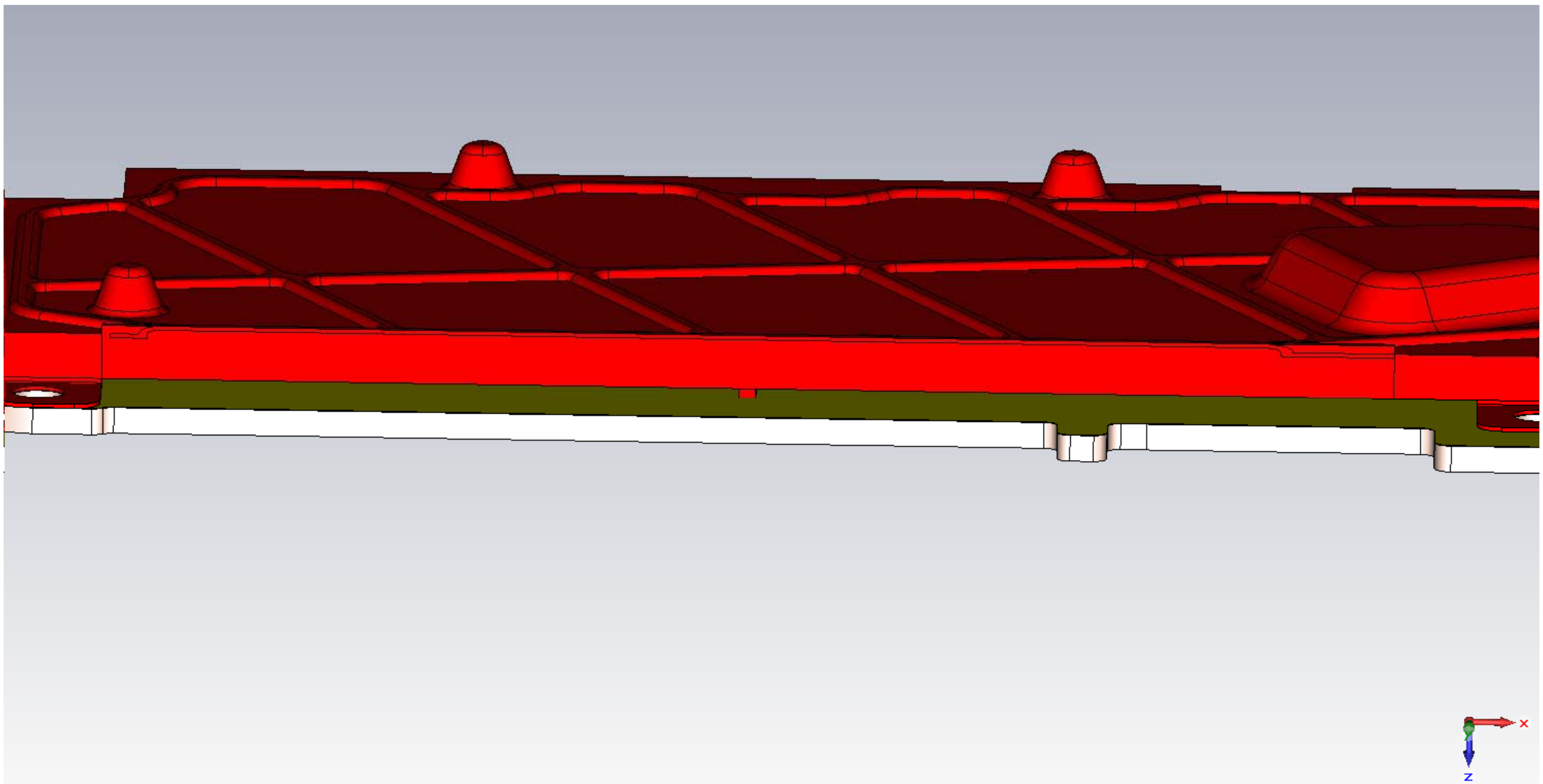
Base Line Shield



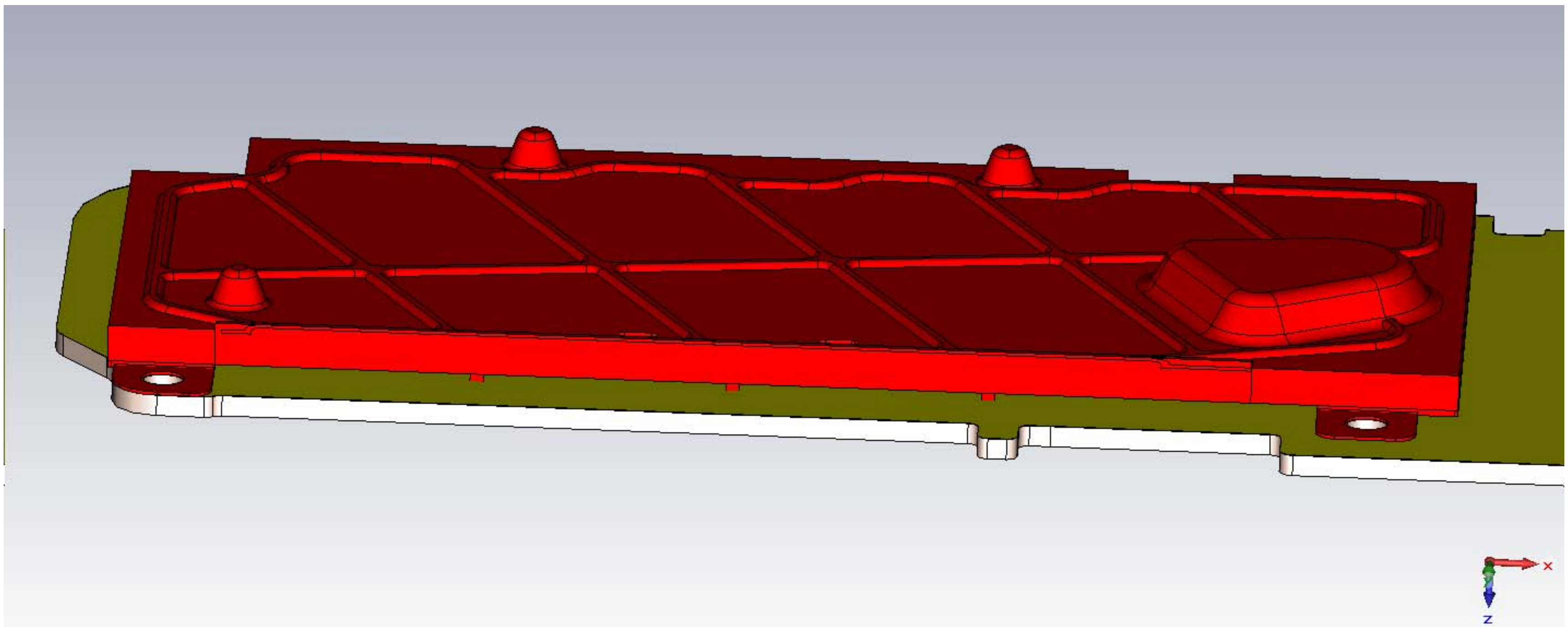
Real Shield with Slot



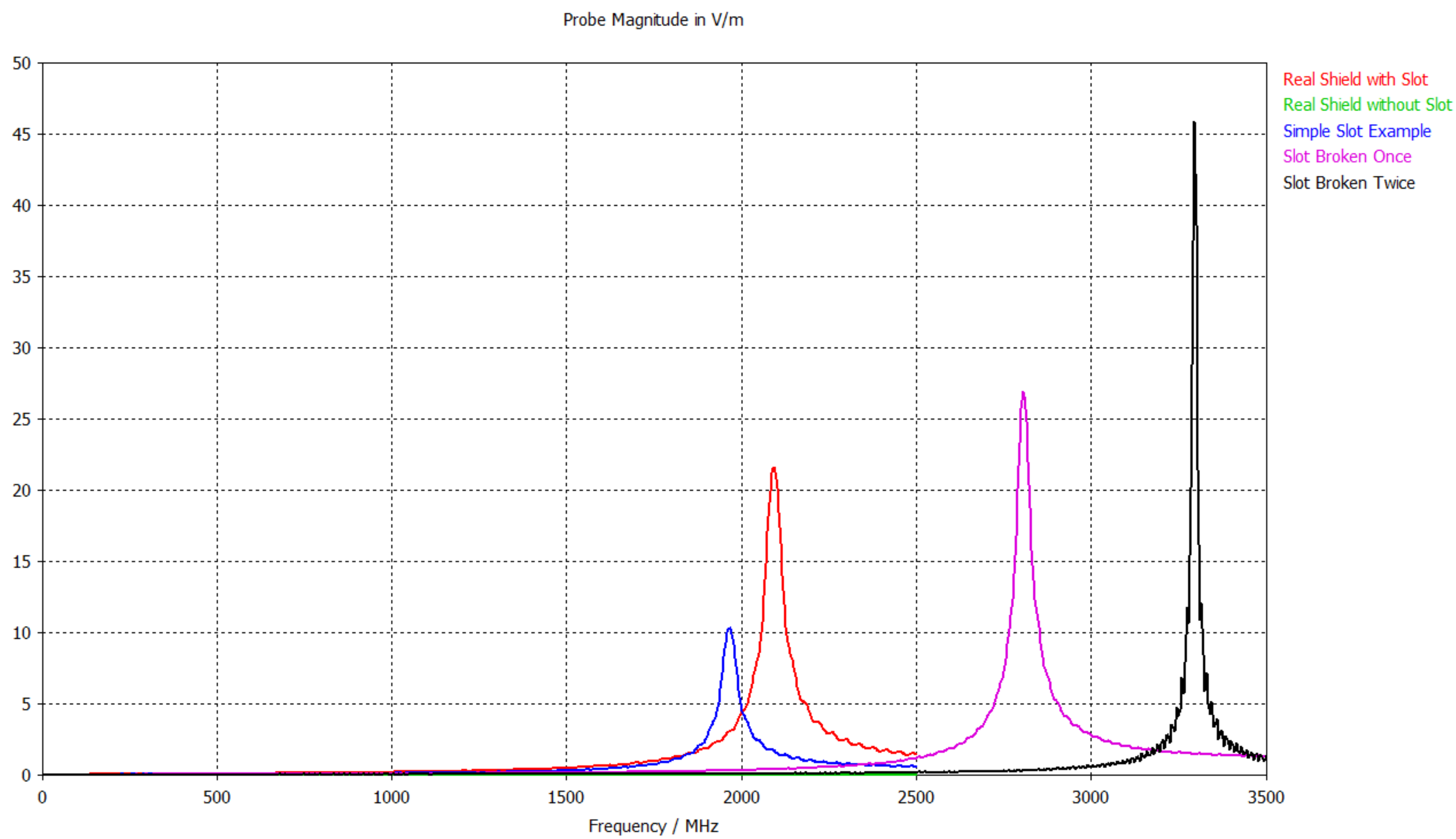
Slot Broken in Two



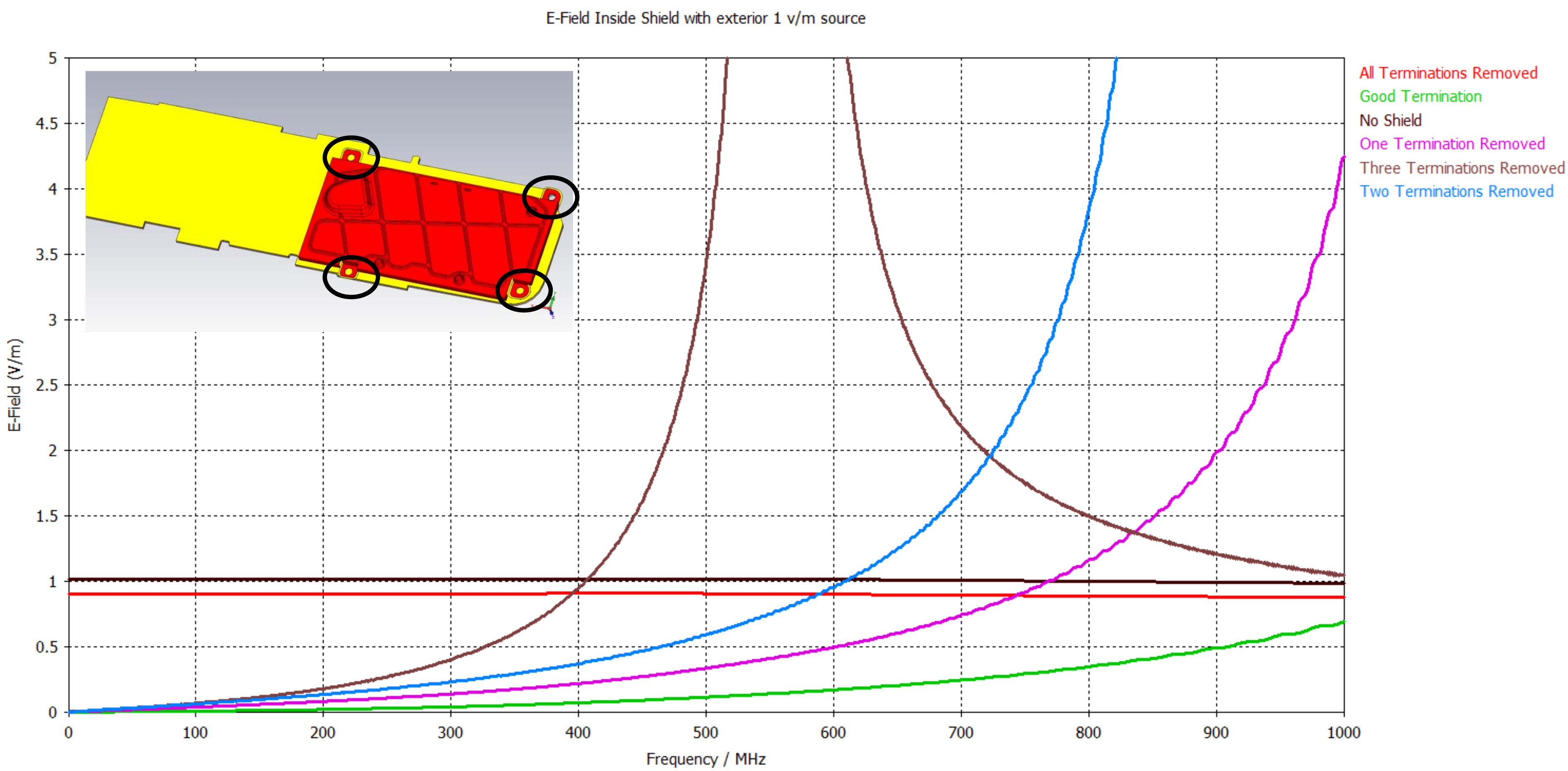
Slot Broken in Four



Summary Graph



CST Microwave Studio Simulation of a RCD Shield with various lifted terminations:



Shield Materials

Key Issues Determining Shield Performance: Shield Materials

Conductivity (σ)

(The measure of the ability of a material to conduct an electric current.)

Permeability (μ)

(The measure of the ability of a material to support the formation of a magnetic field within itself.)

Required Material Size for Equivalent Conductivity

