EFFECTIVE MATERIALS FOR HIGH FREQUENCY EMC DESIGN

Dr. Bruce Archambeault
IEEE Fellow
iNARTE Certified Master EMC Design Engineer
Missouri University of Science/Technology Adjunct Professor

Archambeault EMI/EMC Enterprises
PO Box 1265
Four Oaks, NC 27524 USA
bruce@brucearch.com

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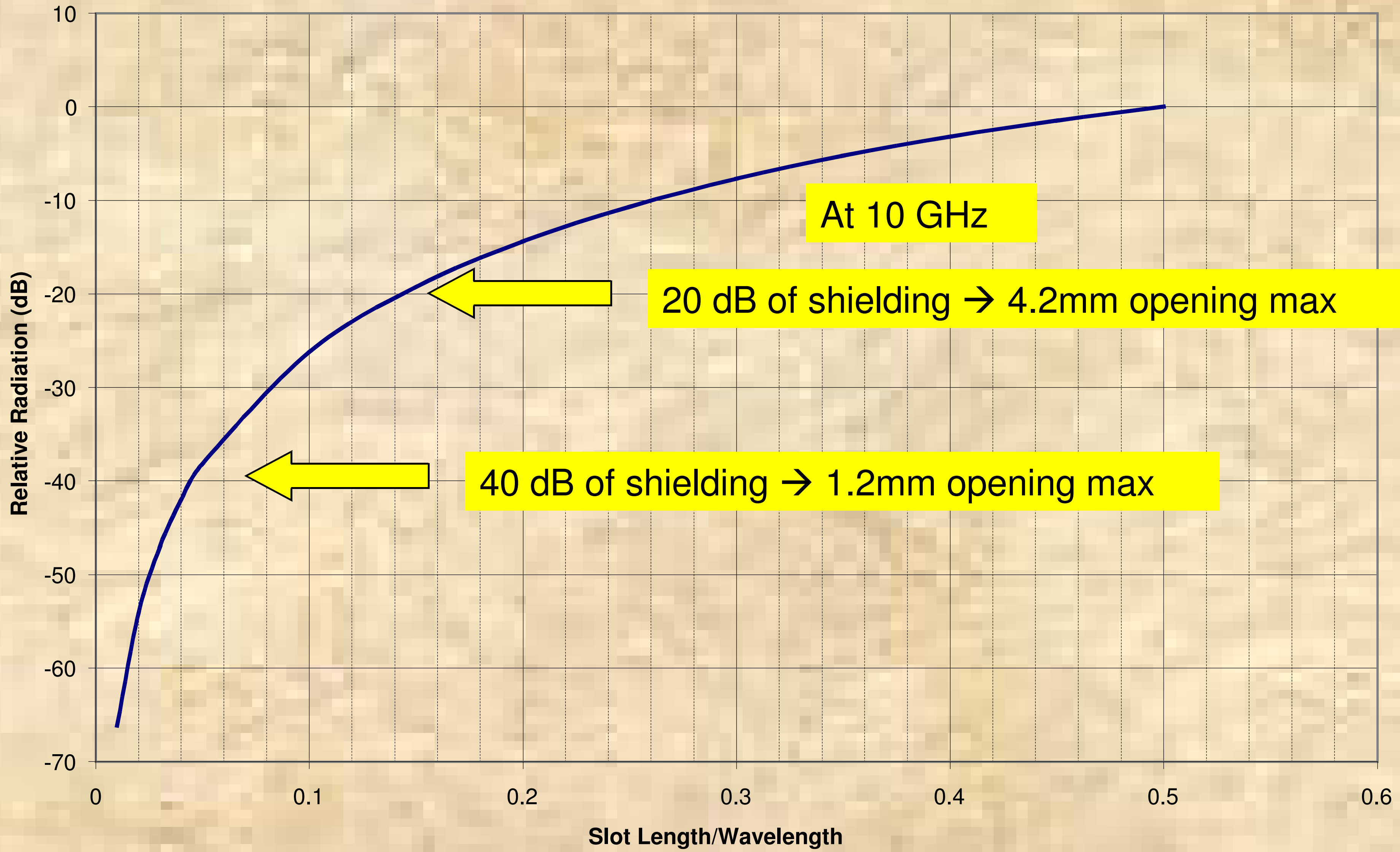
Shielding

- One of the primary EMI control techniques
- Depends on a EM tight enclosure
  - Electrically small openings
  - Conflicts with thermal and functionality
- We are reaching the practical limit of using shielding
  - Emissions can easily occur in tens of GHz range
  - At 10 GHz, lambda = 3 cm
- How effective is a slot opening??

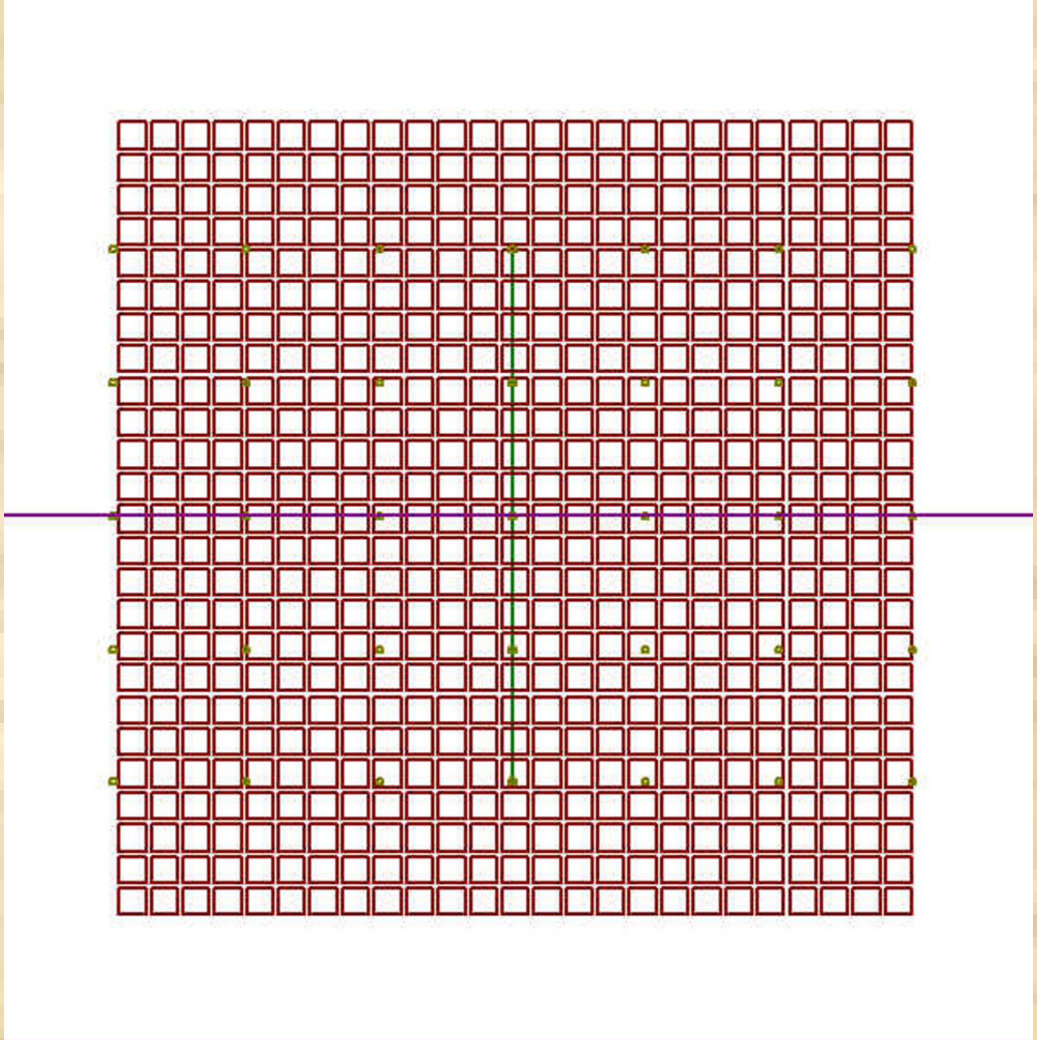
Slot Leakage vs Size and Wavelength



What Can We do to Improve Shielding?

- Reduce hole size options limited
- Add thickness to metal?
  - Honey comb air filters are effective to a certain frequency
    - Limited by wavelength
    - Expensive

