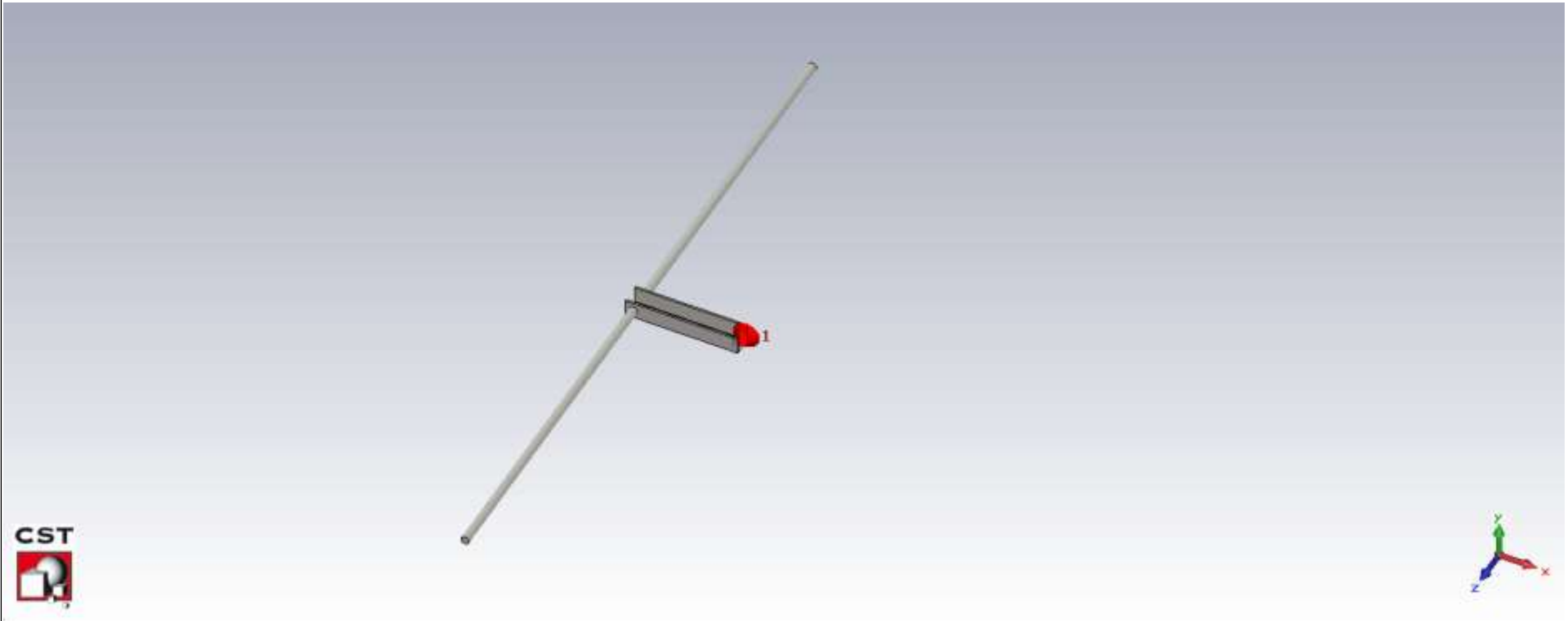
Electromagnetic Shielding

Scott Piper – General Motors

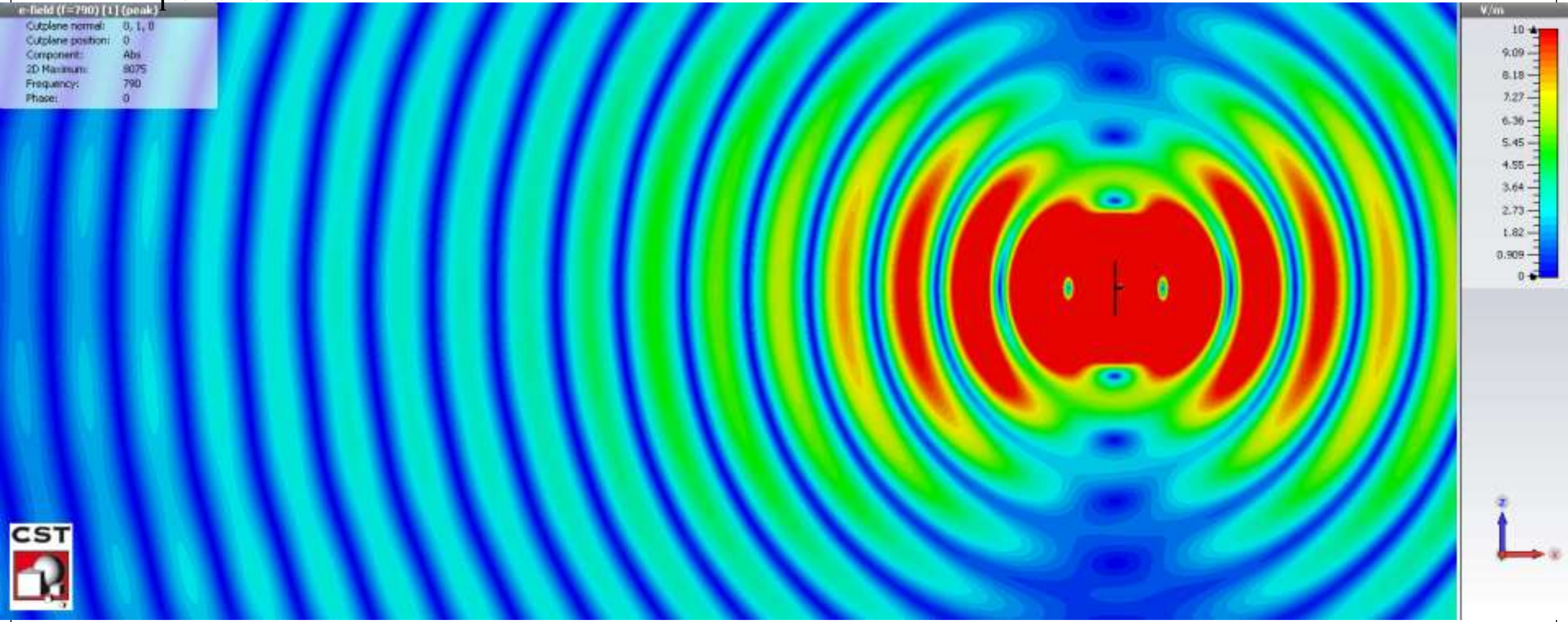
Dipole Antenna – 160mm Long



Electric Field Radiation Pattern

Farfield – 377Ω Wave Impedance

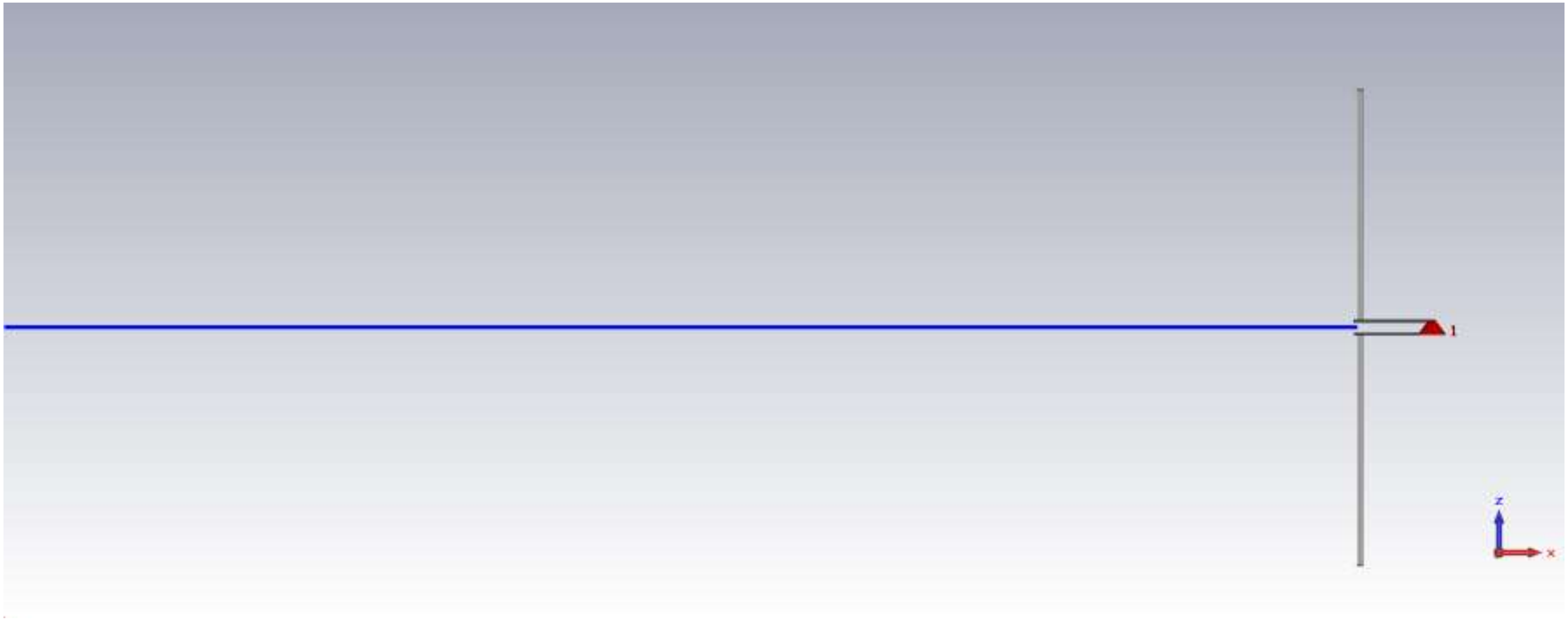
Nearfield



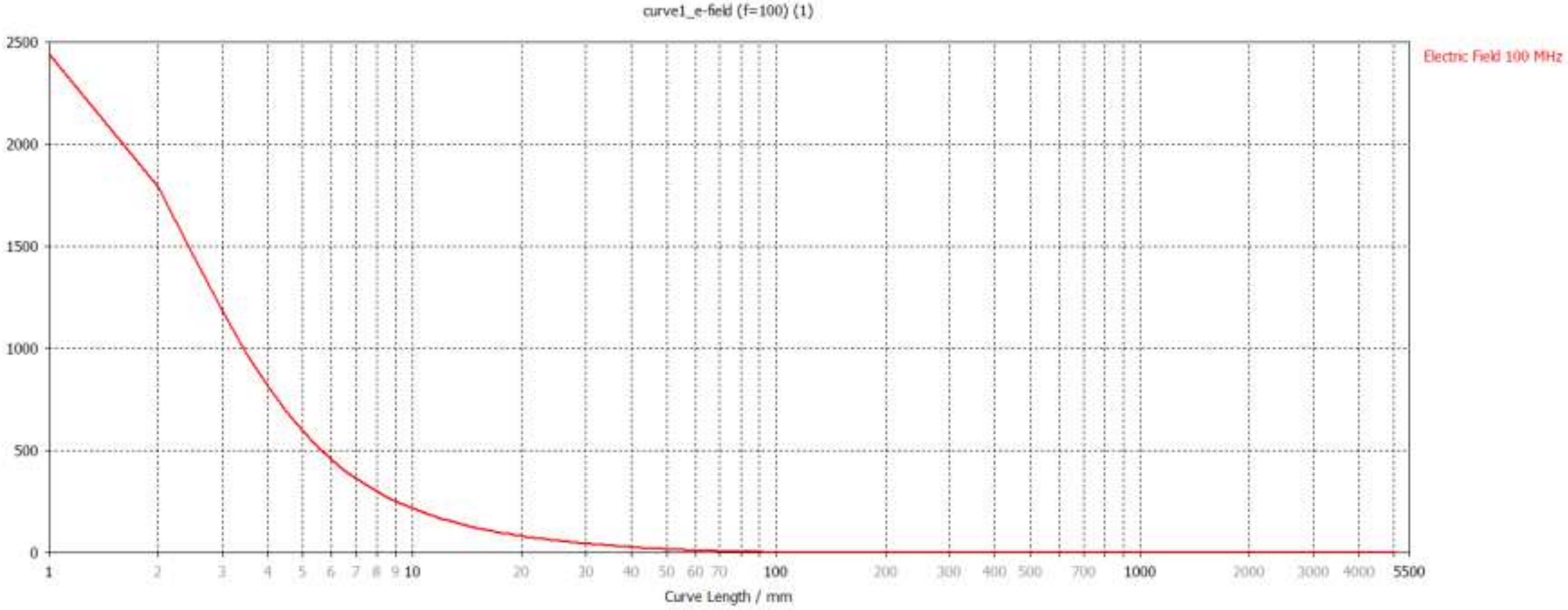
e-field (f=790) [1] (peak)

Cutplane normal: 0, 1, 0
Cutplane position: 0
Component: Abs
2D Maximum: 8075
Frequency: 790
Phase: 0

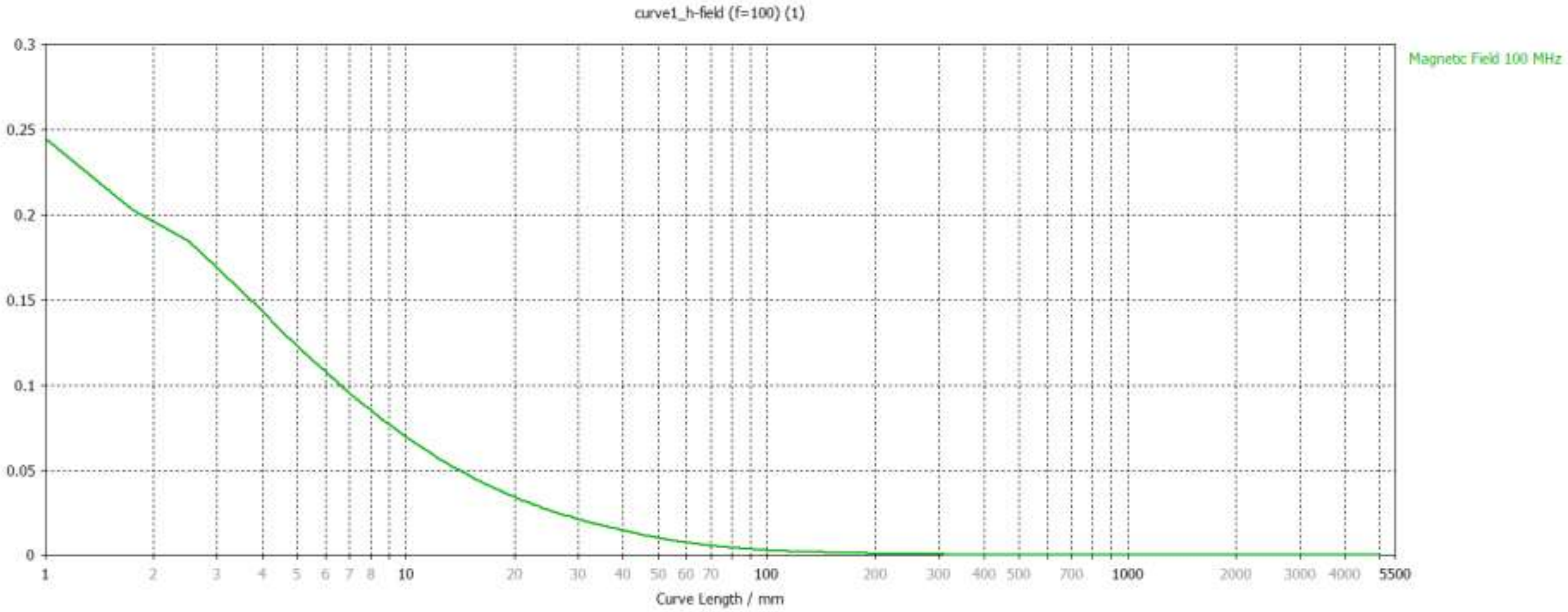
Electric and Magnetic Fields evaluated along blue line



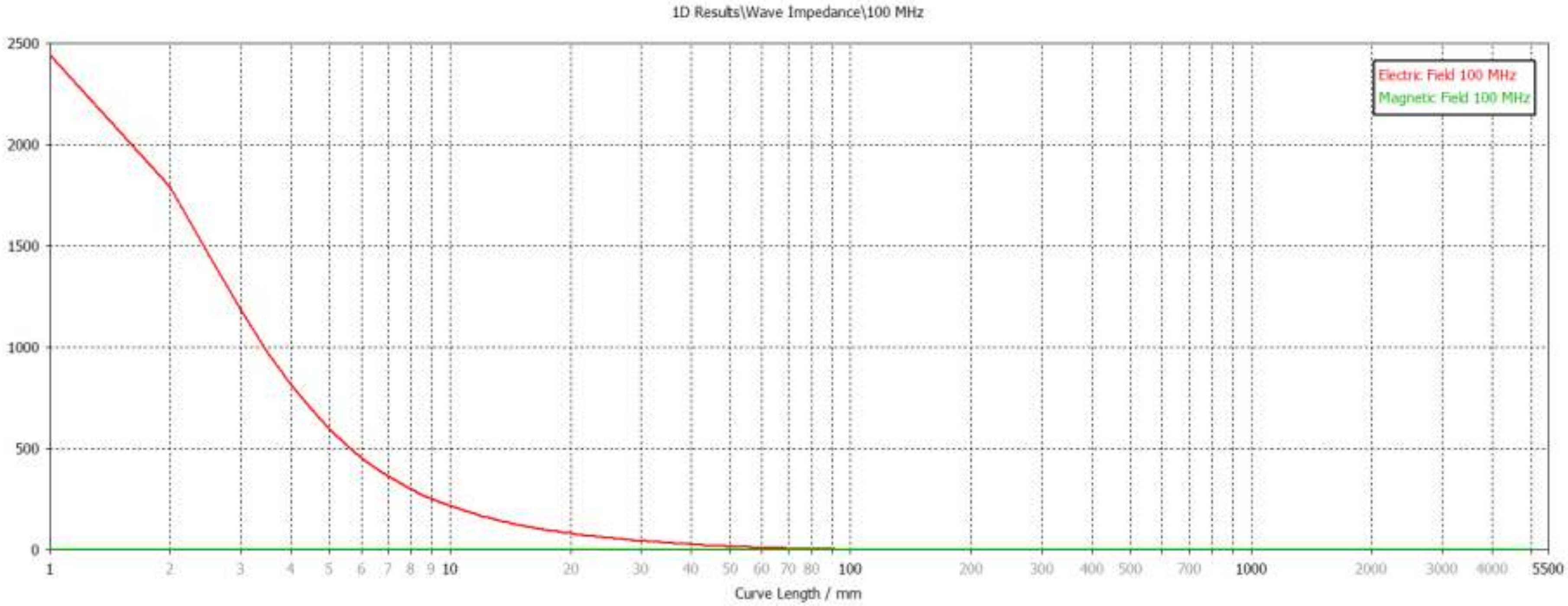
Electric Field vs. Distance from Antenna



Magnetic Field vs. Distance from Antenna



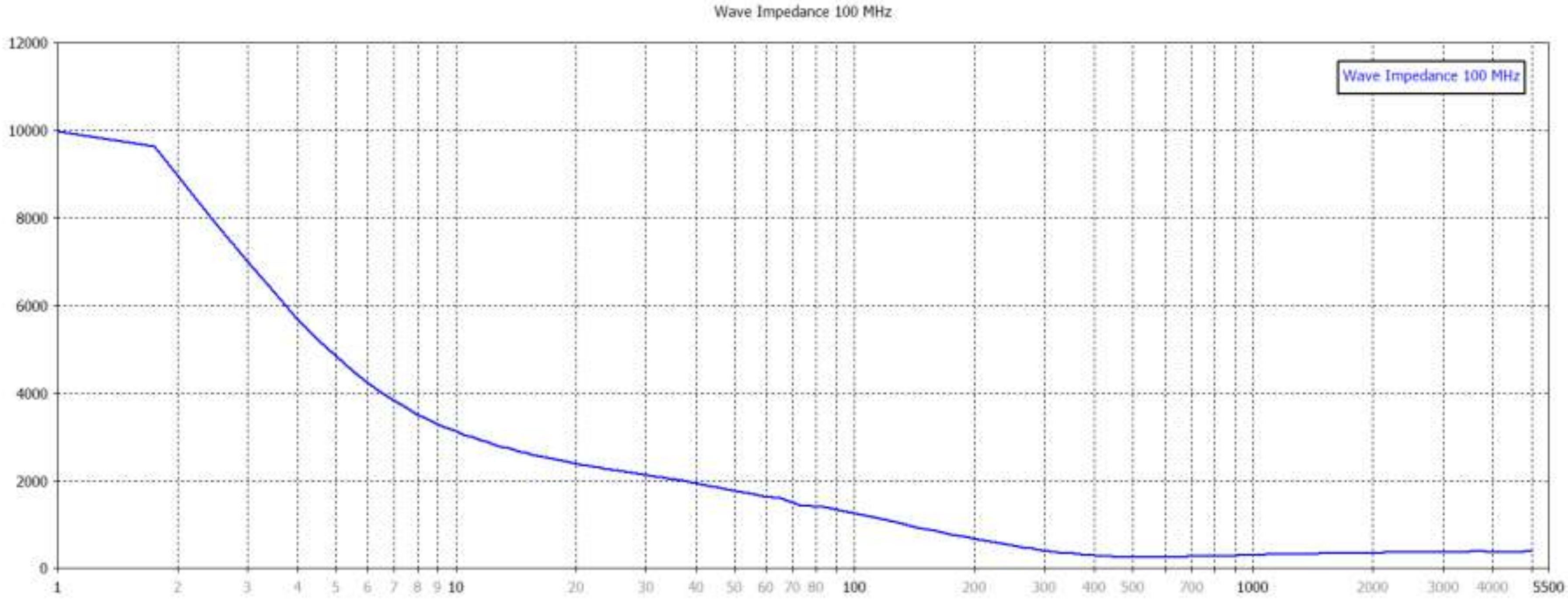
Electric and Magnetic Fields vs. Distance from Antenna



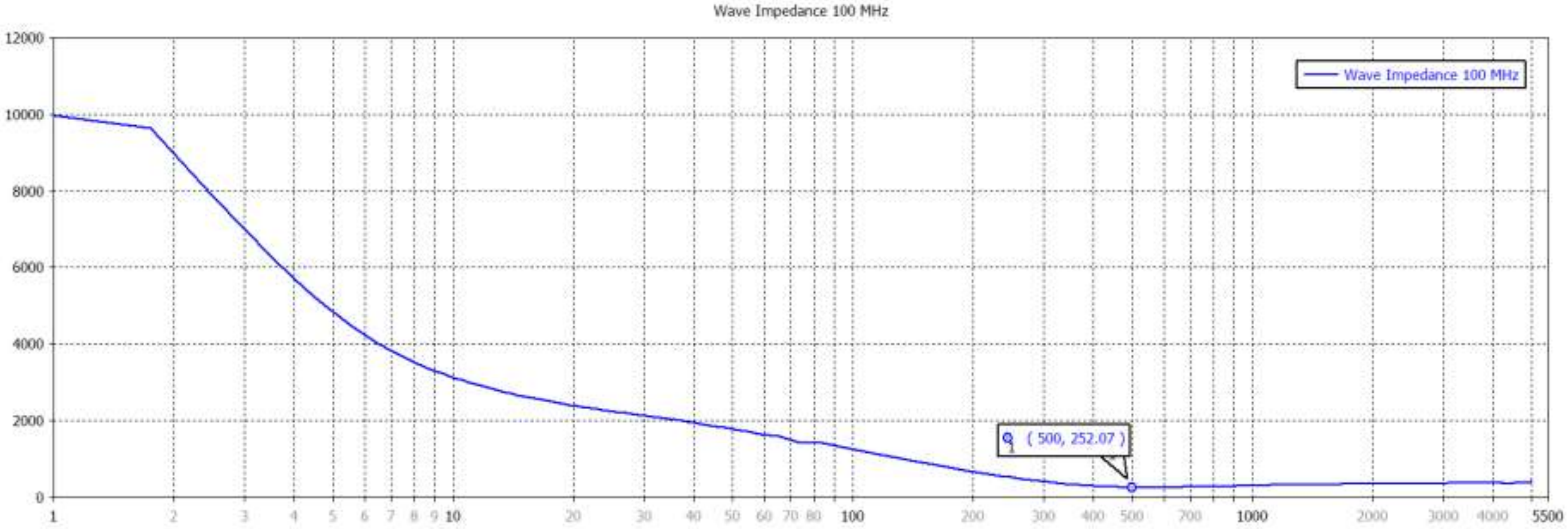
Wave Impedance

$$z(\Omega) = \frac{E\ Field\ (\frac{V}{m})}{H\ Field\ (\frac{A}{m})}$$

Wave Impedance vs. Distance

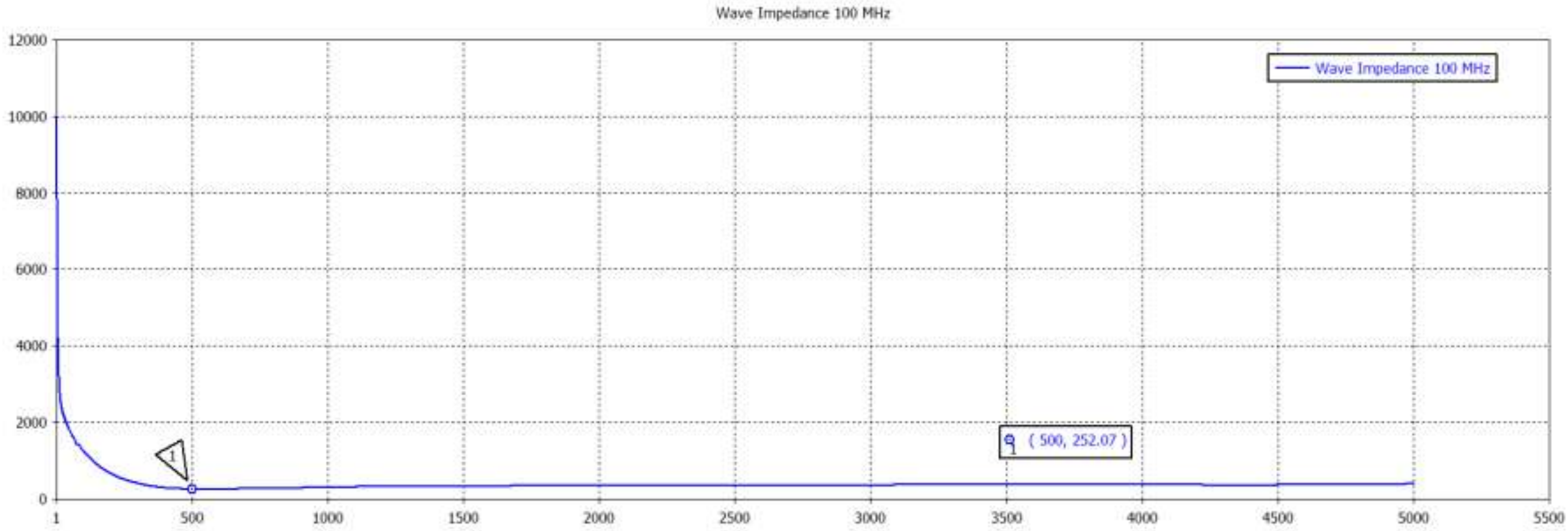


Wavelength / 6 point



500 mm – 252.07Ω

Linear X Axis

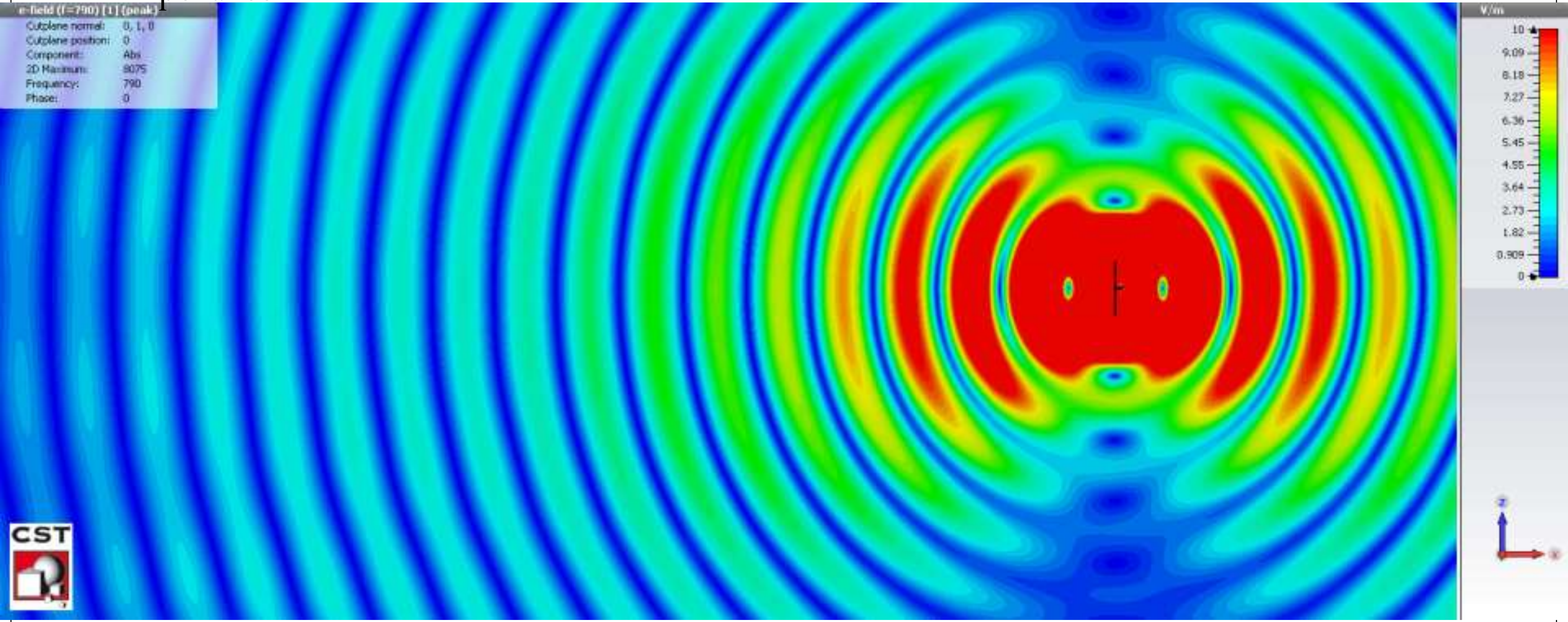


500 mm – 252.07Ω

Electric Field Radiation Pattern

Farfield – 377Ω Wave Impedance

Nearfield



e-field (f=790) [1] (peak)

Cutplane normal: 0, 1, 0
Cutplane position: 0
Component: Abs
2D Maximum: 8075
Frequency: 790
Phase: 0

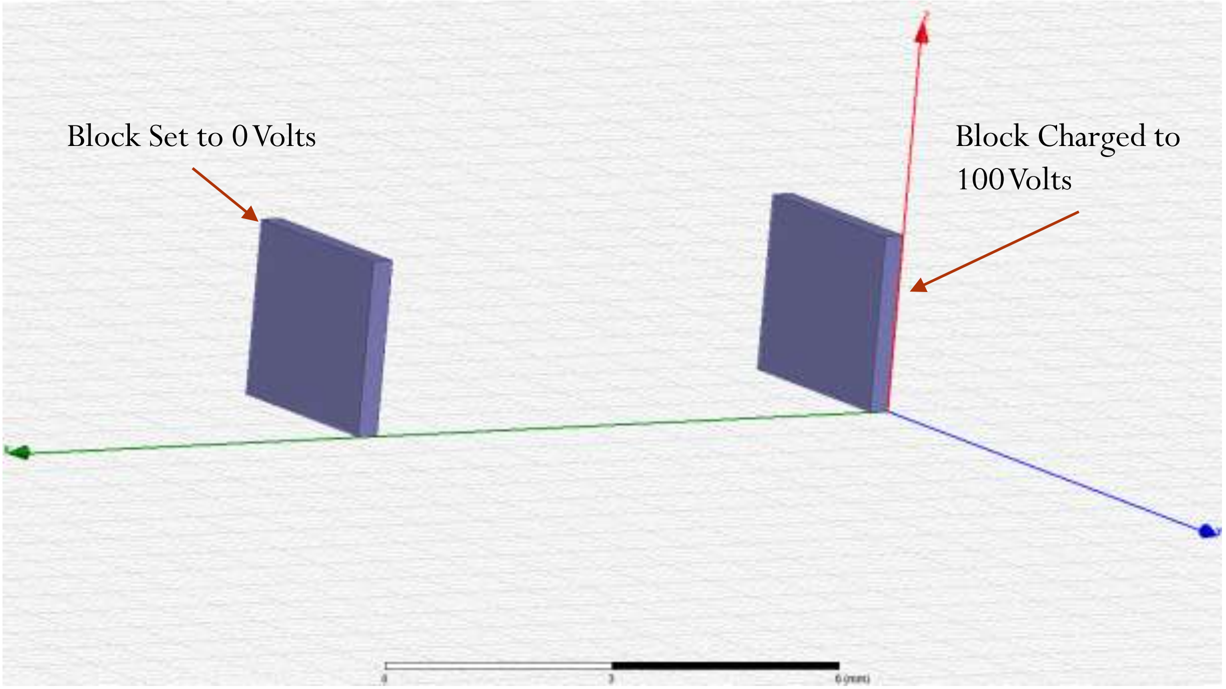
Wave Impedance

- Electromagnetic waves can originate from an electric field or magnetic field source
  - Near the source, electric or magnetic field can dominate
  - Far from the source, the ratio between electric and magnetic fields is 377
- Why do we care?
  - EMC shielding strategies are different depending on which fields (electric or magnetic) are of concern