These squares are different metals sized for constant conductivity:

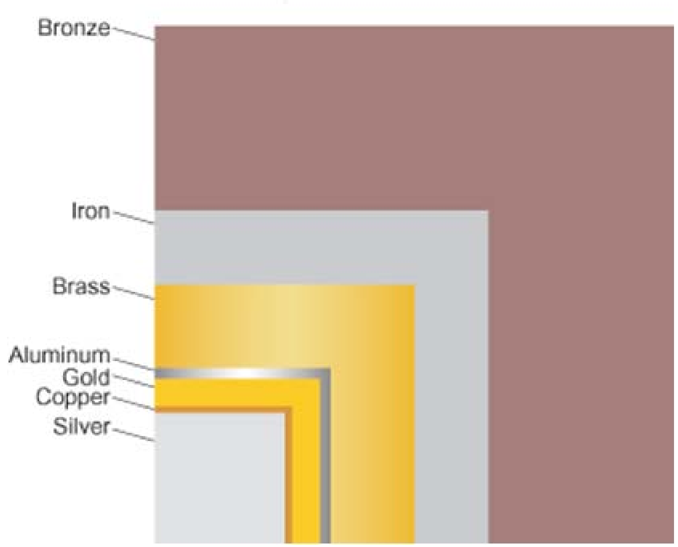
$$\sigma = \ell/(RA)$$

Where:

R is the electrical resistance of a uniform specimen

ℓ is the length

A is the area



Key Issues Determining Shield Performance: Shield Geometry

1. **Continuity** of the shield and connections.
2. **Thickness** (important for low-frequency magnetic field applications).
3. **Apertures** (which always impact negatively Shielding Effectiveness).
4. **Near-Field** or **Far-Field** Emissions (where is the source of emissions?).

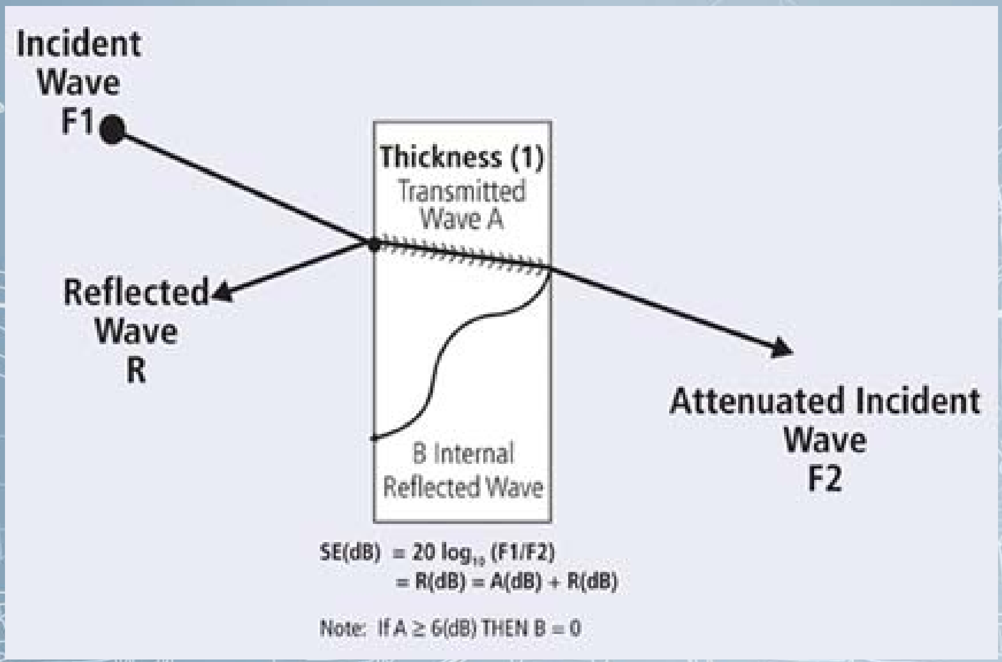
Shielding in a Nutshell:
How do Shields Work?