Air Vent Geometry



TOTAL AREA = 15cm x 15cm

1mm spacing between holes

Hole Sizes

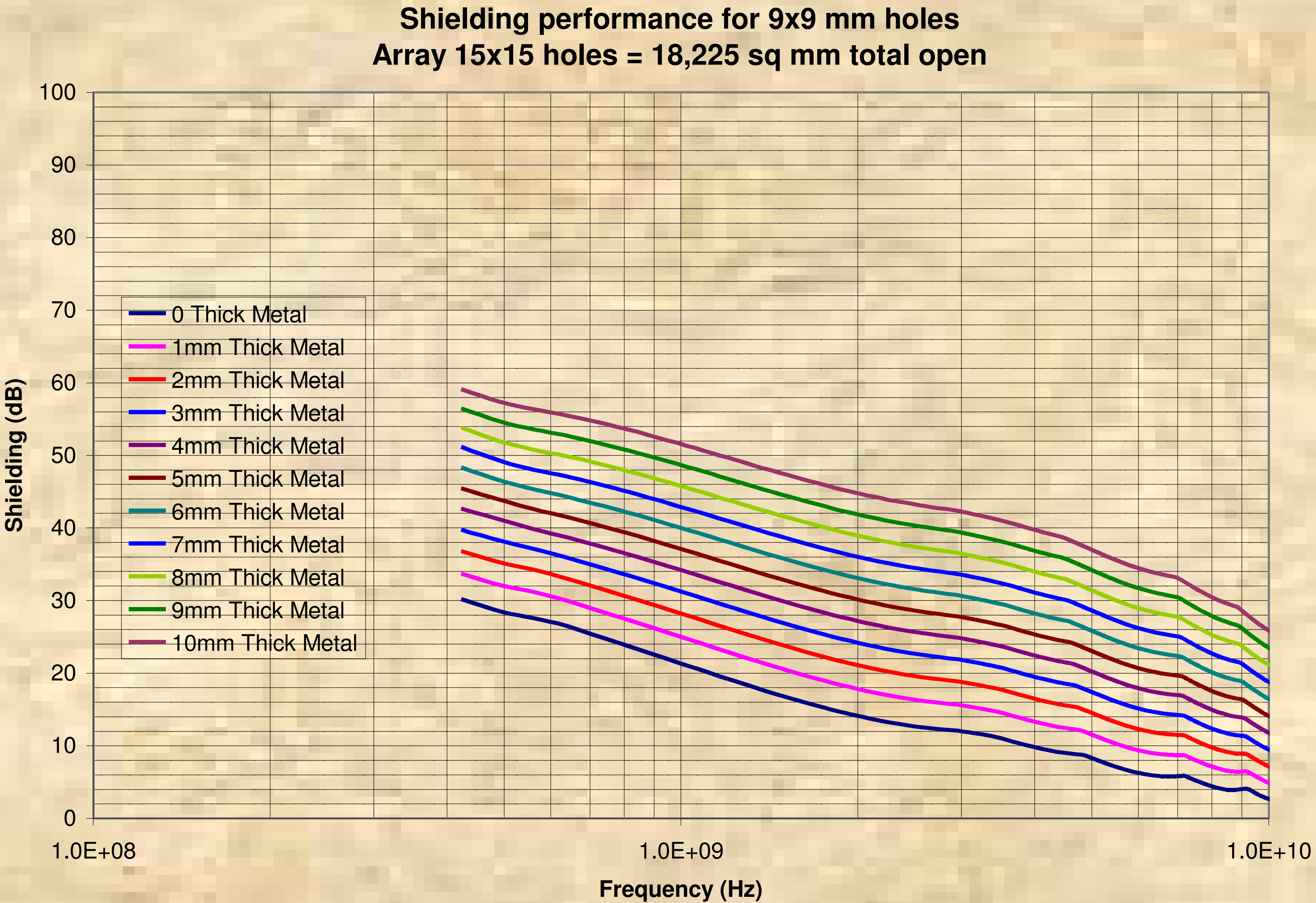
4mm x 4mm

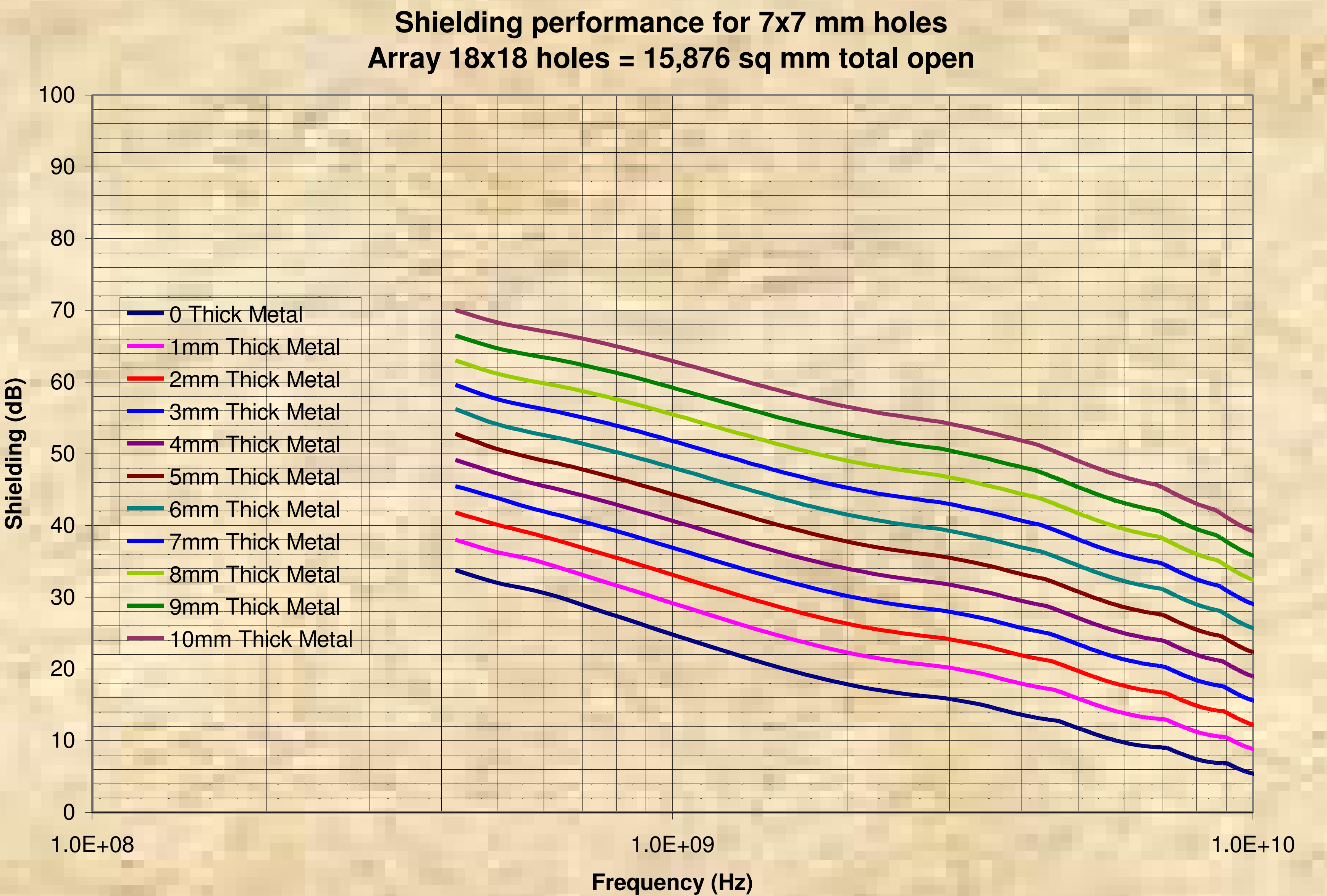
5mm x 5mm

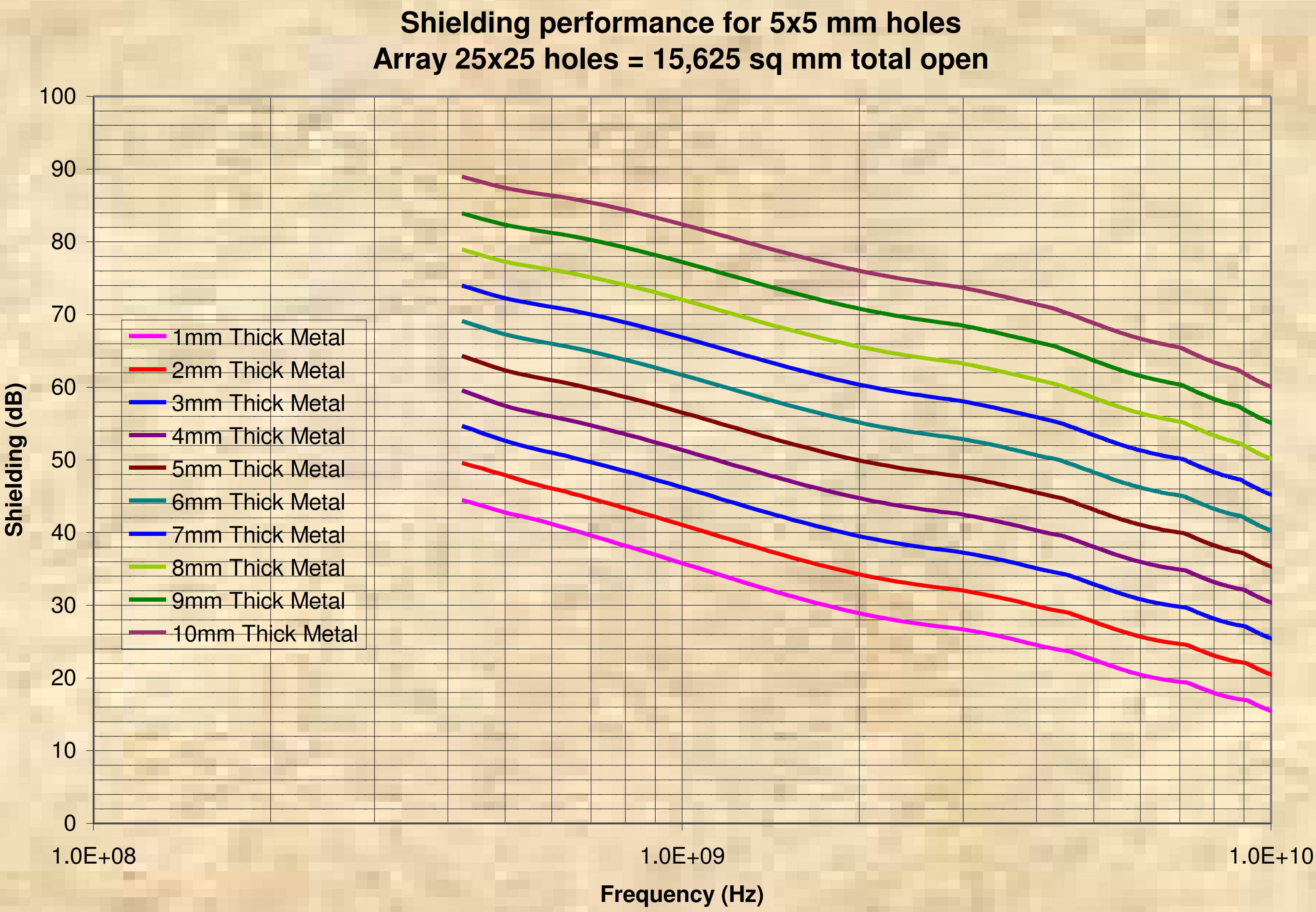
7mm x 7mm

9mm x 9mm

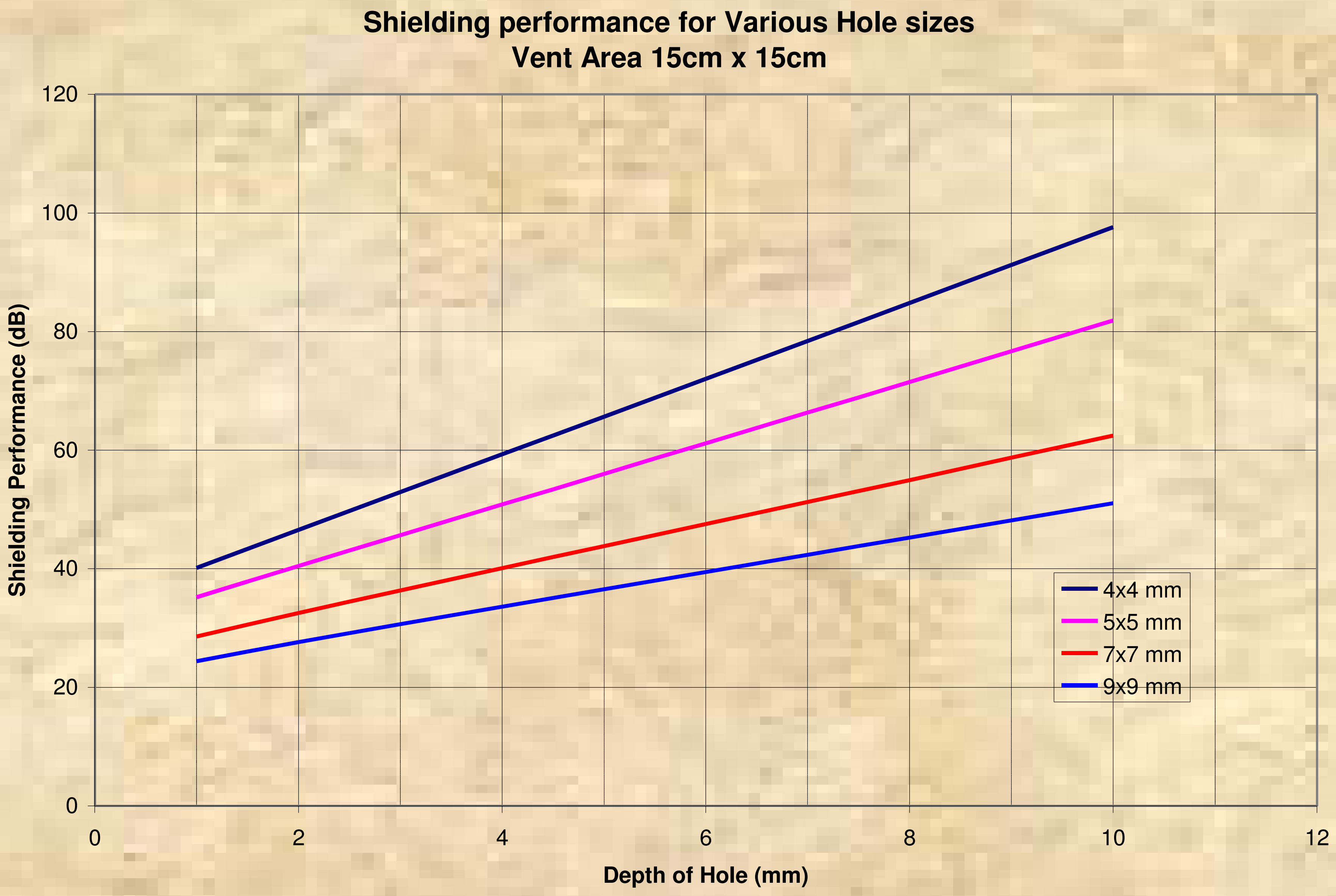
Metal panel thickness varied 1 – 10mm


Shielding performance for 9x9 mm holes
Array 15x15 holes = 18,225 sq mm total open
Shielding (dB)
100
90
80
70
60
50
40
30
20
10
0
0 Thick Metal
1mm Thick Metal
2mm Thick Metal
3mm Thick Metal
4mm Thick Metal
5mm Thick Metal
6mm Thick Metal
7mm Thick Metal
8mm Thick Metal
9mm Thick Metal
10mm Thick Metal
1.0E+08
1.0E+09
1.0E+10
Frequency (Hz)

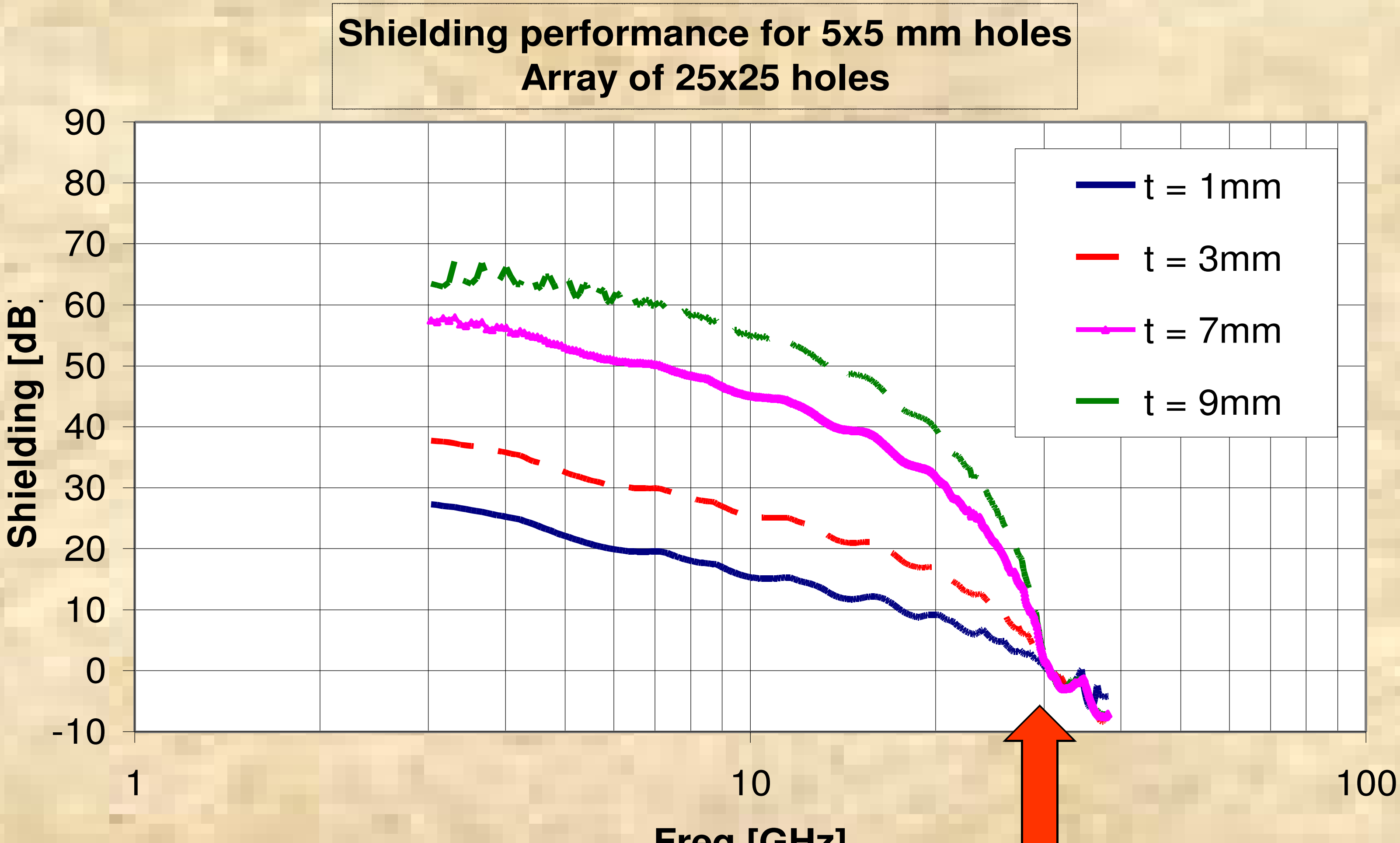

Shielding performance for 7x7 mm holes
Array 18x18 holes = 15,876 sq mm total open
Shielding (dB)
100
90
80
70
60
50
40
30
20
10
0
0 Thick Metal
1mm Thick Metal
2mm Thick Metal
3mm Thick Metal
4mm Thick Metal
5mm Thick Metal
6mm Thick Metal
7mm Thick Metal
8mm Thick Metal
9mm Thick Metal
10mm Thick Metal
1.0E+08
1.0E+09
1.0E+10
Frequency (Hz)


Shielding performance for 5x5 mm holes
Array 25x25 holes = 15,625 sq mm total open
Shielding (dB)
Frequency (Hz)
0
10
20
30
40
50
60
70
80
90
100
1.0E+08
1.0E+09
1.0E+10
1mm Thick Metal
2mm Thick Metal
3mm Thick Metal
4mm Thick Metal
5mm Thick Metal
6mm Thick Metal
7mm Thick Metal
8mm Thick Metal
9mm Thick Metal
10mm Thick Metal


Shielding performance for 4x4 mm holes
Array 30x30 holes = 14,400 sq mm total open
100
90
80
70
60
50
40
30
20
10
0
Shielding (dB)
1.0E+08
1.0E+09
1.0E+10
Frequency (Hz)
0 Thick Metal
1mm Thick Metal
2mm Thick Metal
3mm Thick Metal
4mm Thick Metal
5mm Thick Metal
6mm Thick Metal
7mm Thick Metal
8mm Thick Metal
9mm Thick Metal
10mm Thick Metal


Shielding performance for Various Hole sizes
Vent Area 15cm x 15cm
Shielding Performance (dB)
Depth of Hole (mm)
0
20
40
60
80
100
120
0
2
4
6
8
10
12
4x4 mm
5x5 mm
7x7 mm
9x9 mm

Even additional thickness has limitations once ½ Lambda is reached



So What Now?

- When Shielding fails us…..
- And we can not reduce the energy at the source
  - Direct from the IC
  - Signals needed for proper operation
- Absorption with lossy materials is the only alternative

Material Parameters

- Sigma → electrical conductivity
- Eps → dielectric properties
- Mu → magnetic properties

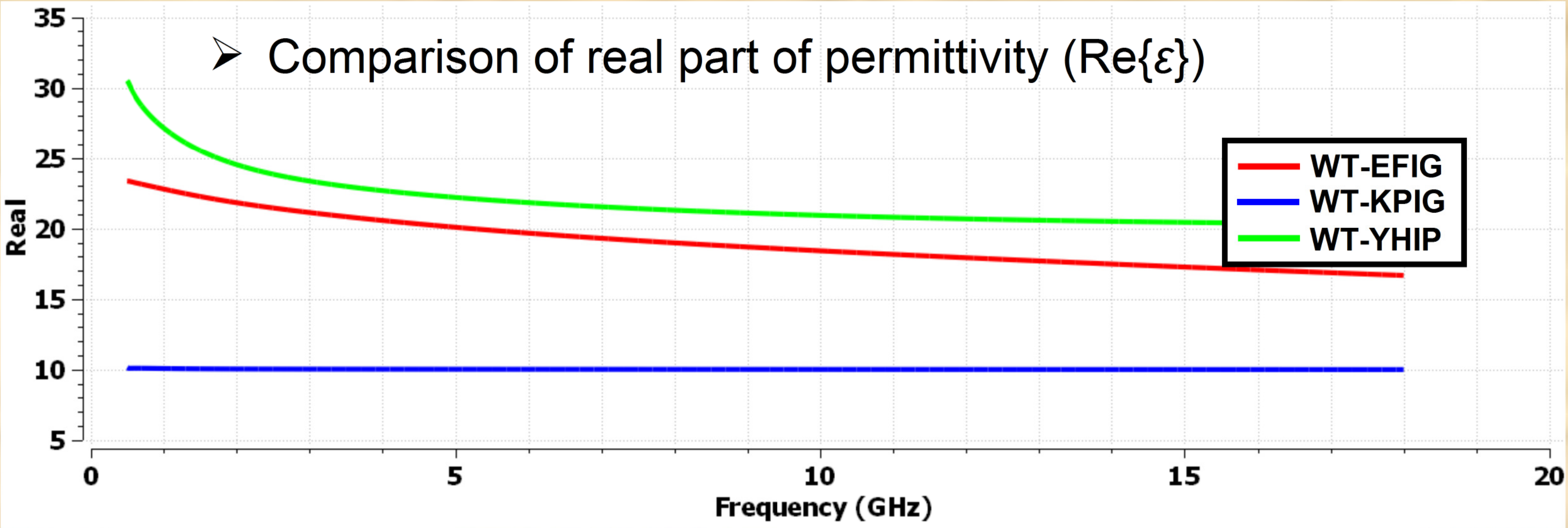
$$\varepsilon = (\varepsilon_r' + \varepsilon_r'')\varepsilon_0$$