Static Shielding Examples

Static Electric Field Shielding

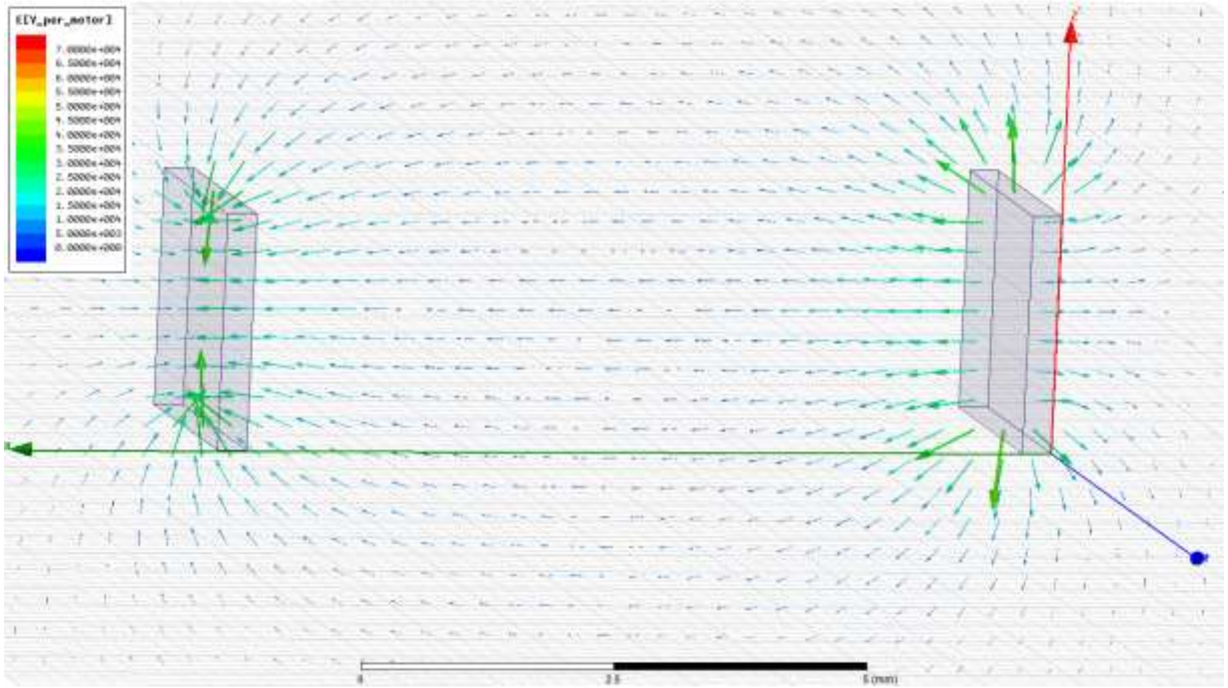
Setup



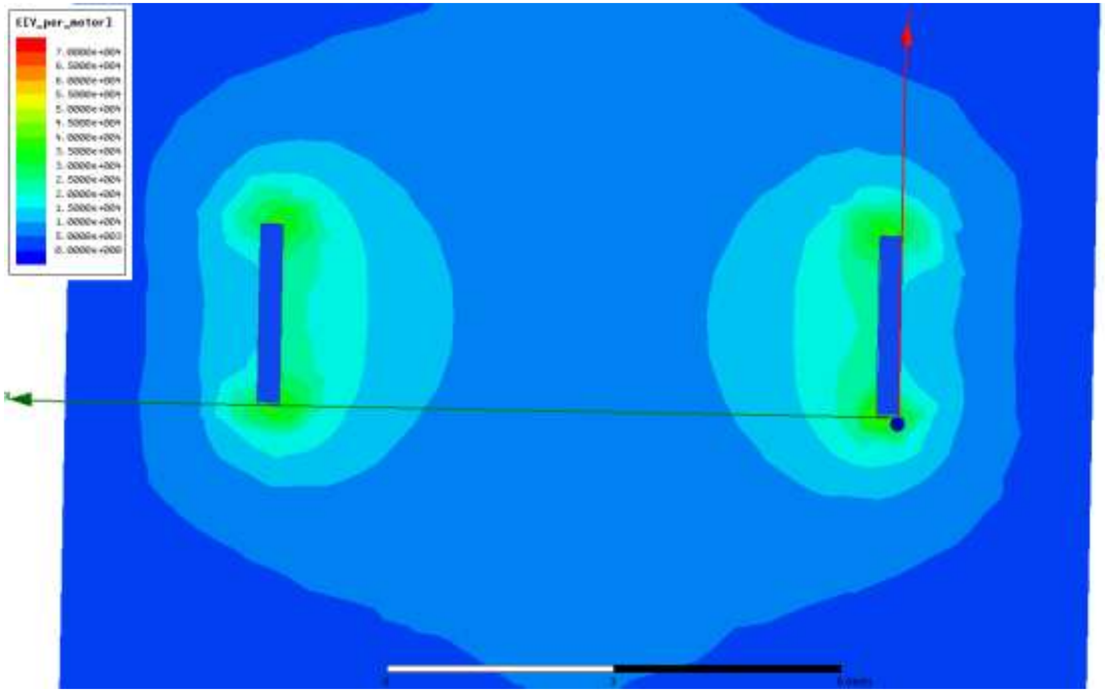
Block Set to 0 Volts

Block Charged to 100 Volts

Electric Field Vectors

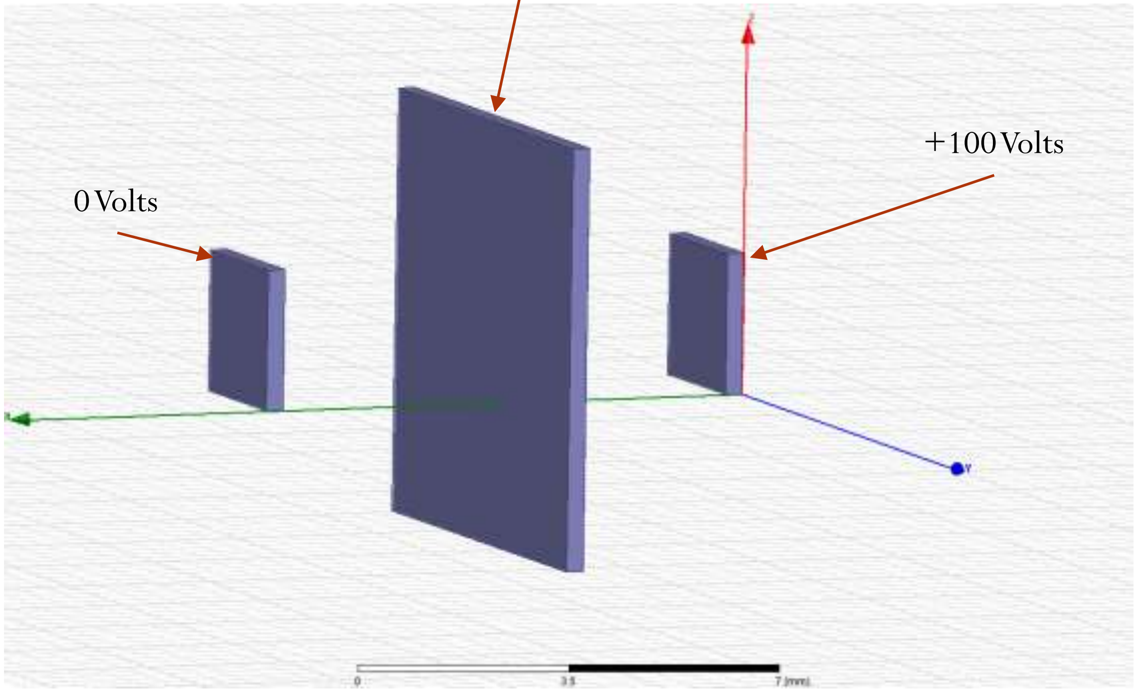


Electric Field Magnitude Between Blocks



We are interested in shielding the 0V block (left) from the electric field generated by the block on the right

Shield Added

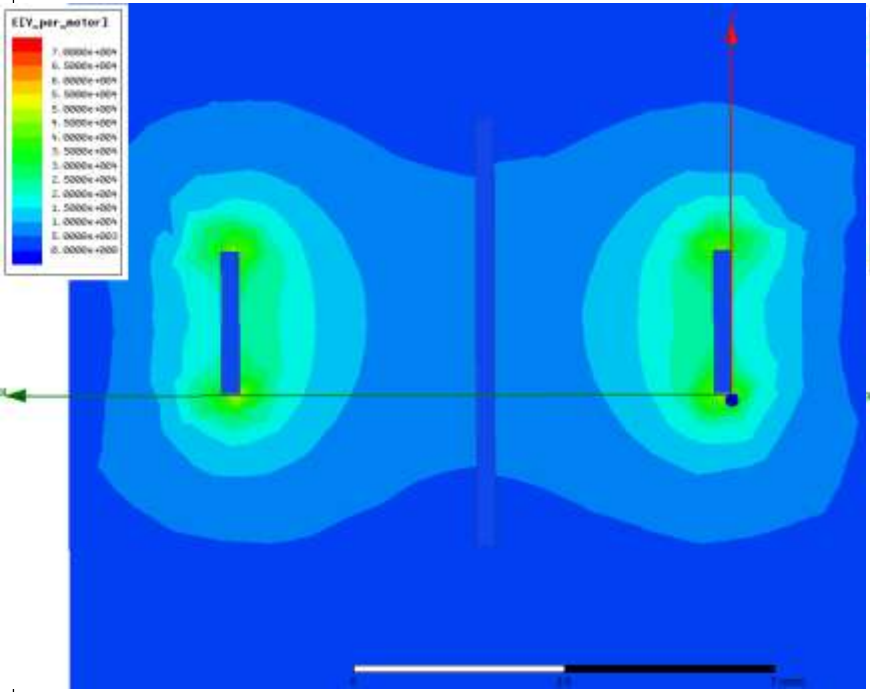


Metal Sheet

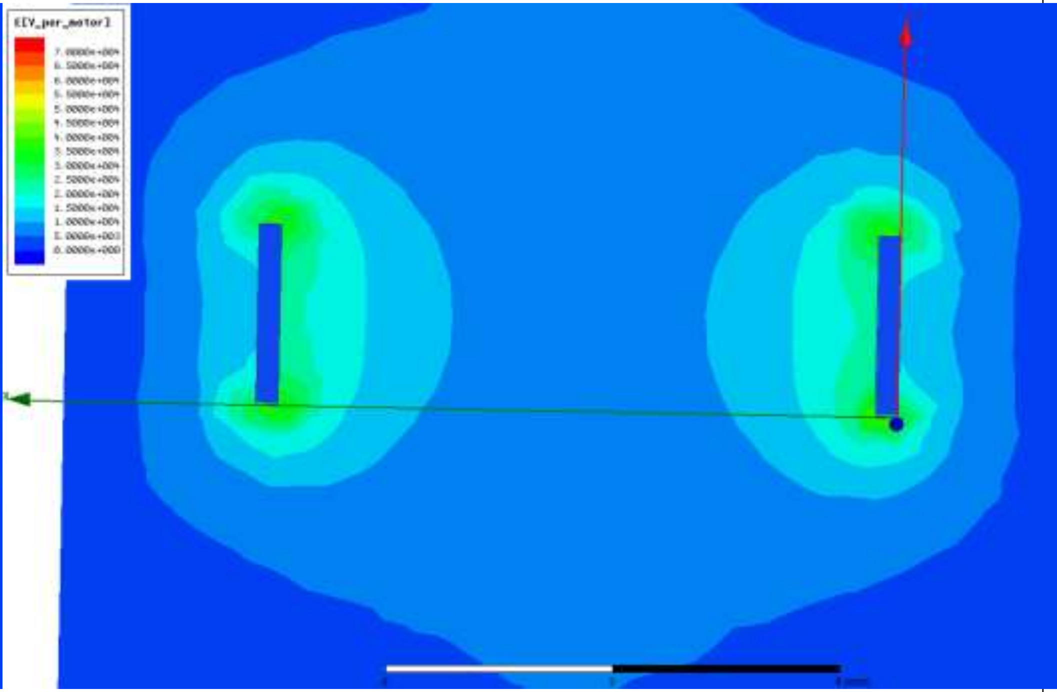
+100 Volts

0 Volts

Electric Field Shielding Performance

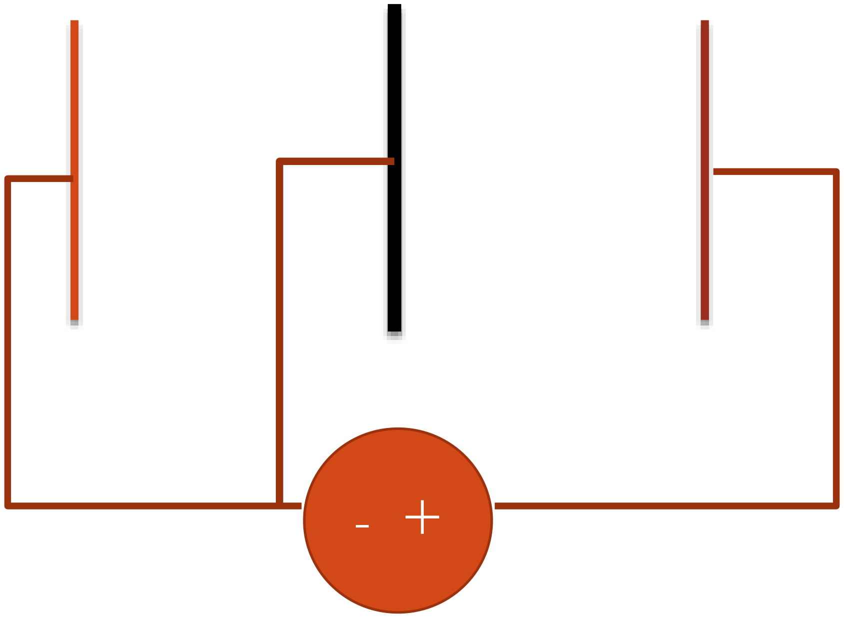


With Shield

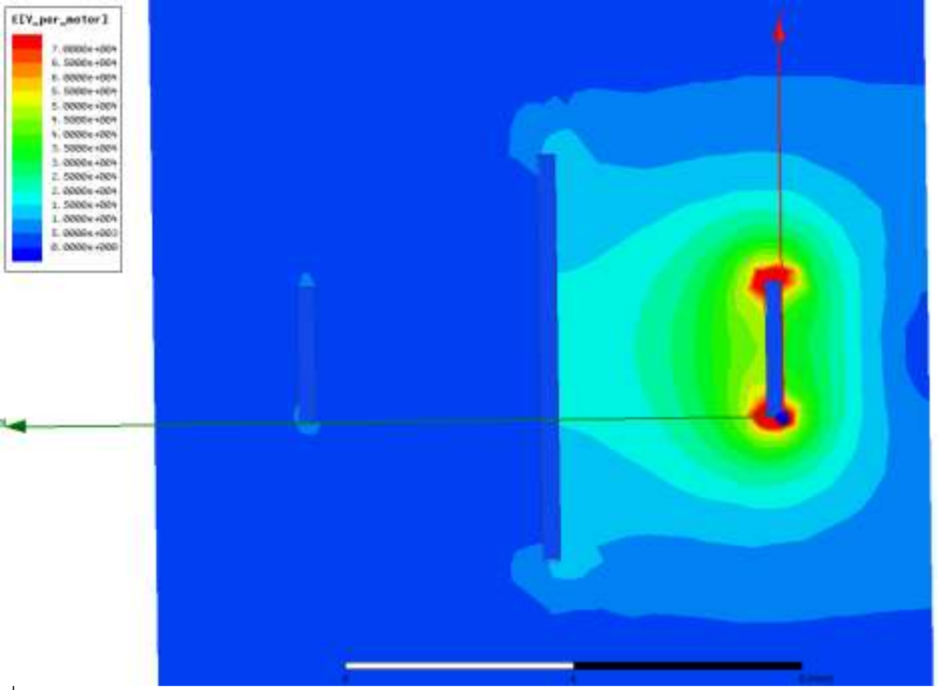


Without Shield

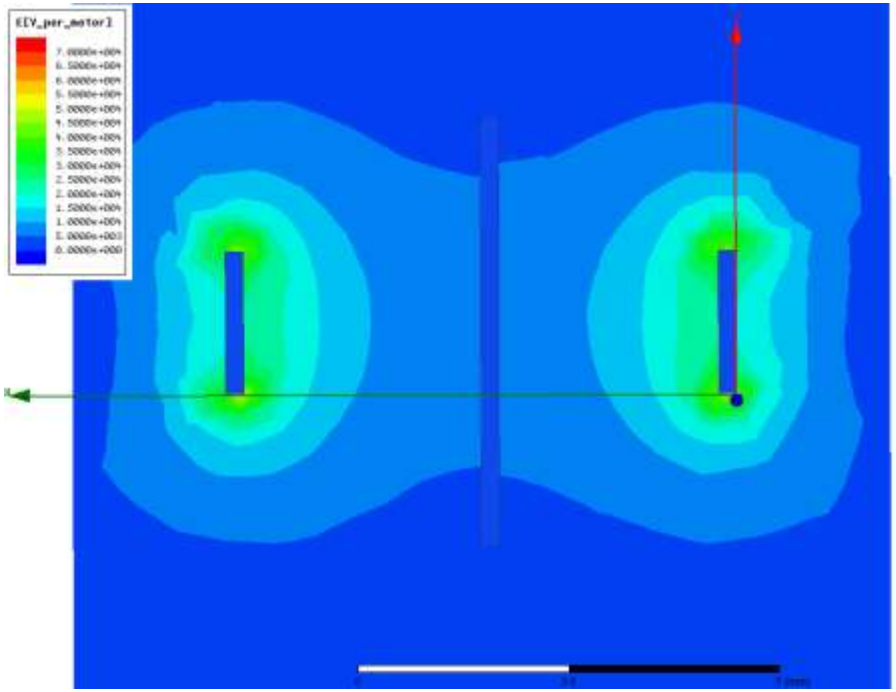
Representation



Electric Field Shielding Performance



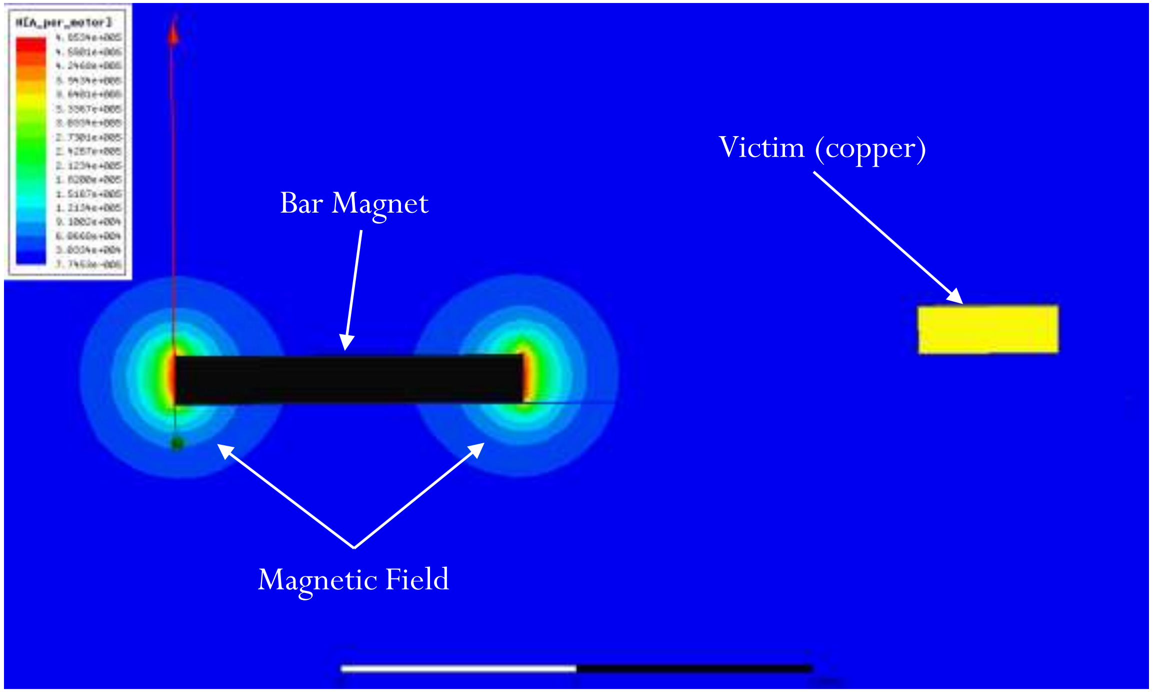
Shield at 0 Volts



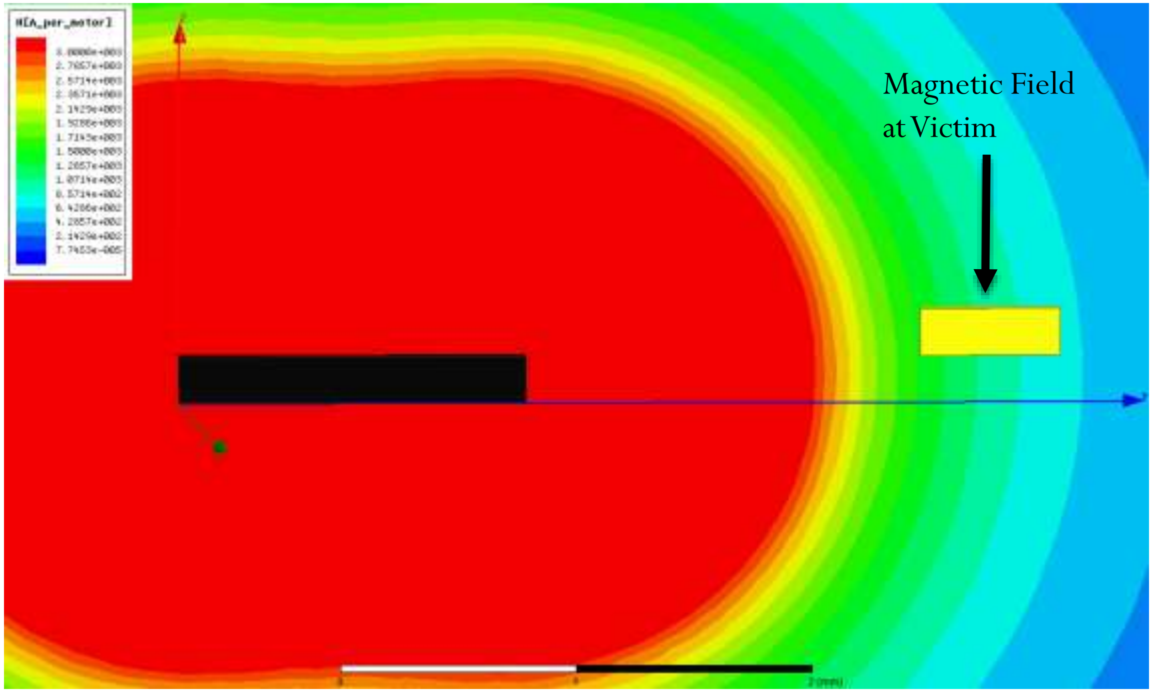
Shield Floating

Static Magnetic Field Shielding

Setup

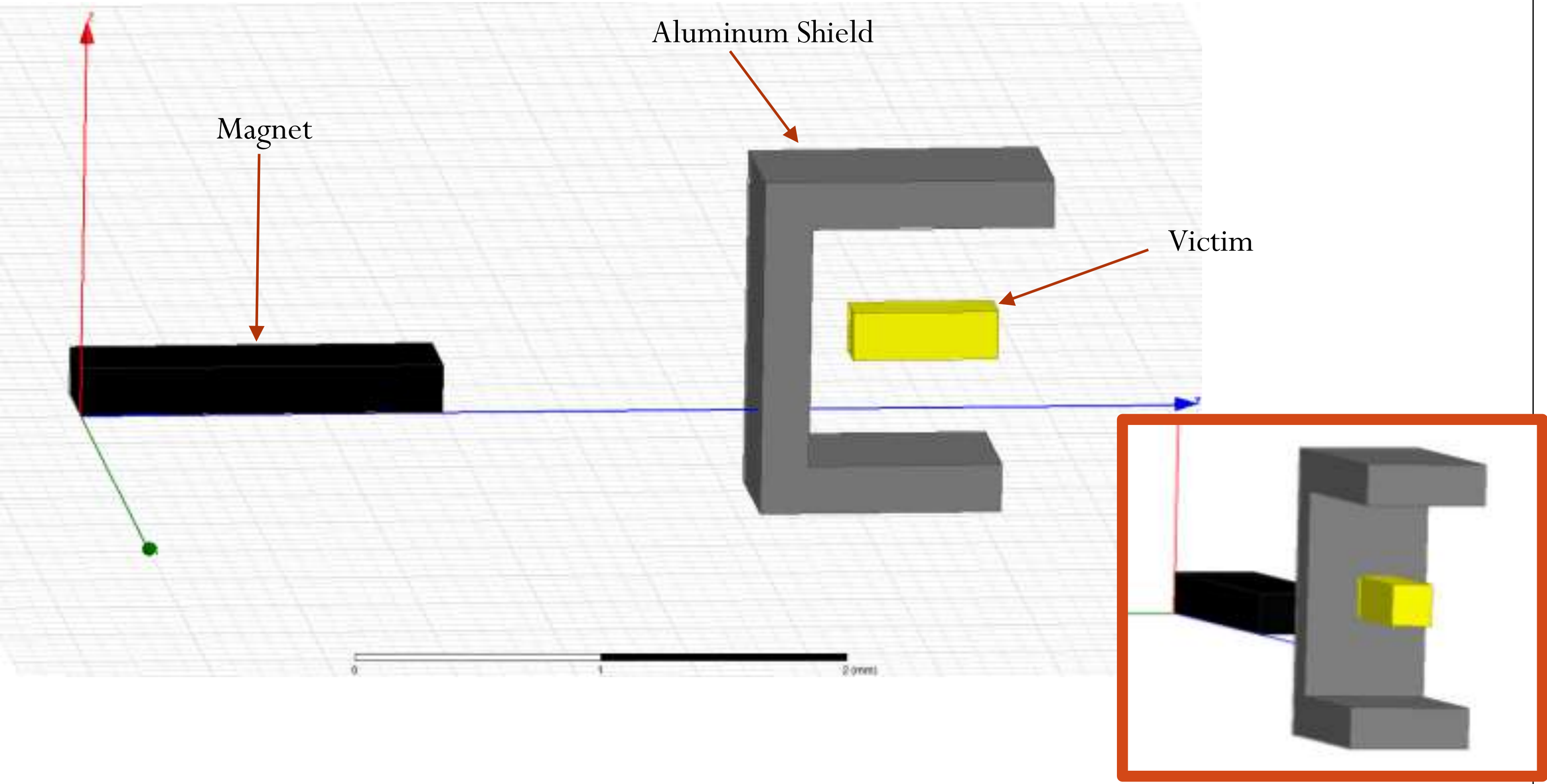

H[A_per_meter]
4.8534e+005
4.5501e+005
4.2468e+005
3.9434e+005
3.6401e+005
3.3367e+005
3.0334e+005
2.7301e+005
2.4267e+005
2.1234e+005
1.8200e+005
1.5167e+005
1.2134e+005
9.1002e+004
6.0668e+004
3.0334e+004
7.7463e-006
Victim (copper)
Bar Magnet
Magnetic Field

Adjusted Scale

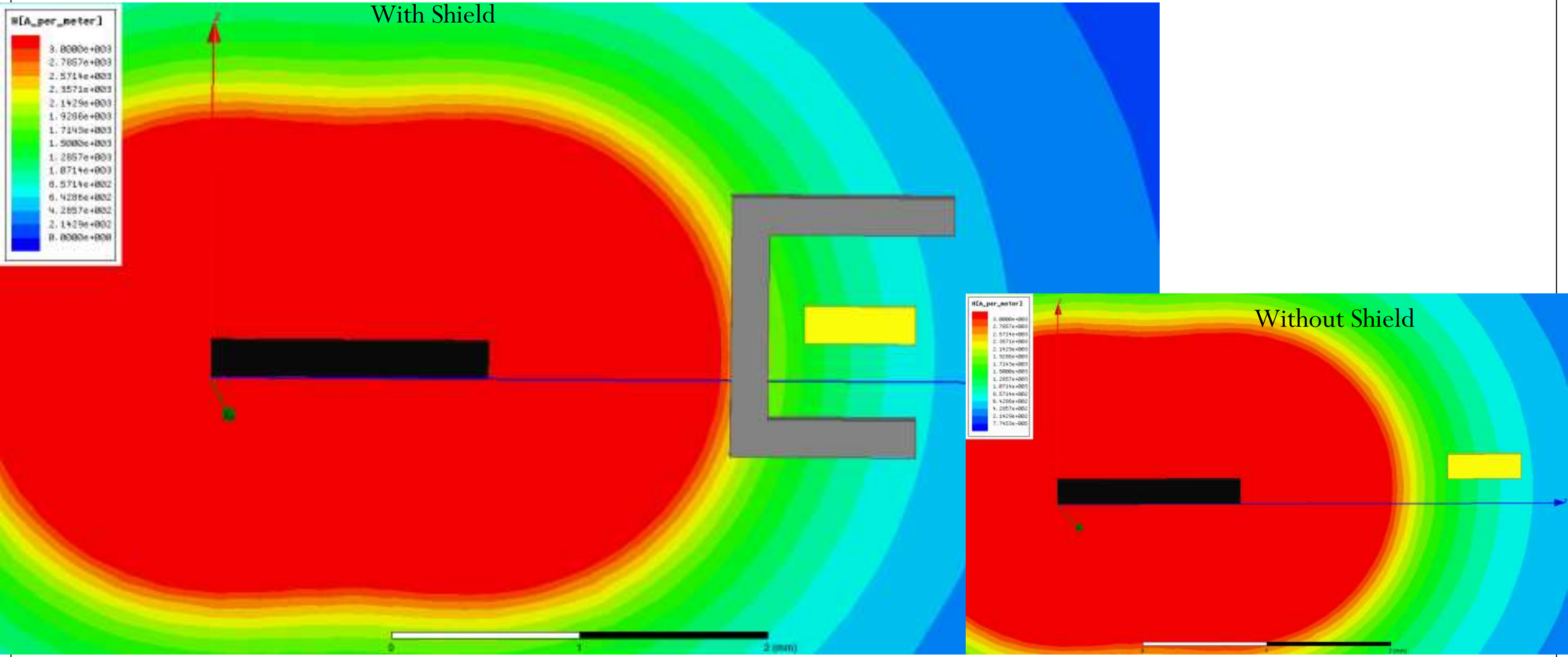


Magnetic Field at Victim

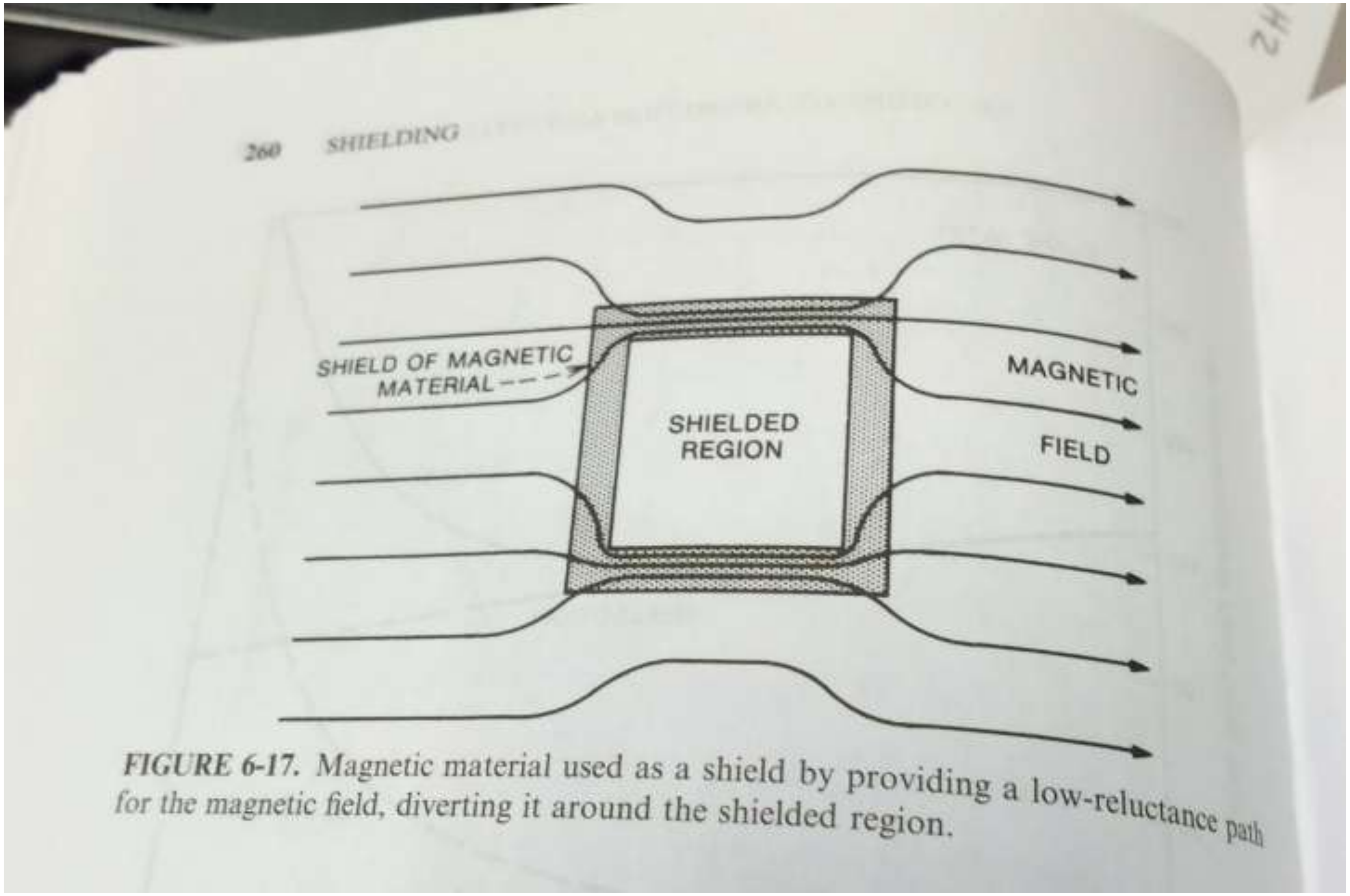
Shield added



Shielded Results



From A Text Book (Henry Ott Electromagnetic Compatibility Engineering)