Reflection at the boundary surfaces (Low Frequencies)

Absorption as fields attempt to transverse the shield (High Frequencies)

Magnetic Field Shunting (Very Low Frequencies)

How Do Shields Work? Reflection and Absorption in a Near or Far-Field



Notes on Near and Far Field Emissions

- 99% of the Emissions Under the Shield will be Near-Field
  - Magnetic (Switched-Mode-Power-Supplies)
  - Electric (DDR RAM, Micro)
- 85-90% of the Emissions Outside of the Shield will be Far-Field
- The External Near-Field Exception:
  - Handheld Antenna Testing:

Basic Shield Effectiveness Formulas:

$$SE_{dB} = 20 \log_{10}(E_t/E_i) \text{ (Electric Field)}$$

$$SE_{dB} = 20 \log_{10}(H_t/H_i) \text{ (Magnetic Field)}$$

Where:

- SE_{dB} is the Shielding Effectiveness
- E_i is the Incident Electric Wave
- E_t is the Transmitted Electric Wave
- H_i is the Incident Magnetic Wave
- H_t is the Transmitted Magnetic Wave

S. A. Schelkunoff Shield Effectiveness Equation:

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

Where:

R_{dB} is Reflected losses at the outer and inner shield surfaces

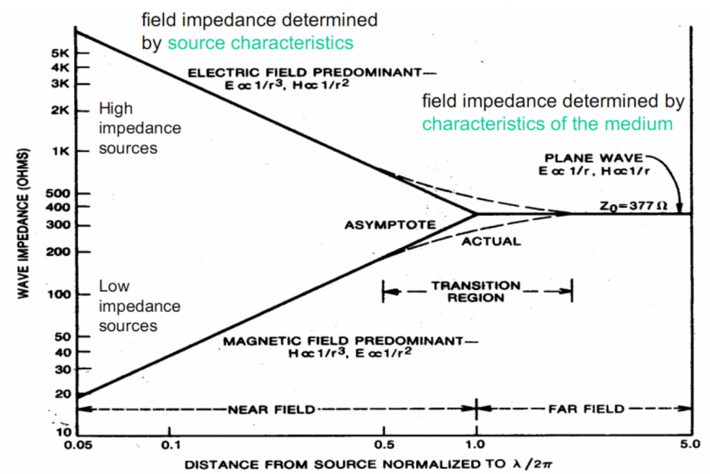
A_{dB} is the Absorption loss through the material

M_{dB} is the additional losses of Multiple reflections and transmissions within the shield*

*M_{dB} can be disregarded for shield thicknesses that are much greater than a skin depth.

Shielding Effectiveness Equations Change if the emissions are Far-Field or Near-Field

- The boundary between the Far and Near-Field is approximately $\lambda_o/2\pi$.
- Far and Near-Field sources have differing source characteristics and E/H ratios.



Reflection Loss (R_{dB}):

- Occurs at a Boundary
- Where the is a difference in the Conductivity (σ) and Permeability (μ) of Two Materials (Air and Shield)
- The Greater the Difference, the Greater the Reflection Loss
- Low Frequency Dominant

  (Switch Mode Power Supplies)

Reflection Loss (R_{dB}) General Formula for Far-Fields:

$$R_{dB}=168 + 10 \log_{10}(\sigma_r/\mu_r f)$$

Where:

σ_r = Conductivity relative to Copper

μ_r = Relative permeability relative to free space

f = Frequency

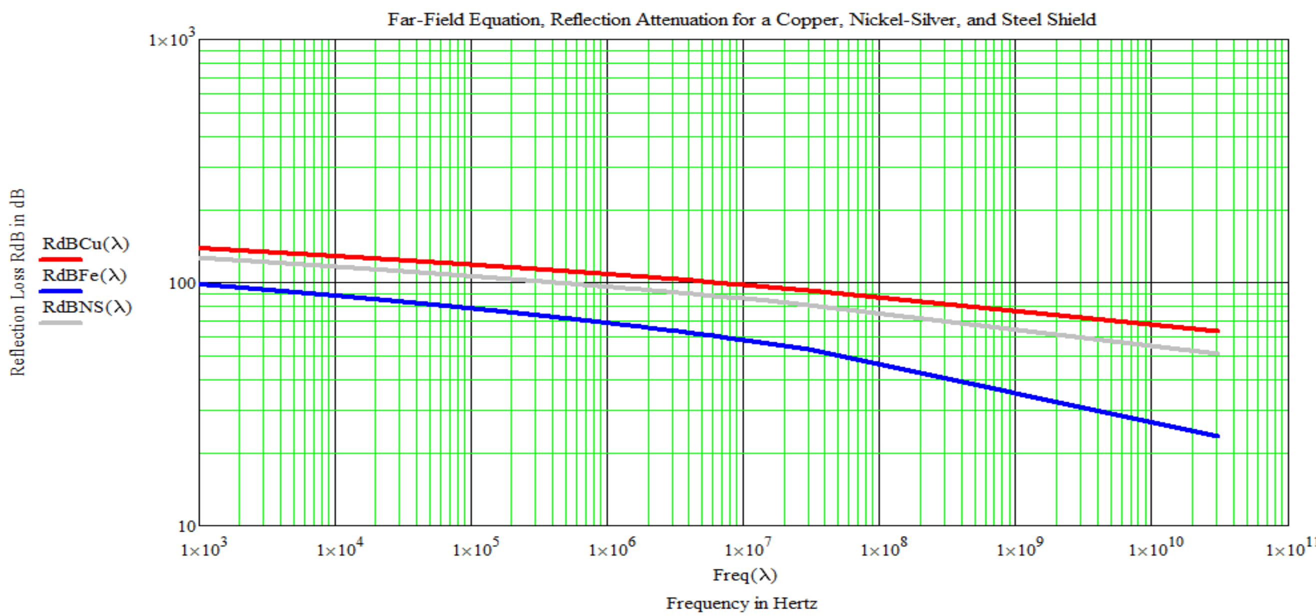
Note, Reflection loss is greatest for:

- Low Frequency (f)
- High Conductivity (σ_r)
- Low Permeability (μ_r)

The larger the R_{dB} the better the Shield.

Far-Field Reflection Loss (R_{dB}) Example:

Material	μ_r	σ_r	R_{dB}@1kHz	R_{dB}@10MHz
Copper	1.0	1.0	138 dB	98 dB
Nickel – Silver	1.0	0.06	126 dB	86 dB
Steel	1000	0.1	98 dB	58 dB



$$R_{dB}=168 + 10 \log_{10}(\sigma_r/\mu_r f)$$

Absorption Loss (A_{dB}):

Absorption Loss is the exponential decay of energy due to ohmic and heating of the material which occurs when an electromagnetic wave passes through a medium.

High Frequency Dominant

(Video Data, DDR, Micro Data Communications)

A little aside, Skin Depth (δ)

To understand Absorption Losses, there is a need to understand the term Skin Depth.

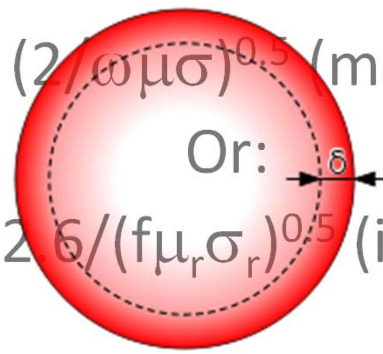
What is Skin Depth?

The distance required for the wave to be attenuated to 1/e or 37% of its original value is defined as the Skin Depth (δ) which is:

$$\delta = (2/\omega\mu\sigma)^{0.5} \text{ (meters)}$$

Or:

$$\delta = 2.6/(f\mu_r\sigma_r)^{0.5} \text{ (inches)}$$



Remember this term: δ (Skin Depth) – it is important.

Back to Absorption Loss (A_{dB}):

$$A = e^{t/\delta}$$

Or in dB:

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

Where:

t = thickness

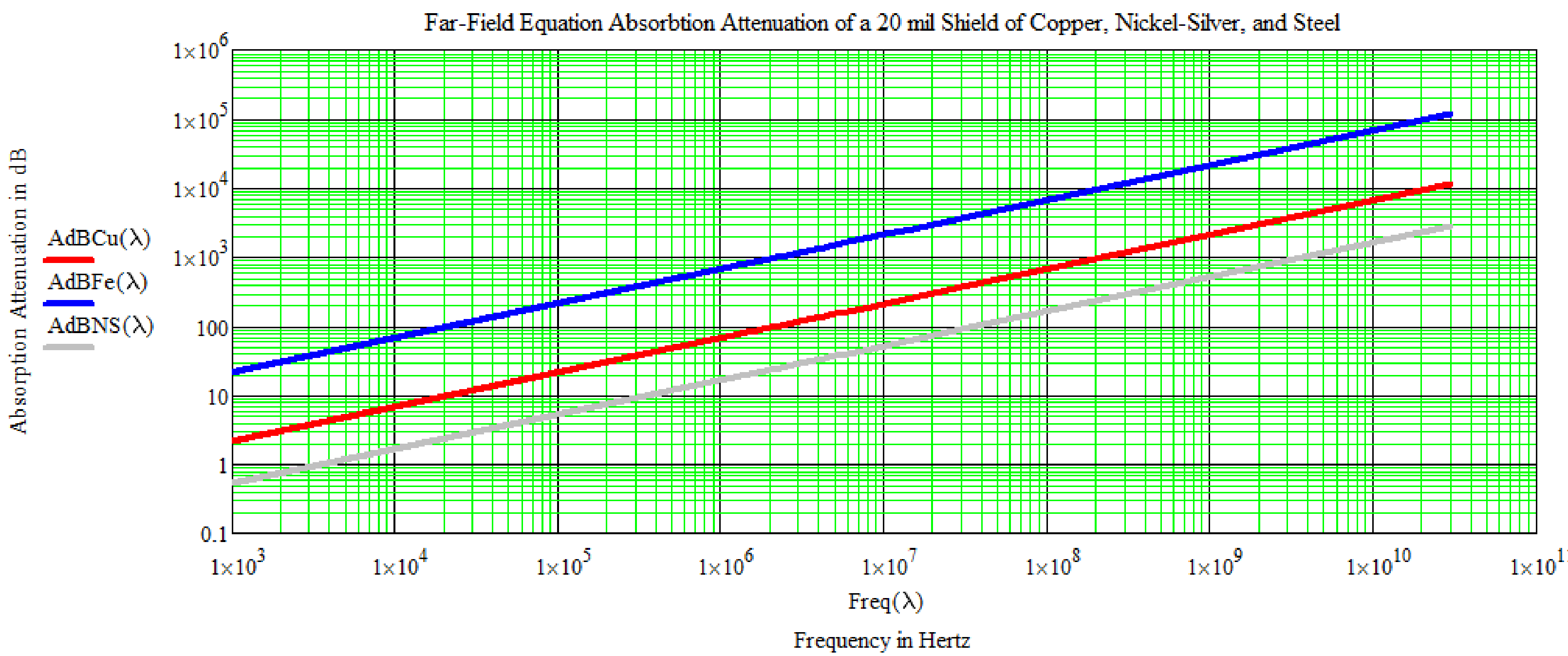
δ = Skin Depth

Note, Absorption Loss is greatest for:

- Greater Thickness (t)
- Smaller Skin Depth (δ)
  - Higher Frequency,
  - Greater Conductivity (σ),
  - Greater Permeability (μ)
- The Larger the A_{dB} the better the Shield

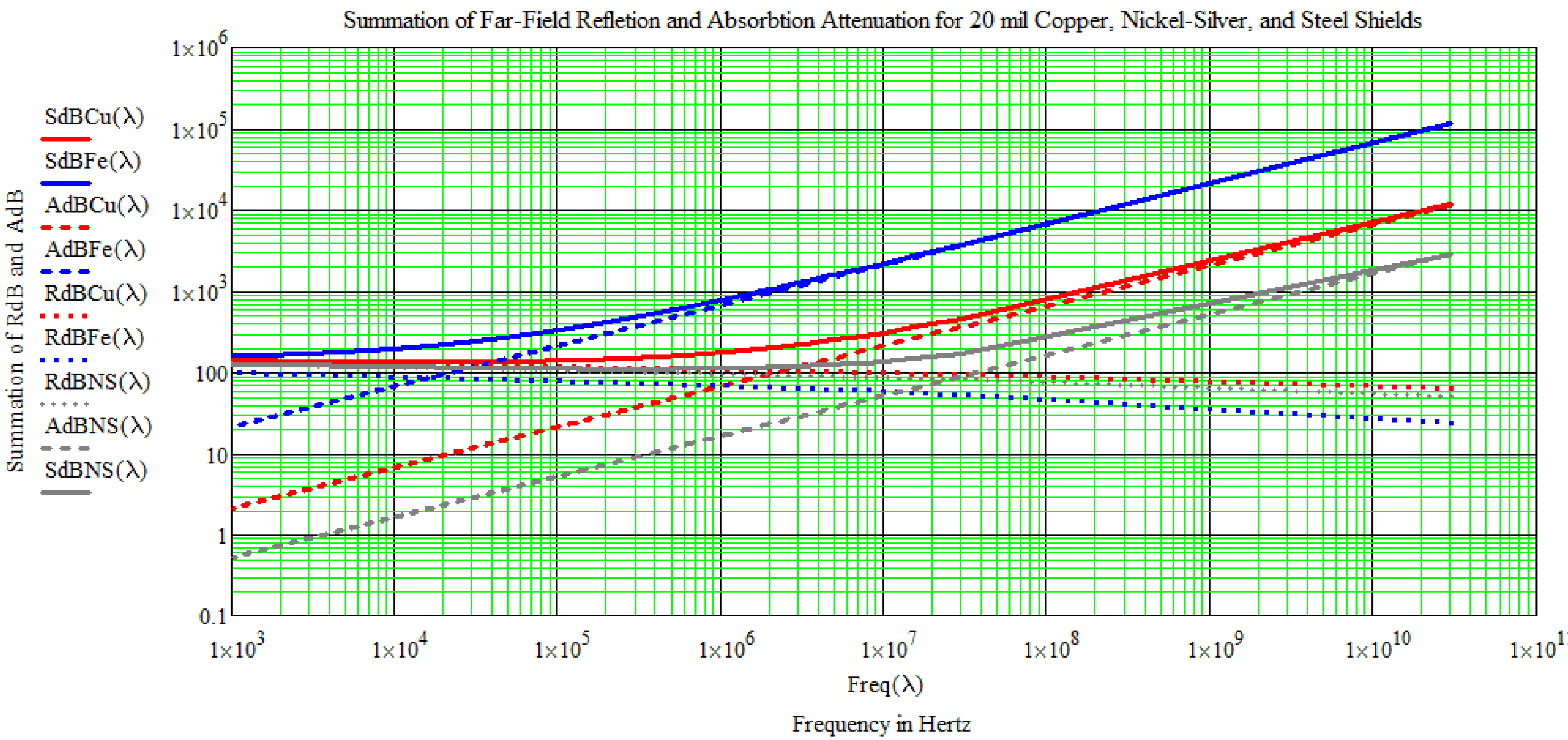
Far-Field Absorption Loss (A_{dB}) for a 20 mil sheet of Copper, Nickel-Silver, and Steel

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

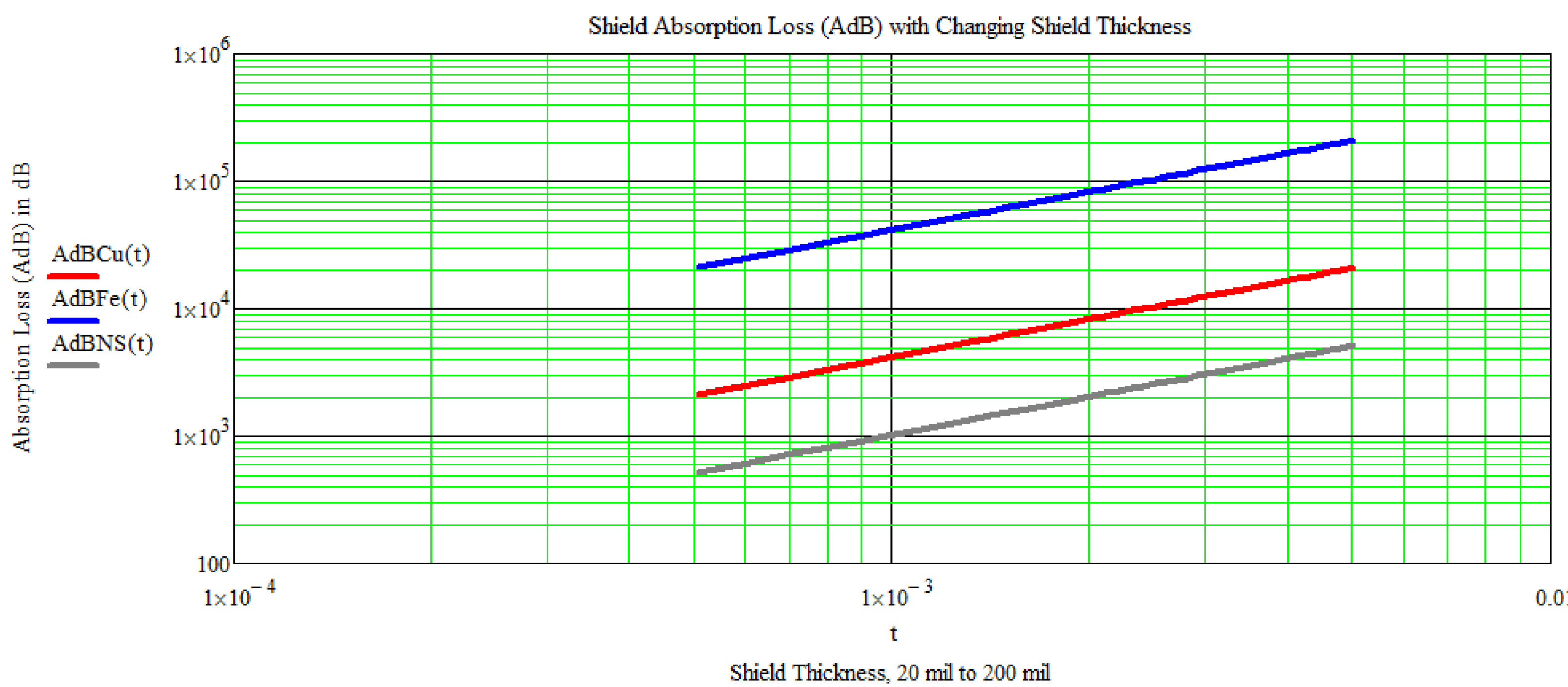


Far-Field Summation of Reflection Loss (R_{dB}) and Absorption Loss (A_{dB}) of a 20 mil Copper, 20 mil Nickel-Silver, and 20 mil Steel Shield