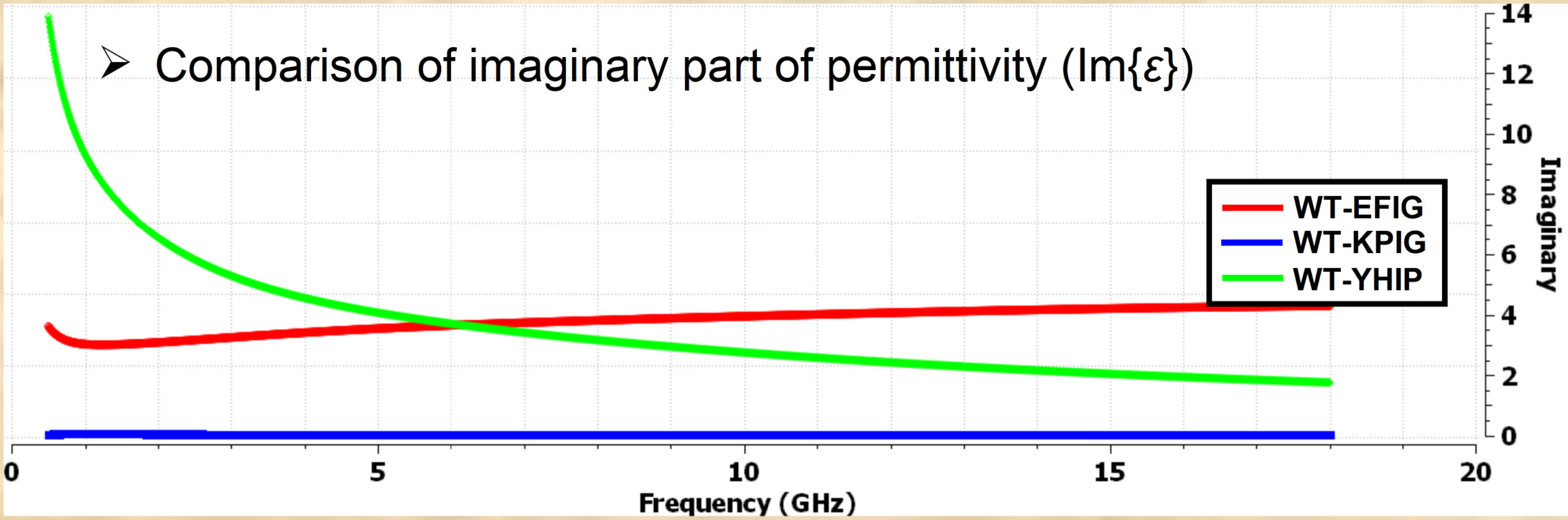
$$\mu = (\mu_r' + \mu_r'')\mu_0$$

Single ' for phase delay

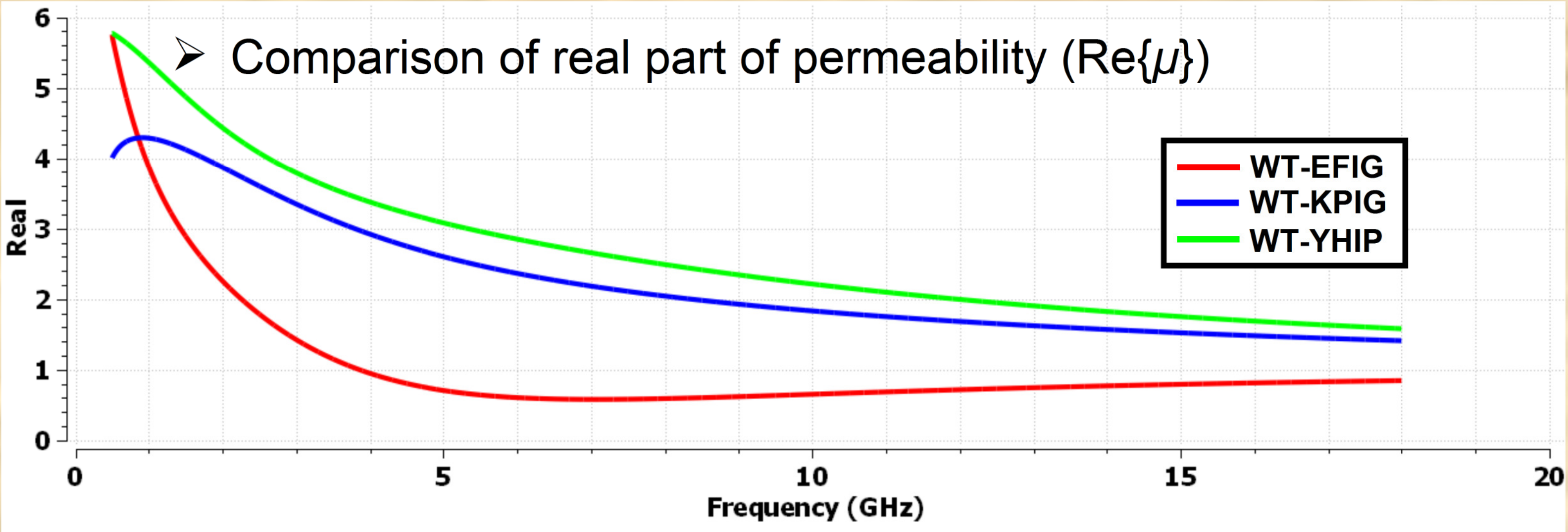
Double " for loss

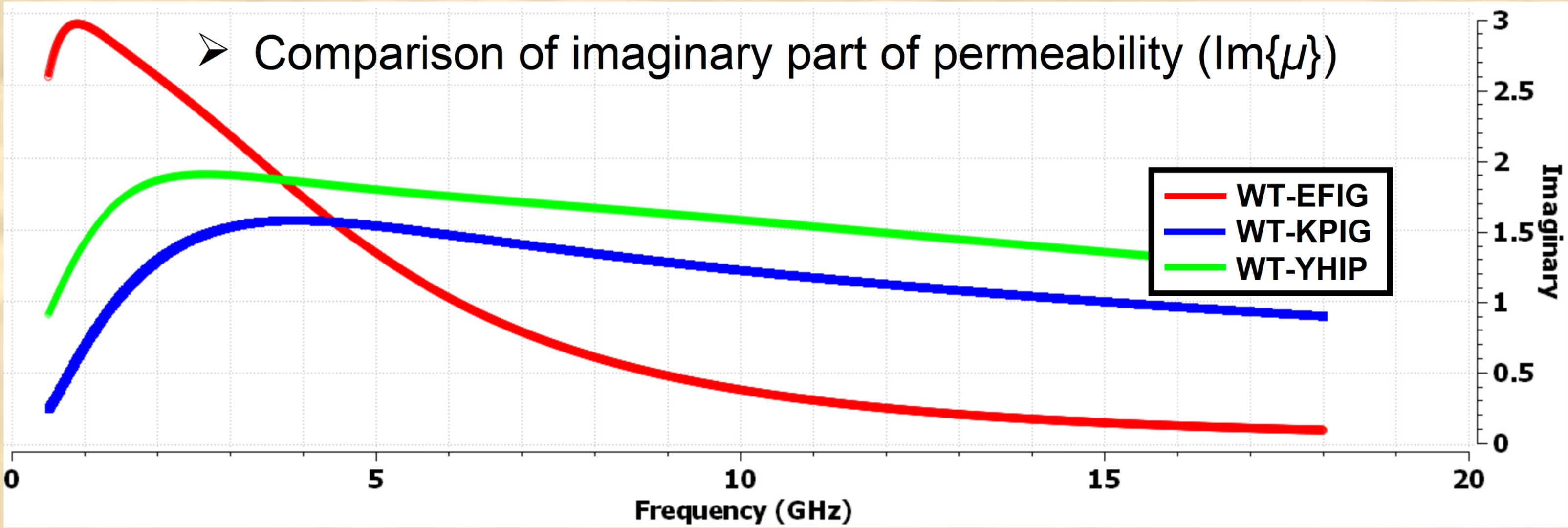
Example of Lossy Material EPS





Example of Lossy Material Mu



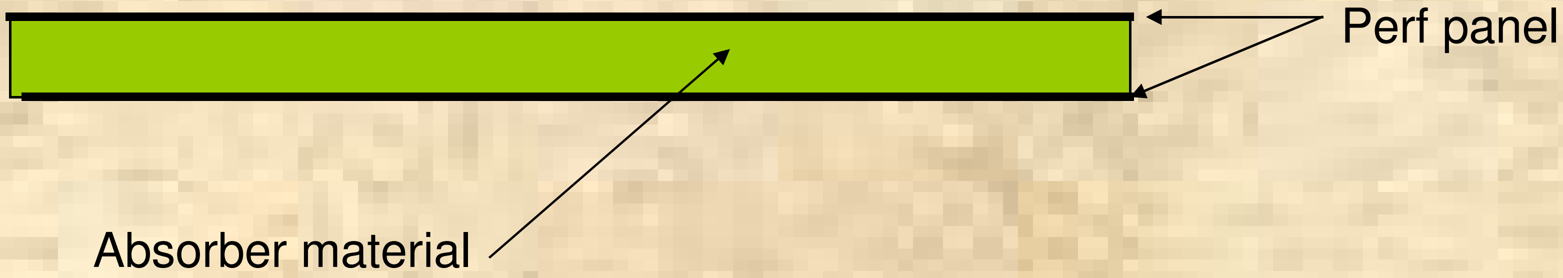


Using Lossy Materials

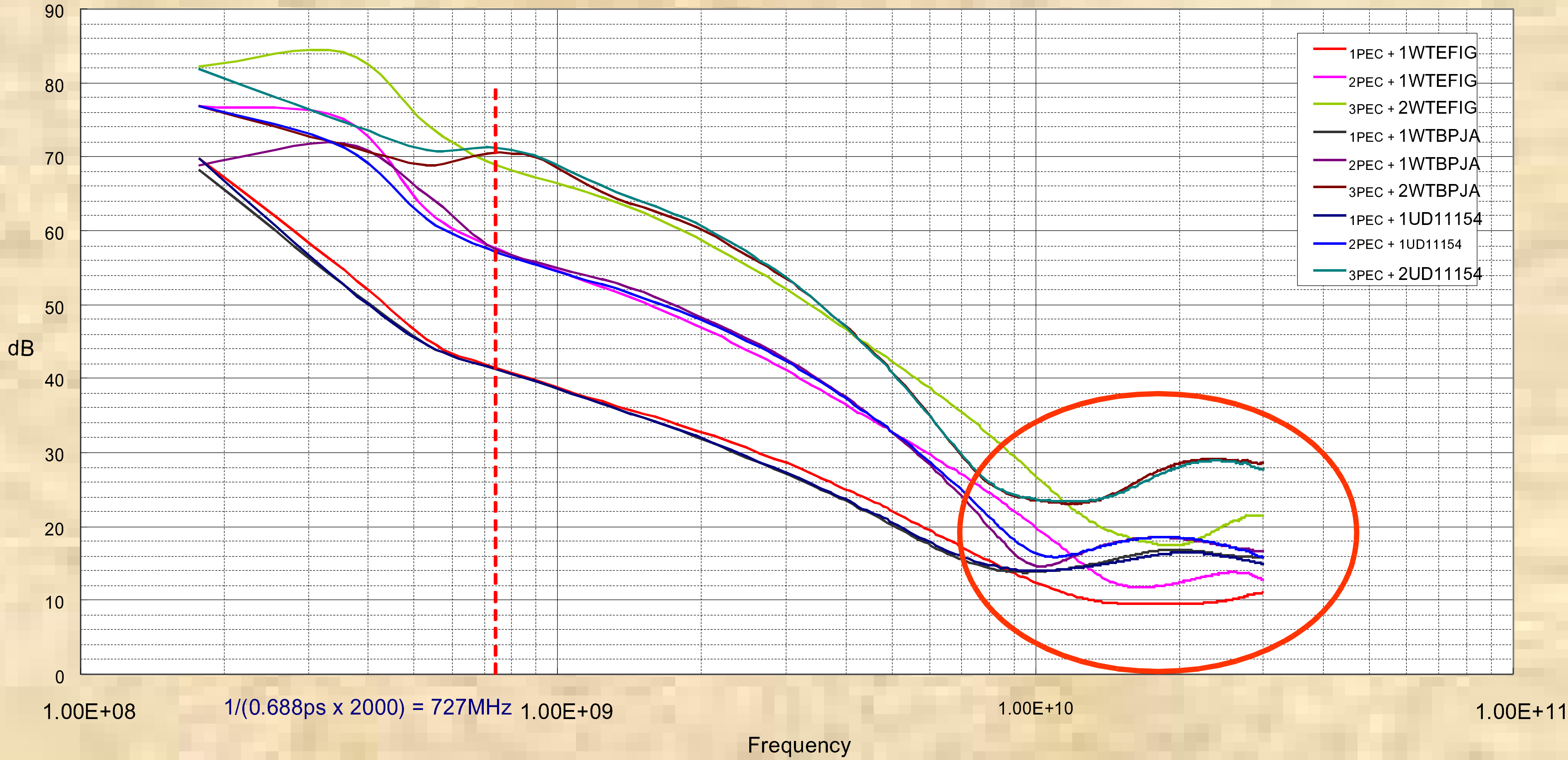
- With perforated panel air vents
- Under IC heatsinks
- Coating cables
- Resonant cavities

Lossy Material Sandwiched Between Perforated Panles

Edge View



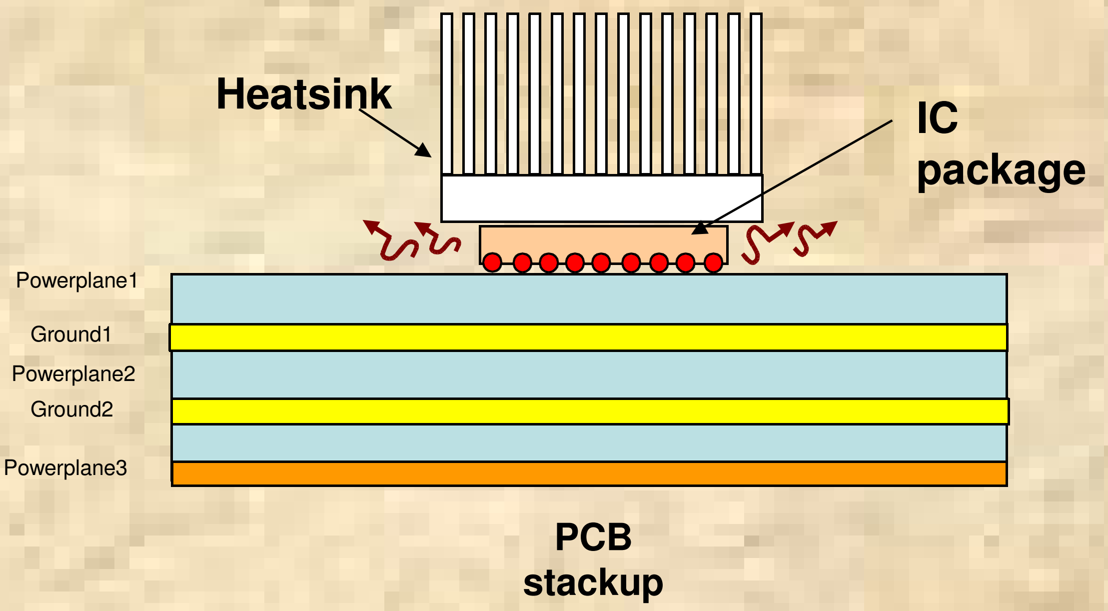
Shielded Air Vent with 3 Different Lossy Materials with 3 Different Stackup Structures

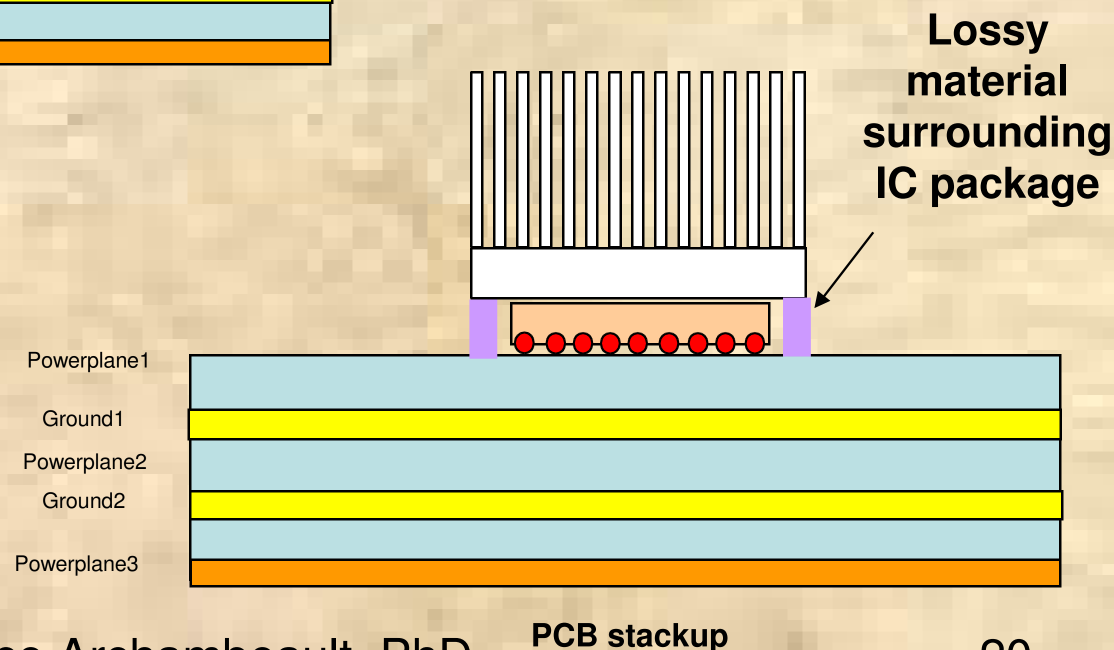


Heatsinks Can Increase Emissions

- Grounding heat sinks to PCB ground-reference is commonly used to reduce heat sink emissions
  - Can actually *increase* emissions if not enough contact points!
  - Without continuous contact, improvement typically limited to < 3-5 GHz
- Lossy materials can make significant improvement at high frequency
  - Reverb chamber used for all measurements