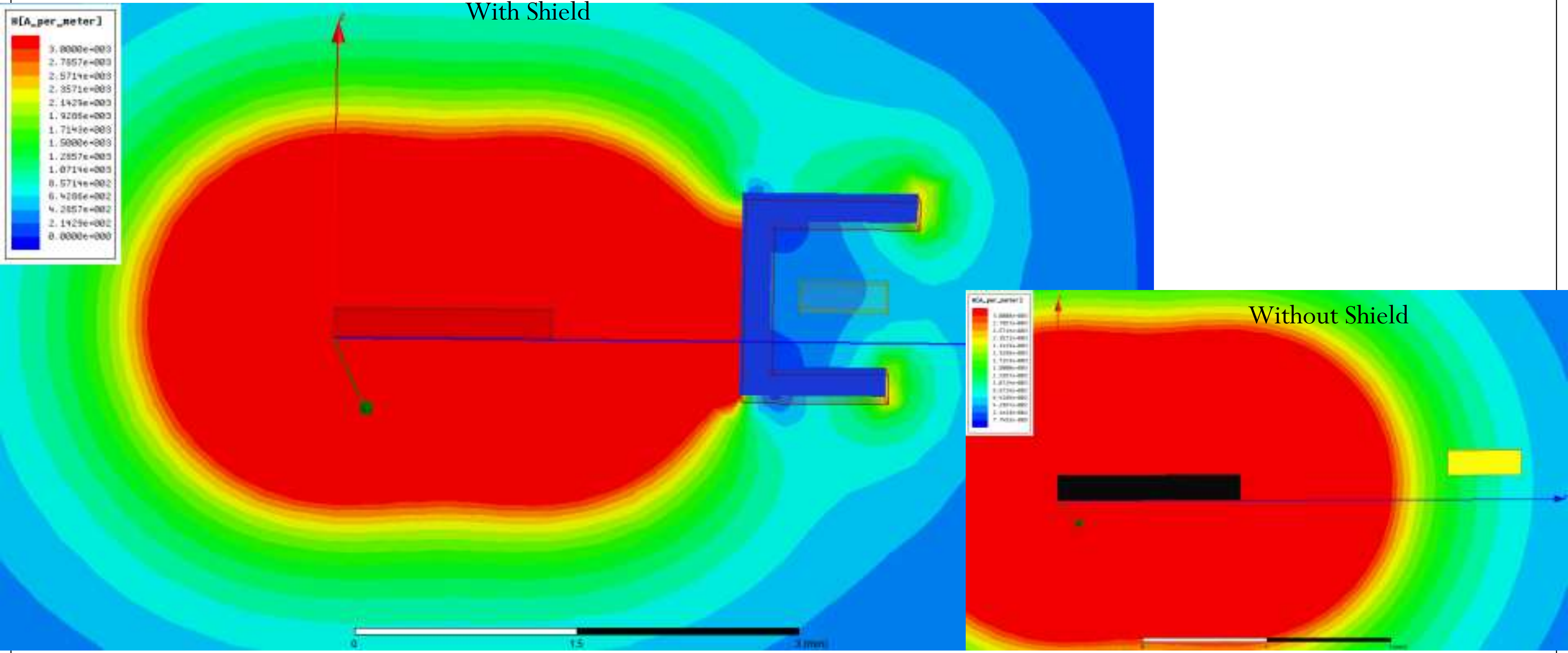
260 SHIELDING

FIGURE 6-17. Magnetic material used as a shield by providing a low-reluctance path *for the magnetic field, diverting it around the shielded region.*

Static magnetic fields can’t be stopped, but can be redirected by providing a low-reluctance path
This path usually involves a material with a relative permeability (μ_r) greater than 1

$$\mathcal{R} = \frac{l}{\mu A}$$

Steel Shield Results

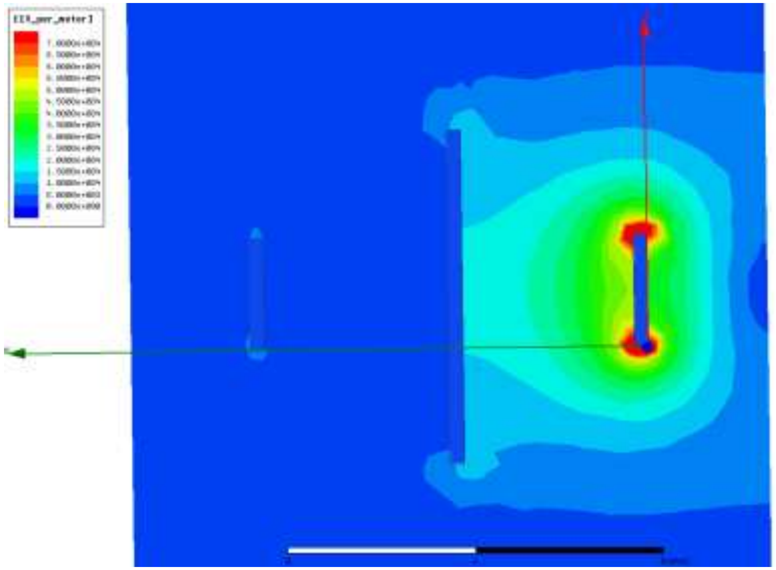


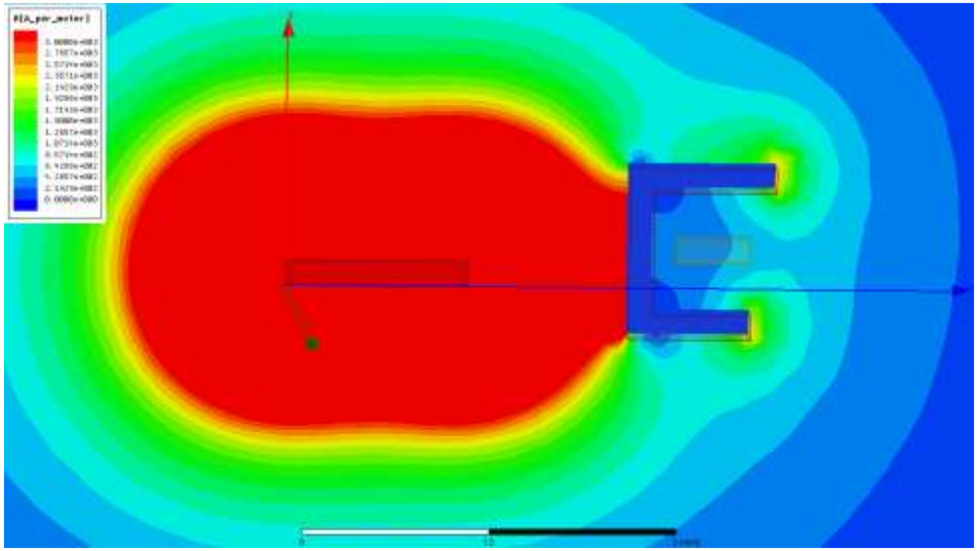
With Shield

Without Shield

Static Shielding

- Electric fields need a shield at the same potential as the victim circuit
- Magnetic fields need a shield with high permeability (μ)





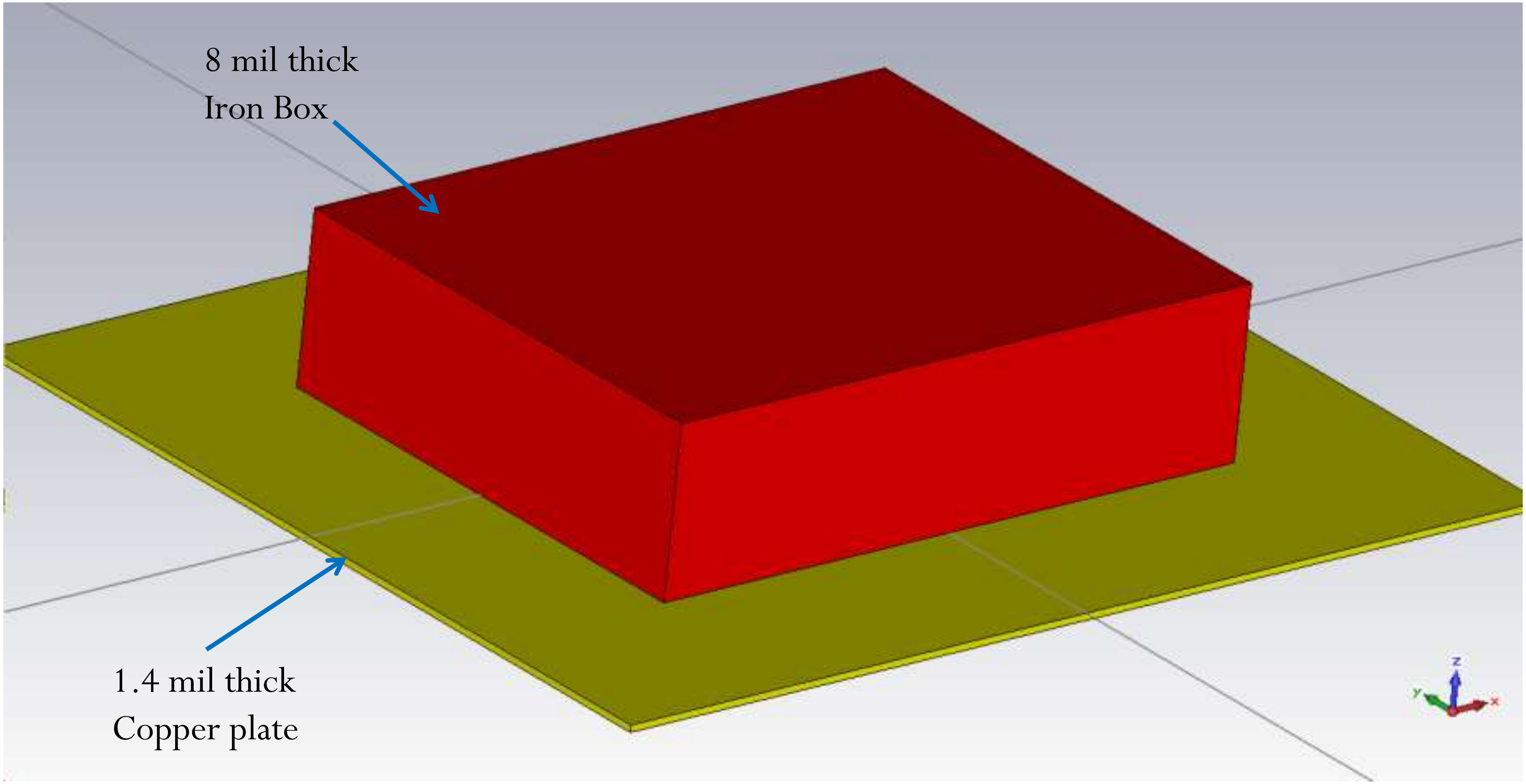
Demonstration of Electromagnetic Shielding Principles

Scott Piper – General Motors

Acknowledgement to Jim Teune and Bogdan Adamczyk of
Gentex Corporation and Grand Valley State University

Low Frequency Magnetic Field Shielding

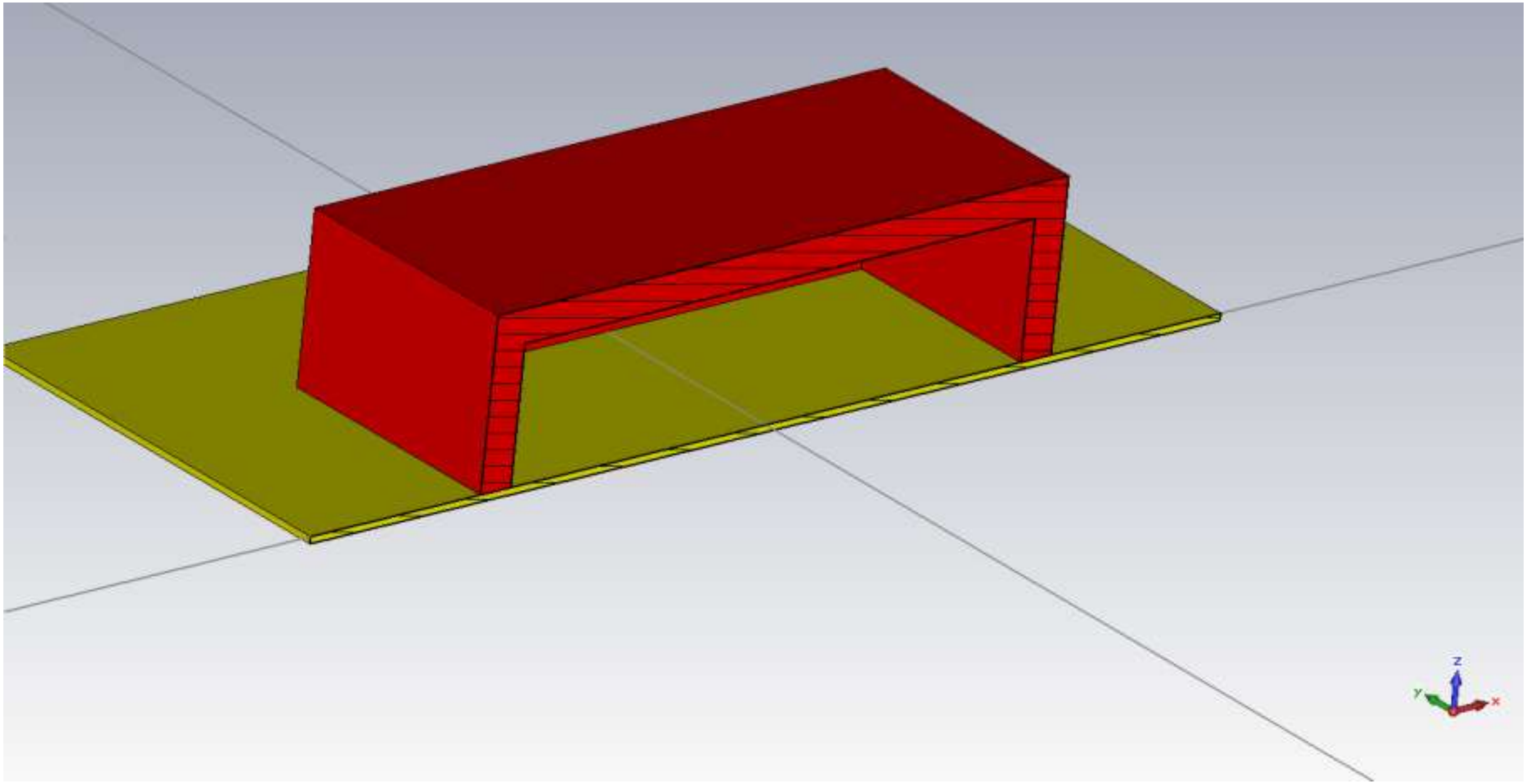
3D Model Setup



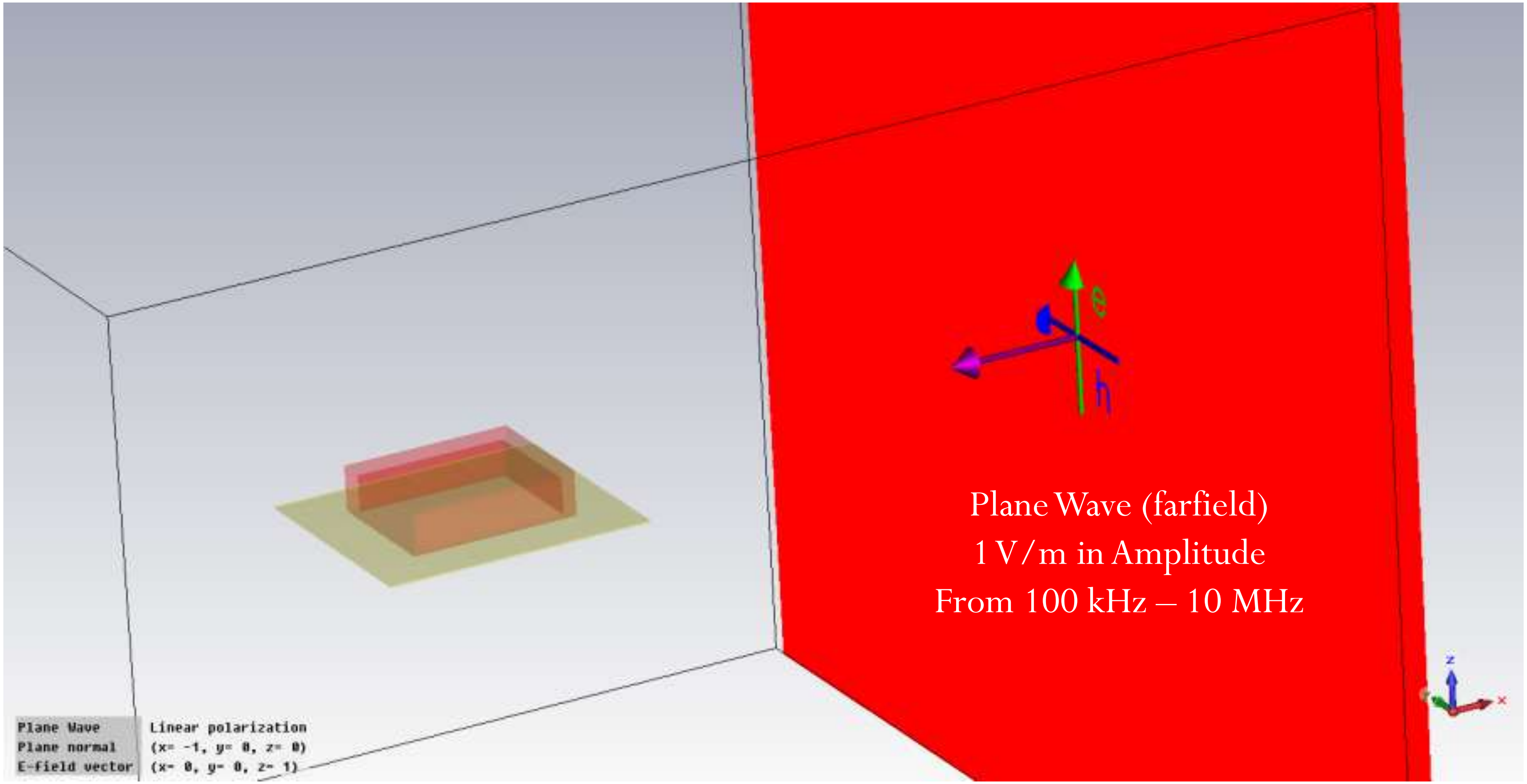
8 mil thick
Iron Box

1.4 mil thick
Copper plate

Cross Section of Box



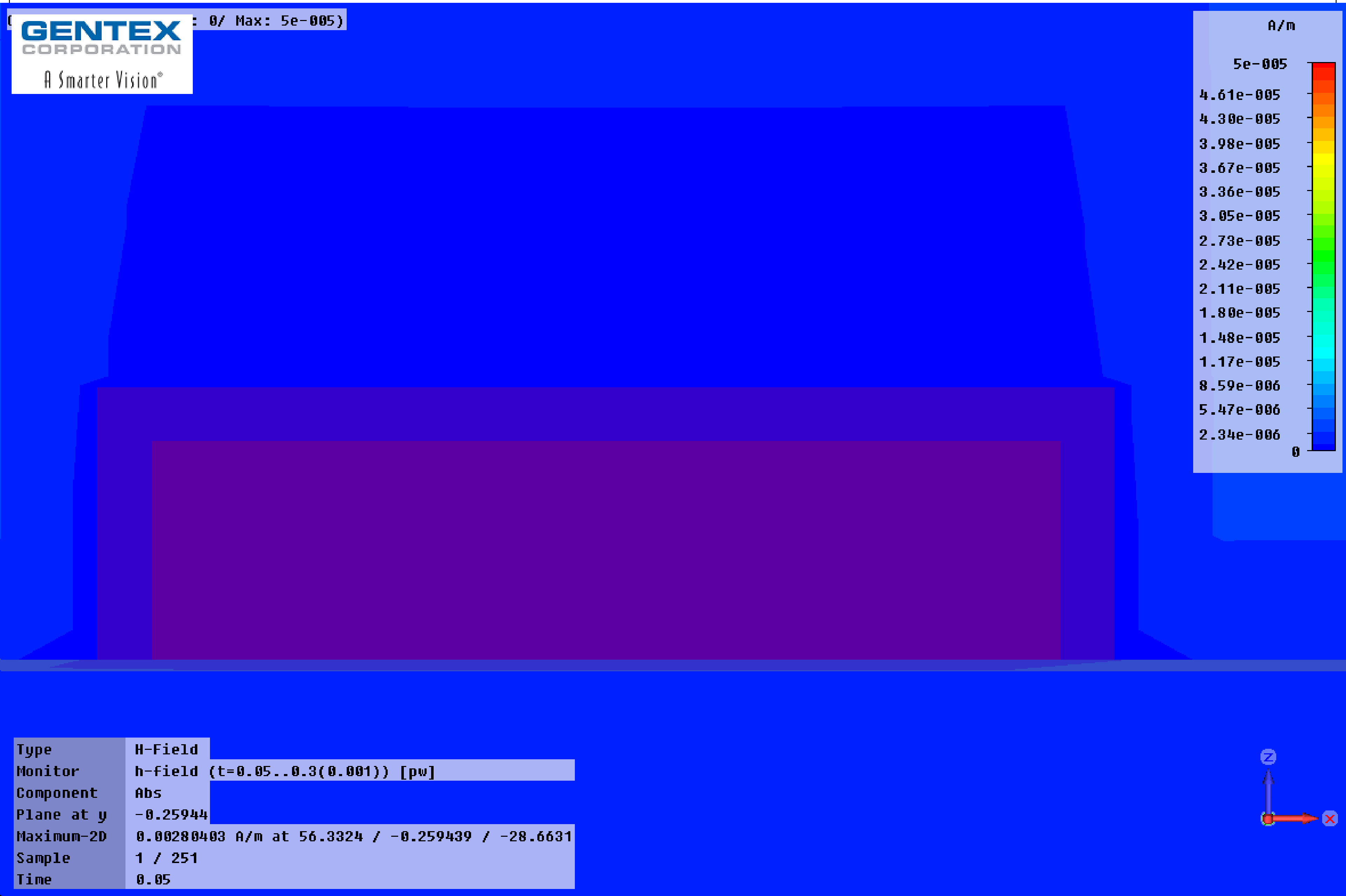
Model Excitation



Plane Wave (farfield)
1 V/m in Amplitude
From 100 kHz – 10 MHz

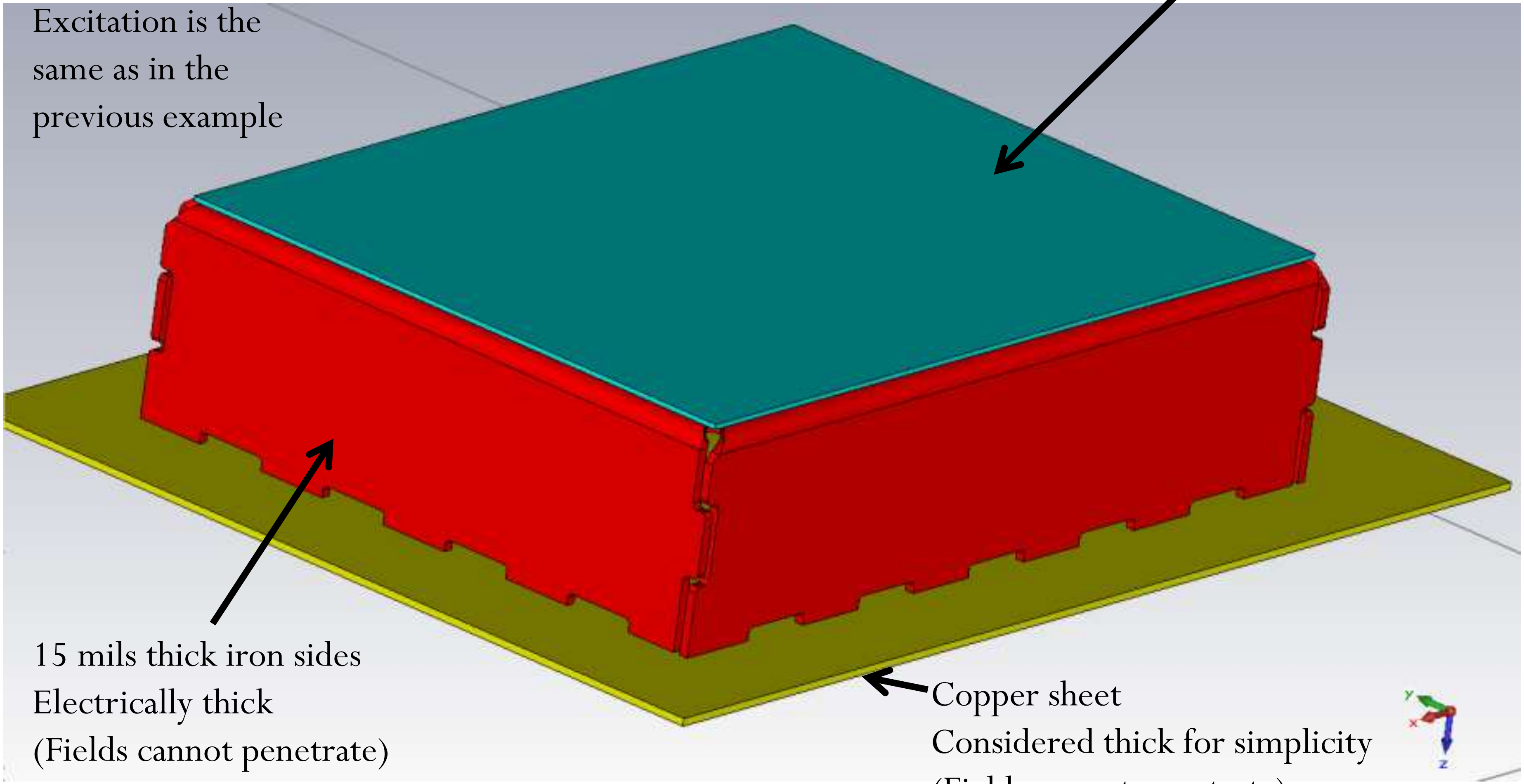
Plane Wave	Linear polarization
Plane normal	(x= -1, y= 0, z= 0)
E-field vector	(x= 0, y= 0, z= 1)

Time Animation of H Field Showing Box Cross Section



Type	H-Field
Monitor	h-field (t=0.05..0.3(0.001)) [pw]
Component	Abs
Plane at y	-0.25944
Maximum-2D	0.00280403 A/m at 56.3324 / -0.259439 / -28.6631
Sample	1 / 251
Time	0.05

New Model



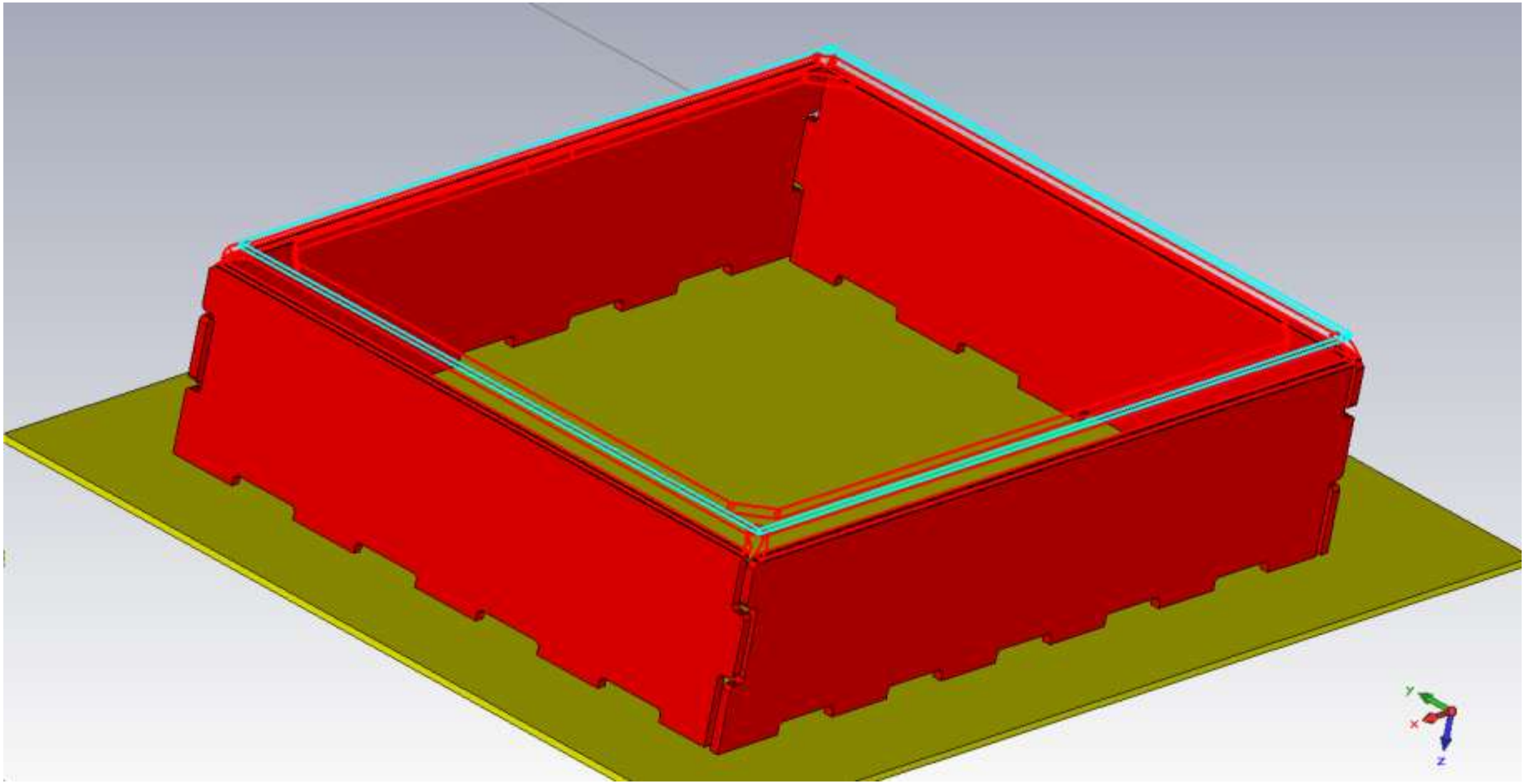
Nickel Silver
8 mils thick

Excitation is the same as in the previous example

15 mils thick iron sides
Electrically thick
(Fields cannot penetrate)