Schelkunoff Shield Effectiveness Equation: $SE_{dB} = R_{dB} + A_{dB}$



Far-Field Shield Absorption Loss (A_{dB}) with Changing Shield Thicknesses for Copper, Steel, and Nickel-Silver:



Near Field Reflection Losses

For Both Magnetic and Electric Fields

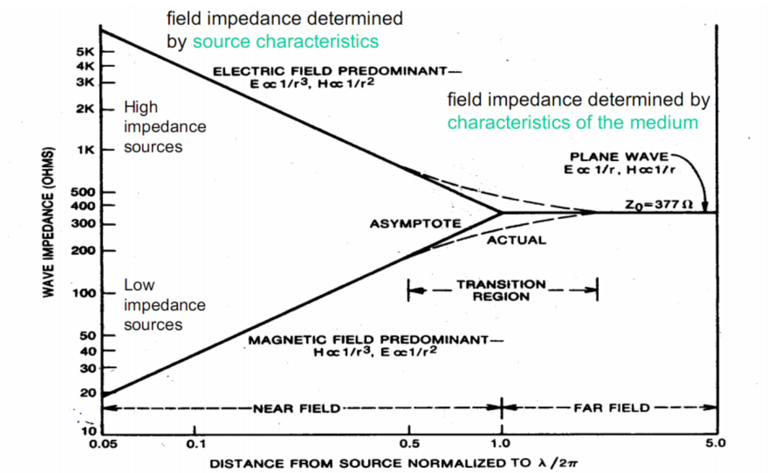
Magnetic Field Source:

$$R_{m,dB} = 14.57 + 10 \log_{10}(fr^2\sigma_r/\mu_r)$$

Electric Field Source:

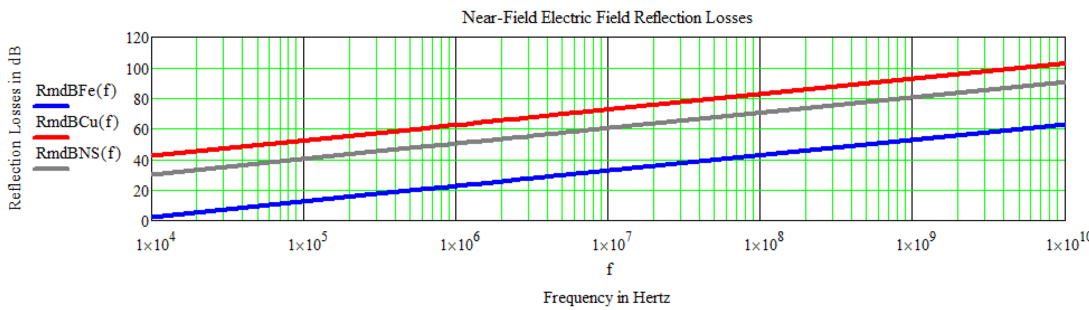
$$R_{e,dB} = 322 + 10 \log_{10}(\sigma_r/\mu_r f^3 r^2)$$

Where r = distance from source

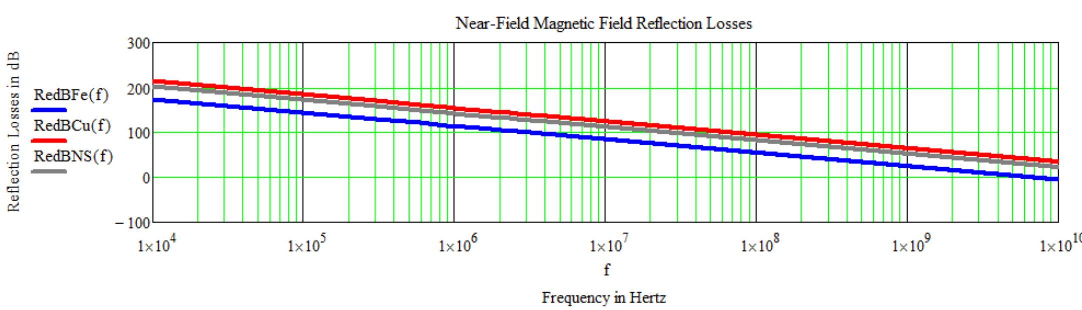


Near-Field Reflection Losses for Steel, Copper, and Nickel-Silver:

Reflection Losses of Magnetic Field



Reflection Losses of Electric Field



Near-Field Absorption Losses:

$A = e^{t/\delta}$ where t = thickness

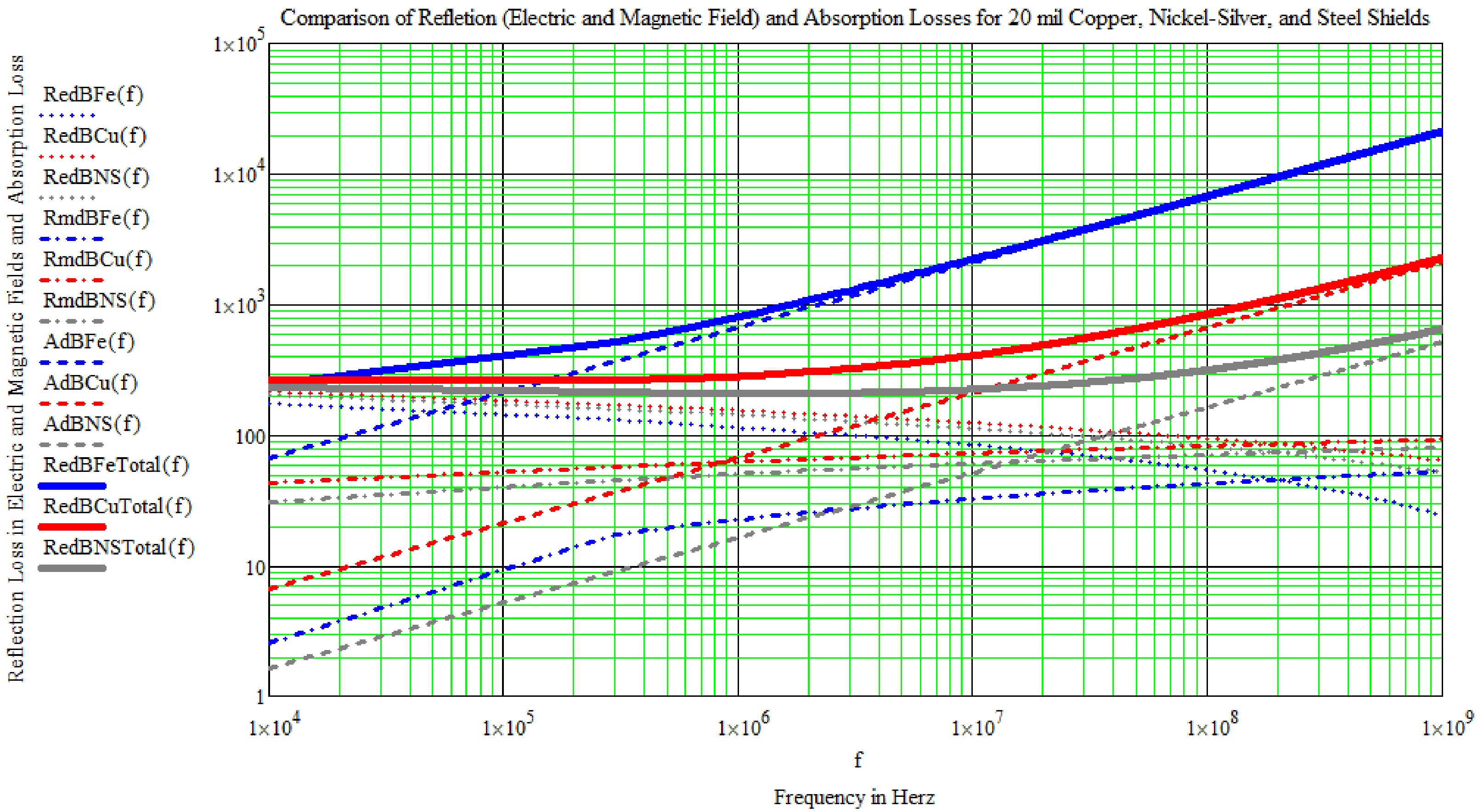
Or

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

This is the same equation as the far-field.

Comparison of Near-Field Reflection Loss (Electric and Magnetic) and Absorption Loss in a 20 mil Steel, Nickel-Silver, and Copper Shield:

$A_{dB} = 20 \log_{10} e^{t/\delta}$ $R_{m,dB} = 14.57 + 10 \log_{10}(fr^2\sigma_r/\mu_r)$ $R_{e,dB} = 322 + 10 \log_{10}(\sigma_r/\mu_r f^3 r^2)$



$\delta = (2/\omega\mu\sigma)^{1/2}$ (meters)

Summary of Fields and Losses:

I. For far-field sources:
   A. Reflection loss is predominant at the lower frequencies
   B. Absorption loss is predominant at the higher frequencies.
II. For near-field, **electric sources**:
   A. Reflection loss is predominant at the lower frequencies
   B. Absorption loss is predominant at the higher frequencies.
III. For near-field, **magnetic sources**:
   A. Absorption loss is the dominant shielding mechanism for all frequencies.
   B. However, both reflection and absorption losses are quite small for near-field, magnetic sources at low frequencies.