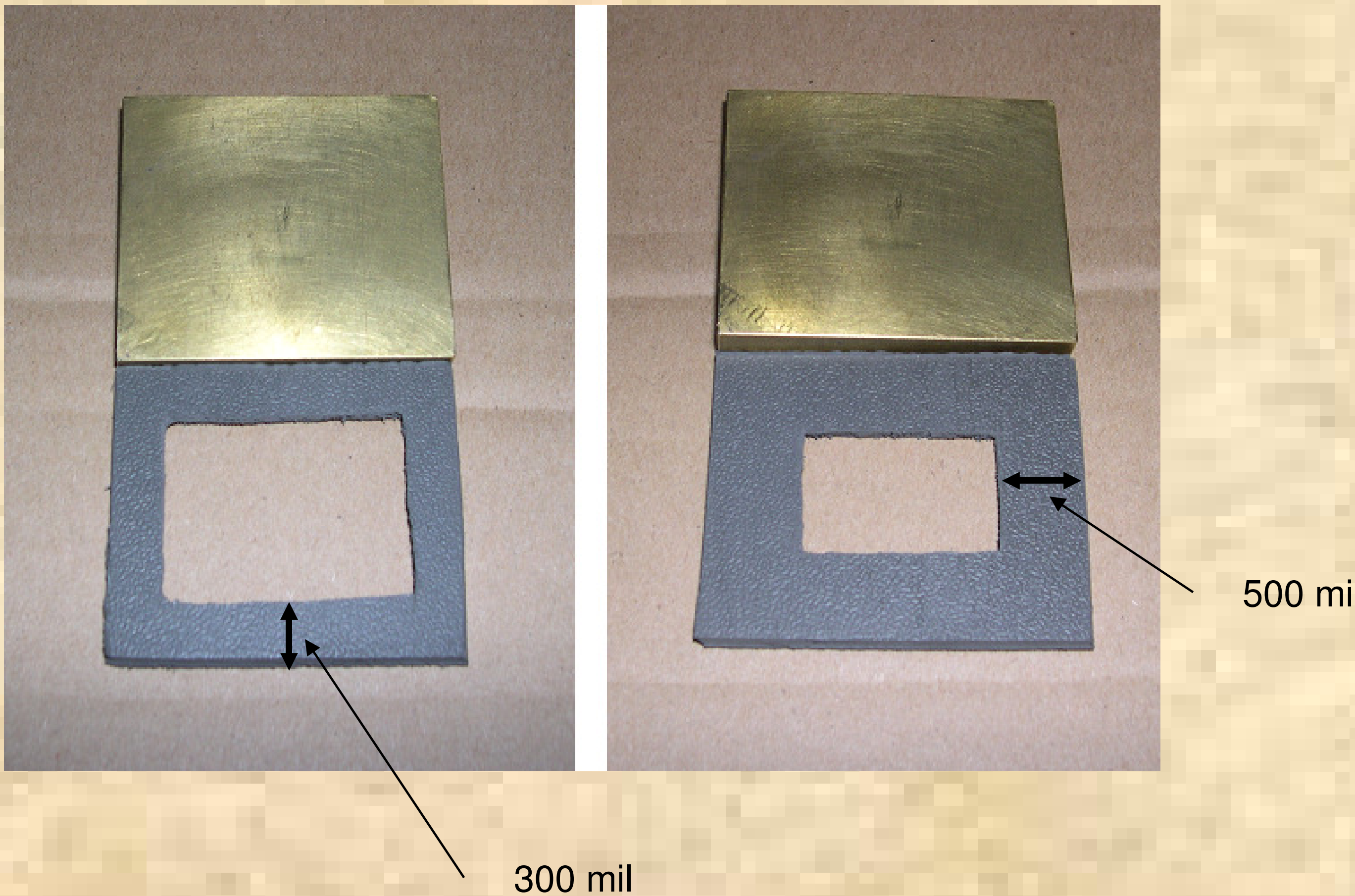
Geometry


Heatsink
IC
package
Powerplane1
Ground1
Powerplane2
Ground2
Powerplane3
PCB
stackup


Lossy
material
surrounding
IC package
Powerplane1
Ground1
Powerplane2
Ground2
Powerplane3
PCB stackup

Test Fixture Example

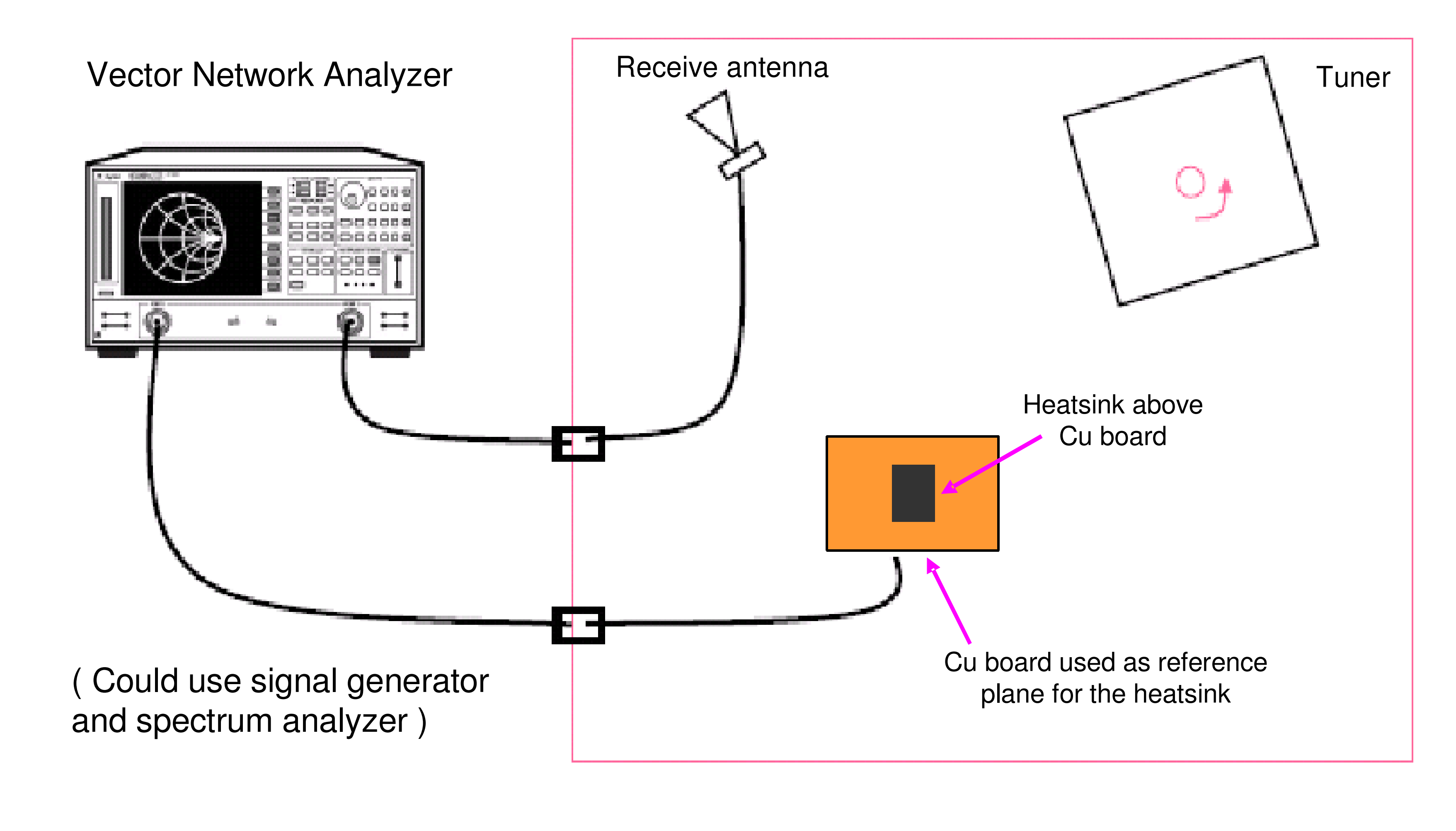
Lossy Material Cut into Square 'Donut'



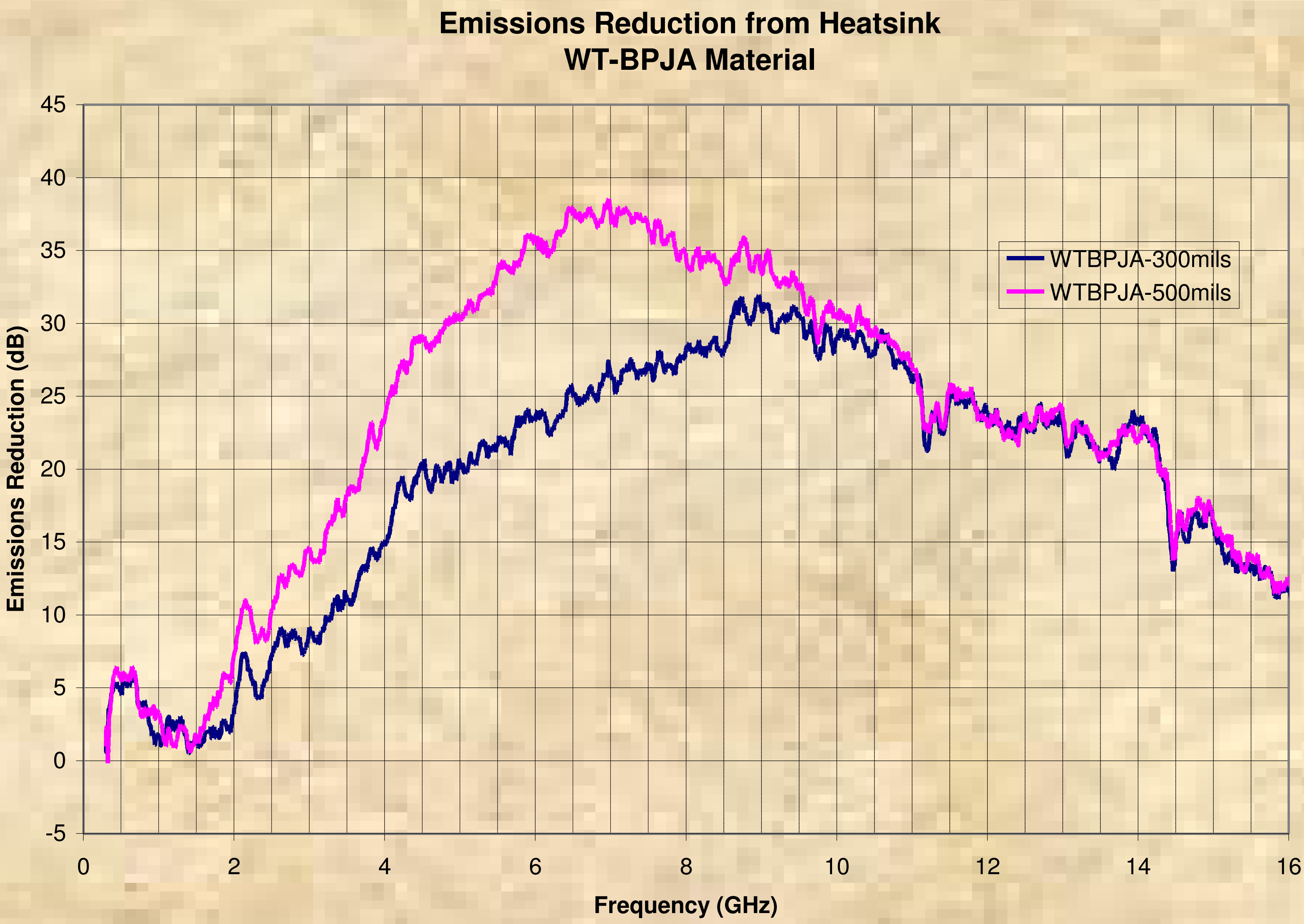
Measurement Techniques

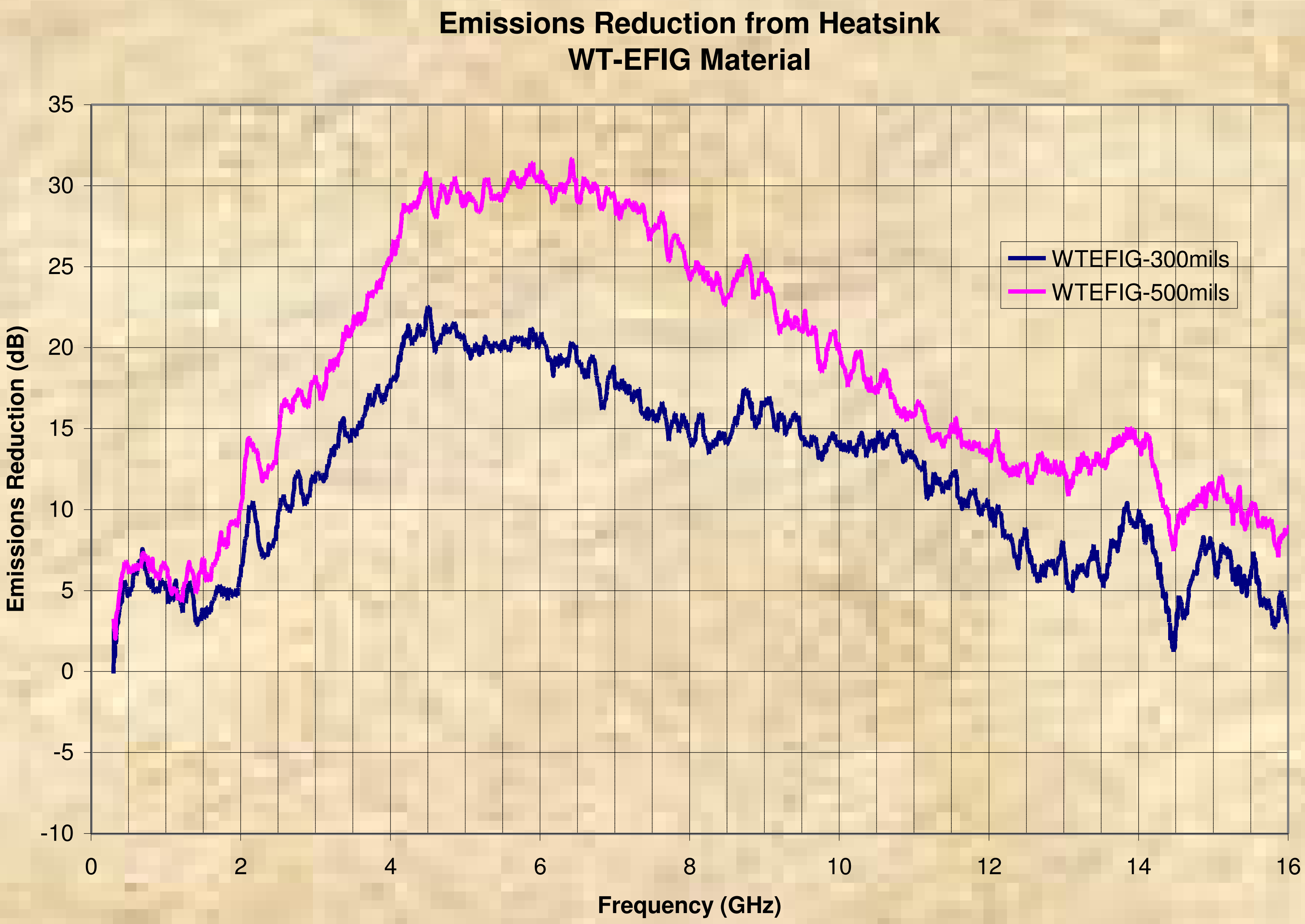
- Semi-anechoic chamber
  - Limited area where emissions are received
- Reverb Chamber
  - Capture emissions regardless of direction of propagation
  - Immune to test fixture size/length, position, configuration resonances