Copper sheet
Considered thick for simplicity
(Fields cannot penetrate)

Fields Observed under Box Lid



Magnetic Field – 10 MHz

Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=10) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0166969 A/m at 64.6947 / 25.5935 / -22.607
Frequency	10

Amplitude Plot

Magnetic Field – 7 MHz

Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=7) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0159855 A/m at 64.6947 / 25.5935 / -22.607
Frequency	7

Amplitude Plot

Magnetic Field – 5 MHz

Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=5) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0154791 A/m at 64.6947 / 25.5935 / -22.607
Frequency	5

Amplitude Plot

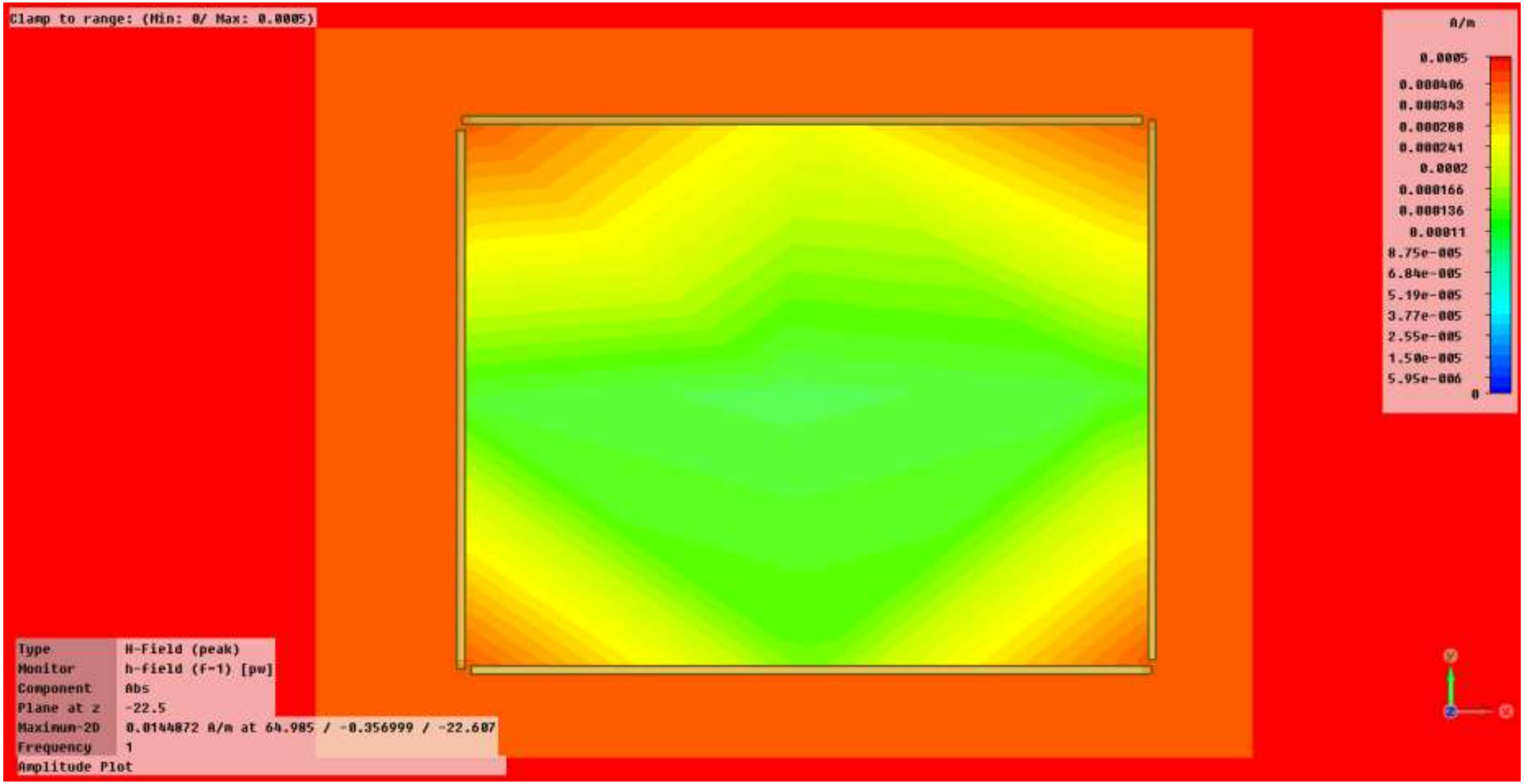
Magnetic Field – 2 MHz

Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=2) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.014576 A/m at 64.6947 / 25.5935 / -22.607
Frequency	2

Amplitude Plot

Magnetic Field – 1 MHz

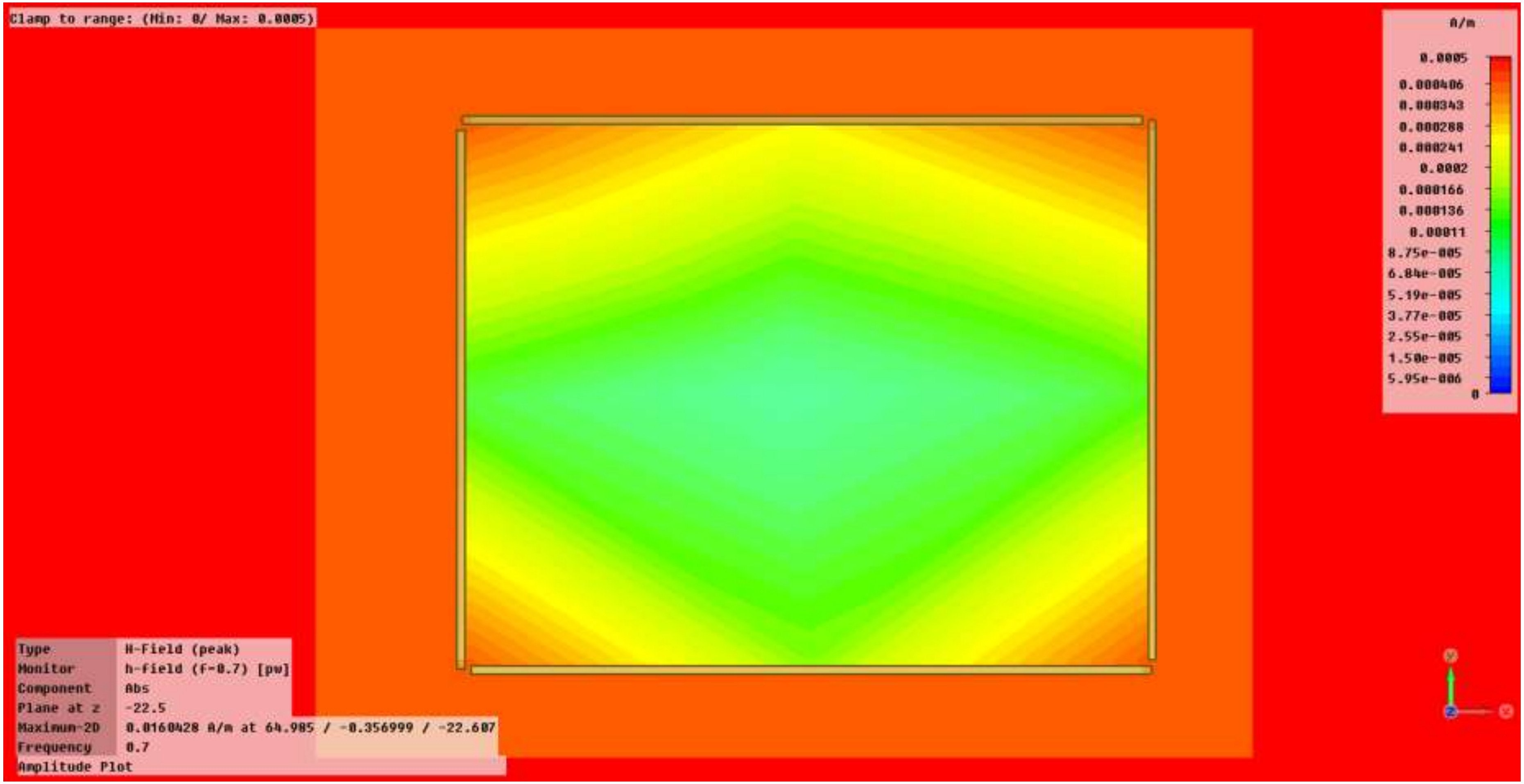


Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=1) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0144872 A/m at 64.985 / -0.356999 / -22.607
Frequency	1

Amplitude Plot

Magnetic Field – 700 kHz

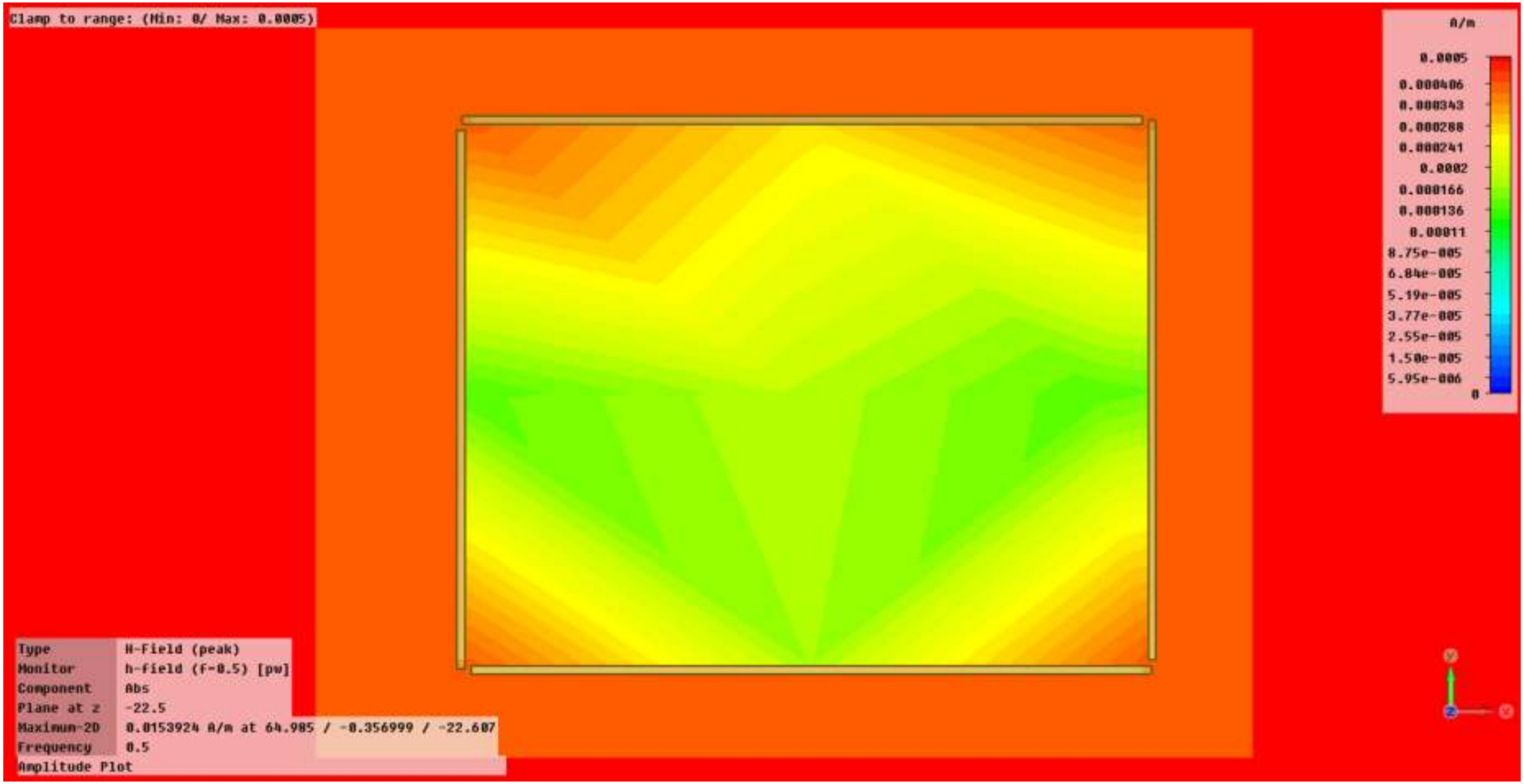


Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=0.7) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0160428 A/m at 64.985 / -0.356999 / -22.607
Frequency	0.7

Amplitude Plot

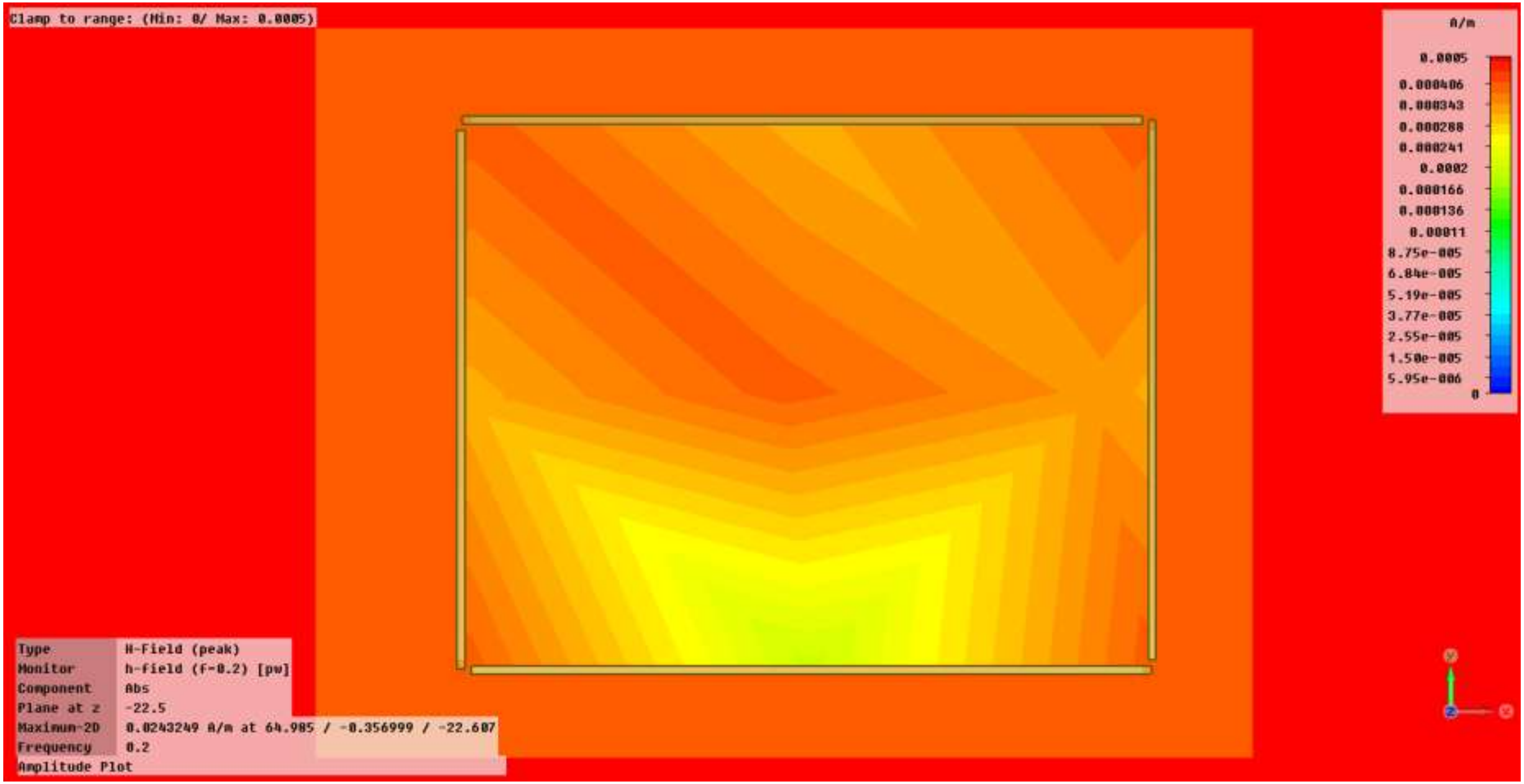
Magnetic Field – 500 kHz


Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=0.5) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0153924 A/m at 64.985 / -0.356999 / -22.607
Frequency	0.5

Amplitude Plot

Magnetic Field – 200 kHz

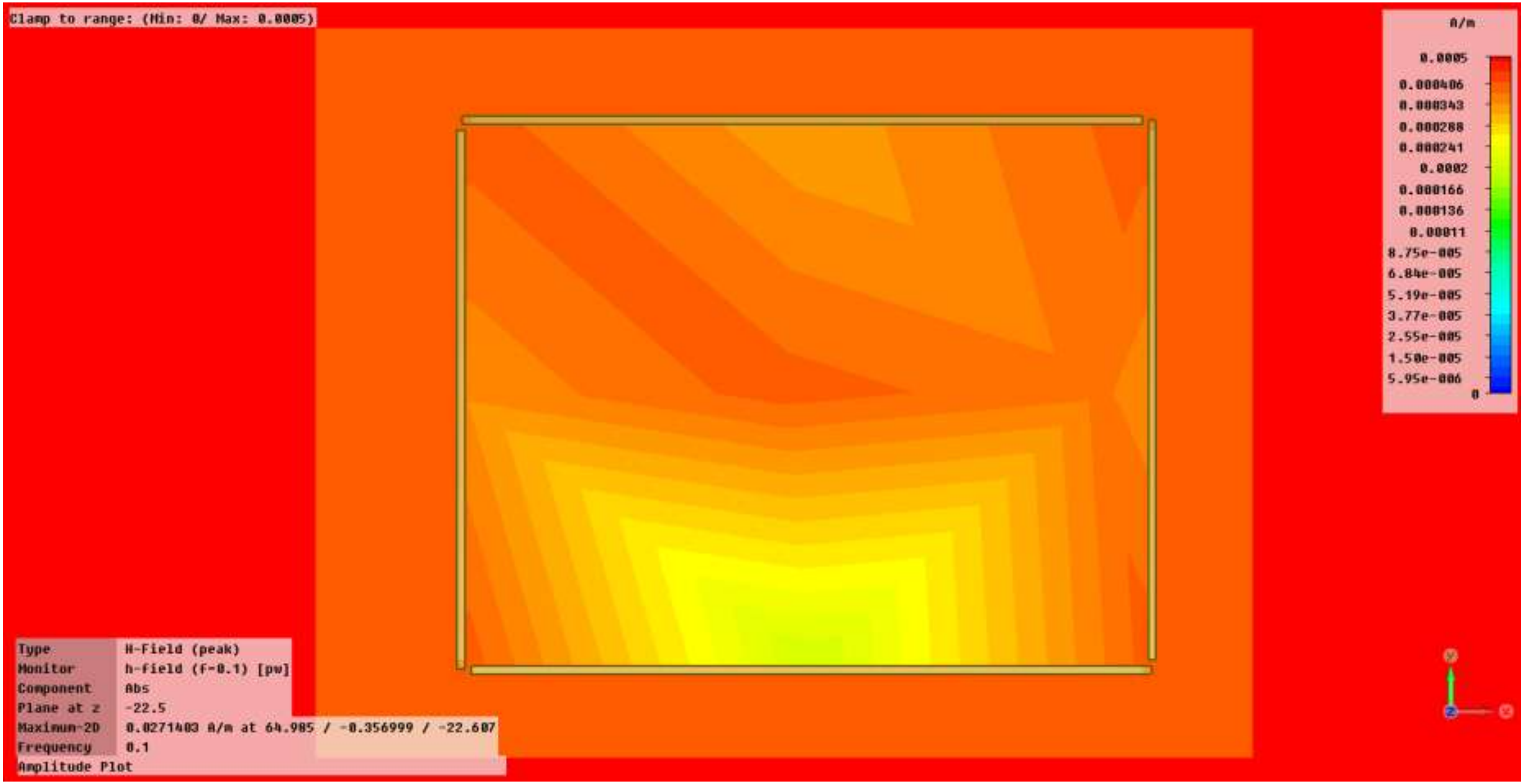


Clamp to range: (Min: 0/ Max: 0.0005)

Type	H-Field (peak)
Monitor	h-field (f=0.2) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0243249 A/m at 64.985 / -0.356999 / -22.607
Frequency	0.2

Amplitude Plot

Magnetic Field – 100 kHz

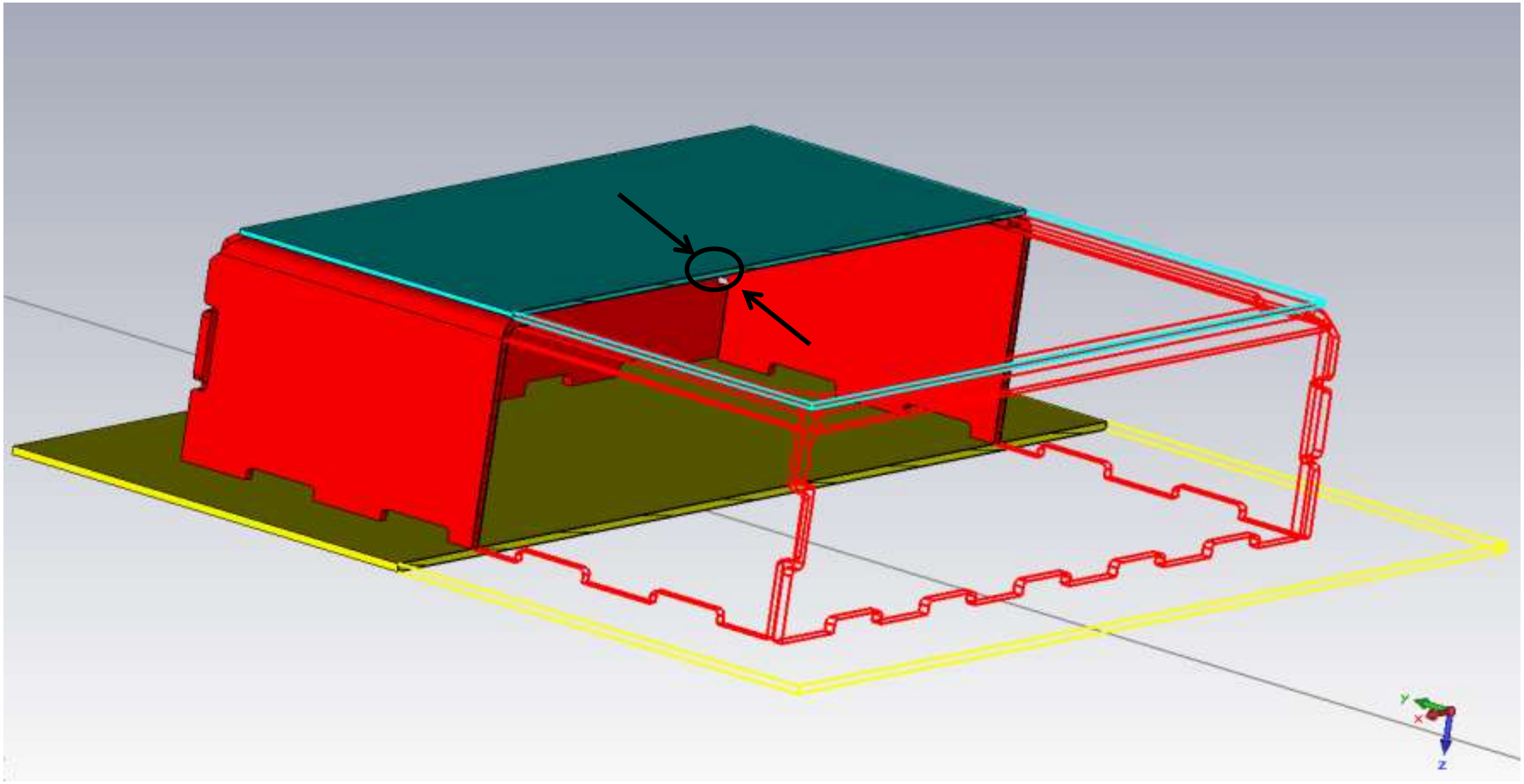


Clamp to range: (Min: 0/ Max: 0.0005)

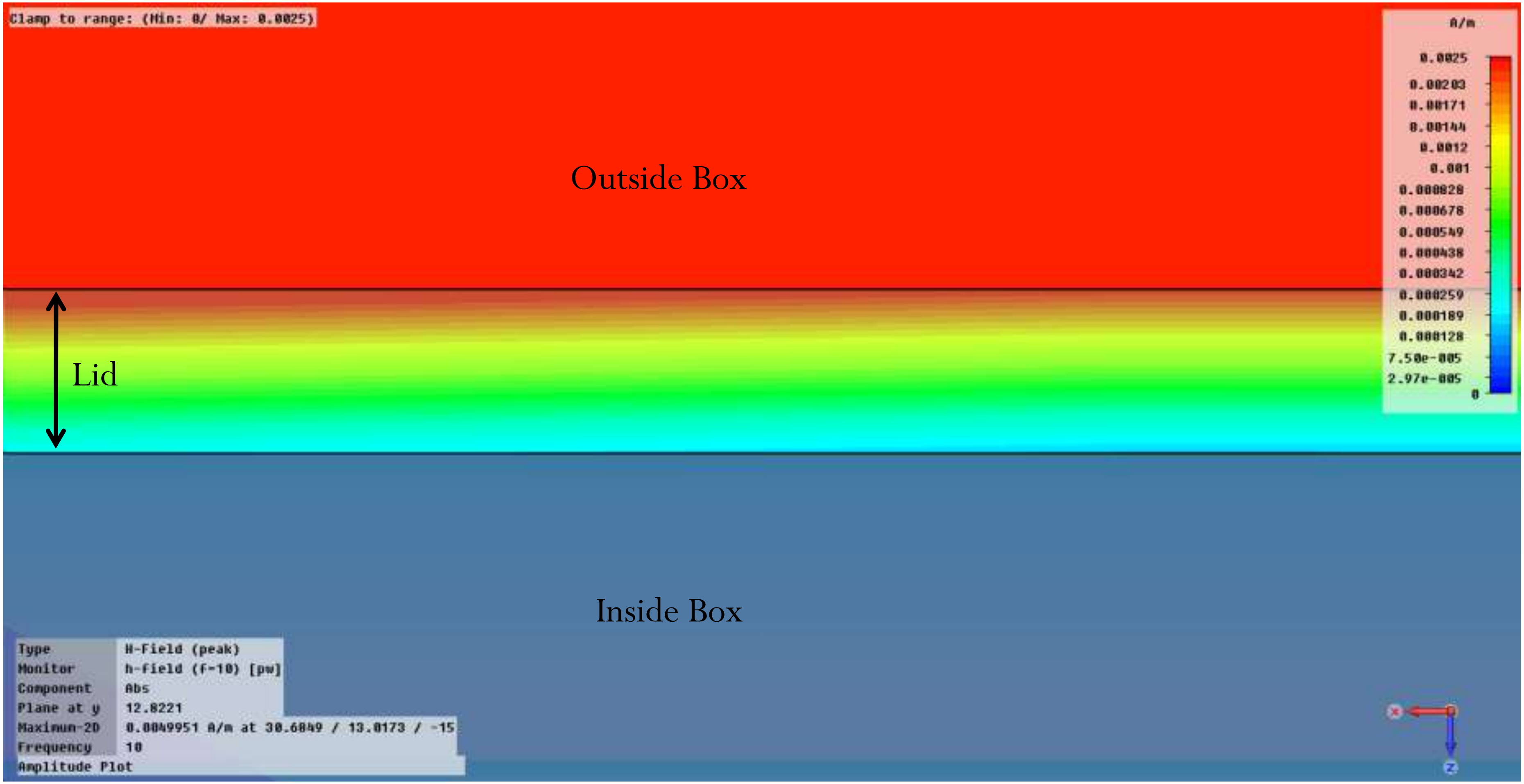
Type	H-Field (peak)
Monitor	h-field (f=0.1) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	0.0271403 A/m at 64.985 / -0.356999 / -22.607
Frequency	0.1

Amplitude Plot

Zoomed on Cross Section of Lid



Magnetic Field– 10 MHz

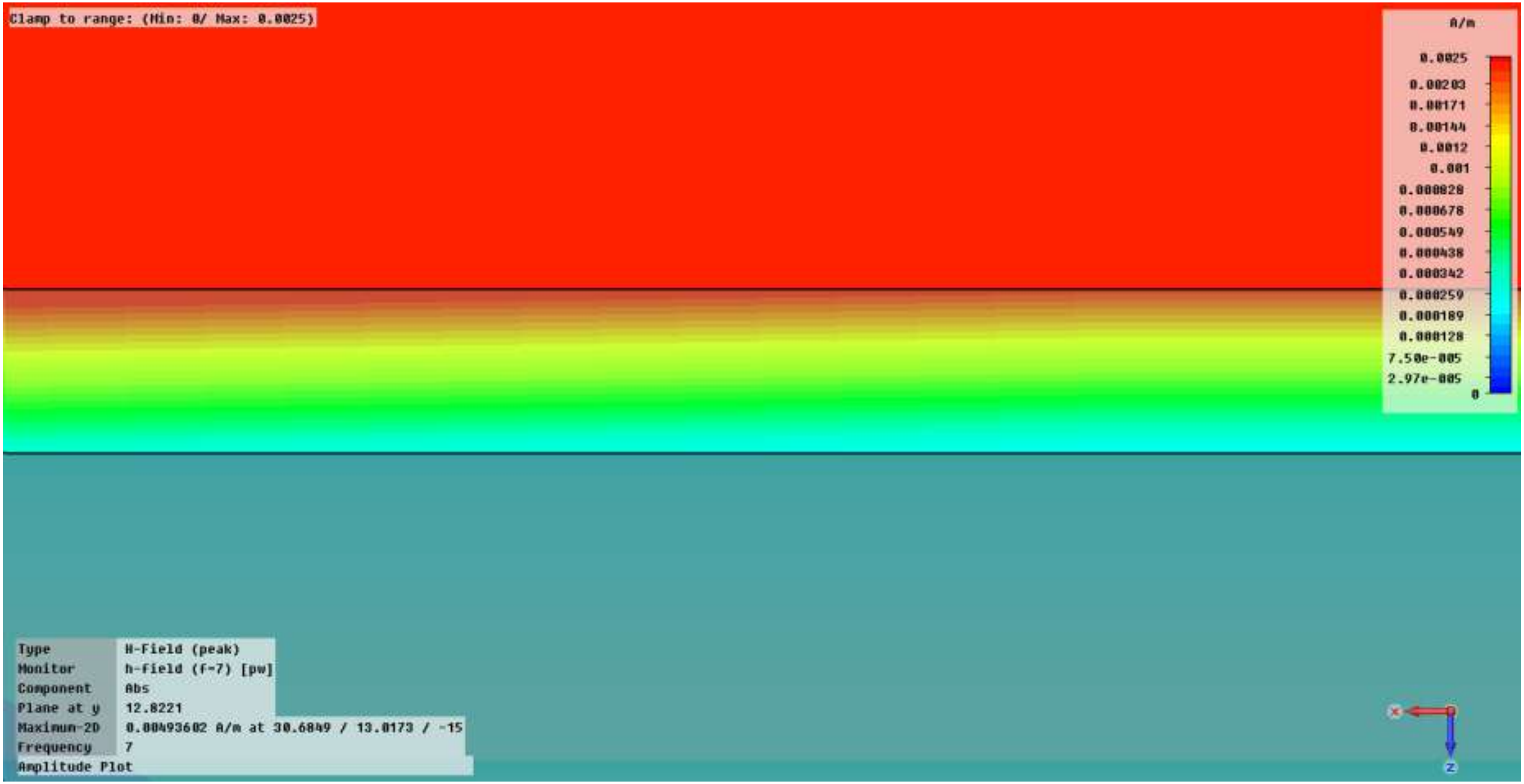


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=10) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.0049951 A/m at 30.6849 / 13.0173 / -15
Frequency	10