Low Frequency Magnetic Shielding in the Near-Field:

Basic methods for shielding against low-frequency sources:

1. Diversion of the magnetic flux with high-μ materials
2. Generation of opposing flux via Faraday's law commonly known as the shorted turn method.

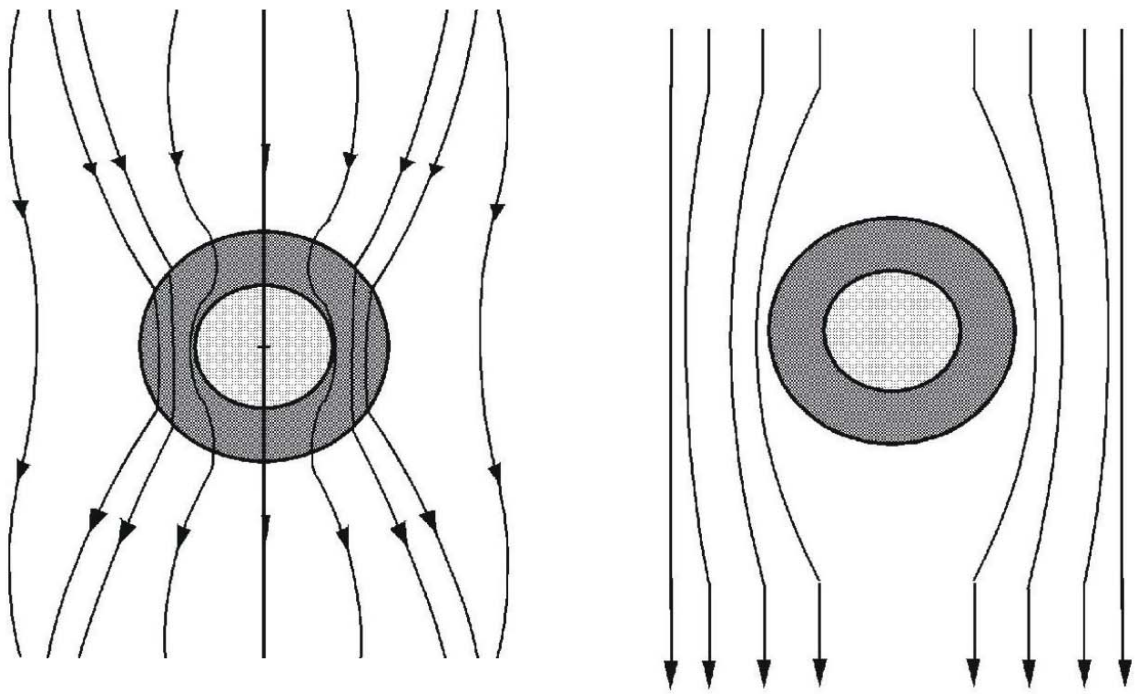
Magnetic Shunting - diverting the magnetic flux:

1. Requires a high-μ material to divert magnetic flux.
2. Problems with high-μ materials (Mumetal):
   1. High-μ materials are expensive
   2. Permeability (μ) is:
      - Nonlinear
      - Decreases with increasing frequency
      - Decreases with increasing magnetic field strength
      - Changes with Mechanical Handling/Treatment
      - Dominant at Very-Low-Frequencies

(High-μ materials are only effective for magnetic fields below 1 kHz. *“This is why shielding enclosures for switching power supplies are constructed from steel rather than Mumetal.”* Professor Clayton Paul, Introduction to Electromagnetic Compatibility, Second Edition, Page 743.)

Magnetic Shunting:

Example of Field Behavior (Spherical Shield)

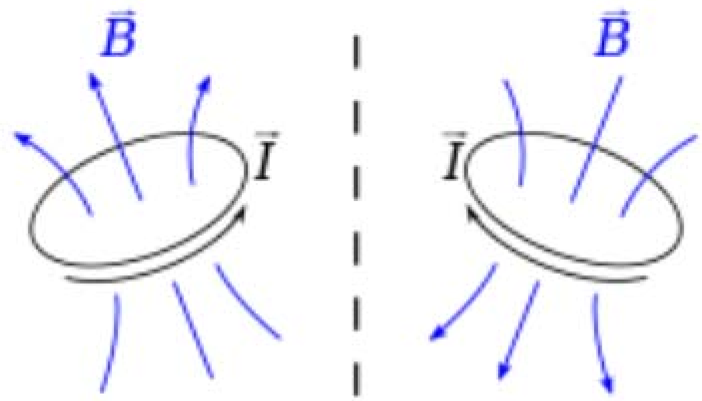


LF – Magnetic Material (no tangential field) HF – Magnetic or Non-Magnetic Material

No effect at High-Frequencies: The μ is approaching 1 in this high-μ material.

Faraday’s Law or Shorted Turn:

A changing current in one wire causes a changing magnetic field that induces a current in the opposite direction in an adjacent wire.



Magnetic Shielding:
What is a Magnetic Shield?

- A shield of high permeability that can “shunt,” “divert,” “attract,” “Channel,” or “guide” (like a duct) a magnetic field.

Because:

- High-permeability magnetic materials have low *reluctance*.

Therefore:

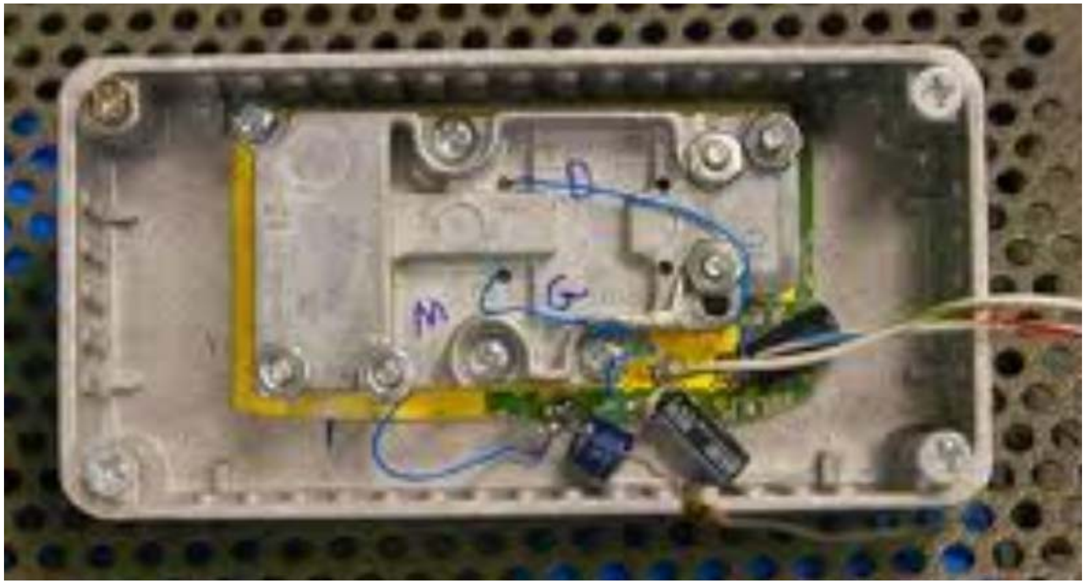
- A magnetic field follows the path of least *reluctance* similar to how current follows the path of least resistance.

Degree of magnetic shielding is determined by:

– Material

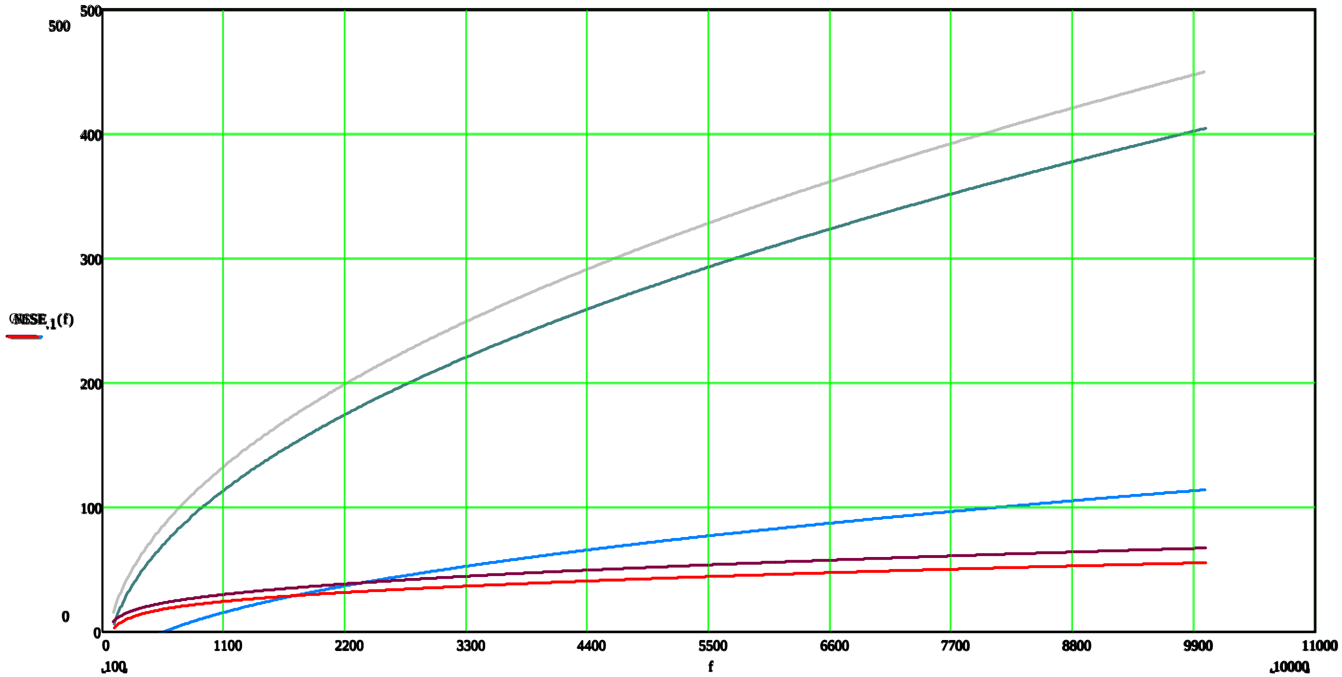
– Thickness

– Shape



– Position relative to the applied Magnetic Field

Shield Effectiveness (SE) of Flat Sheets of Different Materials in a Magnetic Field 15 mil Thick