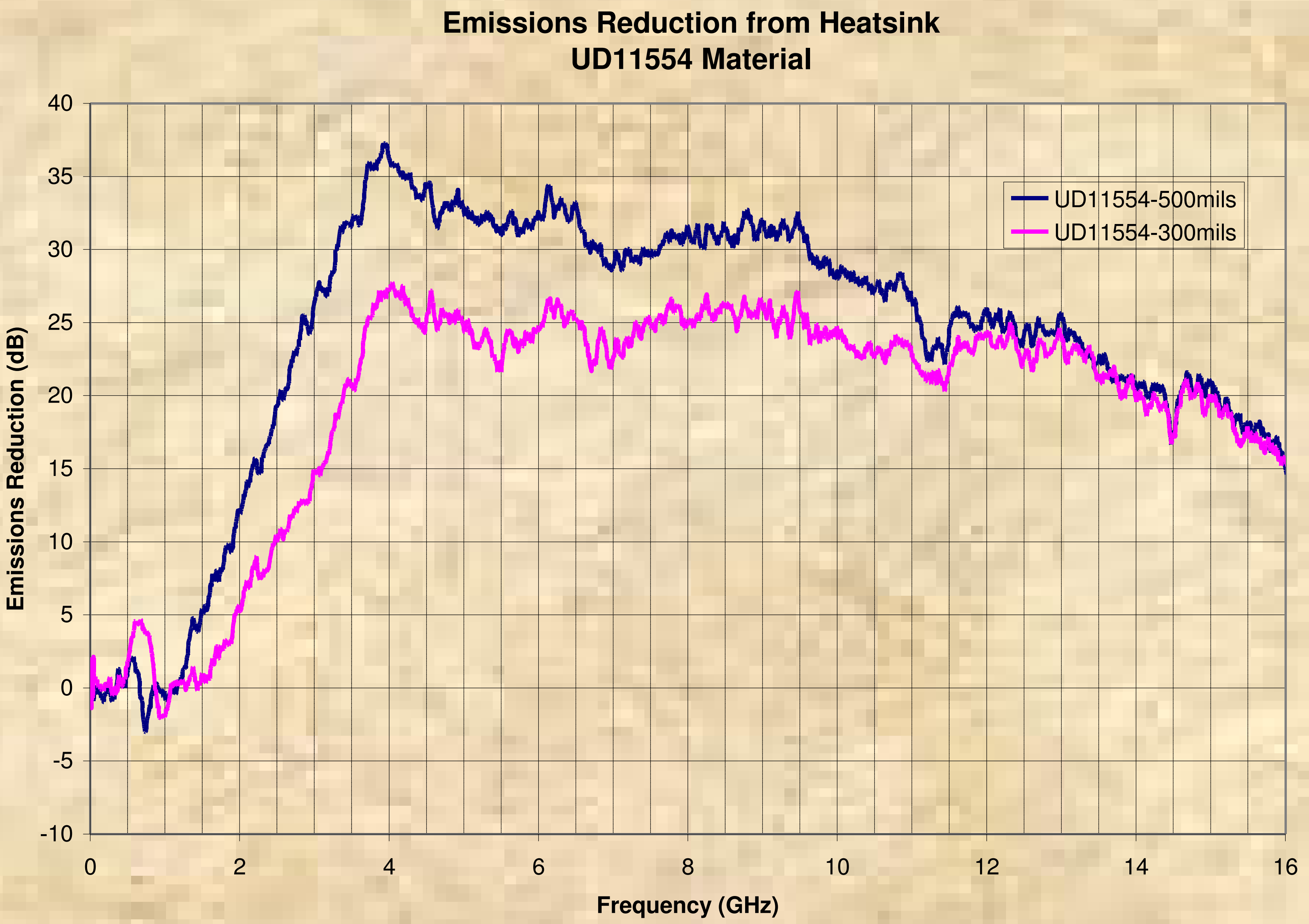
Test Set up in Reverb Chamber



Mode Stirrer

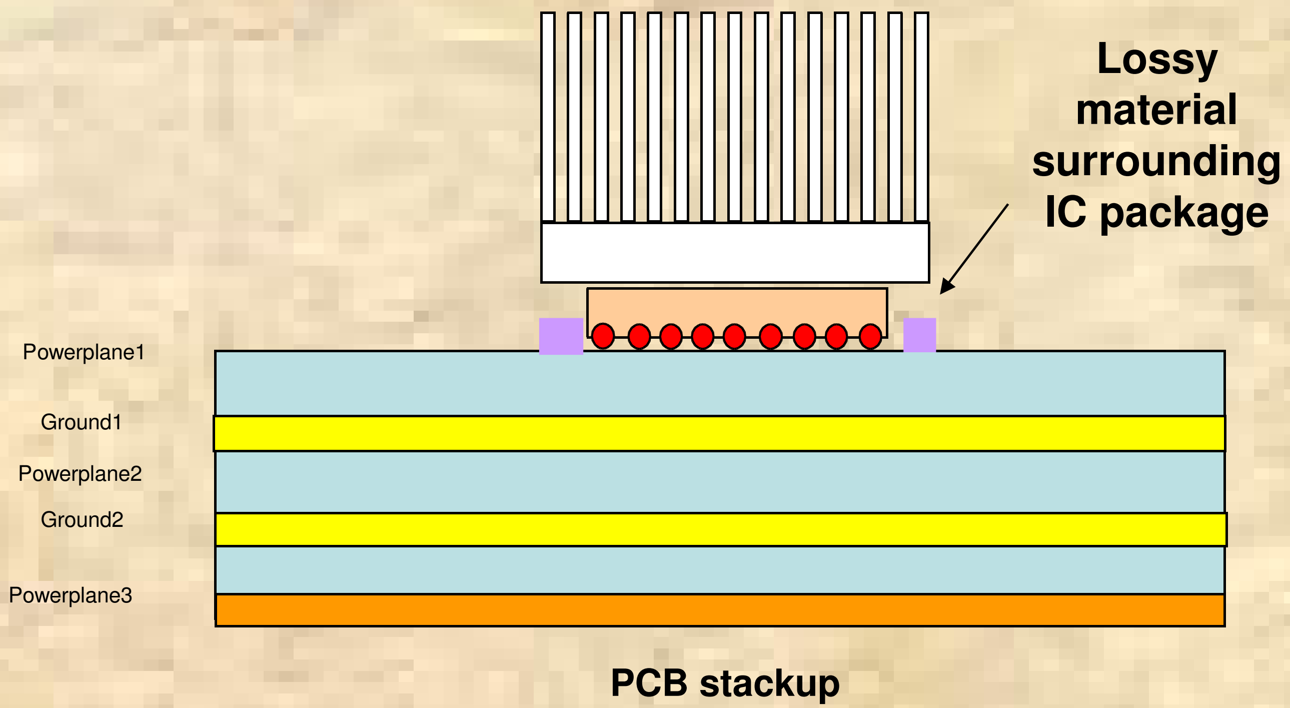

Emissions Reduction from Heatsink
WT-BPJA Material
Emissions Reduction (dB)
45
40
35
30
25
20
15
10
5
0
-5
0
2
4
6
8
10
12
14
16
Frequency (GHz)
WTBPJA-300mils
WTBPJA-500mils

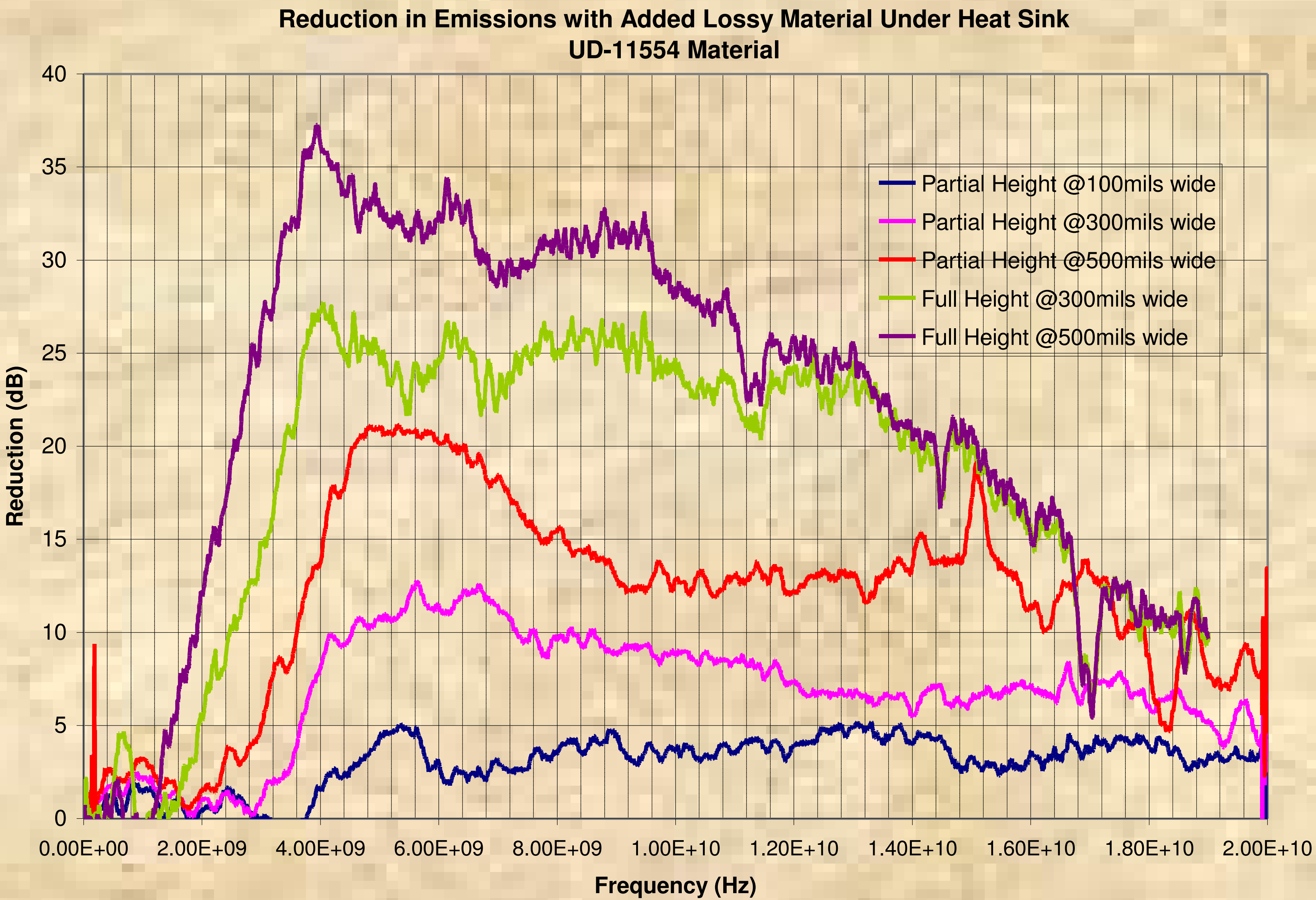

Emissions Reduction from Heatsink
WT-EFIG Material
Emissions Reduction (dB)
35
30
25
20
15
10
5
0
-5
-10
0
2
4
6
8
10
12
14
16
Frequency (GHz)
WTEFIG-300mils
WTEFIG-500mils


Emissions Reduction from Heatsink
UD11554 Material
Emissions Reduction (dB)
40
35
30
25
20
15
10
5
0
-5
-10
0
2
4
6
8
10
12
14
16
Frequency (GHz)
UD11554-500mils
UD11554-300mils

UD11554 Material

- Reduce height under heat sink to ~ 1/2 height




Reduction in Emissions with Added Lossy Material Under Heat Sink
UD-11554 Material
Reduction (dB)
Frequency (Hz)
40
35
30
25
20
15
10
5
0
0.00E+00
2.00E+09
4.00E+09
6.00E+09
8.00E+09
1.00E+10
1.20E+10
1.40E+10
1.60E+10
1.80E+10
2.00E+10
Partial Height @100mils wide
Partial Height @300mils wide
Partial Height @500mils wide
Full Height @300mils wide
Full Height @500mils wide

Heatsink Summary

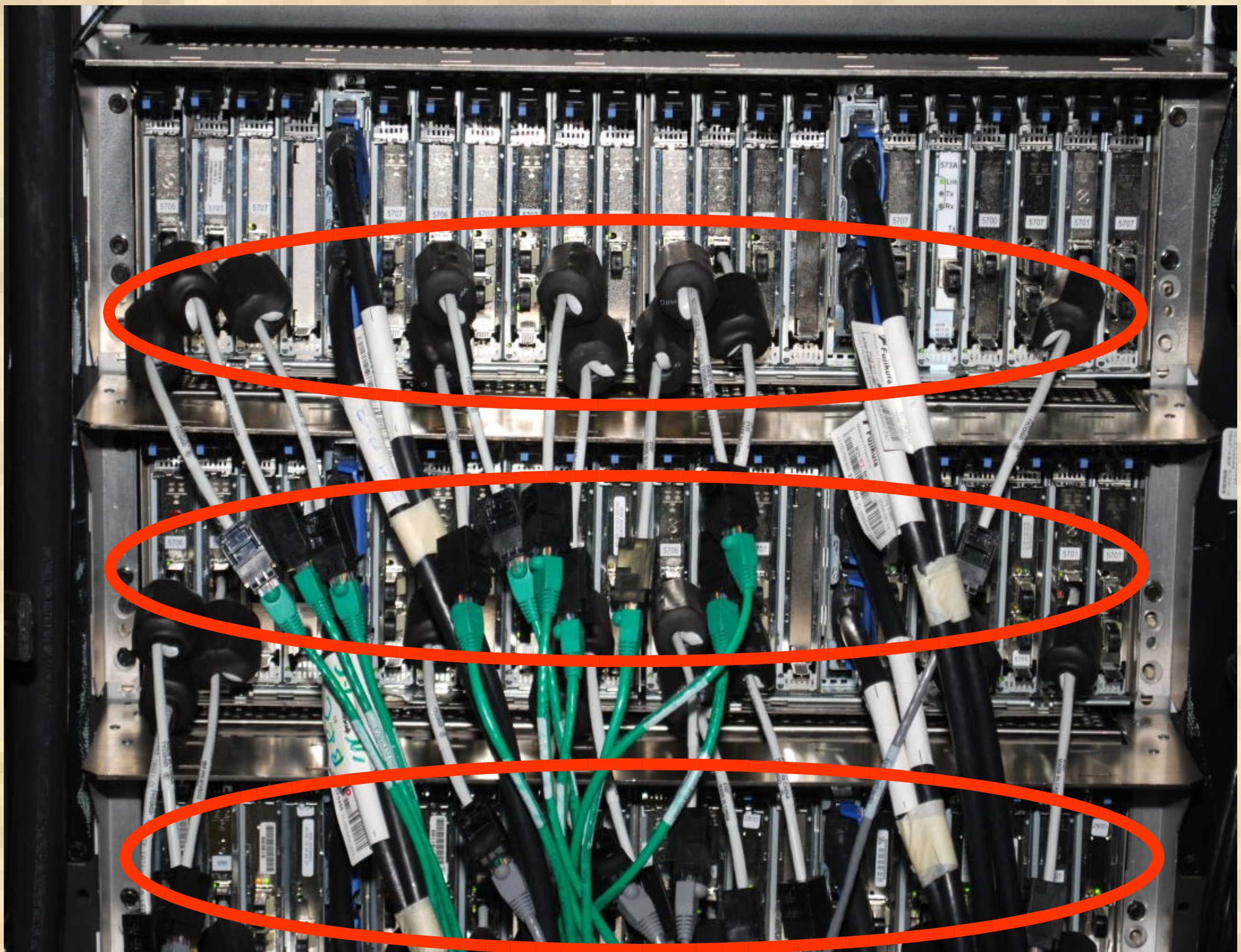
- All materials reduce emissions above 3-4 GHz
- Wider material gives more loss
- Full height between heat sink and PCB give more loss than partial height

Emissions from Cables

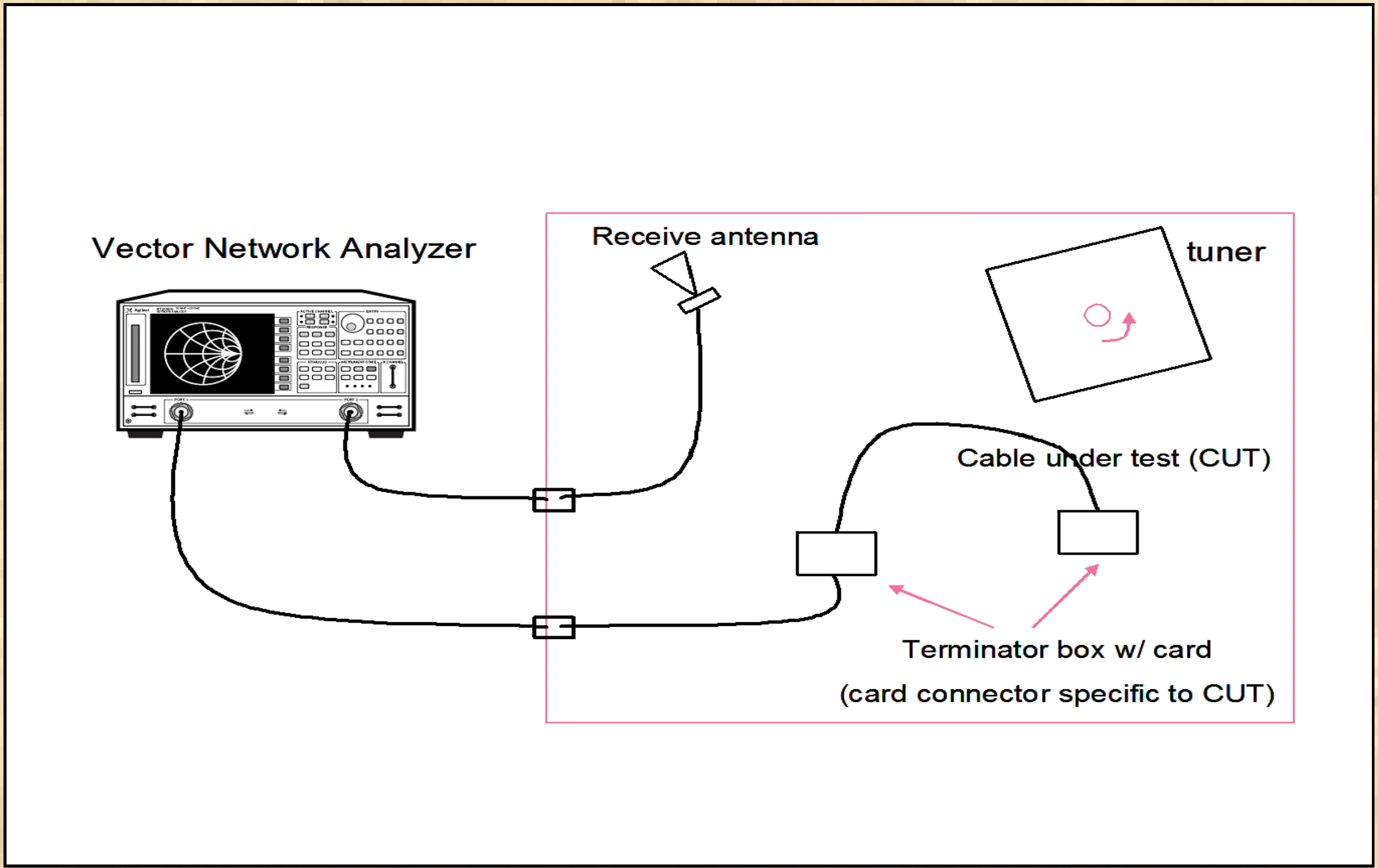
- Often the largest emissions source from a system
- Often unshielded cables
  - High speed differential pairs (with common mode noise)
- Difficult to provide cost effective shielding at > GHz frequencies
- Lossy material examined to determine reduction in cable emissions