Amplitude Plot

Magnetic Field– 7 MHz

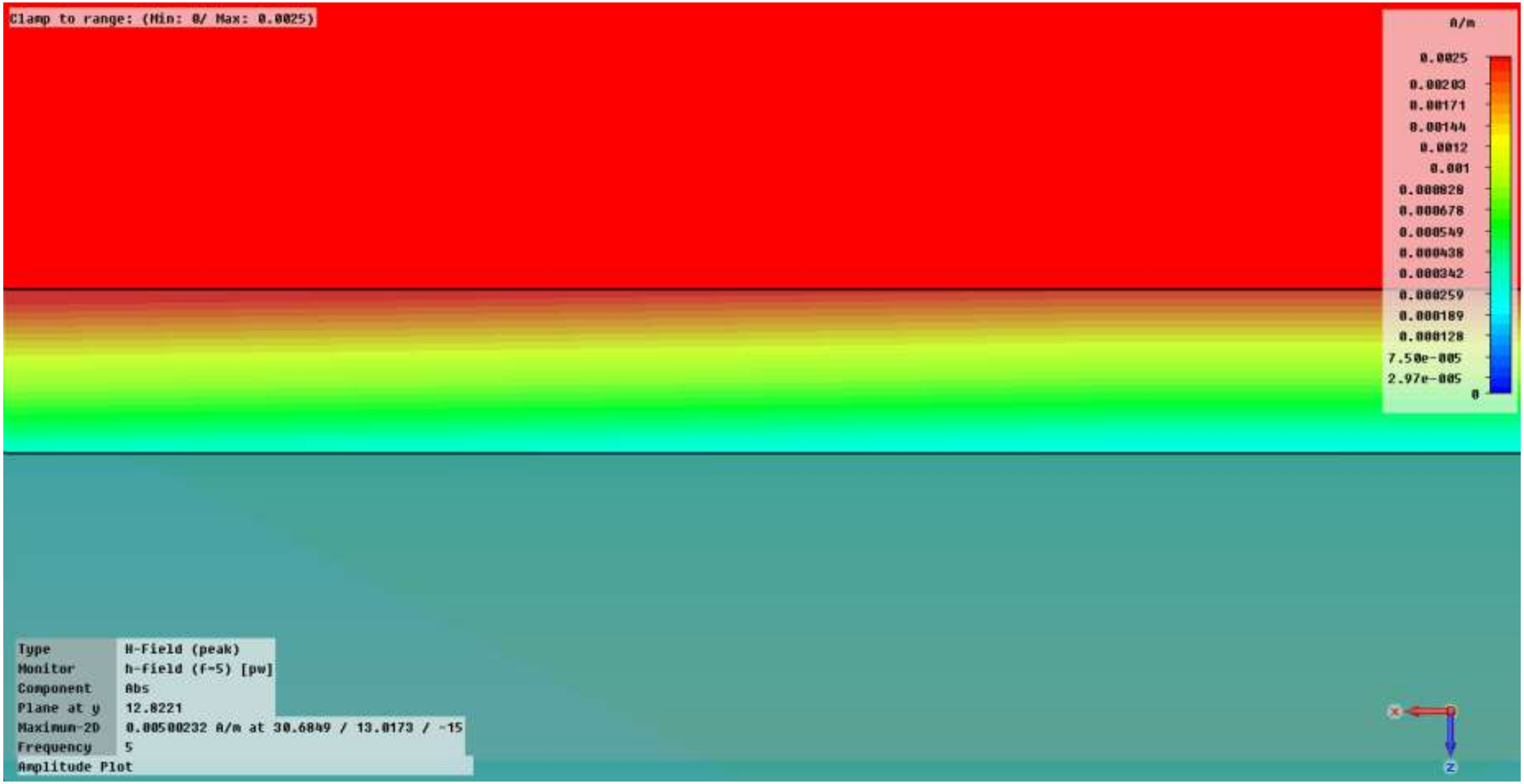


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-Field (f=7) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00493602 A/m at 30.6849 / 13.0173 / -15
Frequency	7

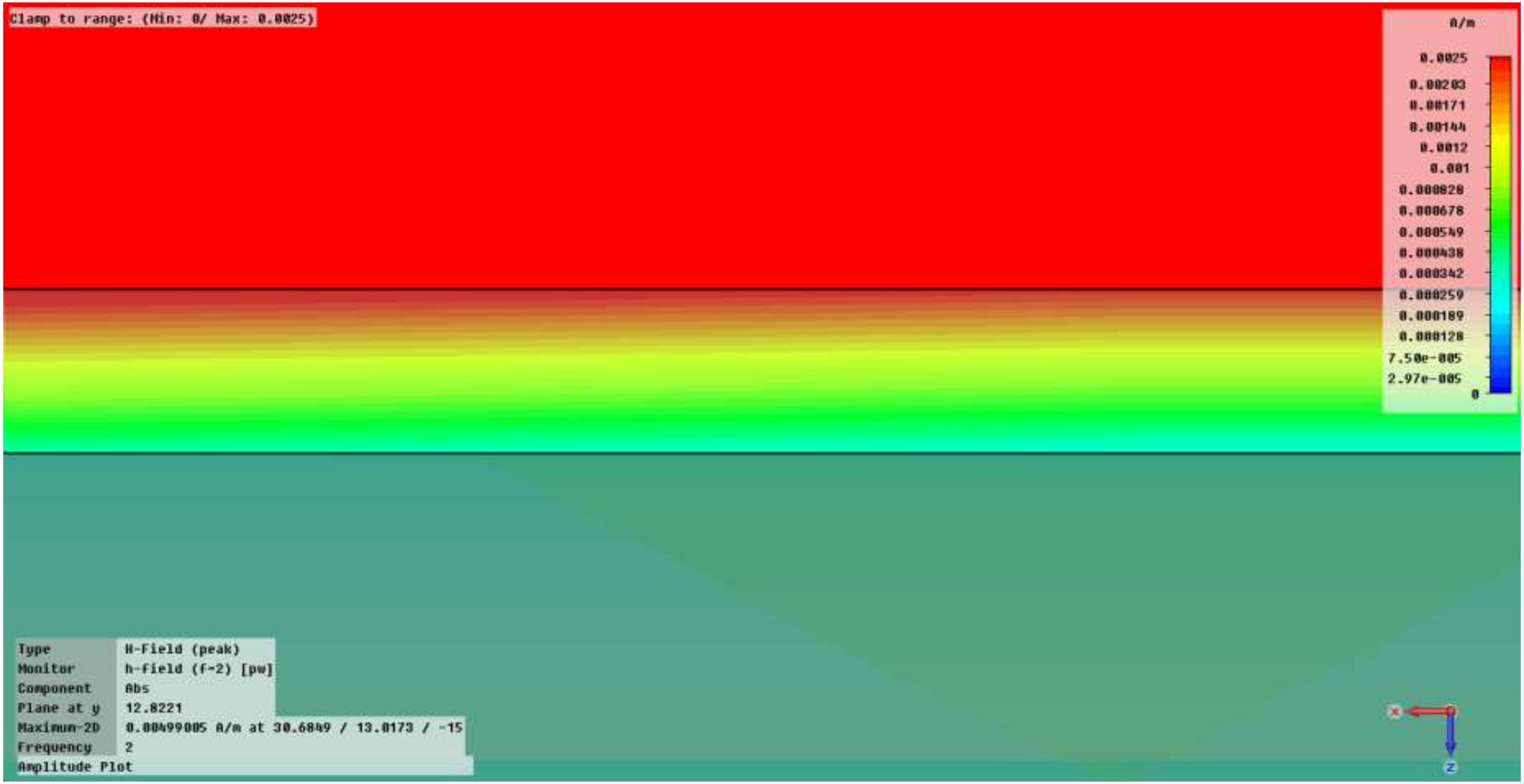
Amplitude Plot

Magnetic Field– 5 MHz


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=5) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00500232 A/m at 30.6849 / 13.0173 / -15
Frequency	5
Amplitude Plot	

Magnetic Field– 2 MHz

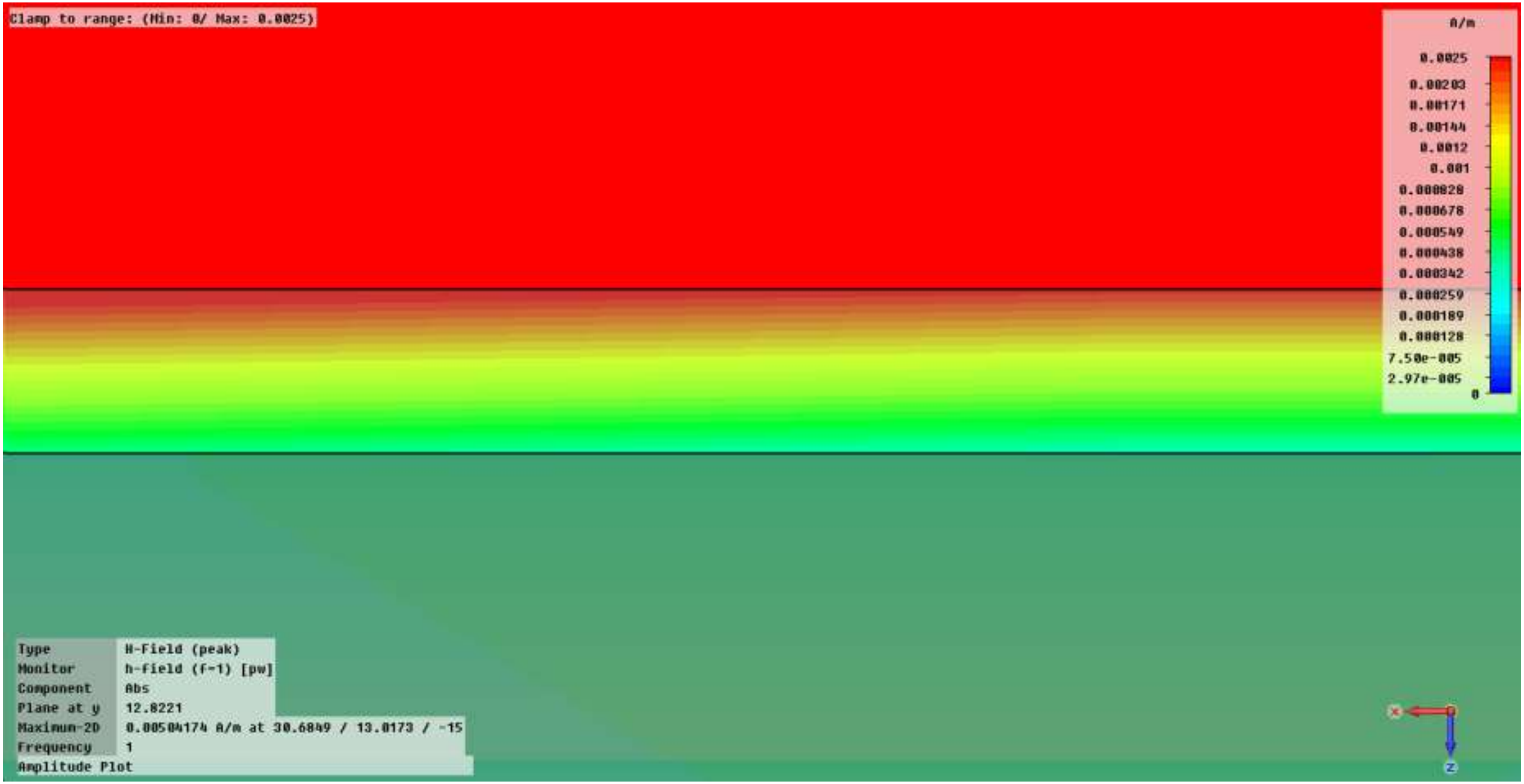


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=2) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00499005 A/m at 30.6849 / 13.0173 / -15
Frequency	2

Amplitude Plot

Magnetic Field– 1 MHz

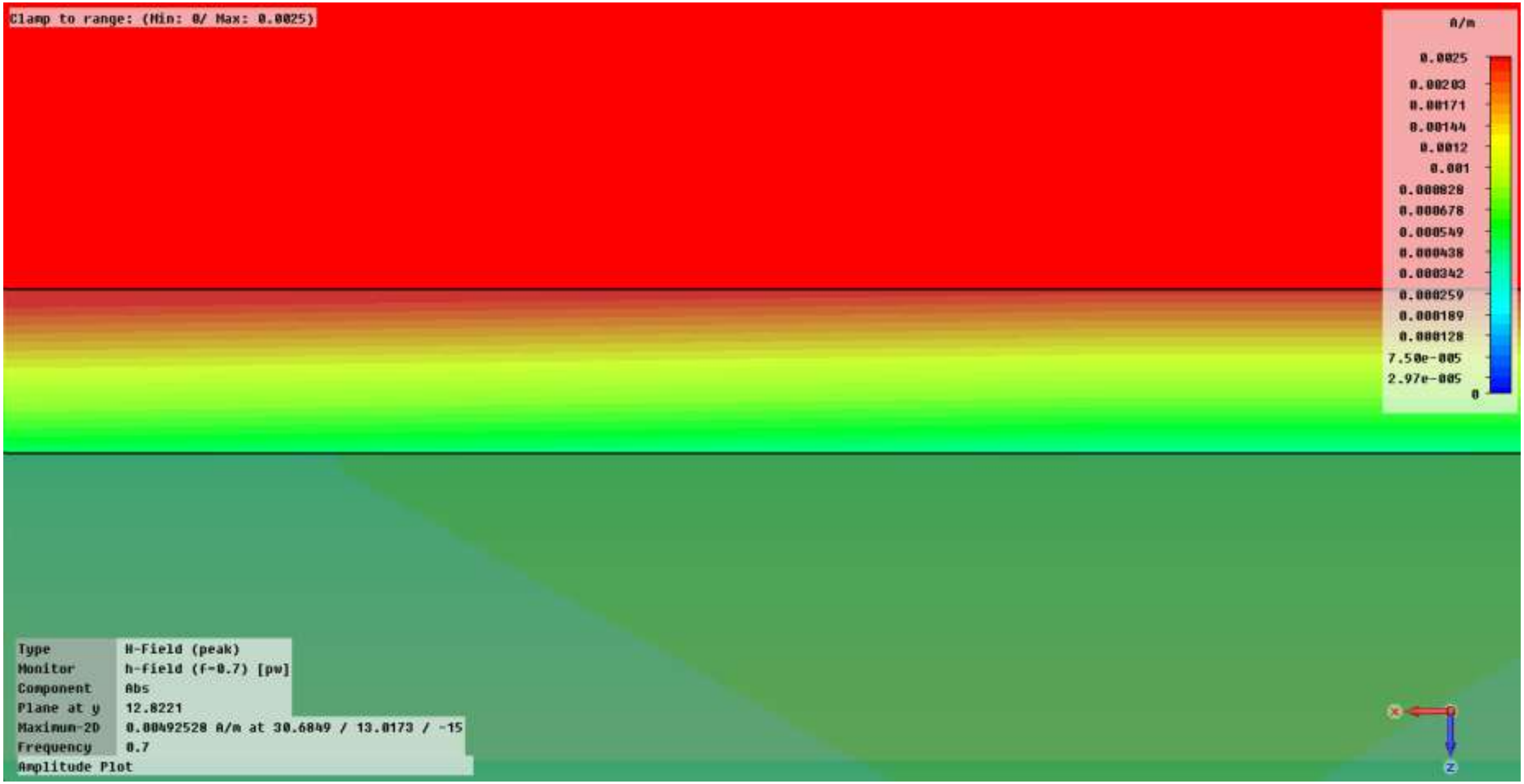


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=1) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00504174 A/m at 30.6849 / 13.0173 / -15
Frequency	1

Amplitude Plot

Magnetic Field– 700 kHz

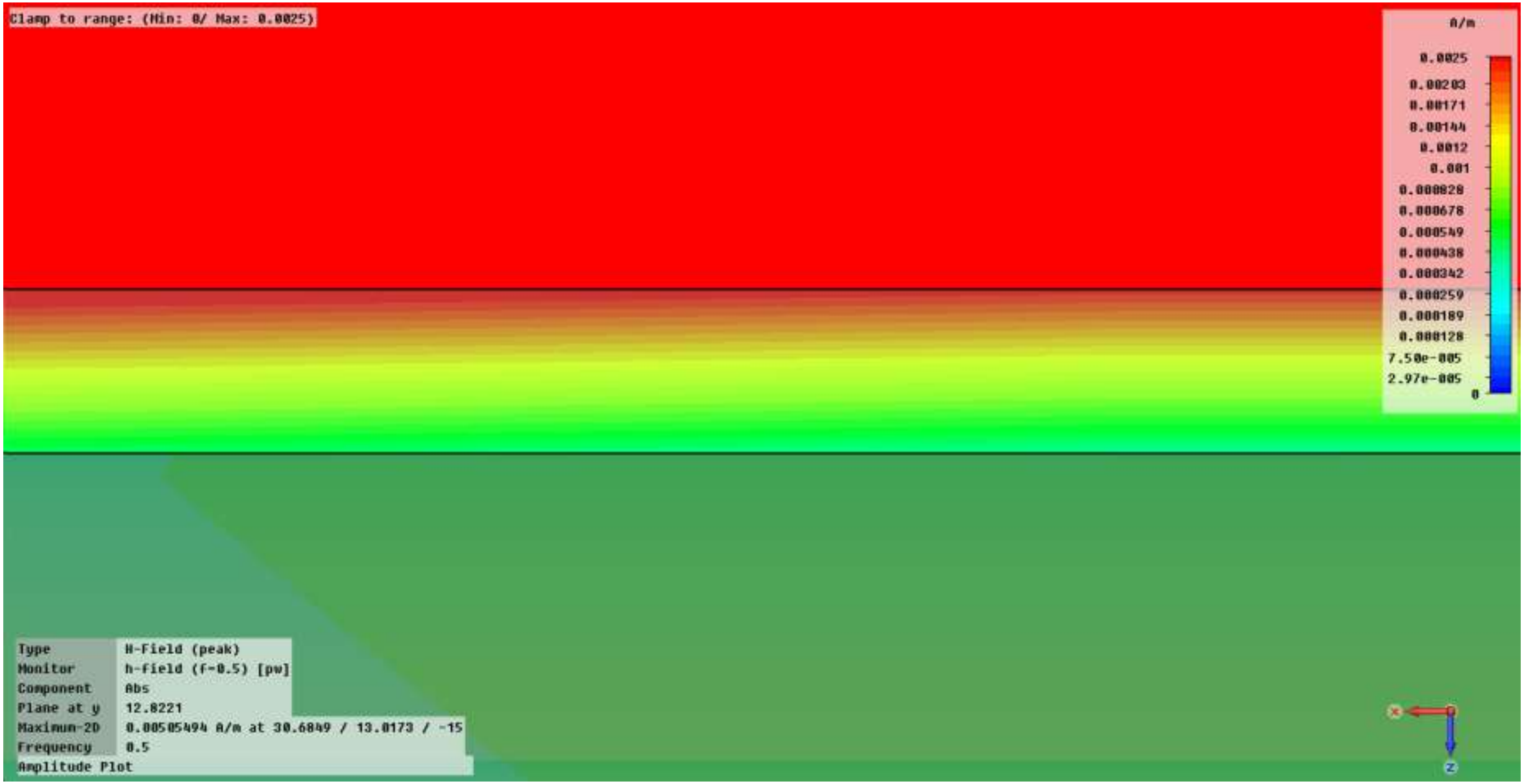


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=0.7) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00492528 A/m at 30.6849 / 13.0173 / -15
Frequency	0.7

Amplitude Plot

Magnetic Field– 500 kHz

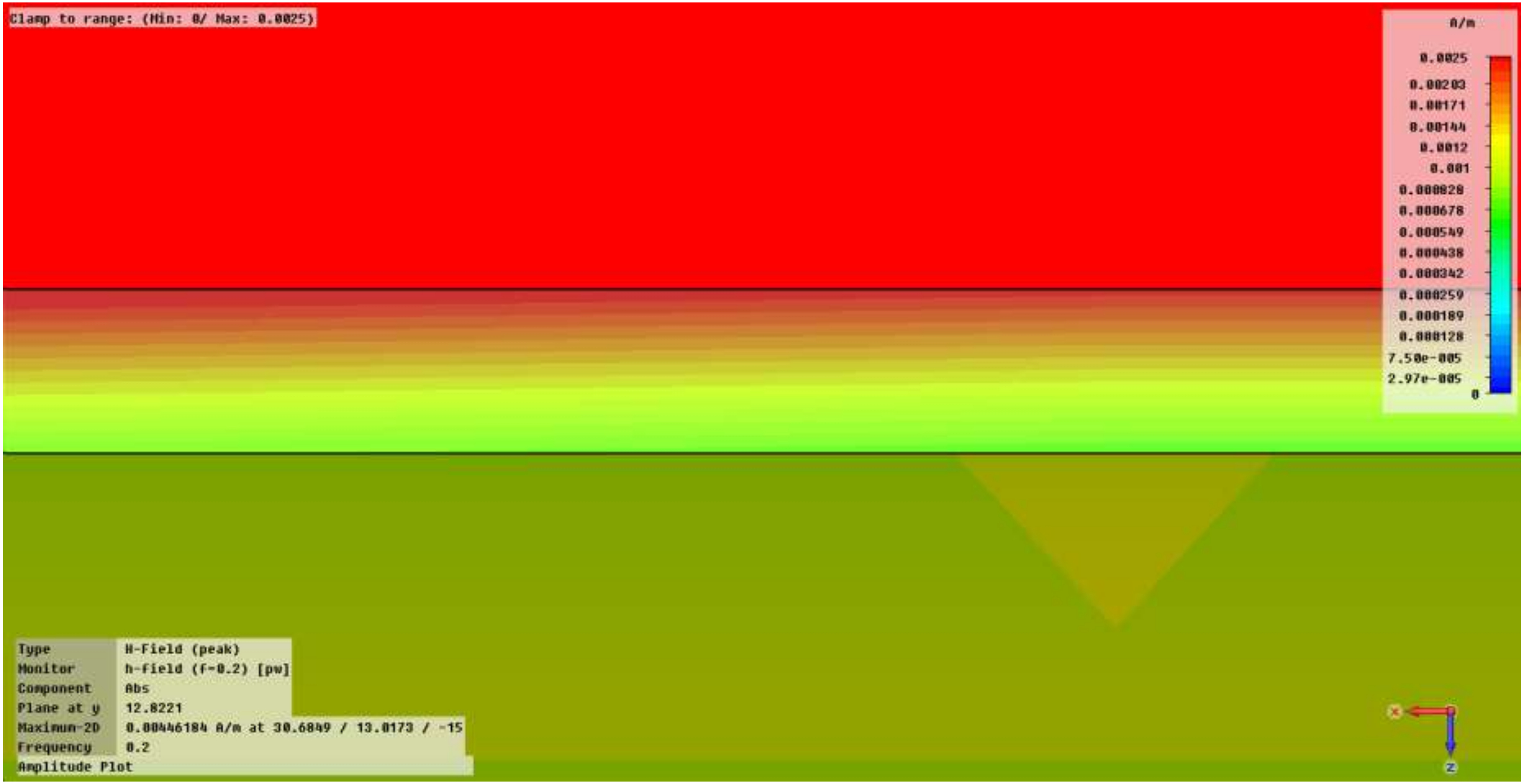


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=0.5) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00505494 A/m at 30.6849 / 13.0173 / -15
Frequency	0.5

Amplitude Plot

Magnetic Field– 200 kHz

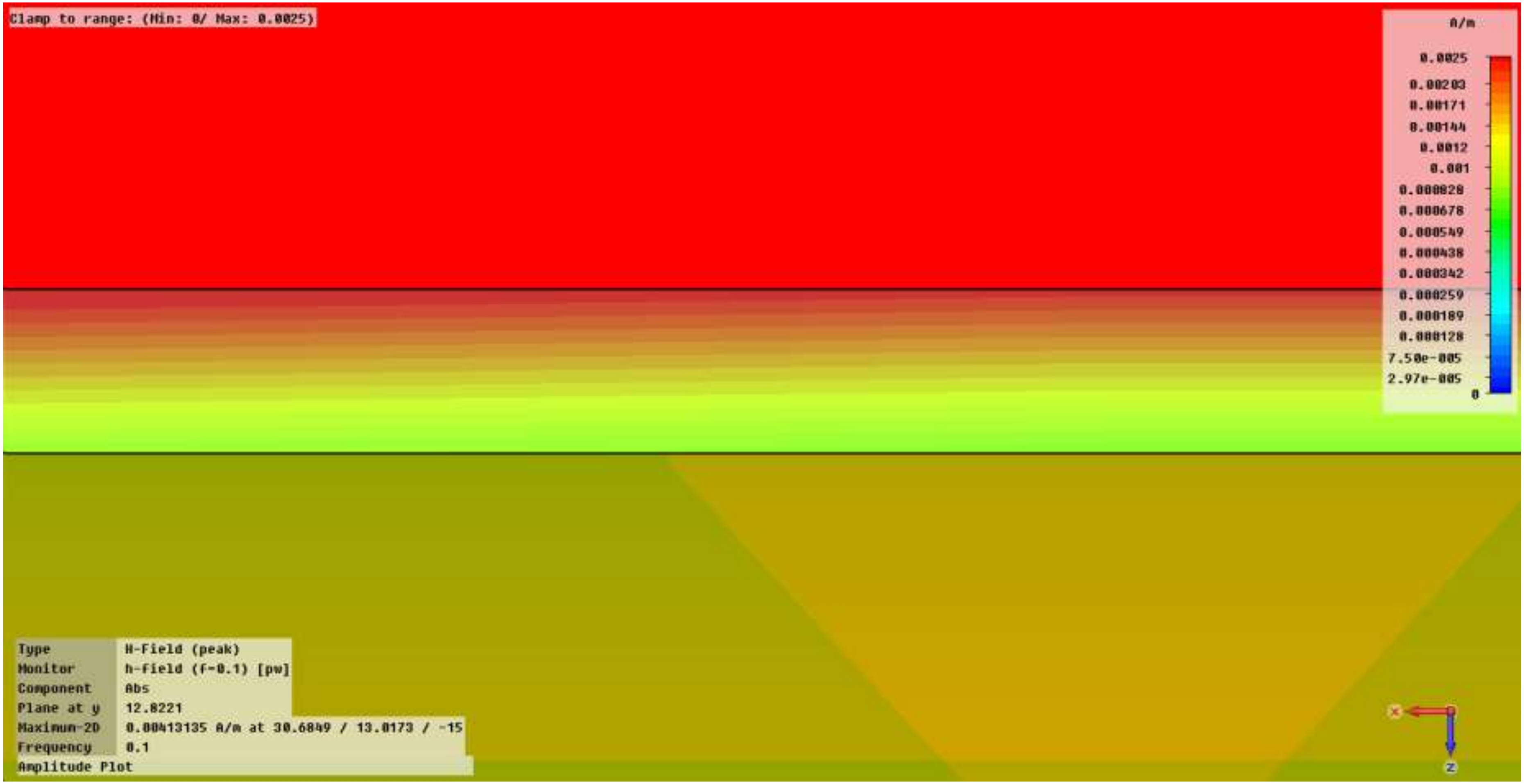


Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-field (f=0.2) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00446184 A/m at 30.6849 / 13.0173 / -15
Frequency	0.2

Amplitude Plot

Magnetic Field– 100 kHz



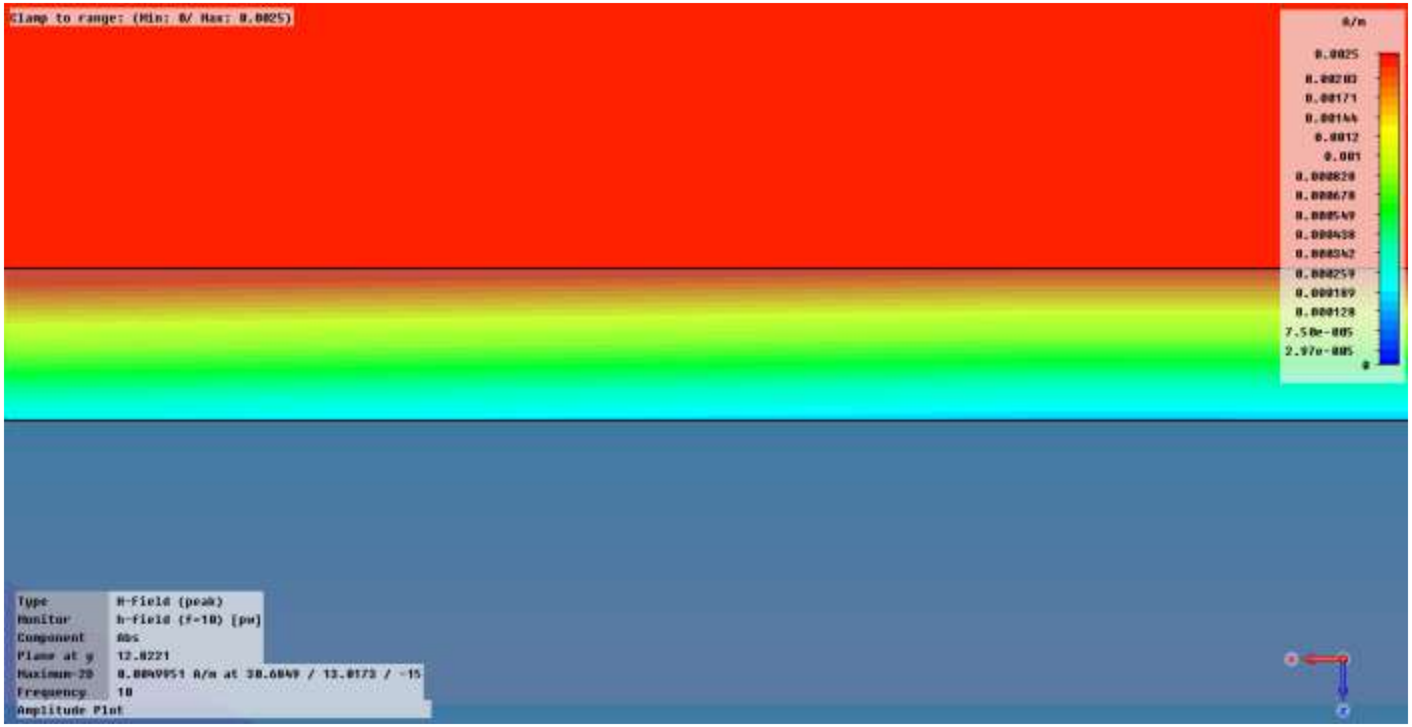
Clamp to range: (Min: 0/ Max: 0.0025)

Type	H-Field (peak)
Monitor	h-Field (f=0.1) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	0.00413135 A/m at 30.6849 / 13.0173 / -15
Frequency	0.1

Amplitude Plot

Magnetic Field Shielding

- Magnetic field attenuates as it passes through a metallic medium – this is called **Absorption Loss**
- Absorption loss is greater as the frequency of the magnetic field increases



Type H-Field (peak)
Monitor h-field (f=10) [pw]
Component Abs
Plane at y 12.8221
Maximum-2D 0.0049951 A/m at 30.6849 / 13.0173 / -15
Frequency 10
Amplitude Plot

Absorption Loss

- The rate of absorption loss depends largely on the shielding material used
- **Skin depth** is the dimension at which the current falls to 1/e of the current found on the surface (was once measured in Nepers) – (this is about 1/3 or 9 dB)
- Skin depth depends on **frequency** (f), **permeability** (μ), and **conductivity** of the material (σ)