Nickel

Cold-Rolled Steel (SAE 1045)

Stainless Steel (430)

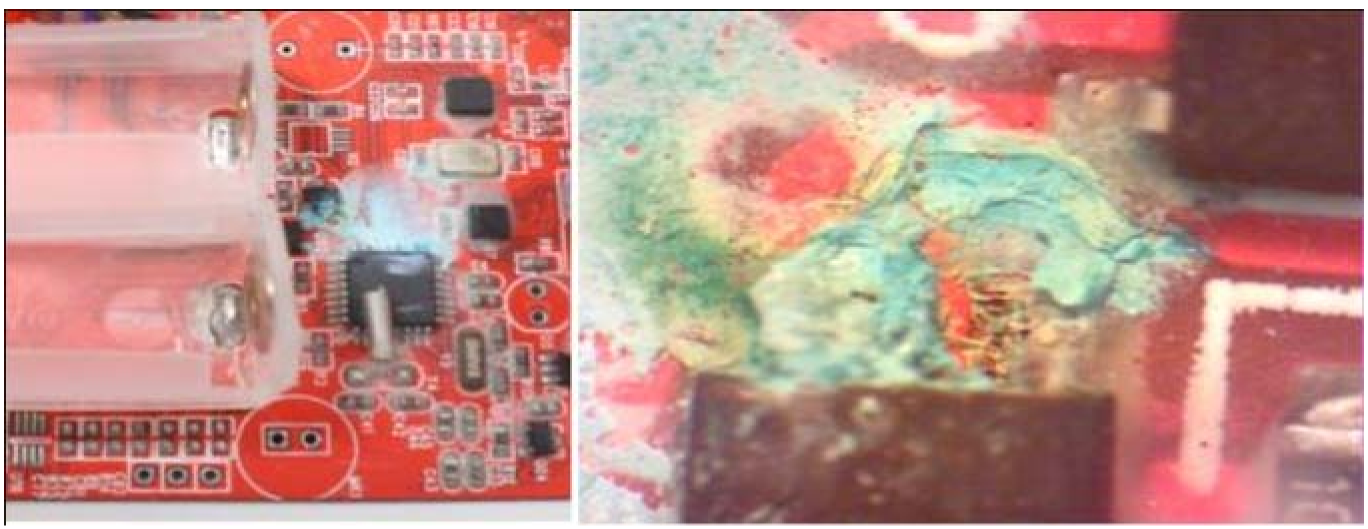
Copper

Aluminum

Corrosion

THEORY OF CORROSION:

- Galvanic and electrolytic corrosion are two types of corrosion suspected in shielding degradation.
- In both cases the anode metal gets corroded.



Galvanic corrosion:

- A natural phenomenon produced:

1. When two dissimilar metals are brought in contact with each other
2. In the presence of acidic atmospheric moisture.

- An electrochemical process where the metal with higher anodic index voltage corrodes and **an external electric current is produced by an internal chemical reaction.**

Electrolytic Corrosion

- An electrochemical process:
  - Where the corrosive internal chemical reaction is induced by an **externally** applied electric potential
  - **Although the metals may be similar** as opposed to galvanic corrosion (dissimilar metals)

Material Electrochemical Potentials

Metal involved ↓ / Partner metal →	Stainless steel	Nickel	Copper	Brass	Tin	Steel	Aluminium	Chromium	Zinc
Stainless steel	0								
Nickel	180								
Copper	320	140	0						
Brass	400	220	80	0					
Tin	550	370	230	150	0				
Steel	750	570	430	350	200	0			
Aluminium	840	660	520	440	290	90	0		
Chromium	950	770	630	550	400	200	110	0	
Zinc	1150	970	830	750	600	400	310	200	0

Galvanic Corrosion Risk

Metal Corroding \ Contact Metal	Magnesium & alloys	Zinc & alloys	Aluminium & alloys	Cadmium	Steel-carbon	Cast iron	Stainless steels	Lead, tin and alloys	Nickel	Brasses, nickel silvers	Copper	Bronzes, cupro-nickels	Nickel copper alloys	Nickel- Chrome_Mo Alloys Titanium, silver, graphite Graphite, gold,platinum
Magnesium & alloys		X	X	X	X	X	X	X	X	X	X	X	X	X
Zinc & alloys			X	X	X	X	X	X	X	X	X	X	X	X
Aluminium & alloys				X	X	X	X	X	X	X	X	X	X	X
Cadmium					X	X	X	X	X	X	X	X	X	X
Steel-carbon				X		X	X	X	X	X	X	X	X	X
Cast iron					X		X	X	X	X	X	X	X	X
Stainless steels					X	X		X	X	X	X	X	X	X
Lead, tin and alloys							X		X	X	X	X	X	X
Nickel										X	X	X	X	X
Brasses, nickel silvers						X	X	X	X		X	X	X	X
Copper							X	X	X			X	X	X
Bronzes, cupro-nickels													X	X
Nickel copper alloys														X
Nickel-Chrome-Mo Alloys Titanium, silver, graphite Graphite, gold,platinum														

X = Galvanic Corrosion Risk

Summations and Conclusions:

Summations and Conclusions: Shields

1. Shield the Whole active circuit
2. Use THICK Steel for Magnetic Shielding-Switch-Mode-Power Supplies
3. Know what type of field (Near/Far) is the threat

   (If you want to keep the field on the board then the field is near. If you want to keep the field off of the board then the field is *usually* far.)

Summations and Conclusions: Shields

1. Reflection loss is large for electric fields.
2. Reflection loss in normally small for low-frequency magnetic fields.
3. Magnetic fields are harder to shield against than electric fields.
4. Use a good conductor to shield against electric fields and high-frequency magnetic fields.
5. Use a magnetic material to shield against low-frequency magnetic fields.

Summations and Conclusions: Apertures

Keep Apertures' dimensions minimal

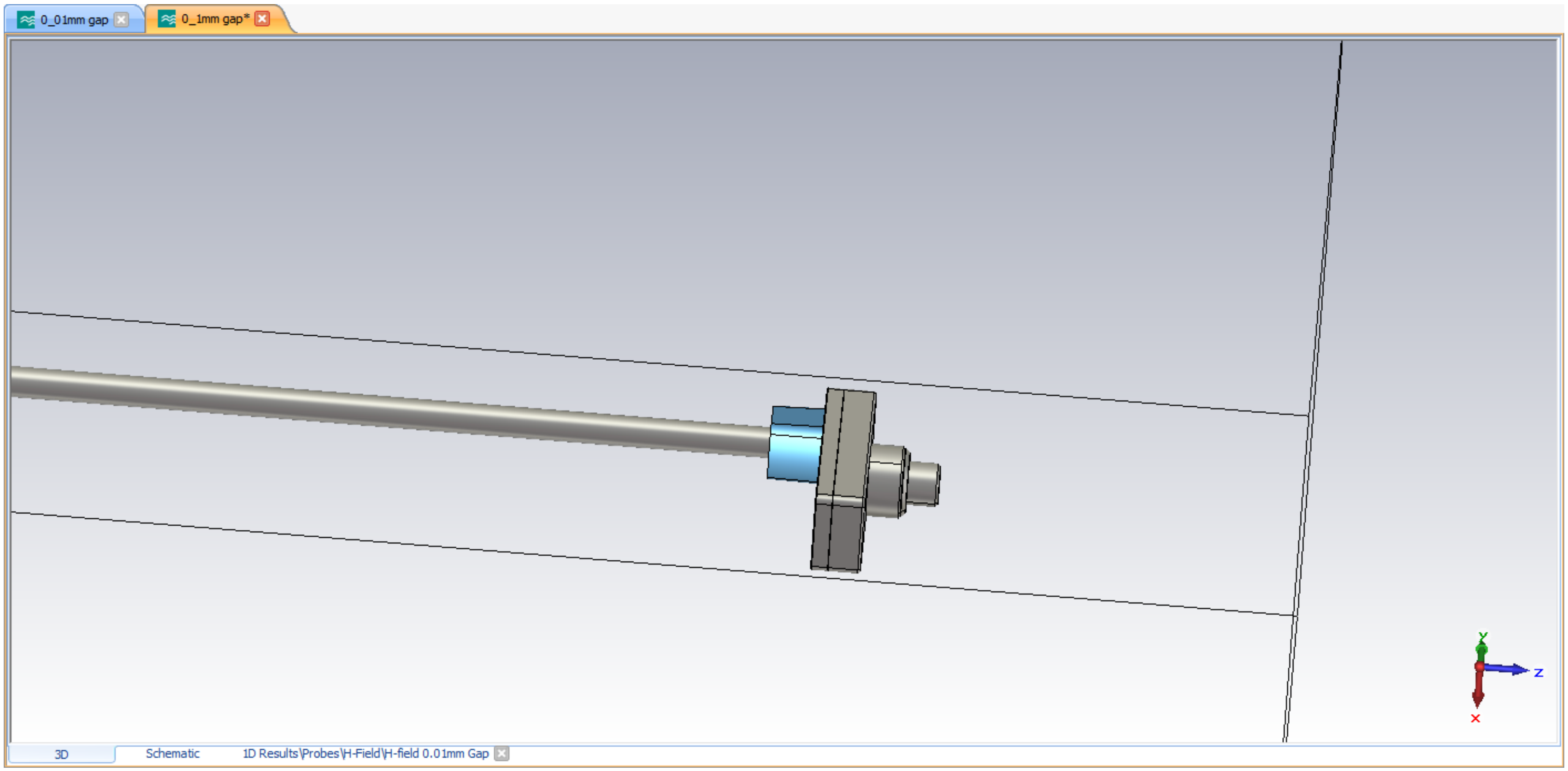
Keep number of Apertures few

Demonstrations:

- Measuring Shielding effectiveness of various materials in a Near-Field Magnetic Field
- Aperture Measurement Program
- Palantir Shield Simulations

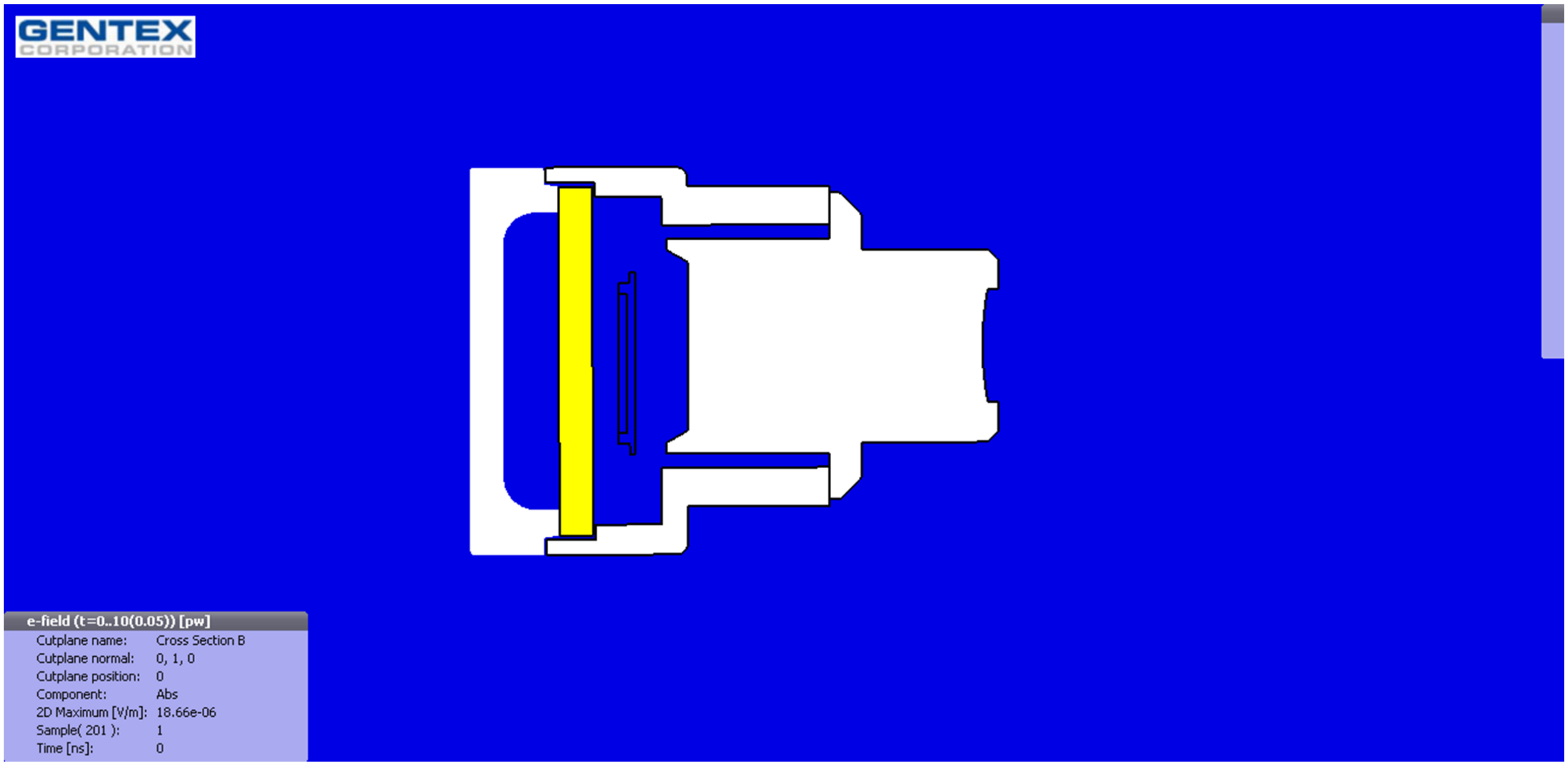
Plane Wave

Setup overview



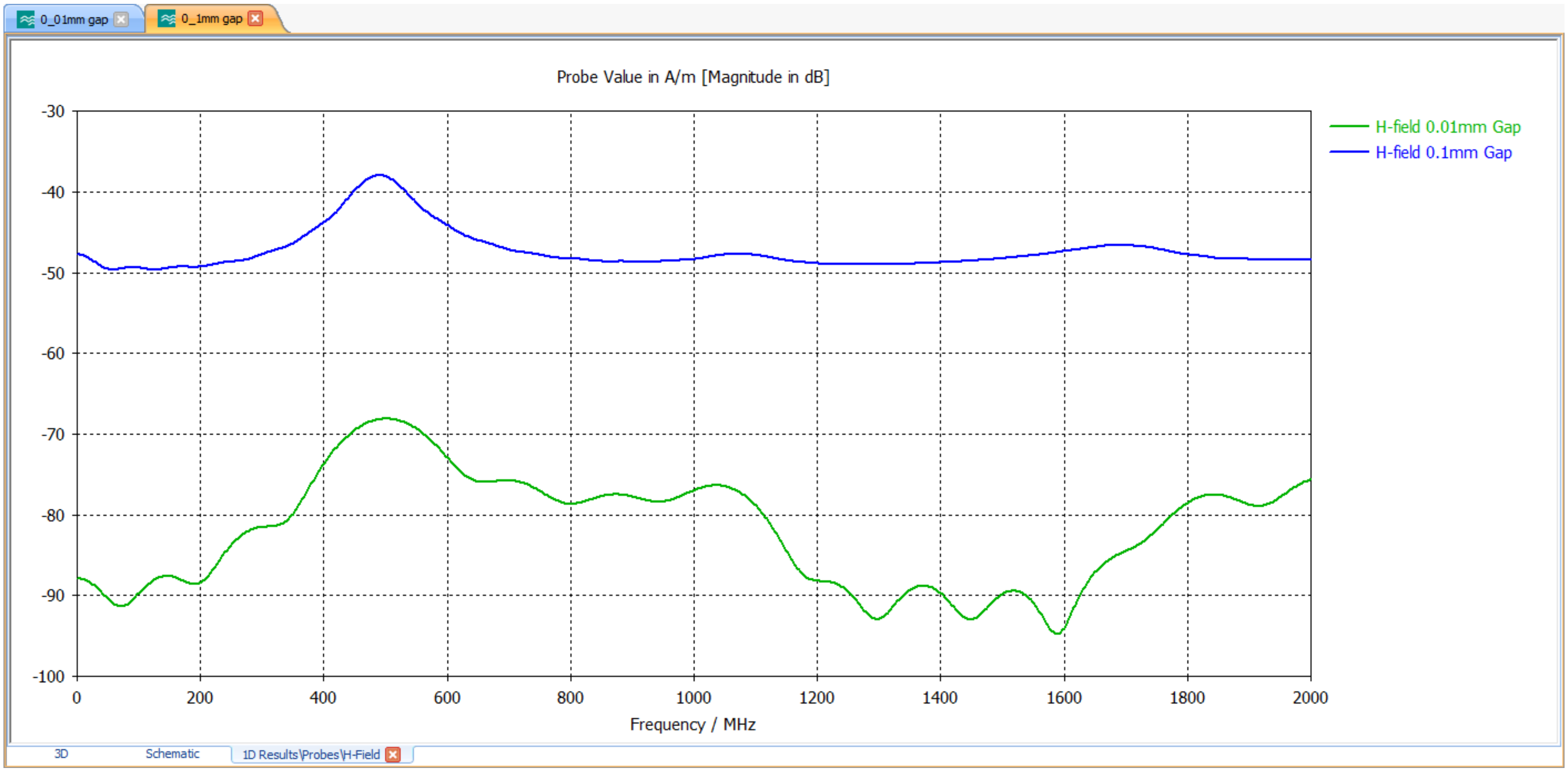
Overview of Plane Wave

Cross Section of Camera



Field Comparison inside of Camera

H-field probe



That’s all…

- Question and Answer Time

- Thank you for attending.

Questions?

References

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