Motivation

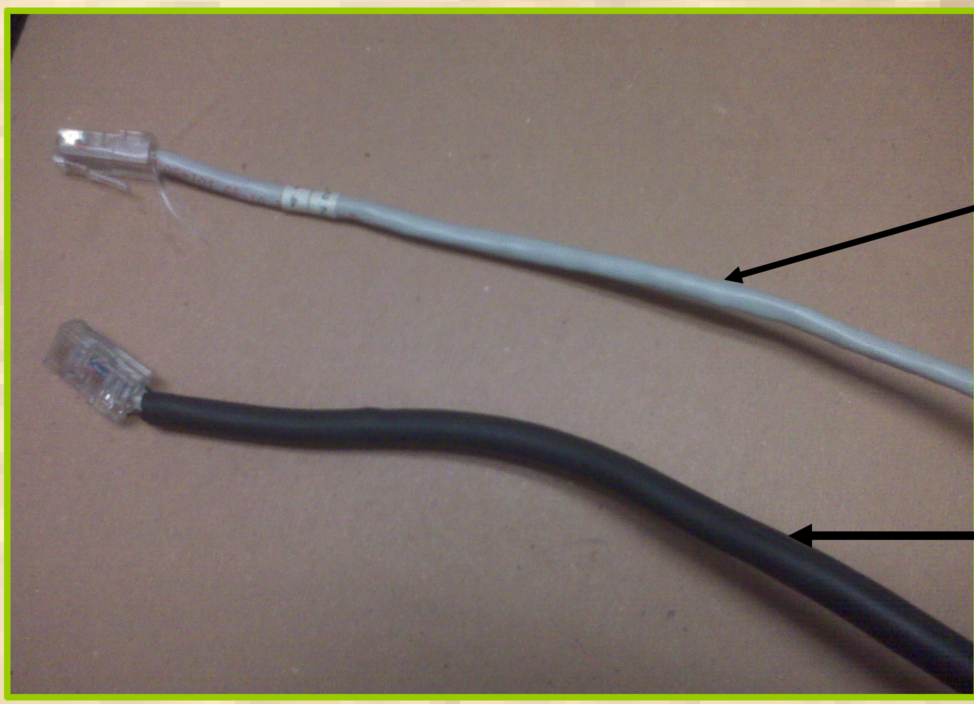
Eliminate Ferrite Cores on Cables



Reverb Chamber Test Configuration



Ethernet Cable with and without Lossy Heat Shrink



Regular cable

Lossy material heat shrink

Lossy Material Benefits

- Does not require a “water-tight” connection at connectors
  - Shielding requires complete coverage
- Potential to be extruded onto cable during cable manufacturing
  - Reduce cost

Partial Coverage Tests

11" Coverage

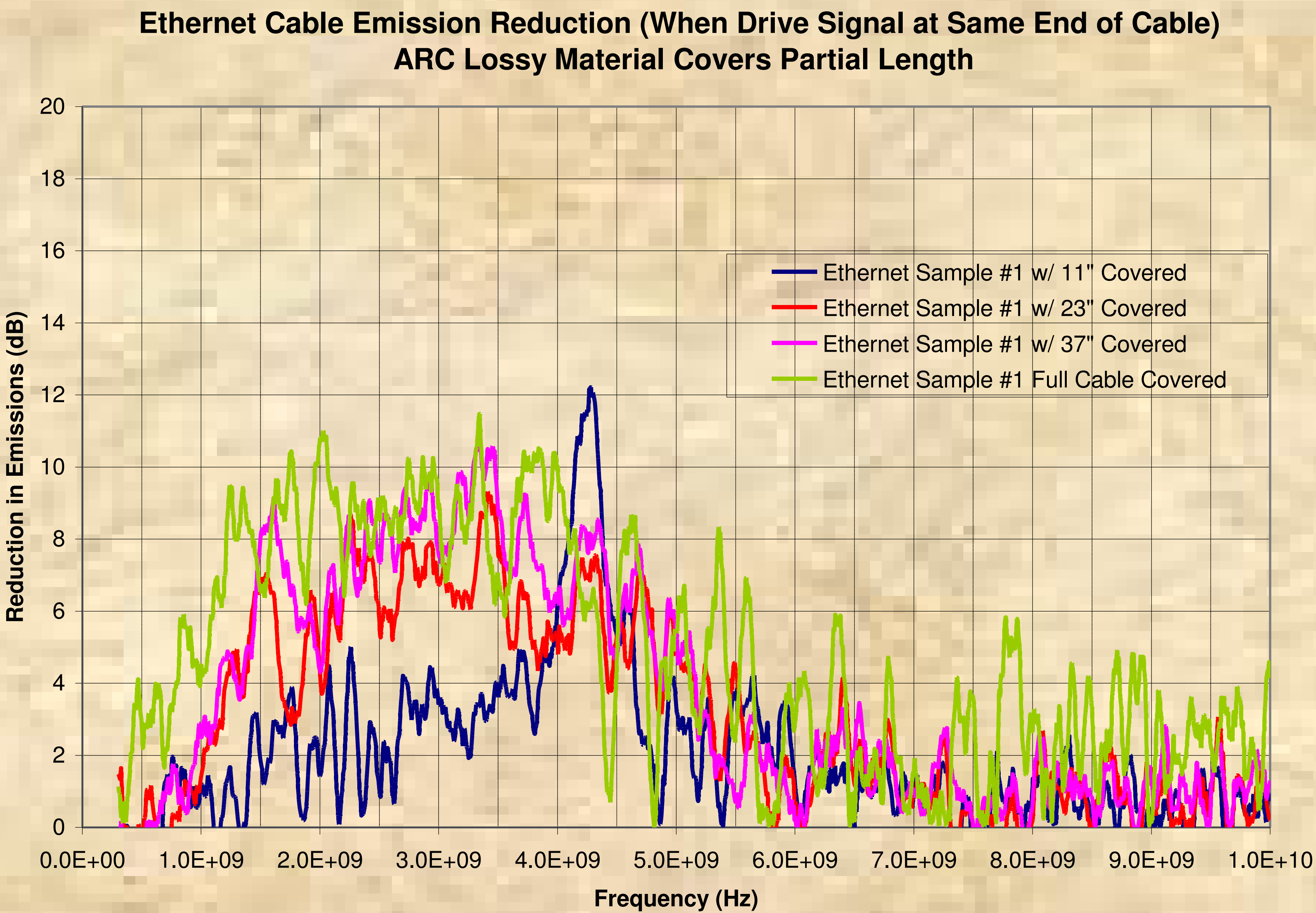
23" Coverage

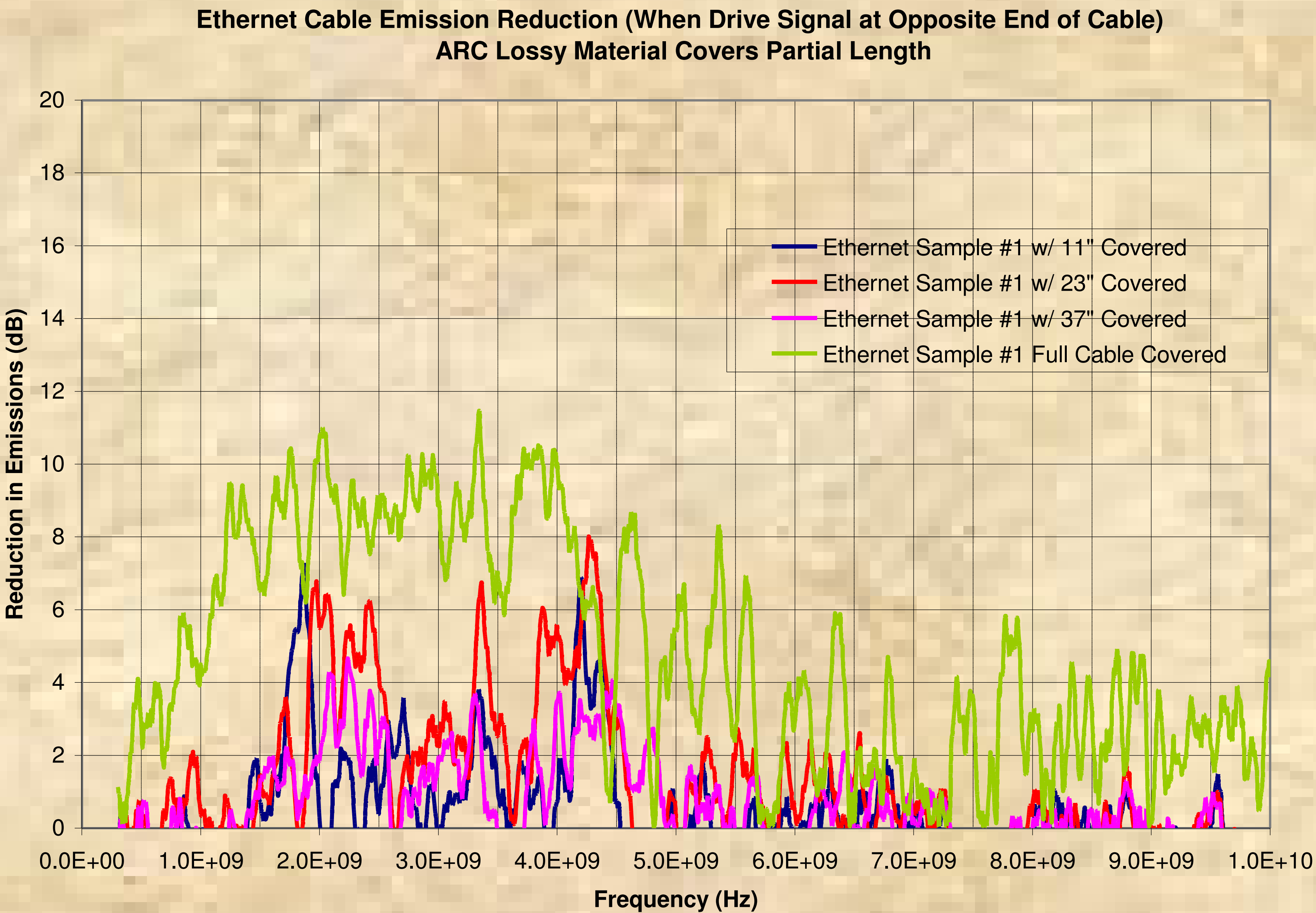
37" Coverage

2" Sections spaced 1" apart

Partial Coverage Tests

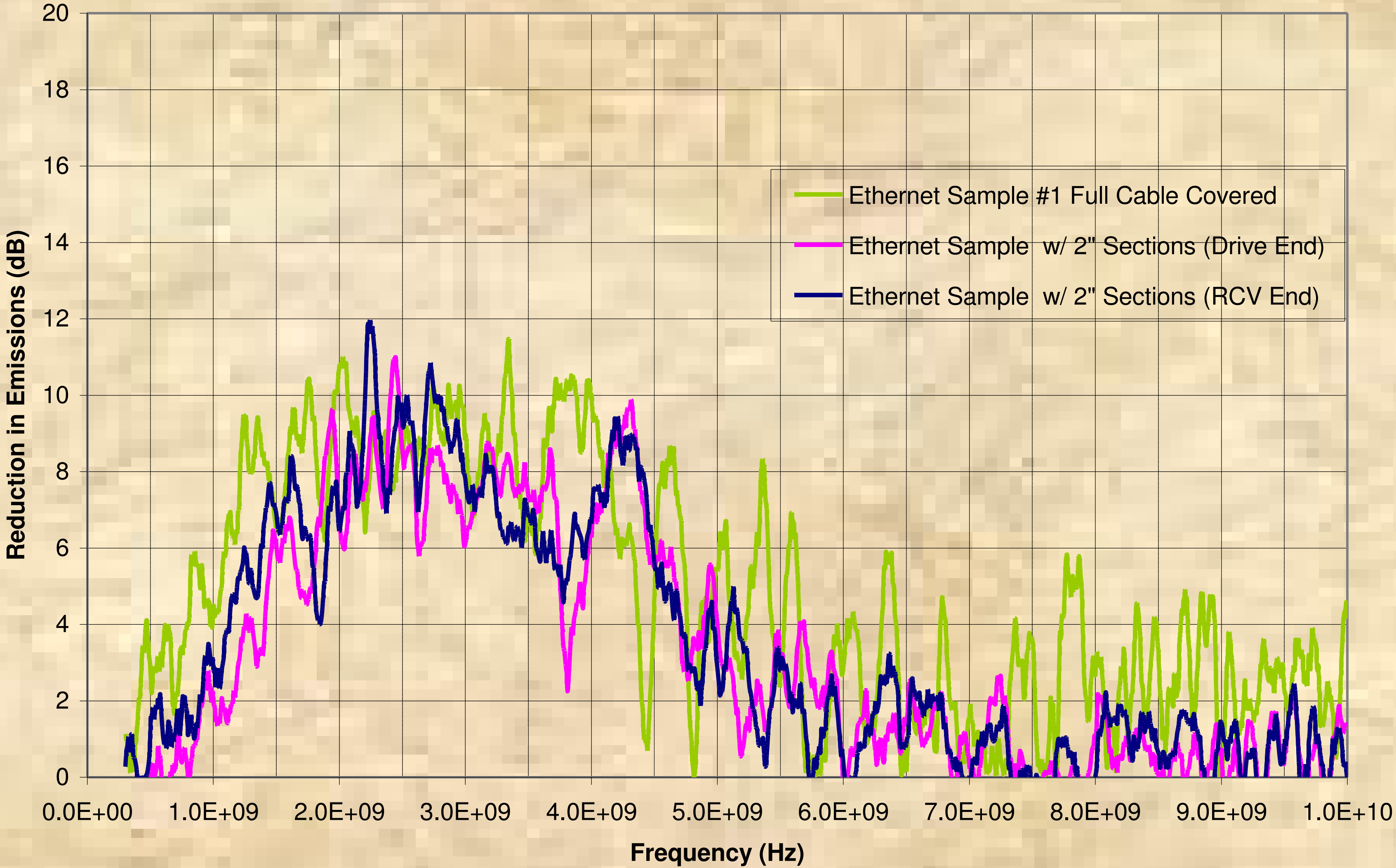
- Determine the effect of which end driven
  - End with lossy material
  - End w/o lossy material
- Determine the effect of not-full coverage
  - Cracks in material
    - Catastrophic in traditional shielding


Ethernet Cable Emission Reduction (When Drive Signal at Same End of Cable)
ARC Lossy Material Covers Partial Length
Reduction in Emissions (dB)
Frequency (Hz)
0
2
4
6
8
10
12
14
16
18
20
0.0E+00
1.0E+09
2.0E+09
3.0E+09
4.0E+09
5.0E+09
6.0E+09
7.0E+09
8.0E+09
9.0E+09
1.0E+10
Ethernet Sample #1 w/ 11" Covered
Ethernet Sample #1 w/ 23" Covered
Ethernet Sample #1 w/ 37" Covered
Ethernet Sample #1 Full Cable Covered