Skin Depth in inches (source: Henry Ott *Electromagnetic Compatibility Engineering*)

$$\delta = \frac{2.6}{\sqrt{f\mu_r\sigma_r}}$$

Skin Depth of Various Materials

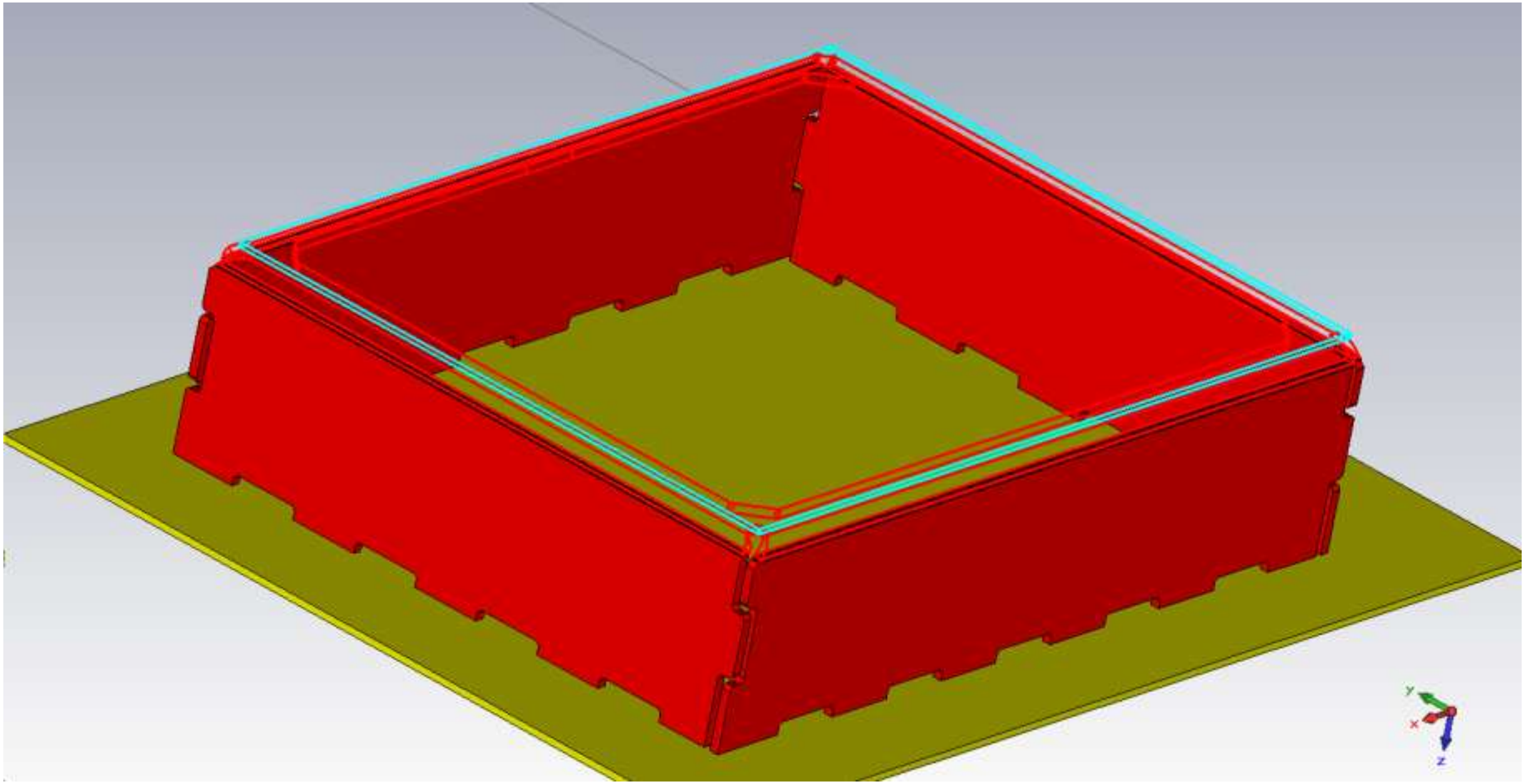
Skin Depth in inches
(source: Henry Ott
*Electromagnetic
Compatibility Engineering*)

$$\delta = \frac{2.6}{\sqrt{f\mu_r\sigma_r}}$$

Material	**μ_r**	**σ_r**	**δ (mils) 100 kHz**	**δ (mils) 10 MHz**
Steel	1000	0.1	0.8	0.1
Copper	1	1	8	0.8
Phosphor Bronze	1	0.15	21	2.1
Nickel Silver	1	0.06	33	3

Low Frequency Electric Field Shielding

Fields Observed under Box Lid

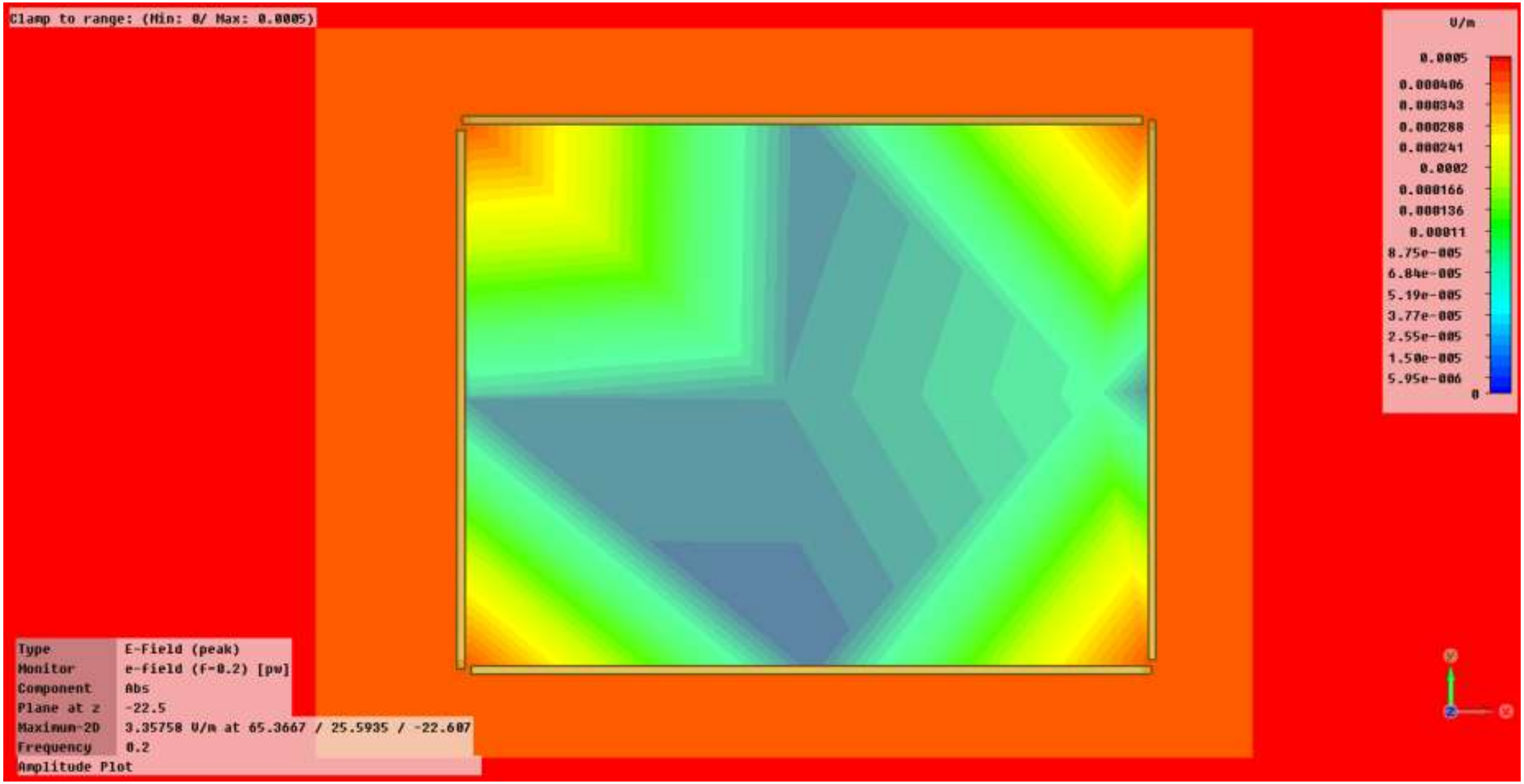


Electric Field – 100 kHz

Type	E-Field (peak)
Monitor	e-field (f=0.1) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.33923 V/m at 65.3667 / 25.5935 / -22.607
Frequency	0.1

Amplitude Plot

Electric Field – 200 kHz



Clamp to range: (Min: 0/ Max: 0.0005)

Type	E-Field (peak)
Monitor	e-field (f=0.2) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.35758 V/m at 65.3667 / 25.5935 / -22.607
Frequency	0.2

Amplitude Plot

Electric Field – 500 kHz

Type	E-Field (peak)
Monitor	e-field (f=0.5) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.37636 V/m at 65.3667 / 25.5935 / -22.607
Frequency	0.5

Amplitude Plot

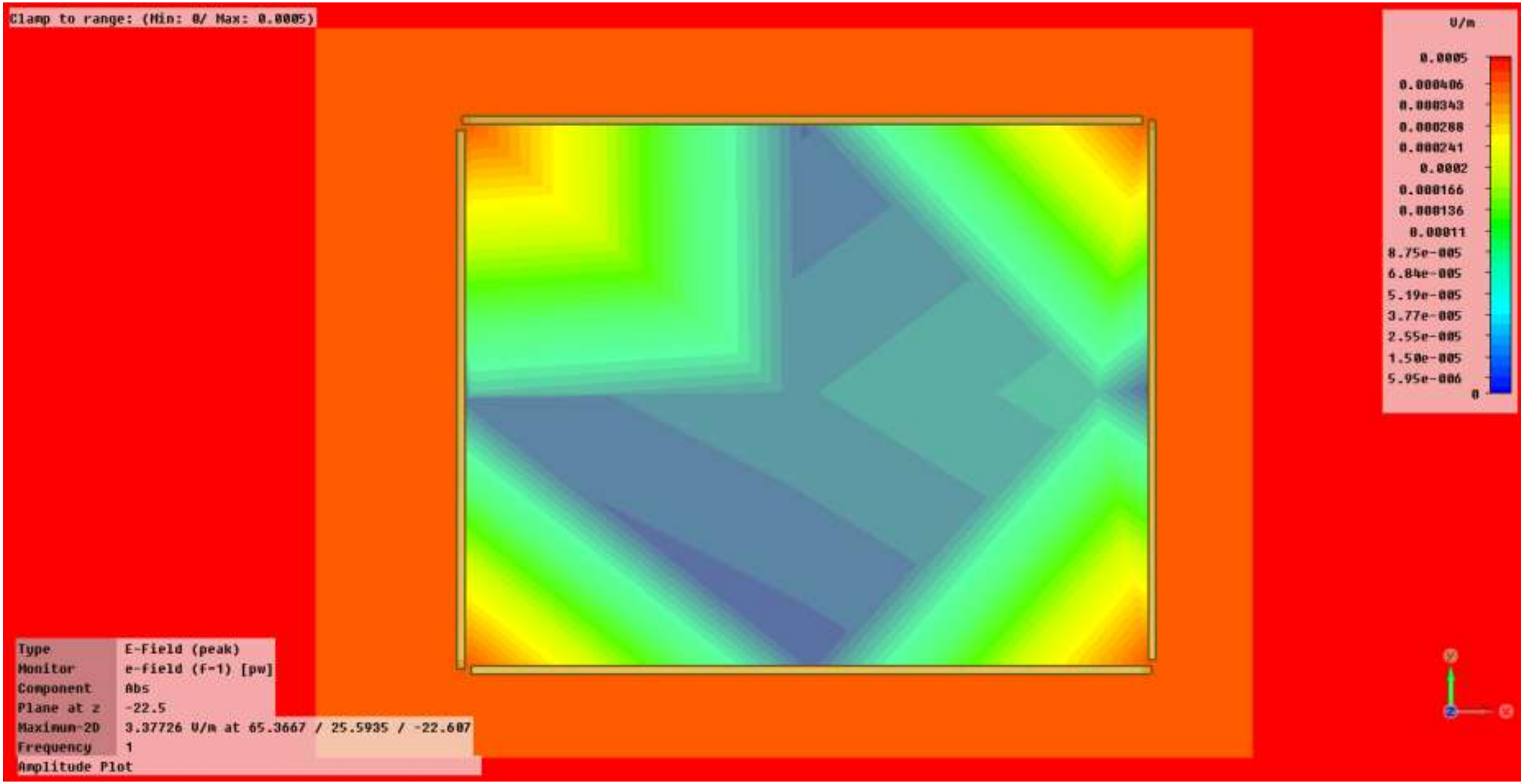
Electric Field – 700 kHz

Clamp to range: (Min: 0/ Max: 0.0005)

Type	E-Field (peak)
Monitor	e-field (f=0.7) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.35908 V/m at 65.3667 / 25.5935 / -22.607
Frequency	0.7

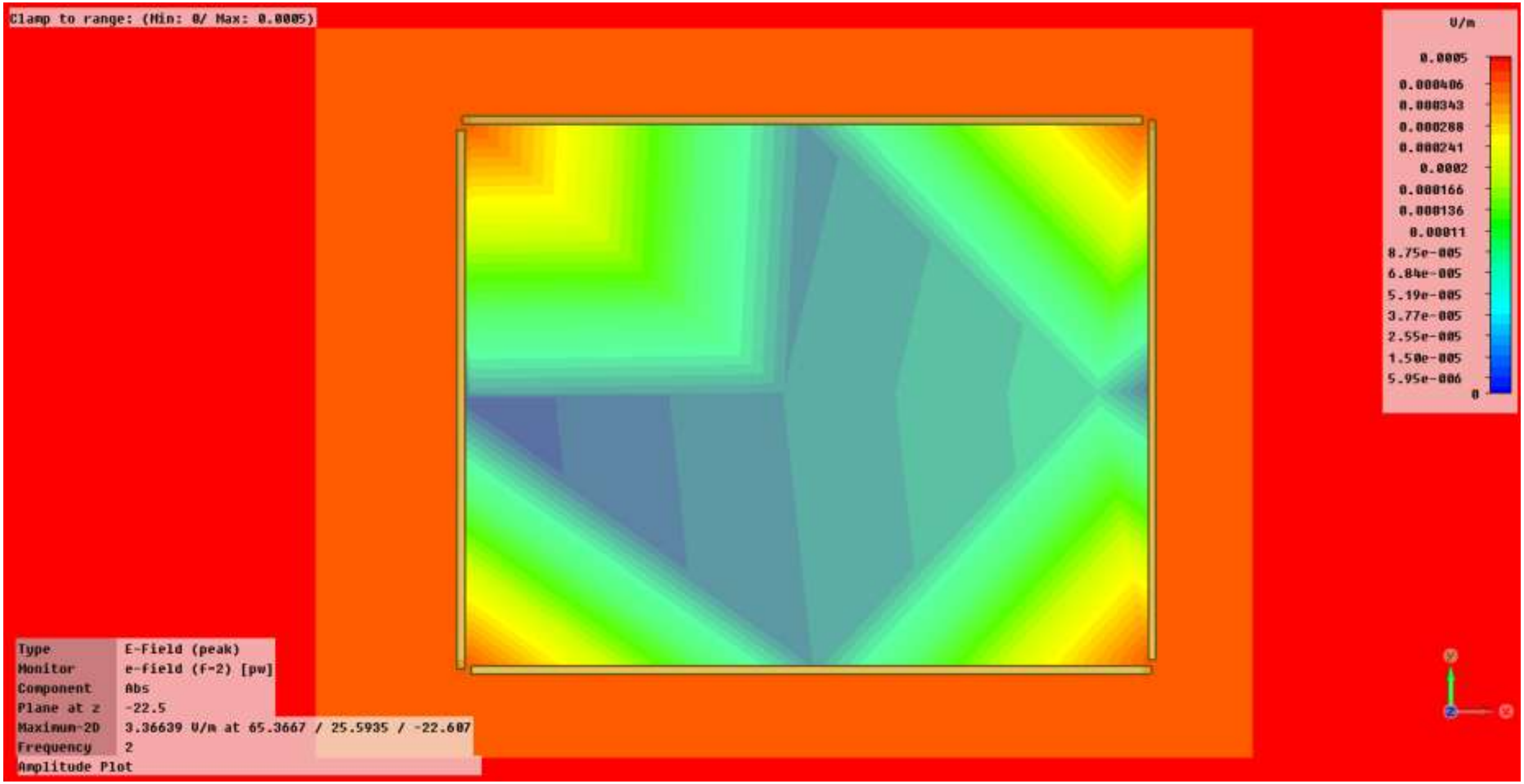
Amplitude Plot

Electric Field – 1 MHz



Type	E-Field (peak)
Monitor	e-field (f=1) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.37726 V/m at 65.3667 / 25.5935 / -22.607
Frequency	1
Amplitude Plot	

Electric Field – 2 MHz



Clamp to range: (Min: 0/ Max: 0.0005)

Type	E-Field (peak)
Monitor	e-field (f=2) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.36639 V/m at 65.3667 / 25.5935 / -22.607
Frequency	2

Amplitude Plot

Electric Field – 5 MHz

Clamp to range: (Min: 0/ Max: 0.0005)

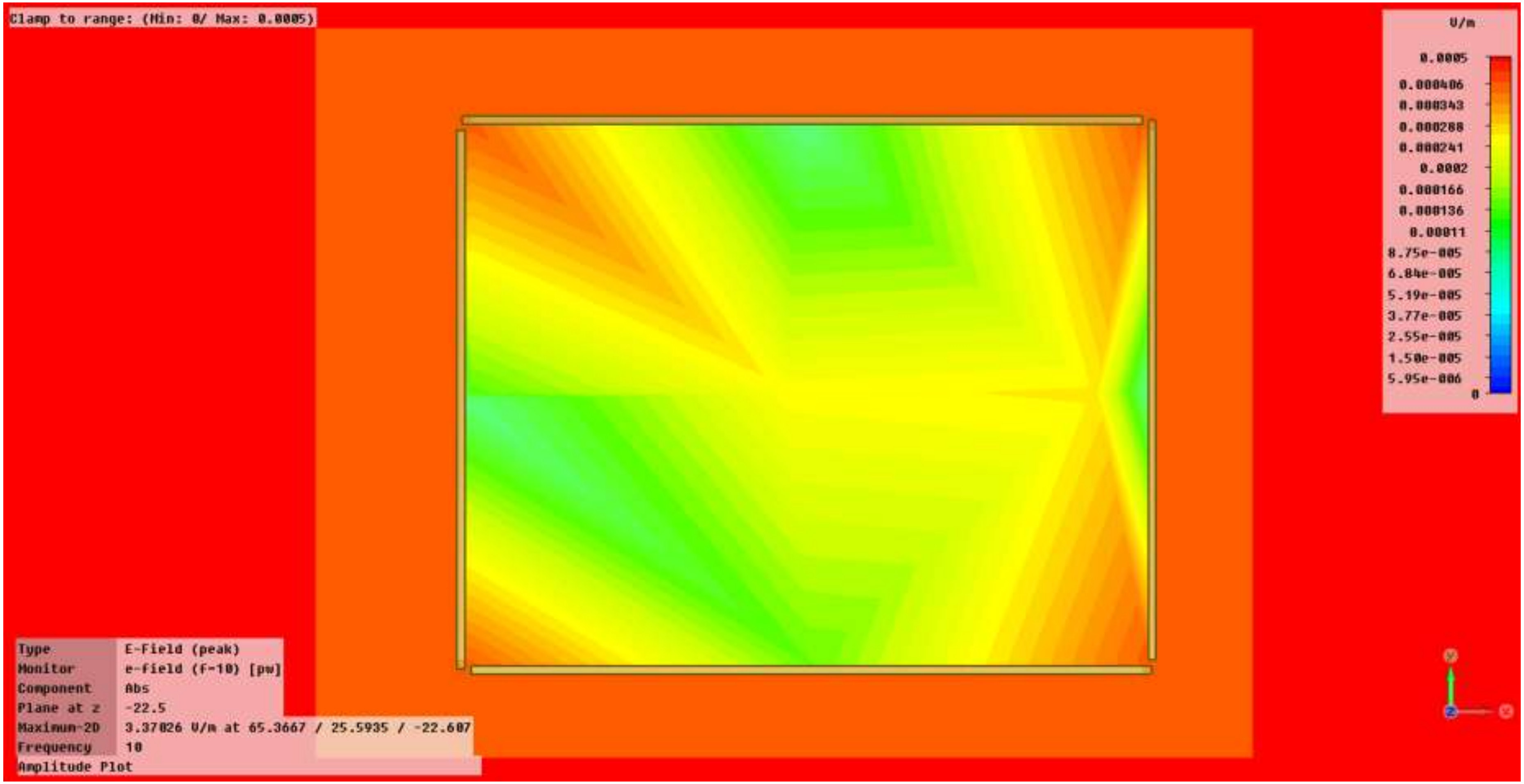
Type	E-Field (peak)
Monitor	e-field (f=5) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.37441 V/m at 65.3667 / 25.5935 / -22.607
Frequency	5
Amplitude Plot	

Electric Field – 7 MHz

Clamp to range: (Min: 0/ Max: 0.0005)

```
Type          E-Field (peak)
Monitor       e-field (f=7) [pw]
Component     Abs
Plane at z    -22.5
Maximum-2D    3.3674 V/m at 65.3667 / 25.5935 / -22.607
Frequency     7
Amplitude Plot
```

Electric Field – 10 MHz

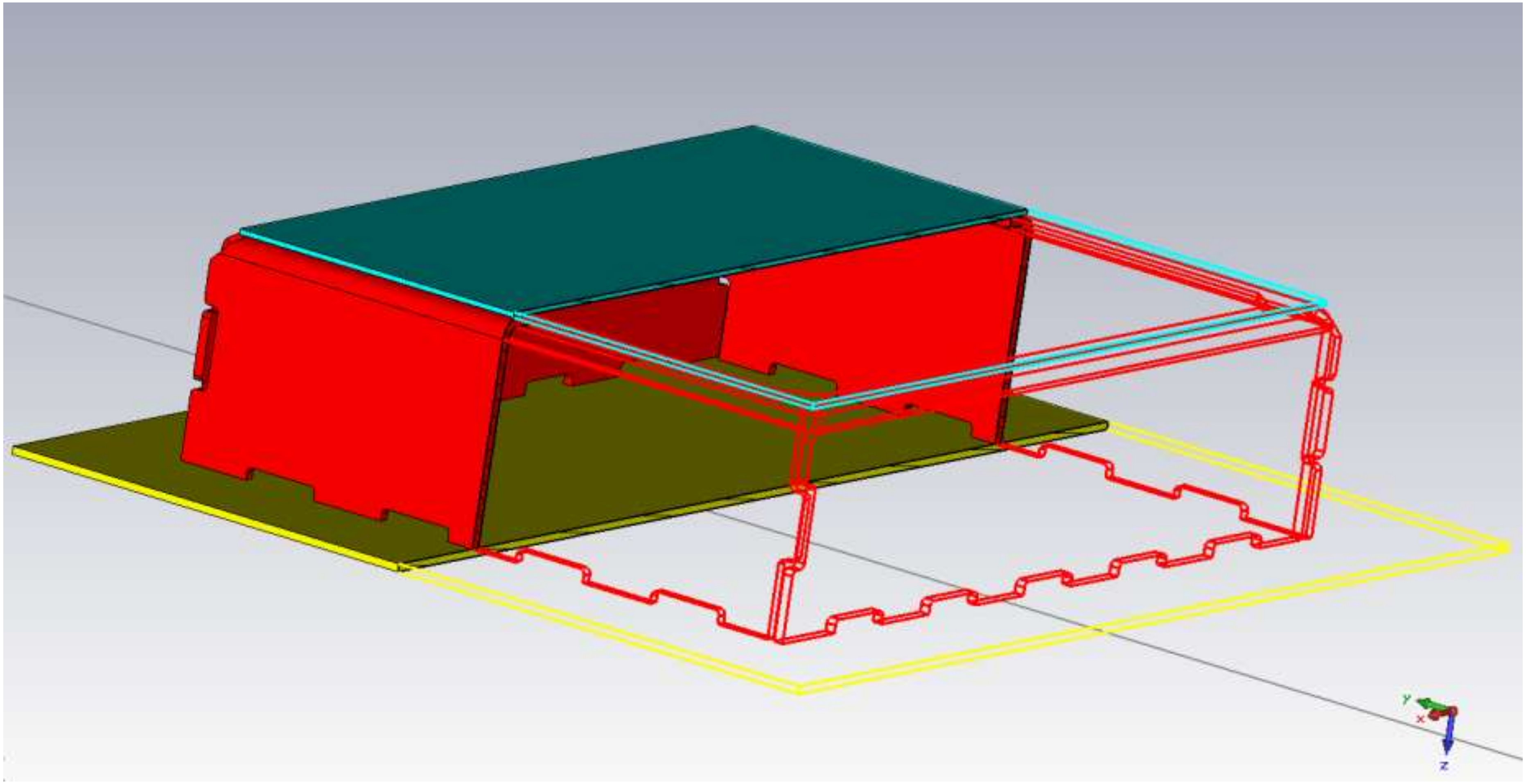


Clamp to range: (Min: 0/ Max: 0.0005)

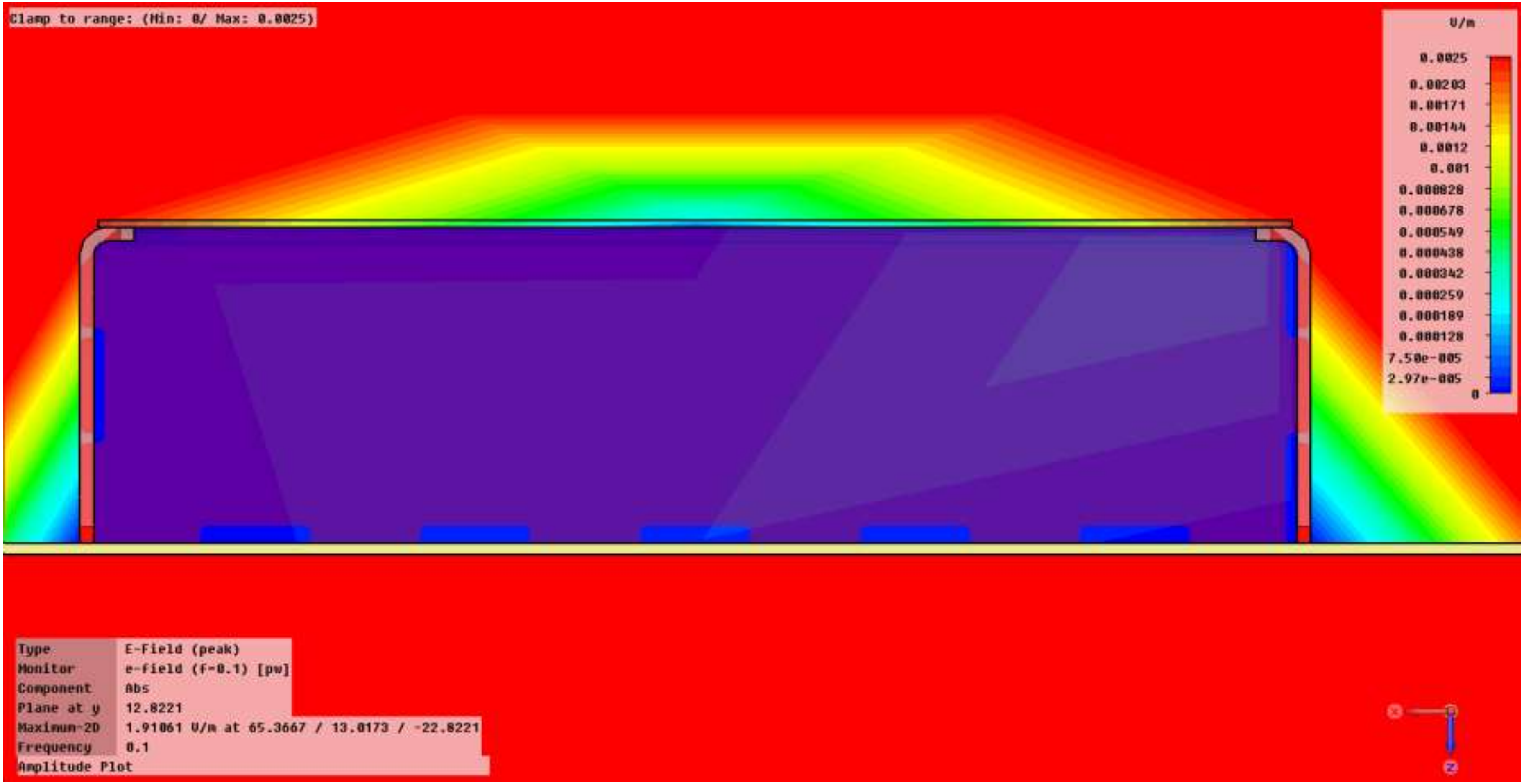
Type	E-Field (peak)
Monitor	e-field (f=10) [pw]
Component	Abs
Plane at z	-22.5
Maximum-2D	3.37026 V/m at 65.3667 / 25.5935 / -22.607
Frequency	10

Amplitude Plot

Fields Viewed from Cross Section through Box



Electric Field – 100 kHz

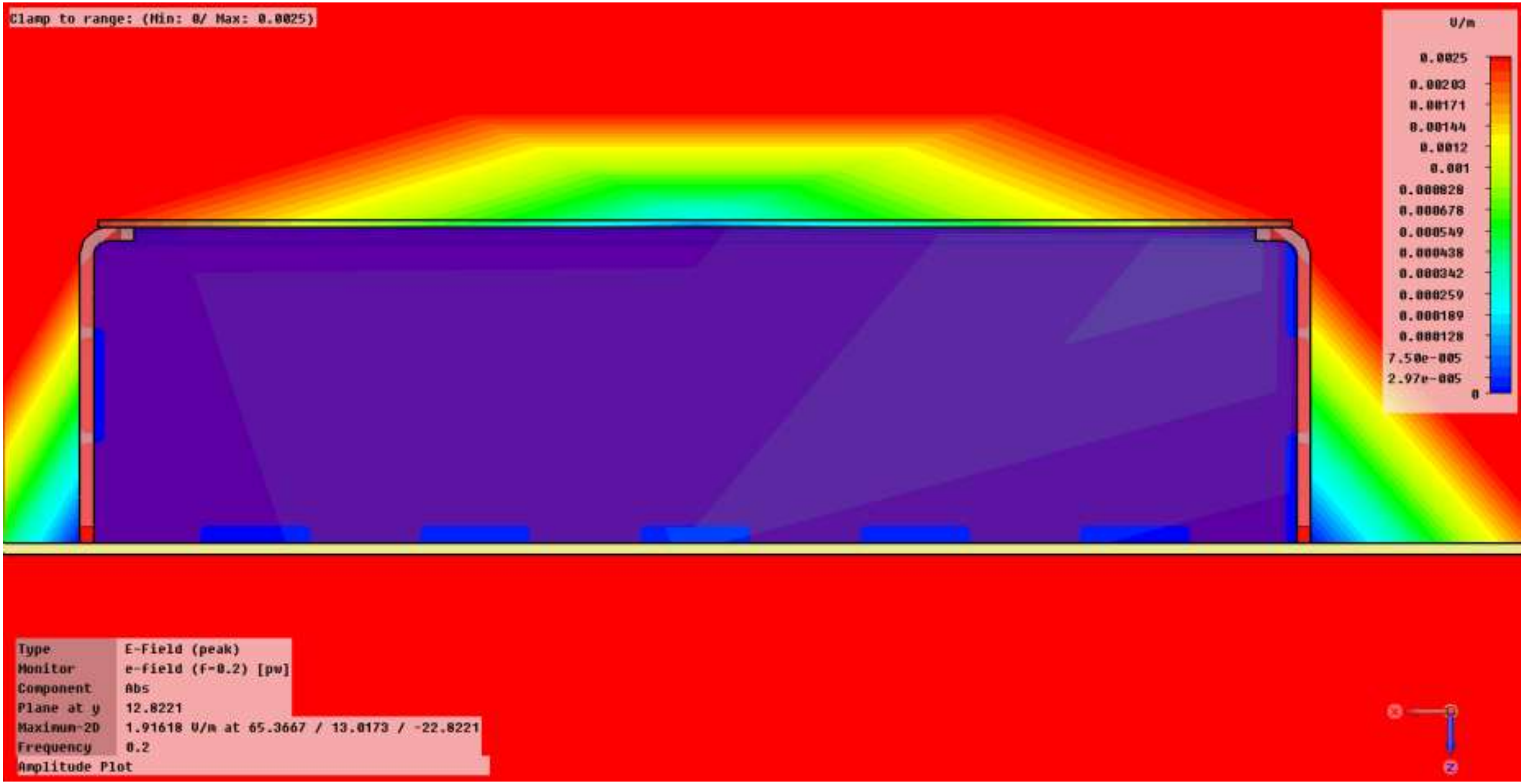


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=0.1) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91061 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	0.1