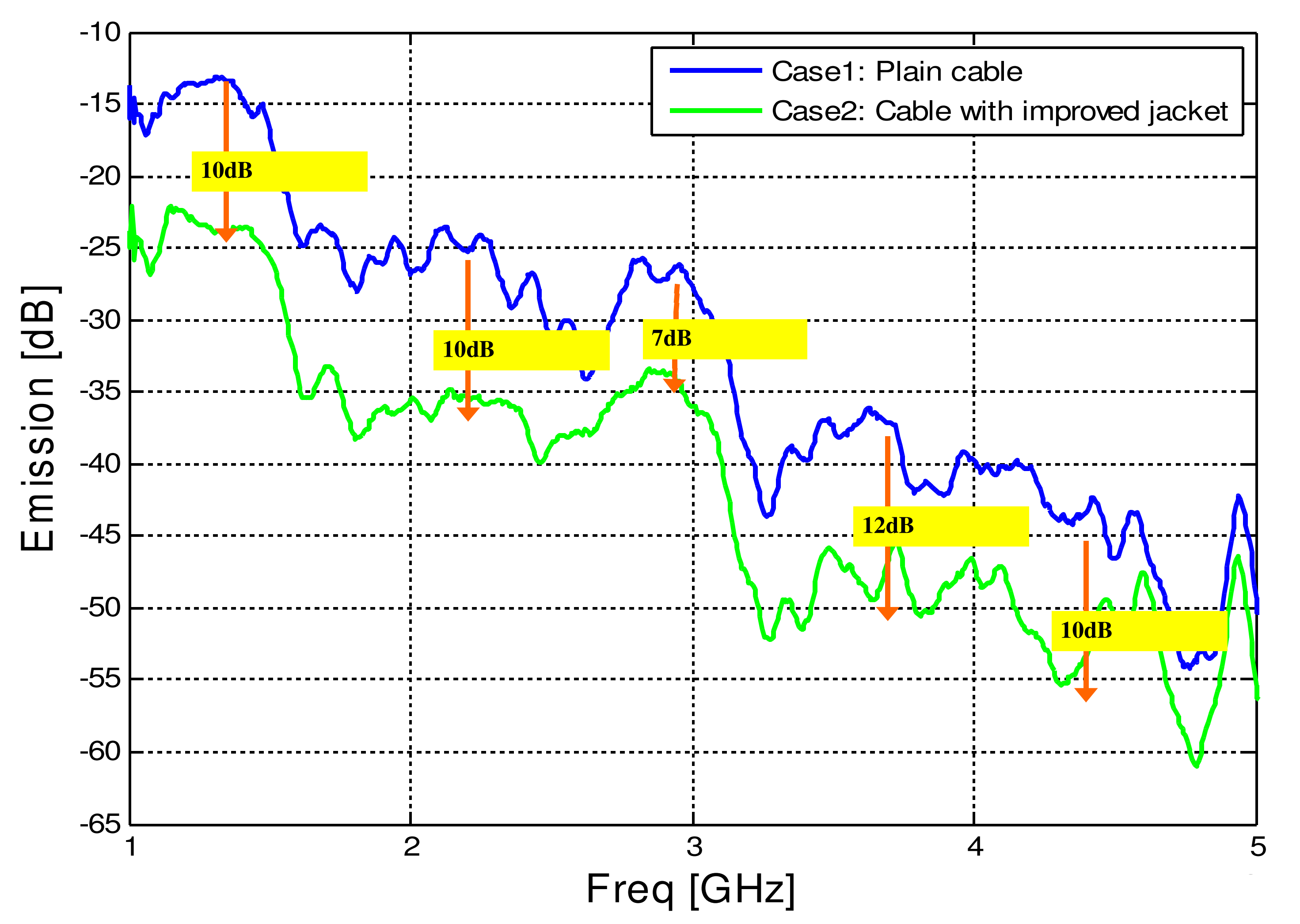


Ethernet Cable Emission Reduction (When Drive Signal at Opposite End of Cable)
ARC Lossy Material Covers Partial Length
Reduction in Emissions (dB)
Frequency (Hz)
Ethernet Sample #1 w/ 11" Covered
Ethernet Sample #1 w/ 23" Covered
Ethernet Sample #1 w/ 37" Covered
Ethernet Sample #1 Full Cable Covered
0
2
4
6
8
10
12
14
16
18
20
0.0E+00
1.0E+09
2.0E+09
3.0E+09
4.0E+09
5.0E+09
6.0E+09
7.0E+09
8.0E+09
9.0E+09
1.0E+10

Ethernet Cable Emission Reduction (When Drive Signal at Same End of Cable)
ARC Lossy Material Covers Partial Length



EMI Control for I/O Cables – Absorbing Material Performance



Cable Summary

- Cables coated with lossy material reduces emissions from cables
- Full coverage not required
  - Effective at transmit end
- Compete (water tight) coverage not required
  - Cracks in lossy material not a concern as for traditional shielding

Reducing Resonance in Cavities

- Empty (or partially empty) enclosures allow standing wave resonant modes to be established
  - If dimensions are right…hard to predict in complex enclosures
- Empty metal box allows us to measure effect of various materials

Metal box photos

Fig 1a – Front view showing horizontal slot

Fig 1b – Rear view showing veritcal slot

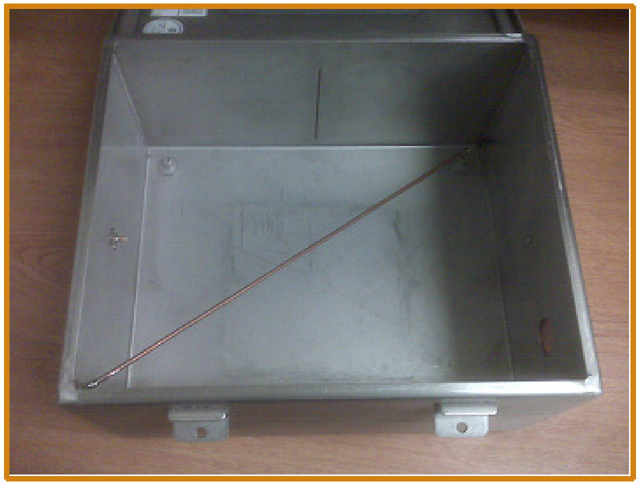
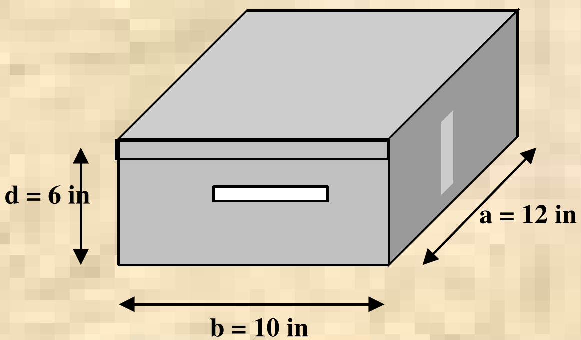


Fig 1c – Inside view showing probe element

Fig 1d – Inside view showing application of ARC material

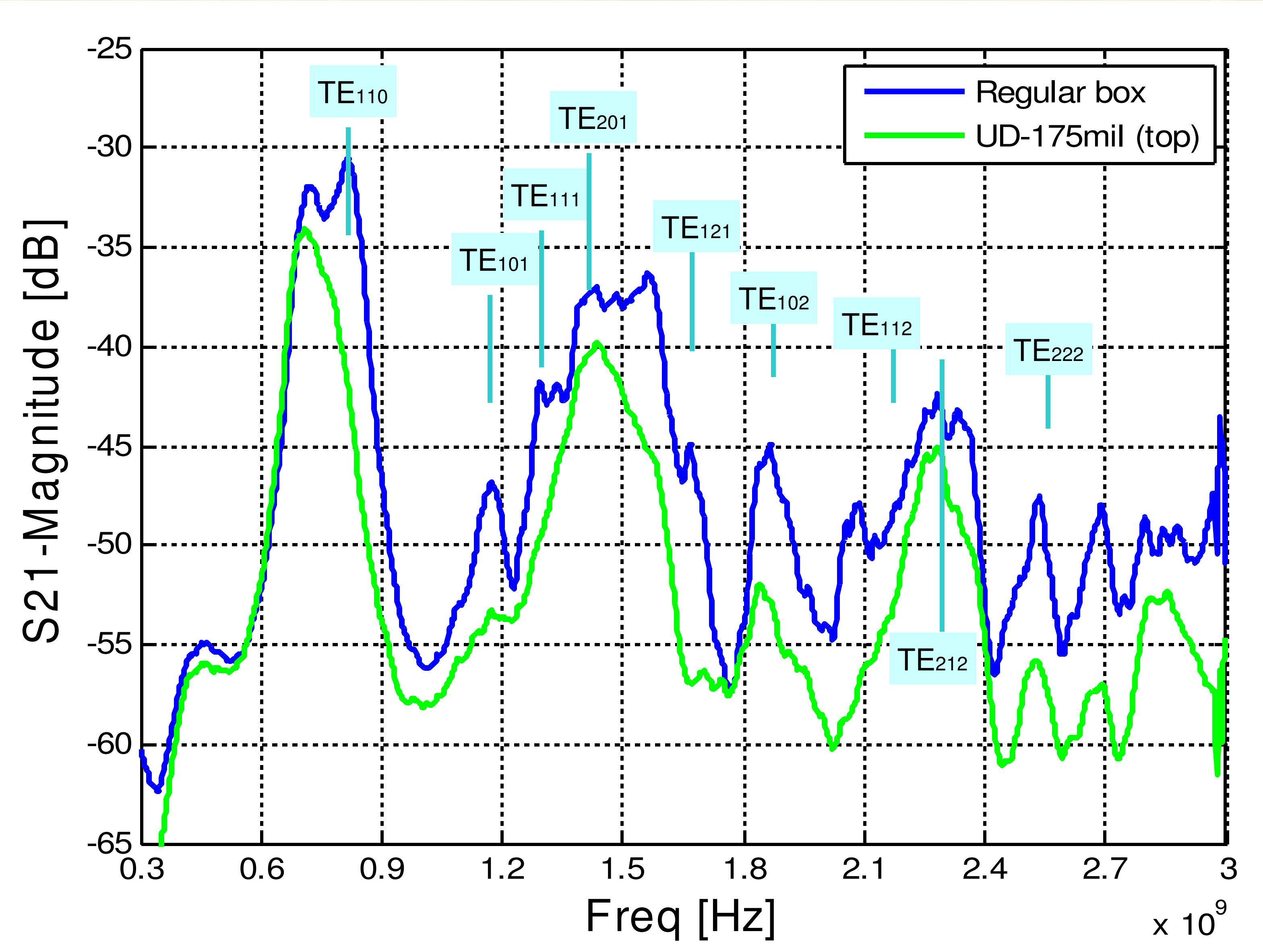
Metal box high order modes computation (up to 2.5GHz)



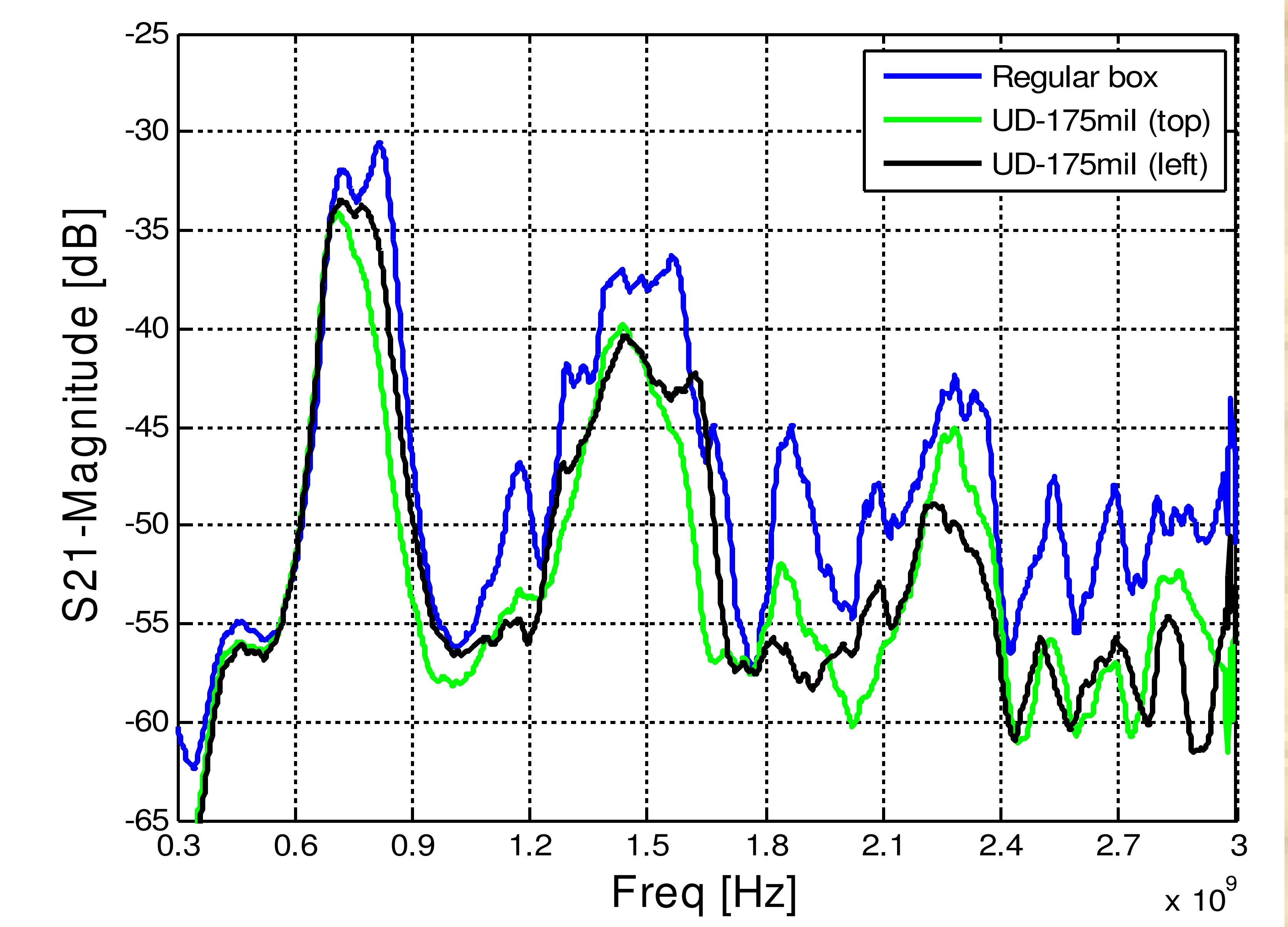
$$f = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{l}{d}\right)^2}$$

12 in	10 in	6 in	TE(n,m,l)			FREQ [GHz]
0.3048	0.254	0.1524	1	1	0	0.768725362
0.3048	0.254	0.1524	1	0	1	1.100427154
0.3048	0.254	0.1524	0	1	1	1.147825176
0.3048	0.254	0.1524	1	1	1	1.248875742
0.3048	0.254	0.1524	2	0	1	1.391942483
0.3048	0.254	0.1524	1	2	1	1.614293255
0.3048	0.254	0.1524	1	0	2	2.029087414
0.3048	0.254	0.1524	1	1	2	2.113278598
0.3048	0.254	0.1524	2	1	2	2.278708052
0.3048	0.254	0.1524	0	2	2	2.295650352
0.3048	0.254	0.1524	2	2	2	2.497751484