Amplitude Plot

Electric Field – 200 kHz

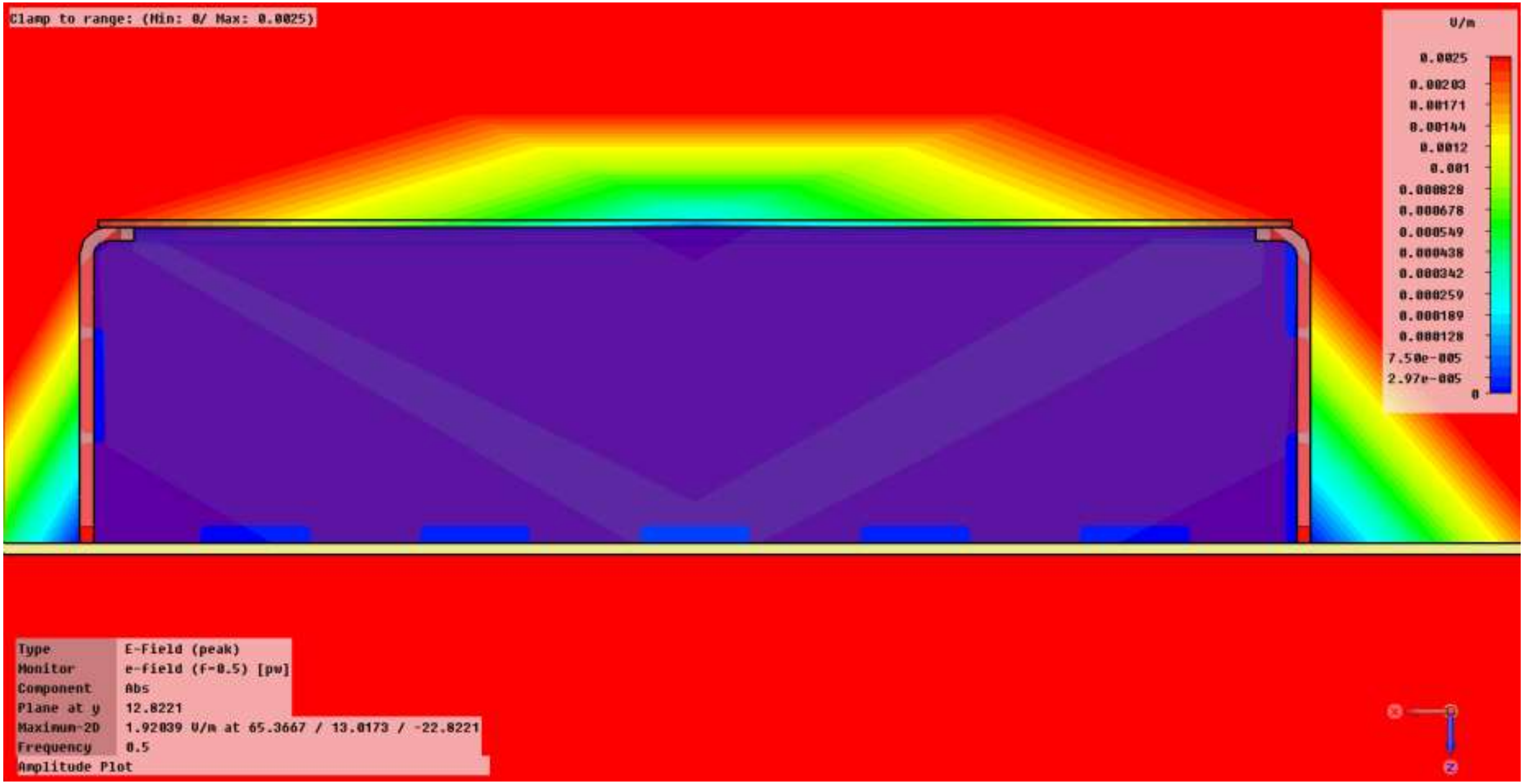


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=0.2) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91618 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	0.2

Amplitude Plot

Electric Field – 500 kHz

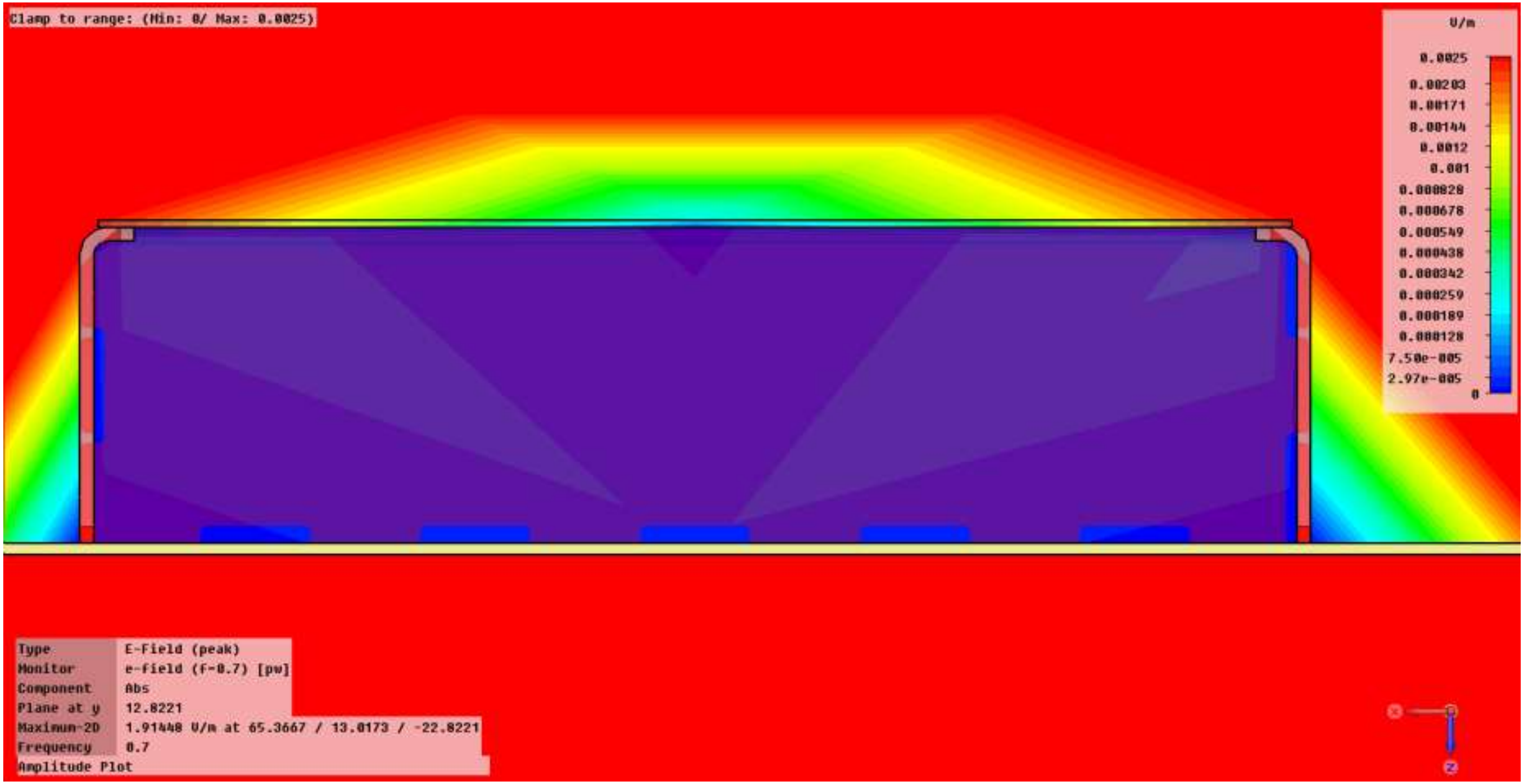


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=0.5) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.92039 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	0.5

Amplitude Plot

Electric Field – 700 kHz

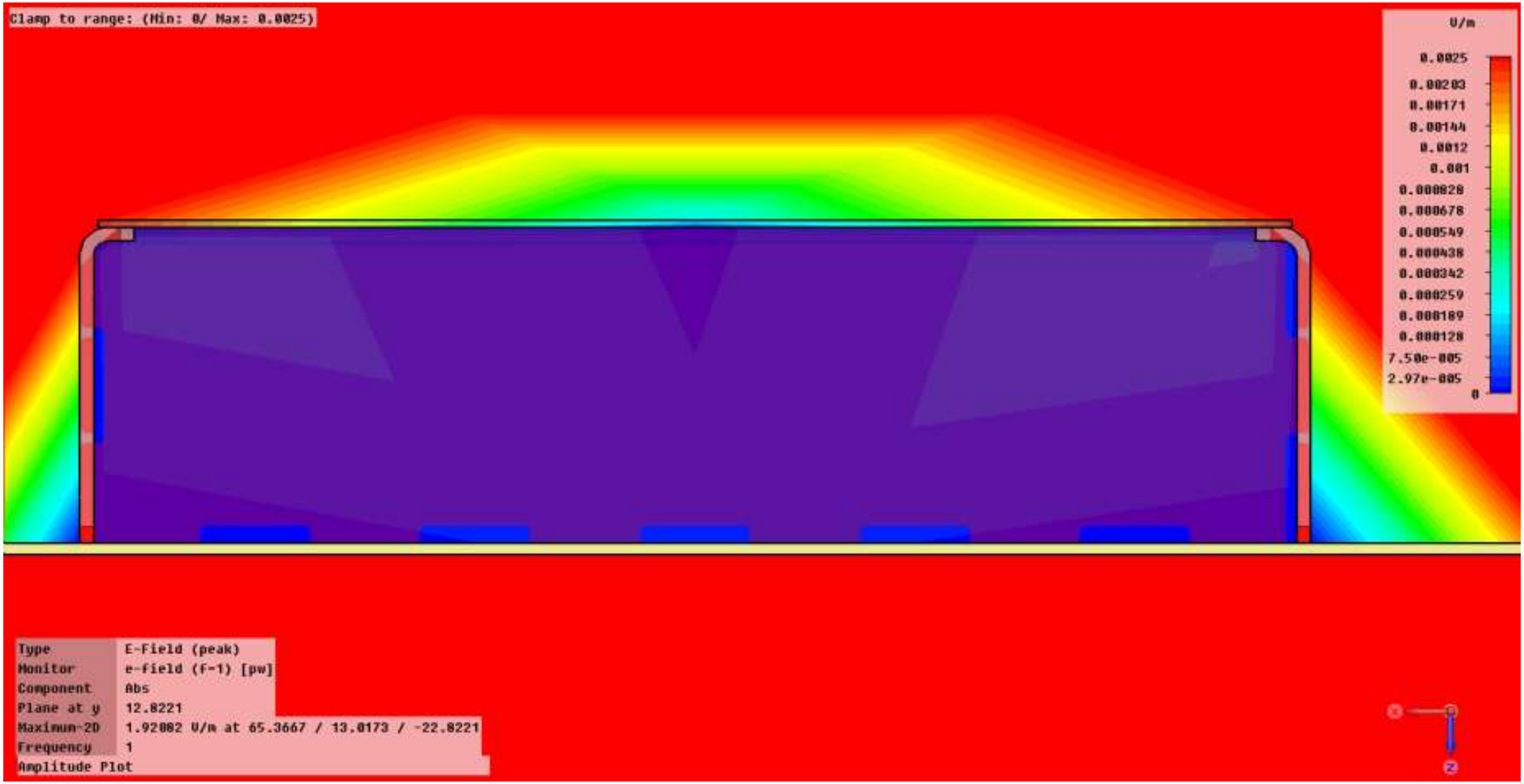


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=0.7) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91448 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	0.7

Amplitude Plot

Electric Field – 1 MHz

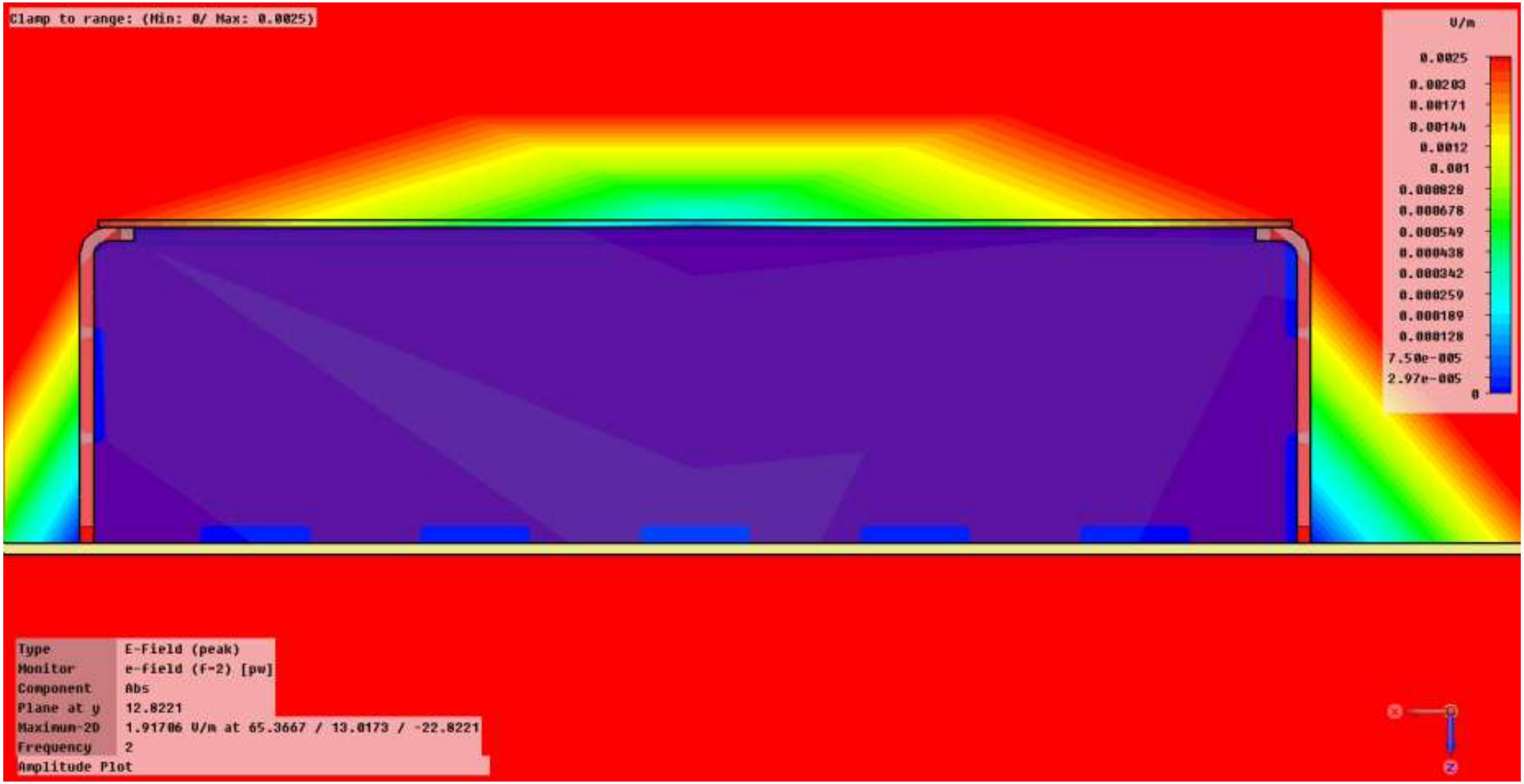


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=1) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.92082 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	1

Amplitude Plot

Electric Field – 2 MHz

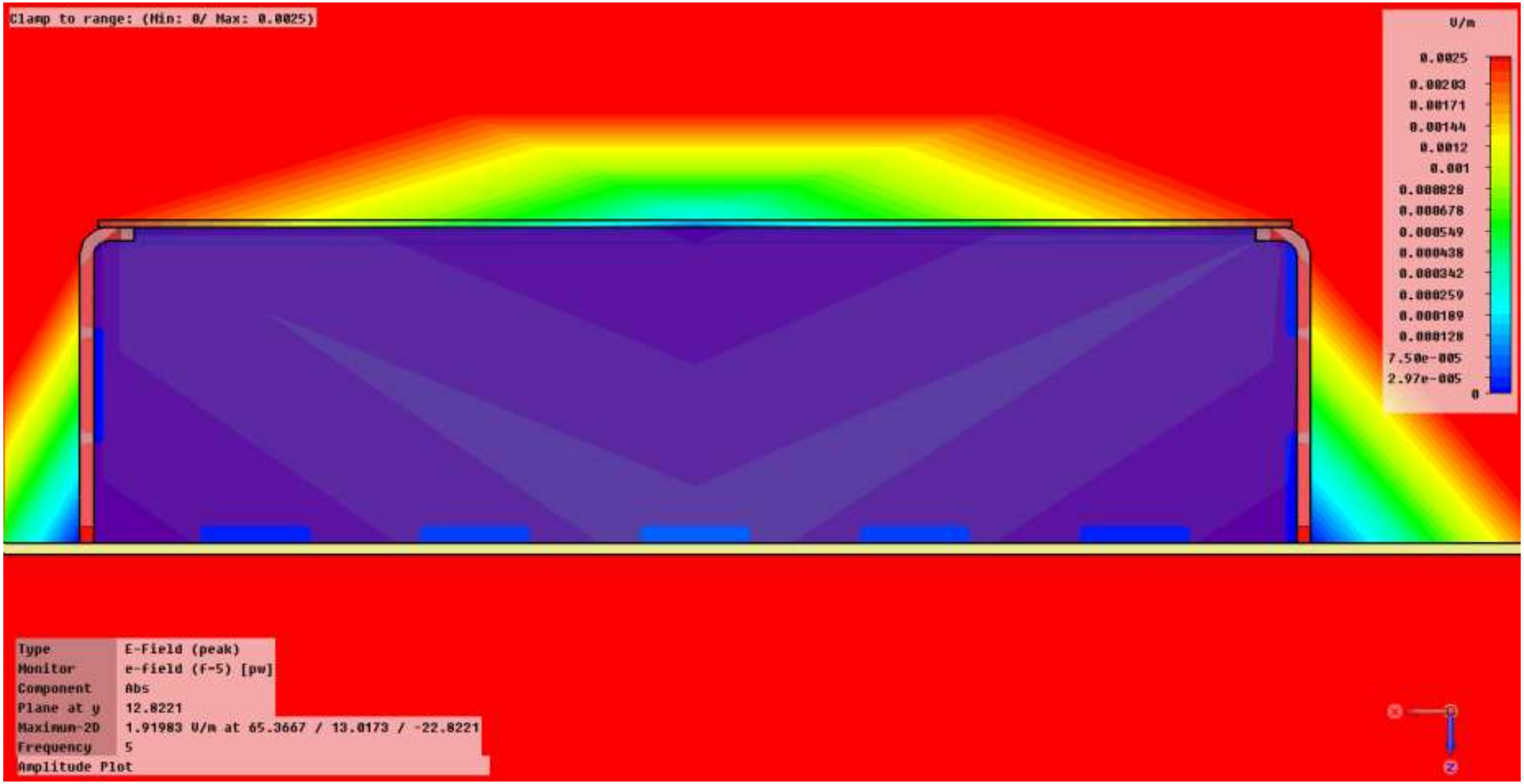


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=2) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91706 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	2

Amplitude Plot

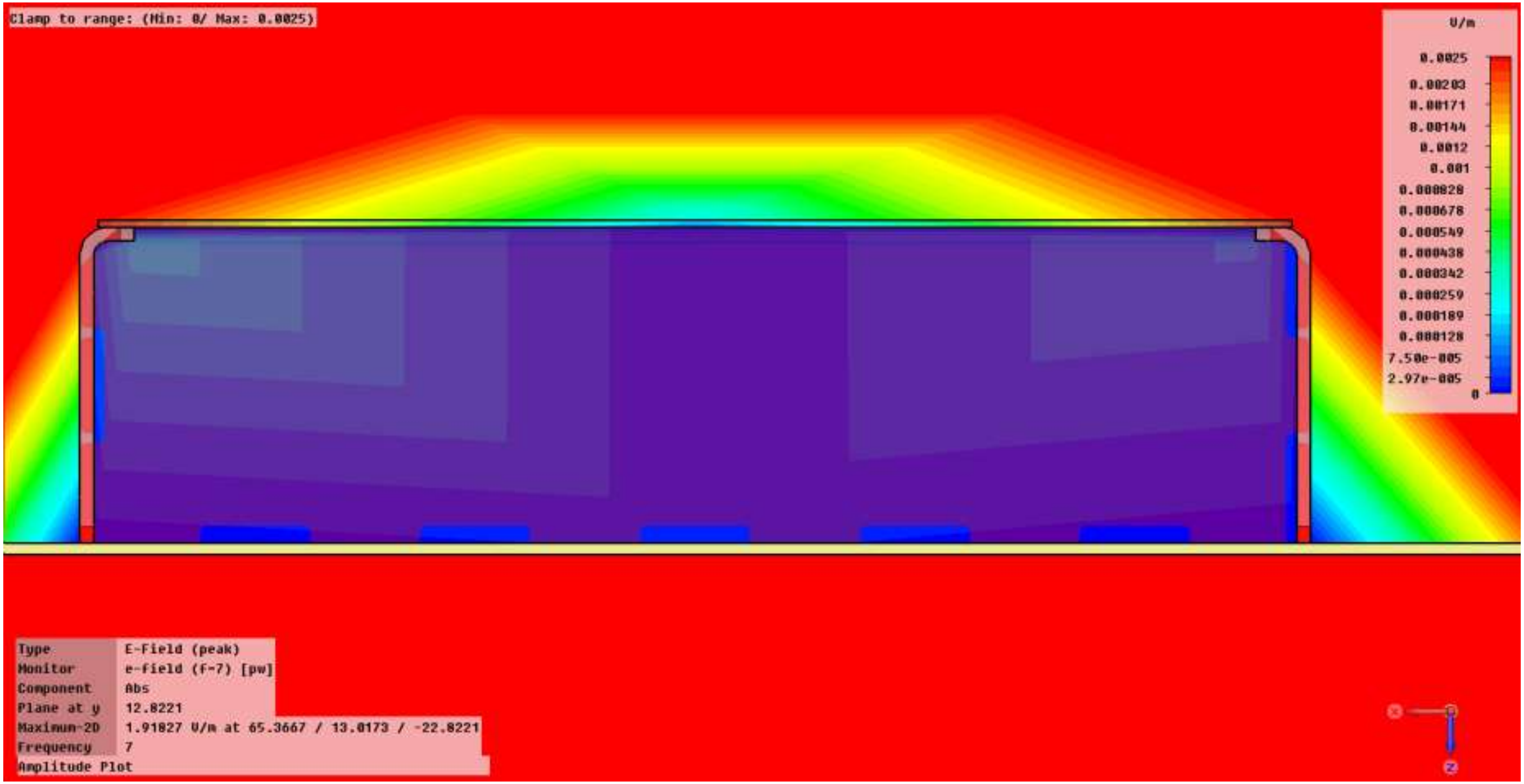
Electric Field – 5 MHz



Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=5) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91983 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	5
Amplitude Plot	

Electric Field – 7 MHz

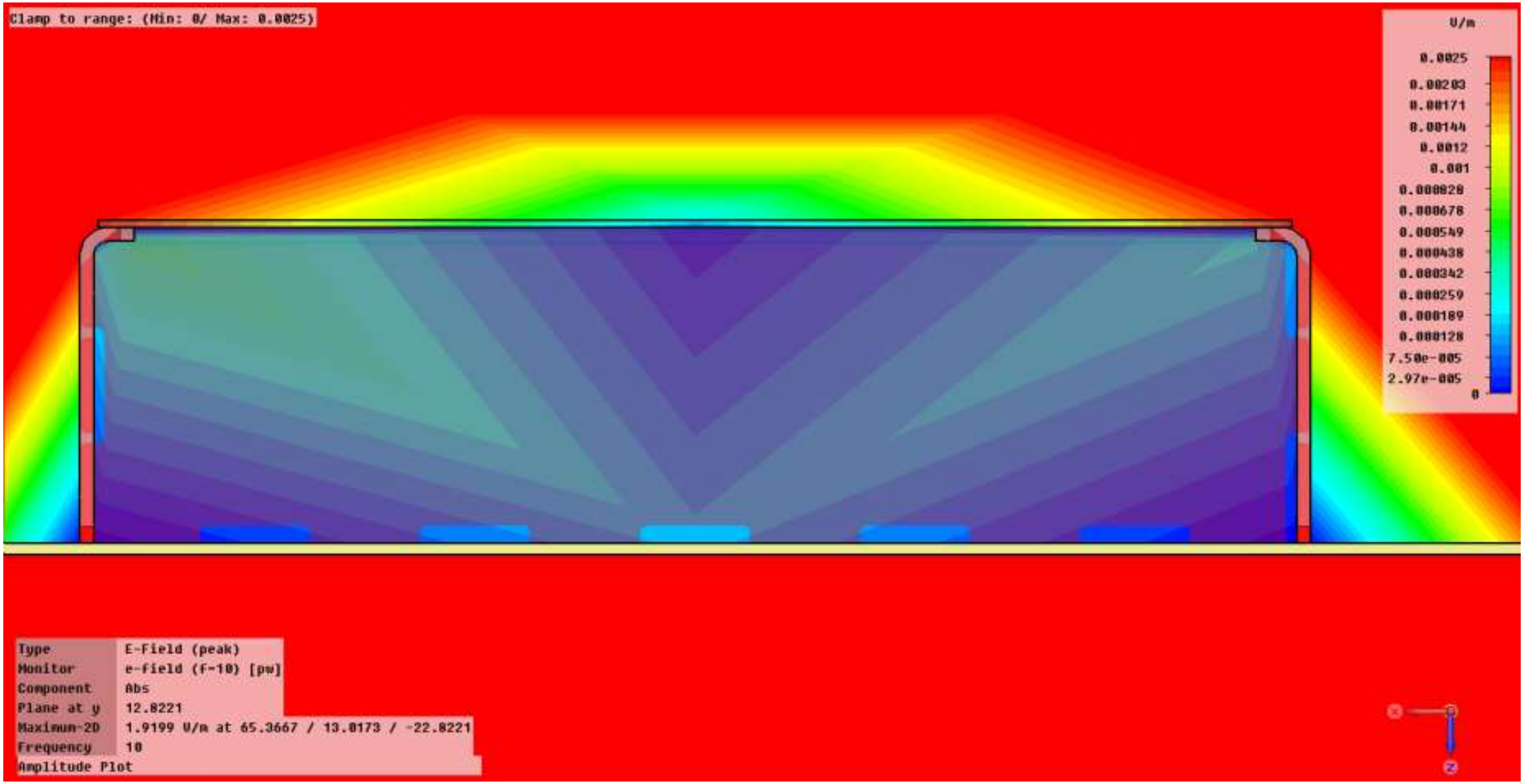


Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=7) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91827 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	7

Amplitude Plot

Electric Field – 10 MHz

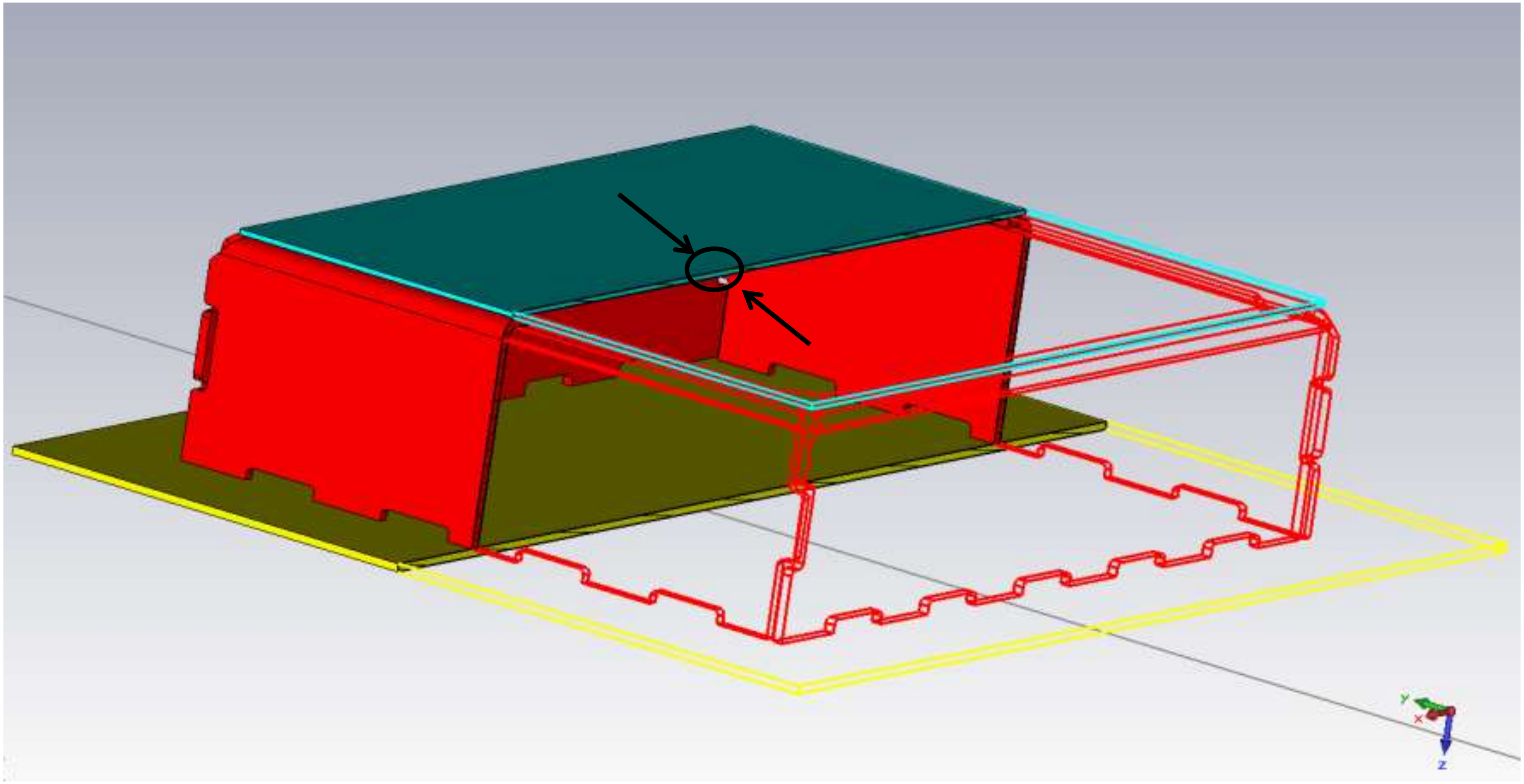


Clamp to range: (Min: 0/ Max: 0.0025)

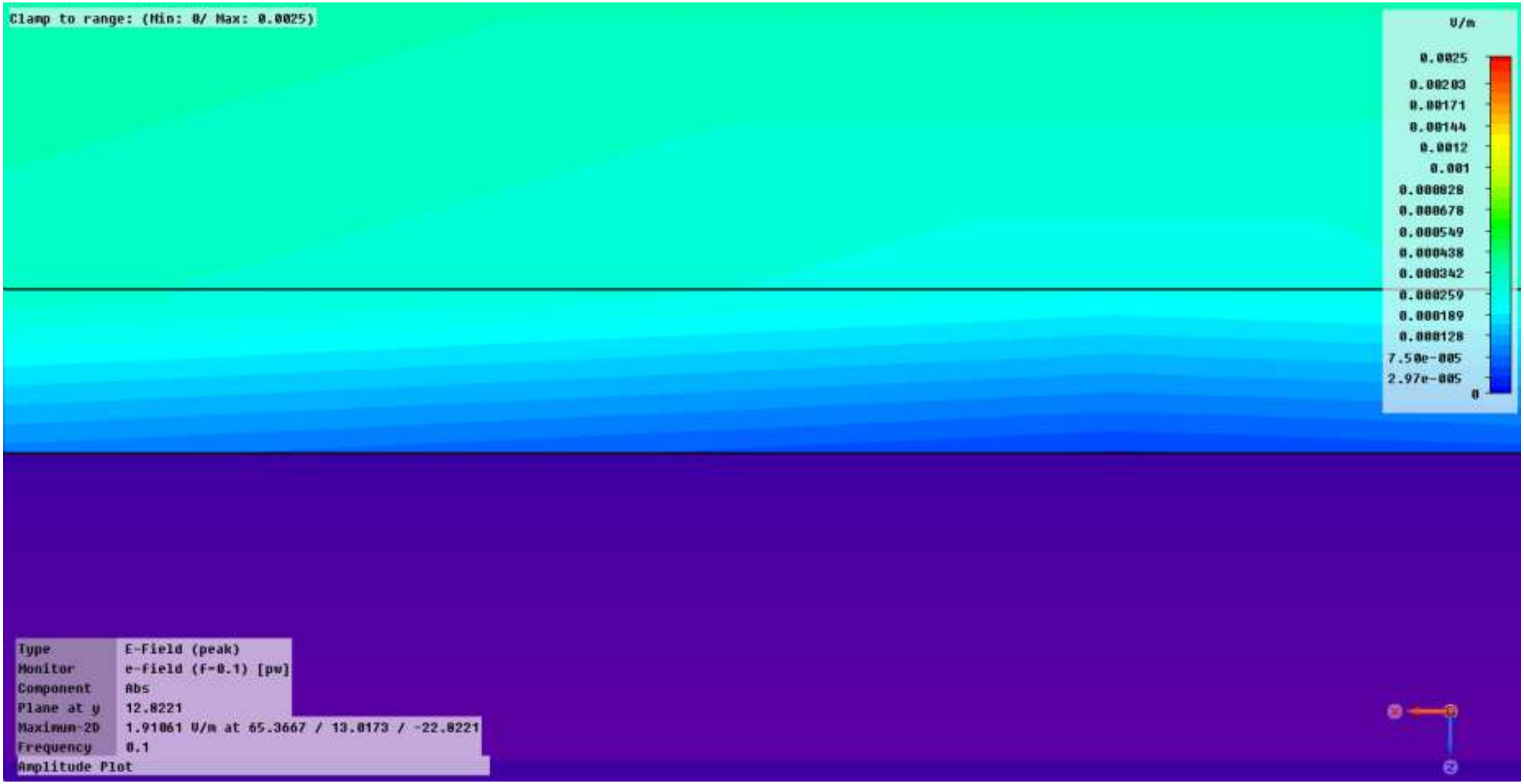
Type	E-Field (peak)
Monitor	e-field (f=10) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.9199 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	10