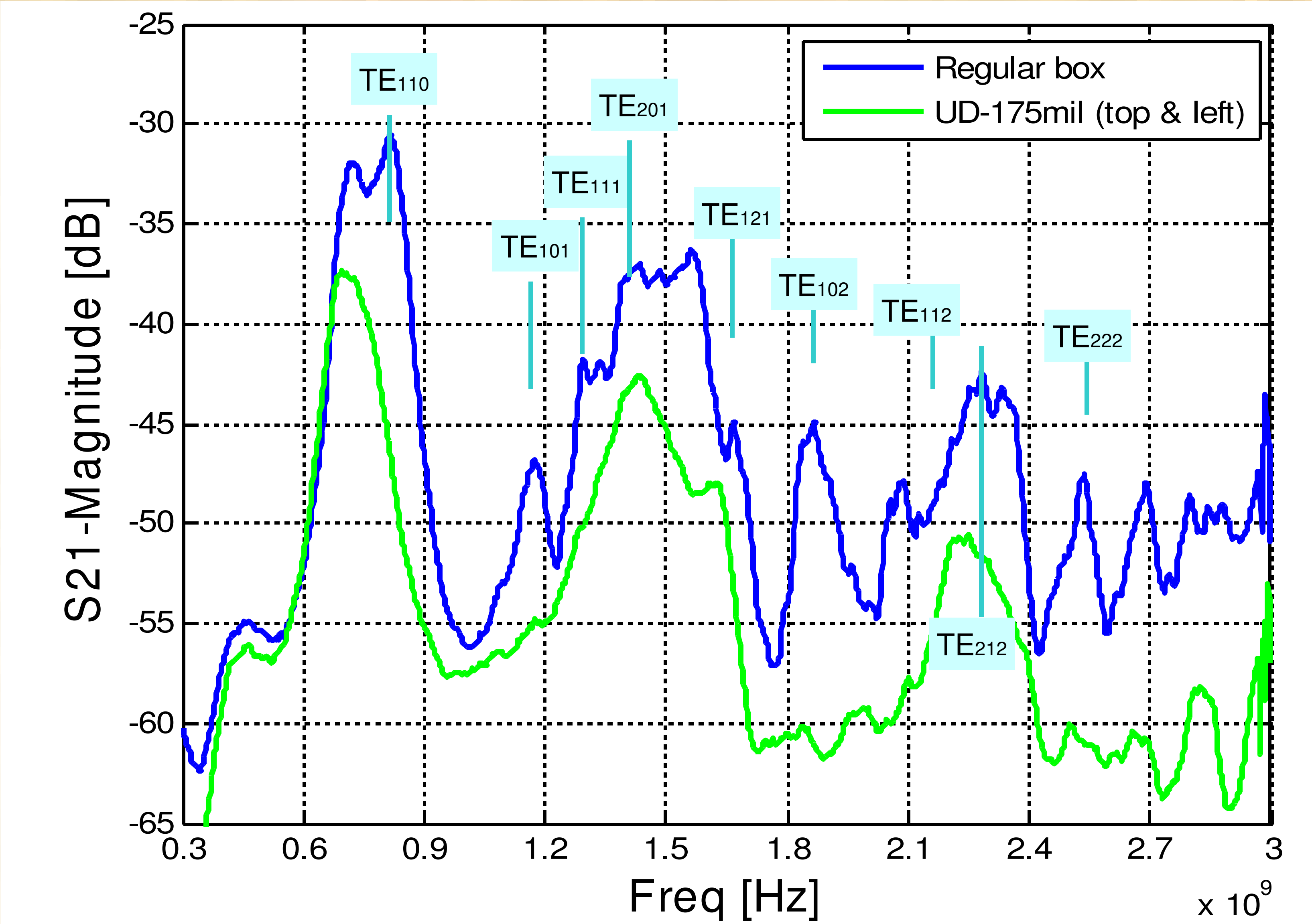
UD-175mil material on top-side



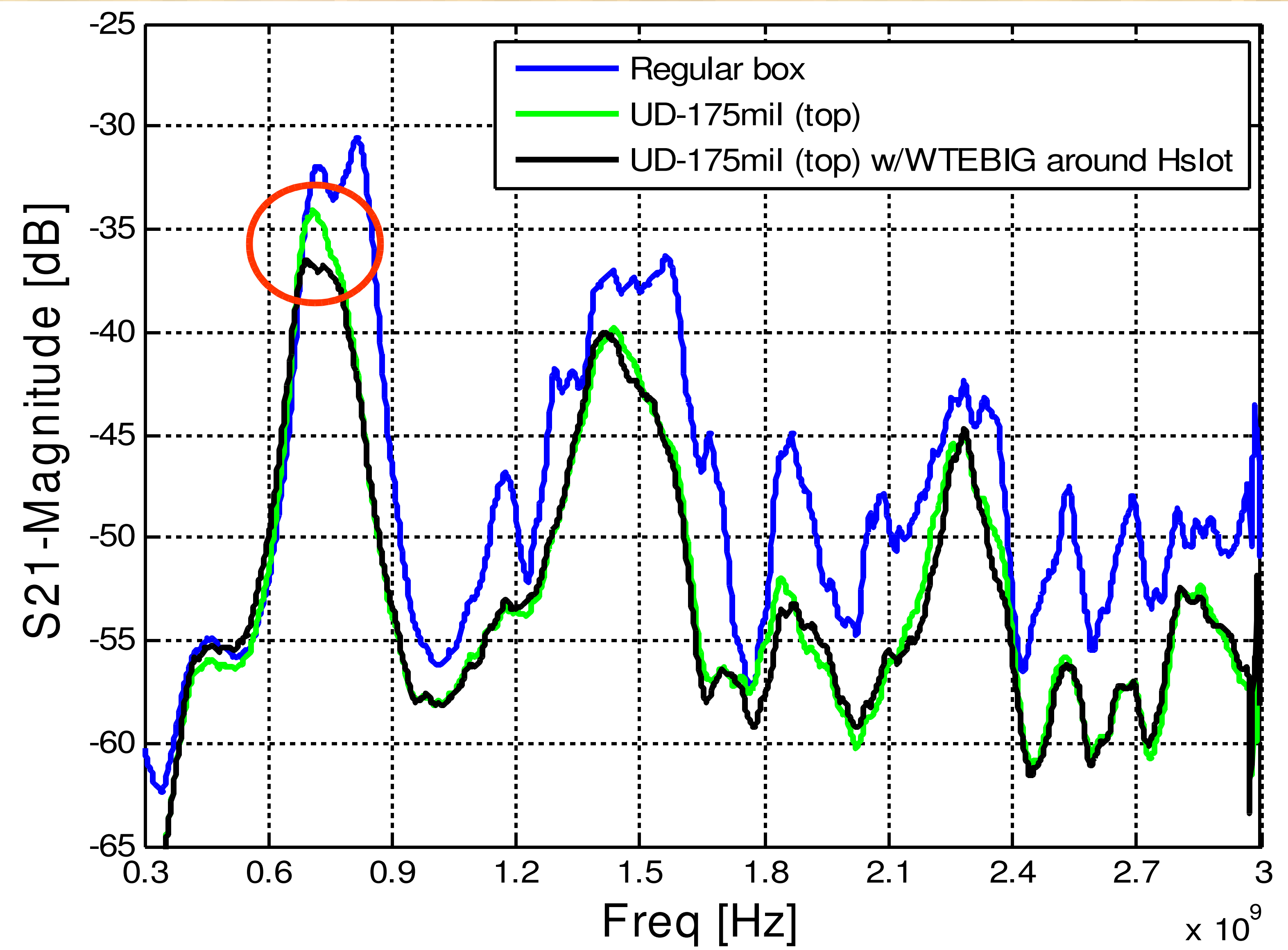
Top -vs- Left side comparison



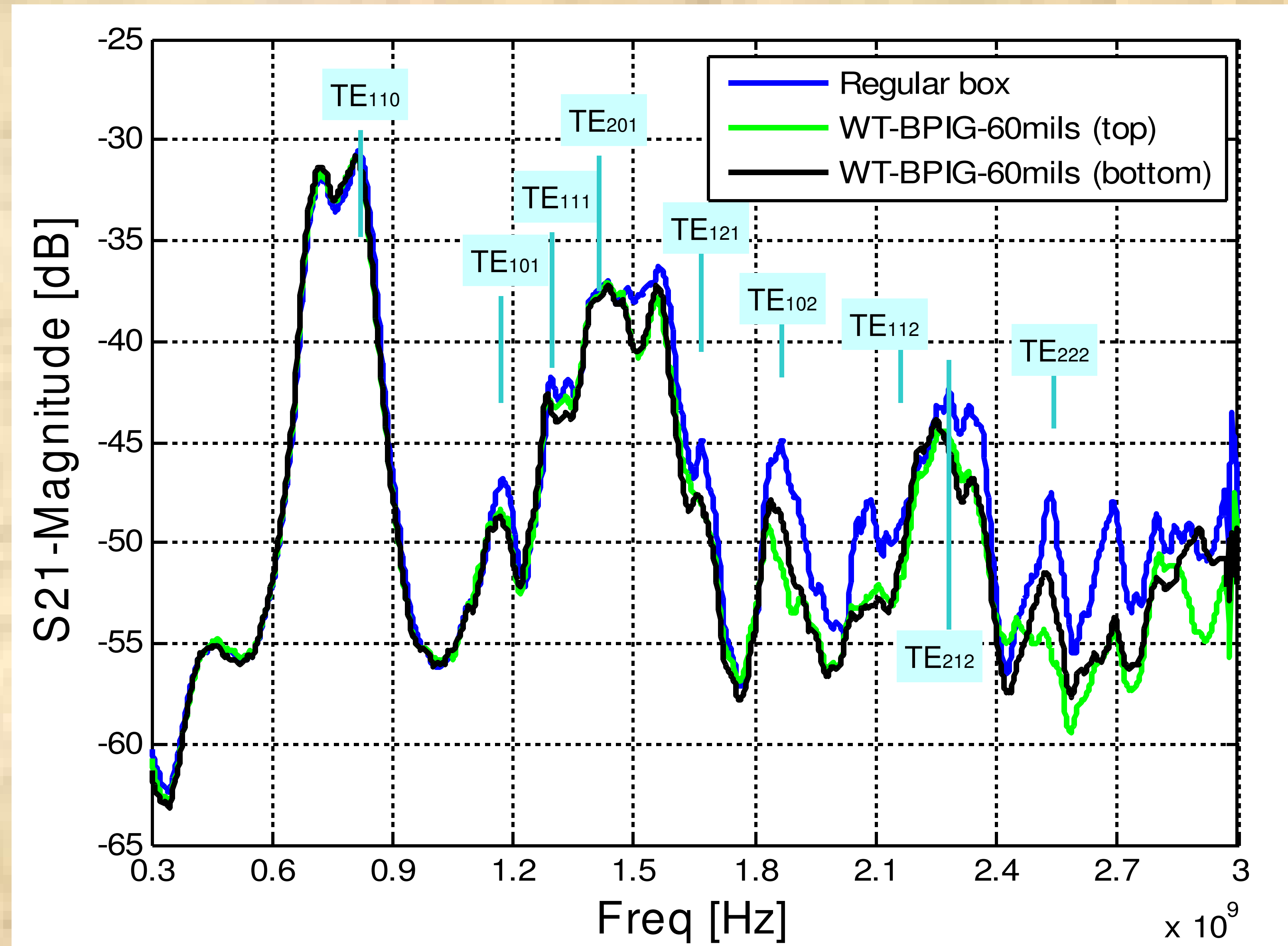
UD material on Top & Left sides



Effect of adding material around H-slot



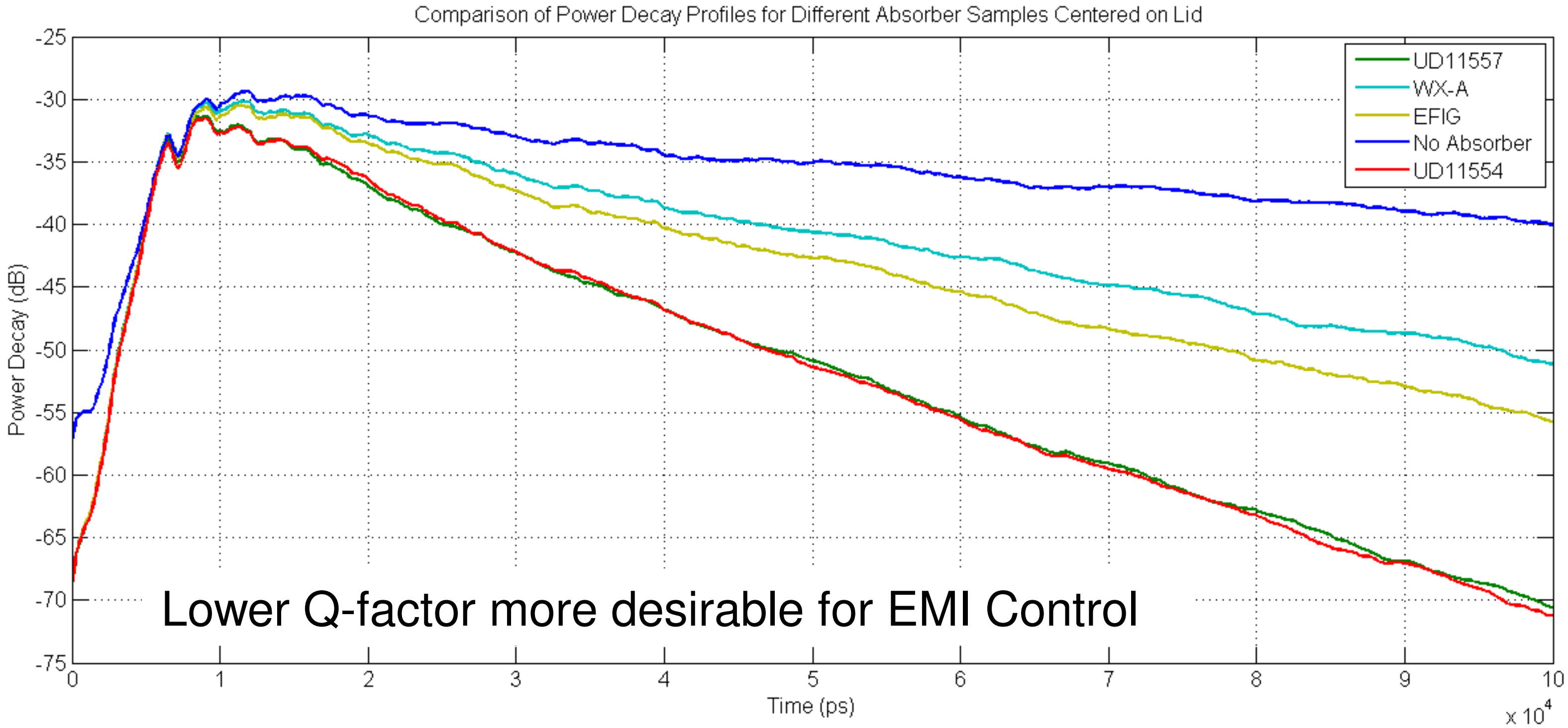
Effect of WT-BPIG material



Effects with Reverb Measurement

- Previous tests show effect w/o reverb within the box
  - Modes must be established before lossy material will have impact
- When reverb inside enclosure, then single port measurement allows Q-factor to be determined
  - Eliminates requirement for slot in box to allow energy out!
- Following slides courtesy of ARC Technology
  - David Green, “ONE-PORT TIME DOMAIN MEASUREMENT TECHNIQUE FOR QUALITY FACTOR ESTIMATION OF LOADED AND UNLOADED CAVITIES,” IEEE EMC Symposium, August 2013, Denver

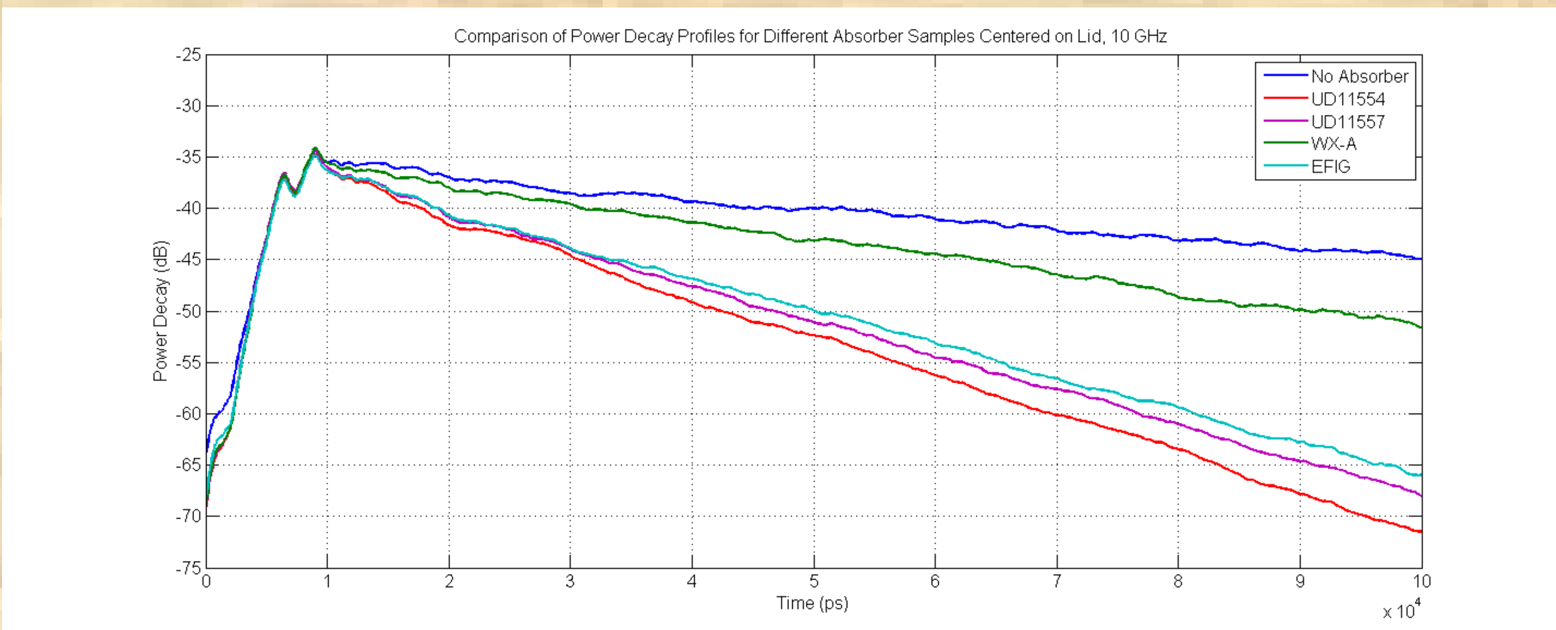
CENTER OF LID ABSORBER PLACEMENT – 3.5 GHZ CENTER FREQUENCY



Cavity Setup	Measured Q (dB)
No Absorber	29.78
UD11554	23.56
UD11557	23.67
WX-A	26.45
EFIG	25.54

Higher slope means more absorption/loss!

CENTER OF LID ABSORBER PLACEMENT – 10 GHZ CENTER FREQUENCY



Cavity Setup	Measured Q (dB) 3.5 GHz	Measured Q (dB) 10 GHz
No Absorber	29.78	34.62
UD11554	23.56	28.57
UD11557	23.67	29.03
WX-A	26.45	32.07
EFIG	25.54	29.33

Summary

- Traditional approaches to EM shielding at high frequencies will not work in practical products without excessive cost, weight, etc.
- Using lossy/absorbing materials allows designers to reduce EMC issues (emissions and immunity)
- Lossy/absorptive materials can be used
  - Under heatsinks
  - As coating to cables
  - To break cavity based resonances

Further Development Needed!

- Currently, it is difficult to predict effects of materials from simple material parameter analysis
- Full wave simulations with complex eps & mu are possible and on-going
- More work needed to allow relationship between complex eps & mu vs. frequency to help predict performance faster