Amplitude Plot

Zoomed on Cross Section of Lid

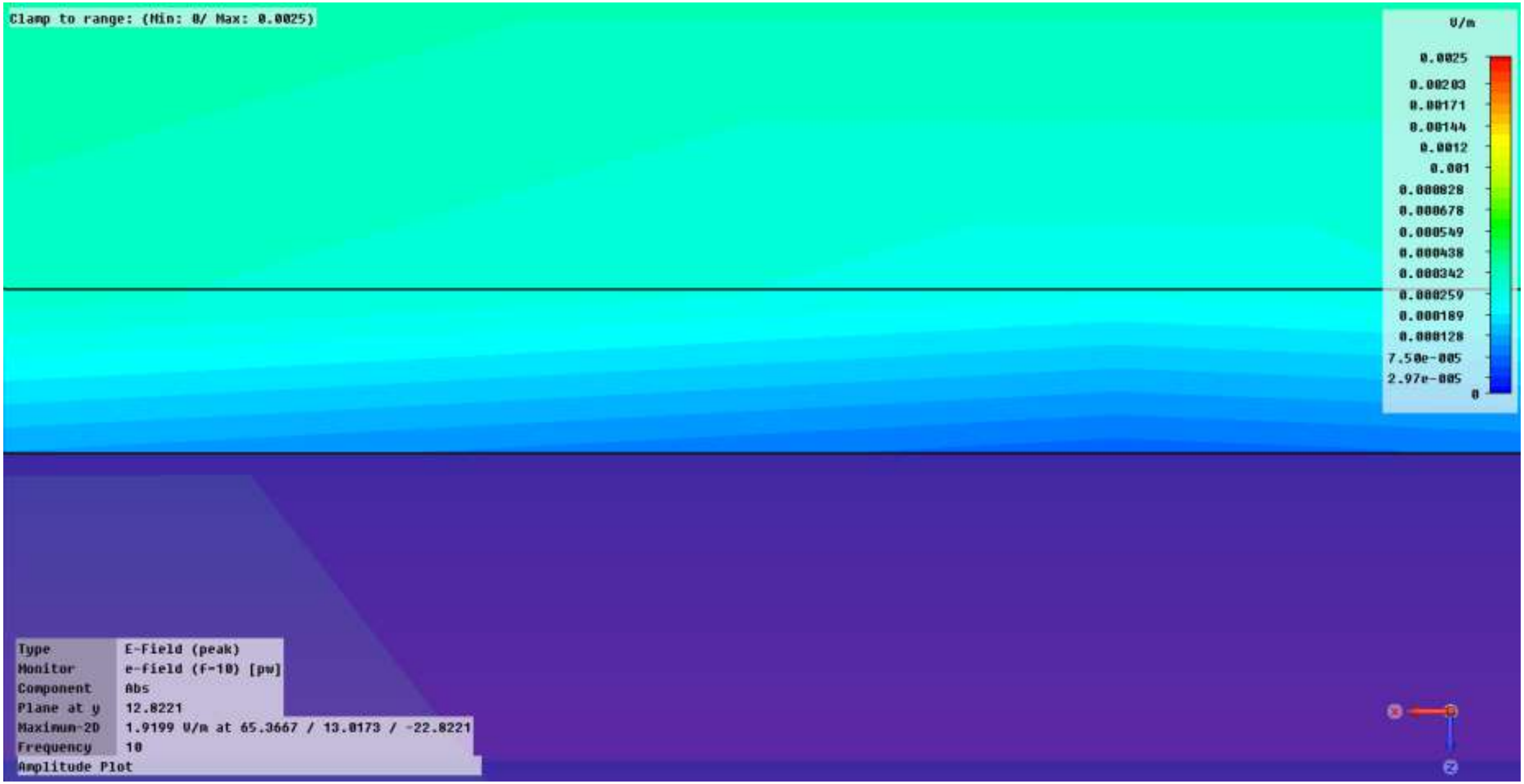


Electric Field– 100 kHz



Type	E-Field (peak)
Monitor	e-field (f=0.1) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.91061 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	0.1
Amplitude Plot	

Electric Field – 10 MHz



Clamp to range: (Min: 0/ Max: 0.0025)

Type	E-Field (peak)
Monitor	e-field (f=10) [pw]
Component	Abs
Plane at y	12.8221
Maximum-2D	1.9199 V/m at 65.3667 / 13.0173 / -22.8221
Frequency	10

Amplitude Plot

Electric Field Shielding

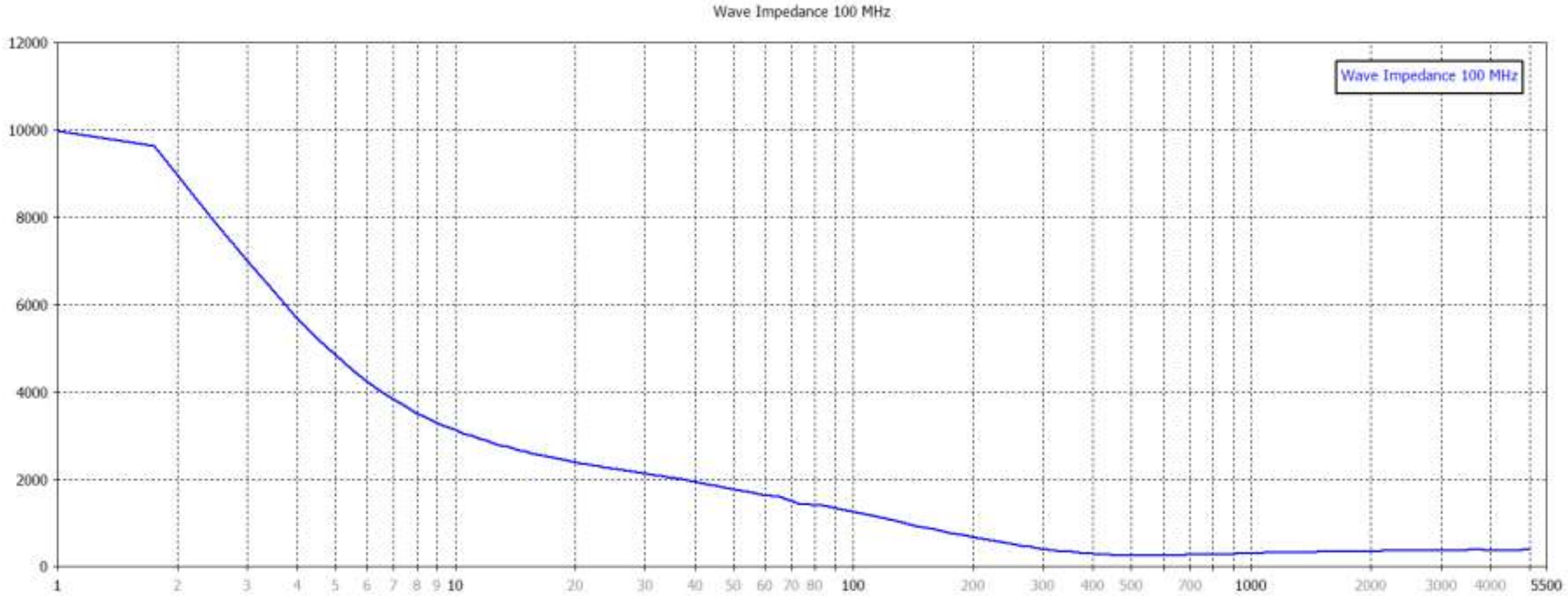
- A sudden change of impedance causes electric fields to reflect off the surface of a metal shield – this is called **Reflection Loss**
- Reflection loss is somewhat independent of frequency
- As frequency increases, typically the shielding effectiveness of a shield decreases due to apertures in the shield

Wave Impedance

$$R = 20\log\frac{|z_w|}{4|z_s|}$$

Shield Impedance

Wave Impedance vs. Distance



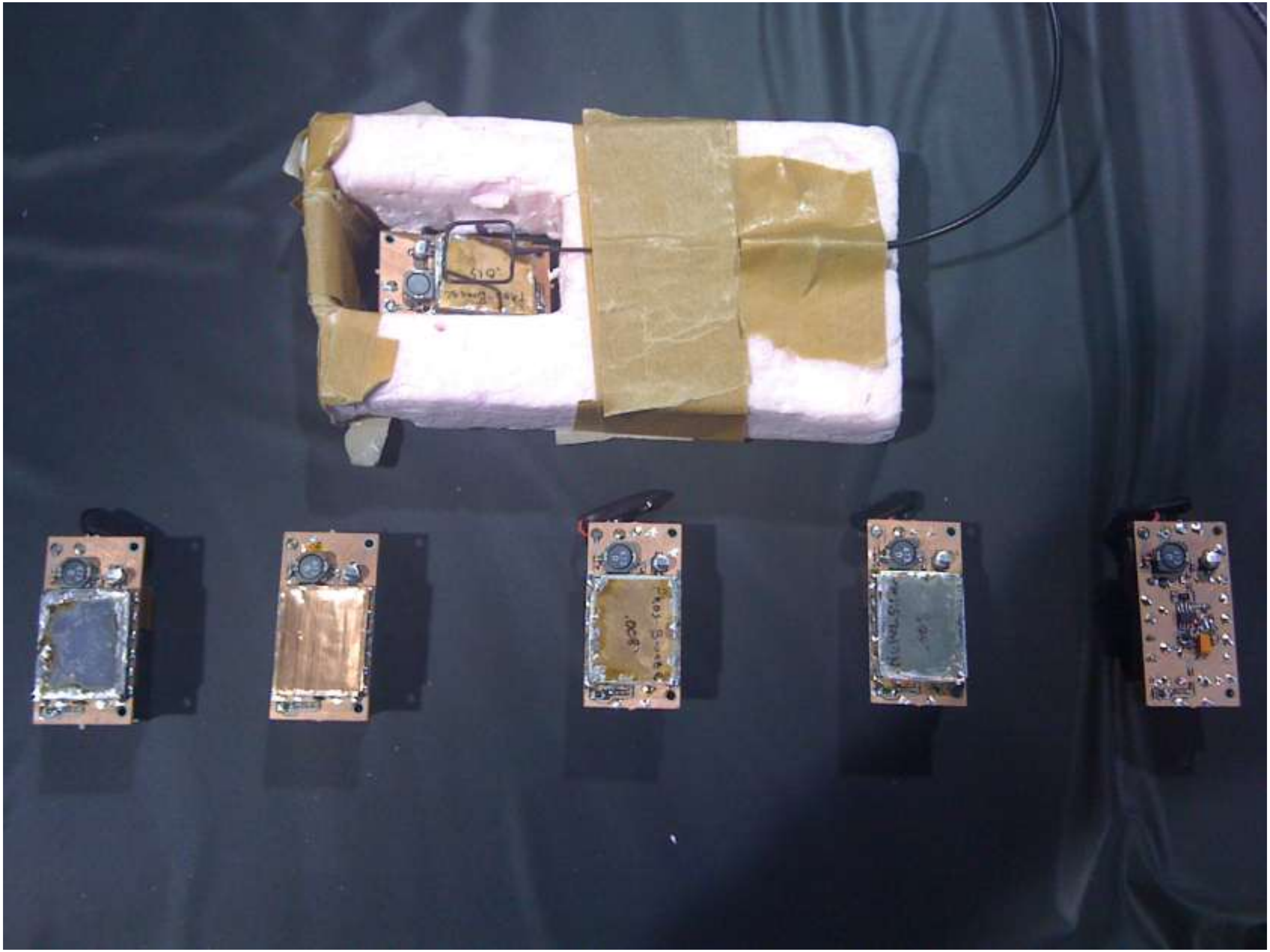
The Characteristic Impedance of Copper is **$3.68 \text{ x } 10^{-7}\sqrt{f}$ Ω**
(3.68 mΩ at 100 MHz - Big difference from 10kΩ)

As frequency goes up (and distance gets further), this gap narrows

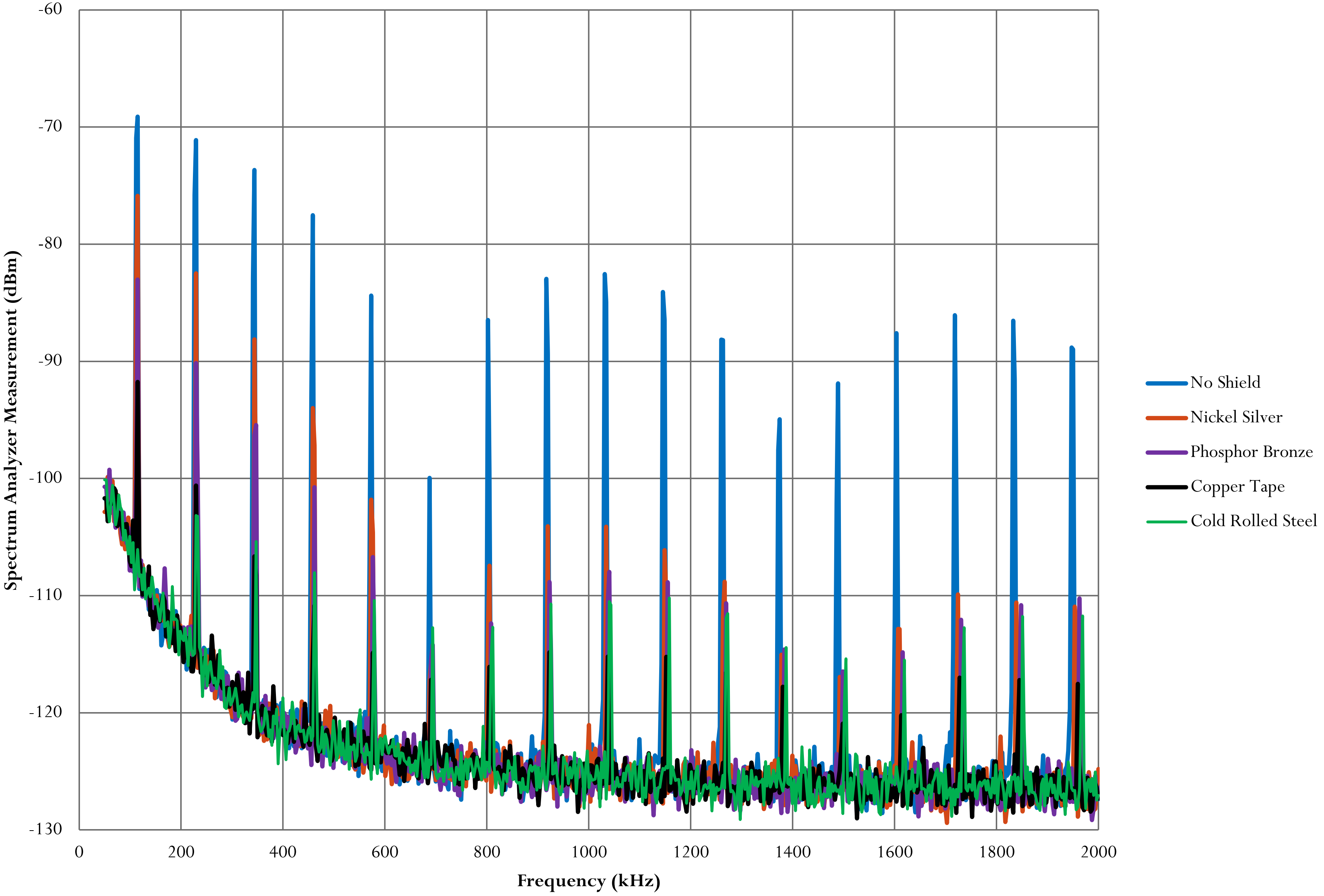
Shielding Effectiveness

- Absorption Loss + Reflection Loss will give (in most cases) shielding effectiveness
- Shielding effectiveness is given in decibels and is a ratio of the signal with the shield present vs. the shield absent
- When communicating values of shielding effectiveness, it's important to indicate if this is for electric or magnetic field shielding.
- Transmitted power shielding effectiveness is also used

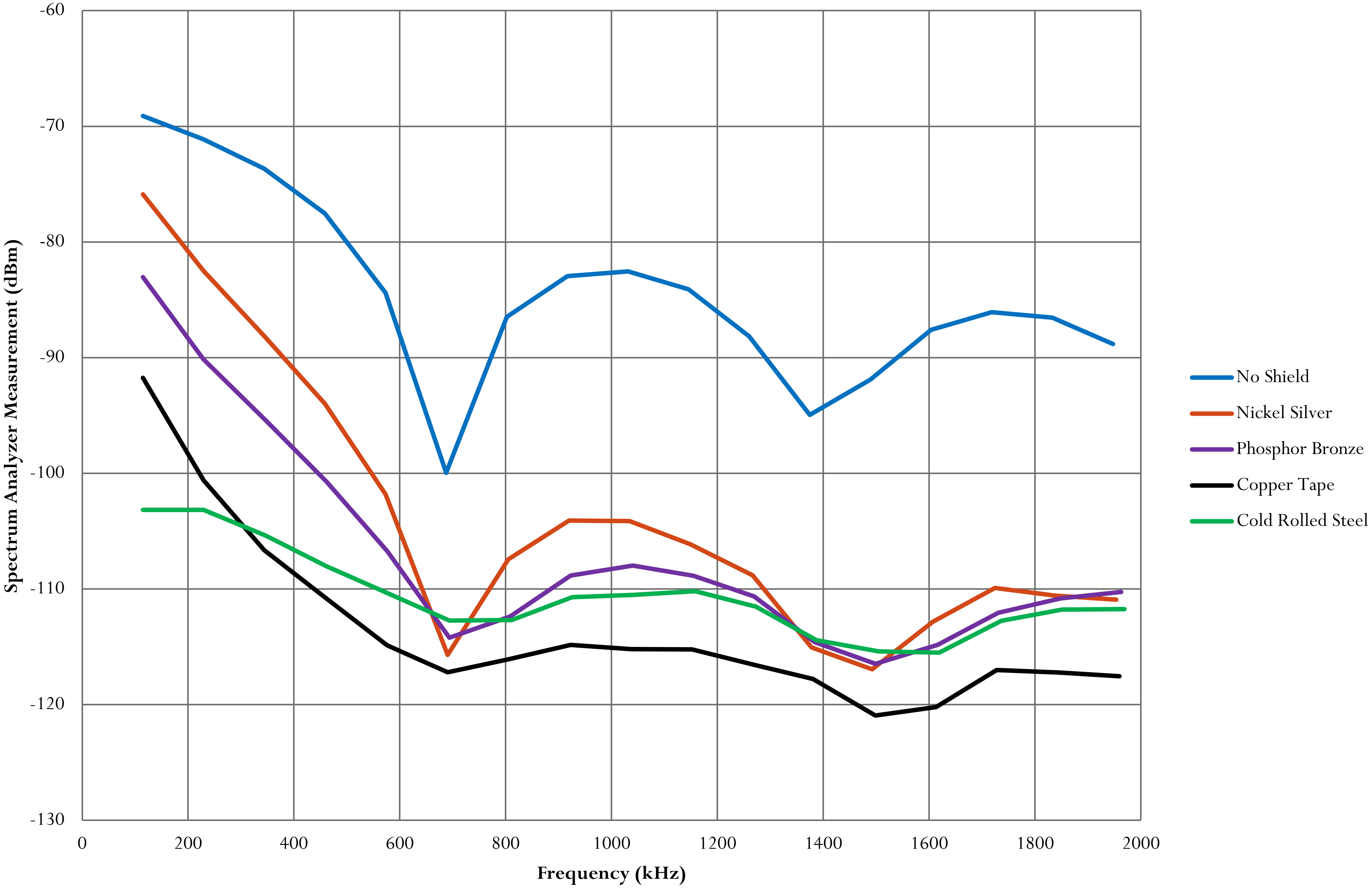
Demonstration Setup



Power Supply Shielding of Various 8 Mil Thick Materials



Power Supply Shielding of Various 8 Mil Thick Materials (Envelope)



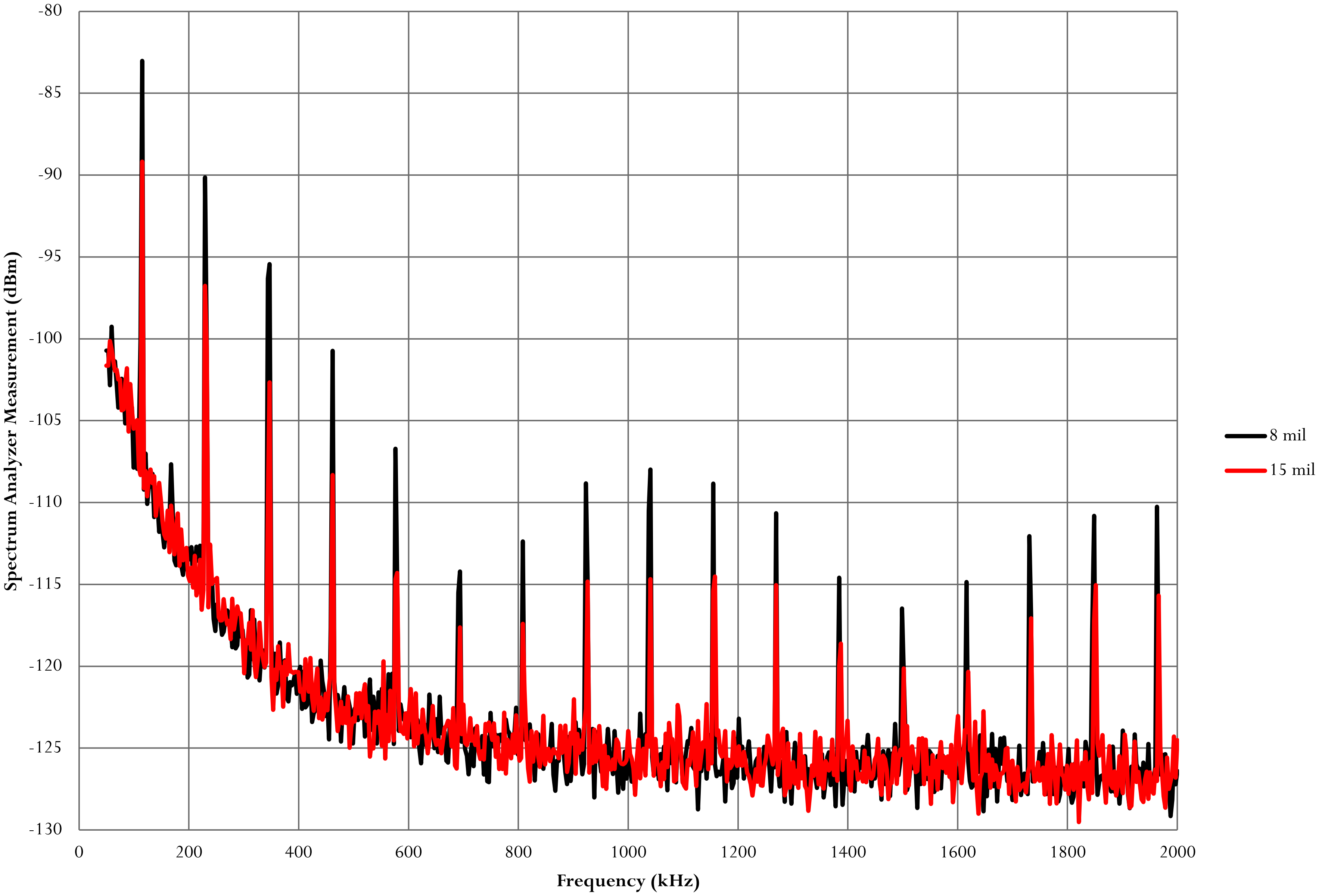
Skin Depth of Various Materials

Skin Depth in inches
(source: Henry Ott
Electromagnetic
Compatibility Engineering)

$$\delta = \frac{2.6}{\sqrt{f \mu_r \sigma_r}}$$

Material	μ_r	σ_r	**δ (mils) 100 kHz**	**δ (mils) 10 MHz**
Steel	1000	0.1	0.8	0.1
Copper	1	1	8	0.8
Phosphor Bronze	1	0.15	21	2.1
Nickel Silver	1	0.06	33	3

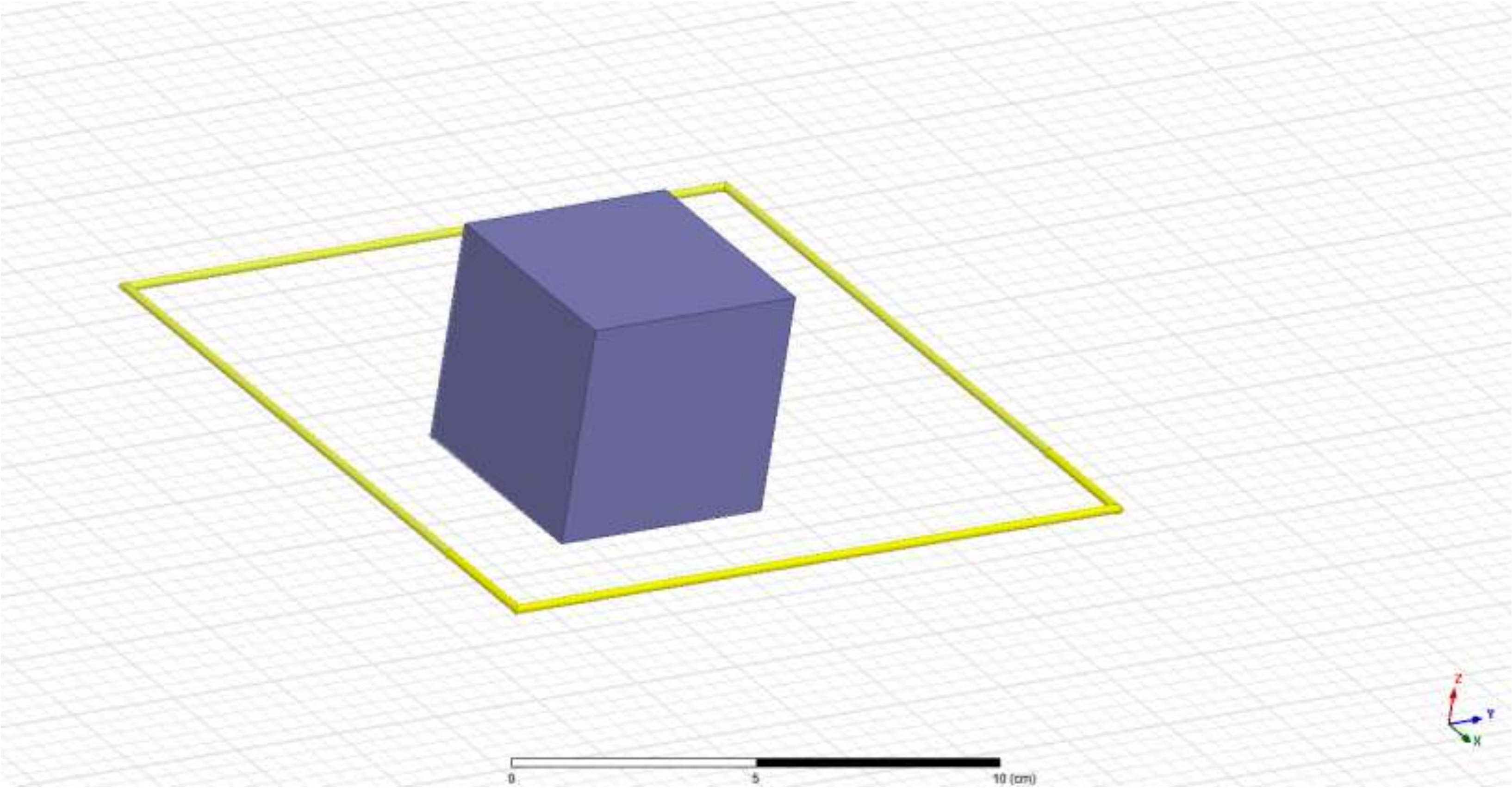
Power Supply Shielding of Phosphor Bronze of Different Thickness



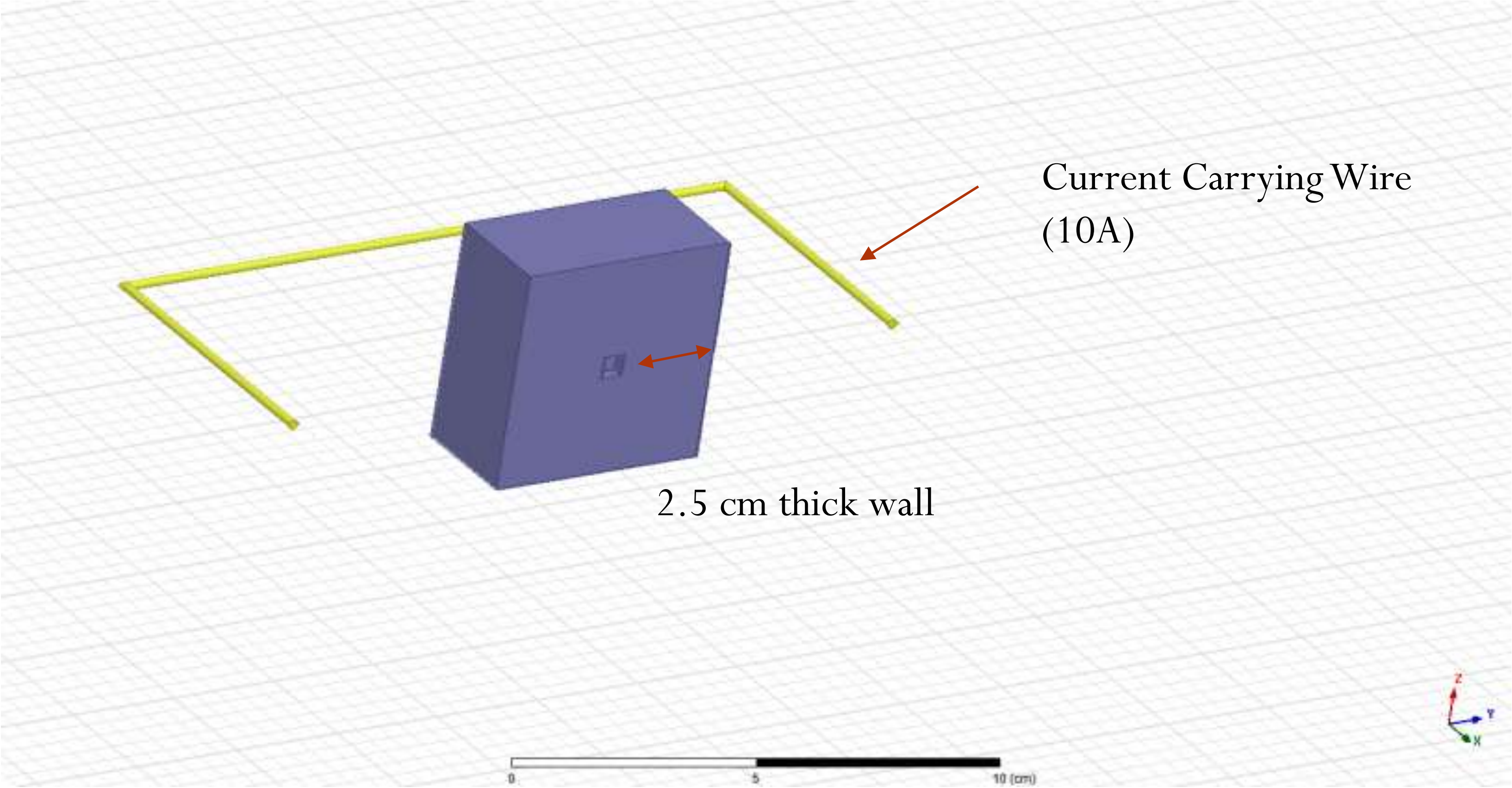
Shielding Materials

- Low frequency magnetic field shielding requires a material with a thin skin depth.
- At higher frequencies, skin depth of most materials becomes thin enough creating effective shields
- Increasing shield thickness improves shielding until the material becomes thick enough.

Additional Thought about Magnetic Field Shielding



Setup



Current Carrying Wire (10A)

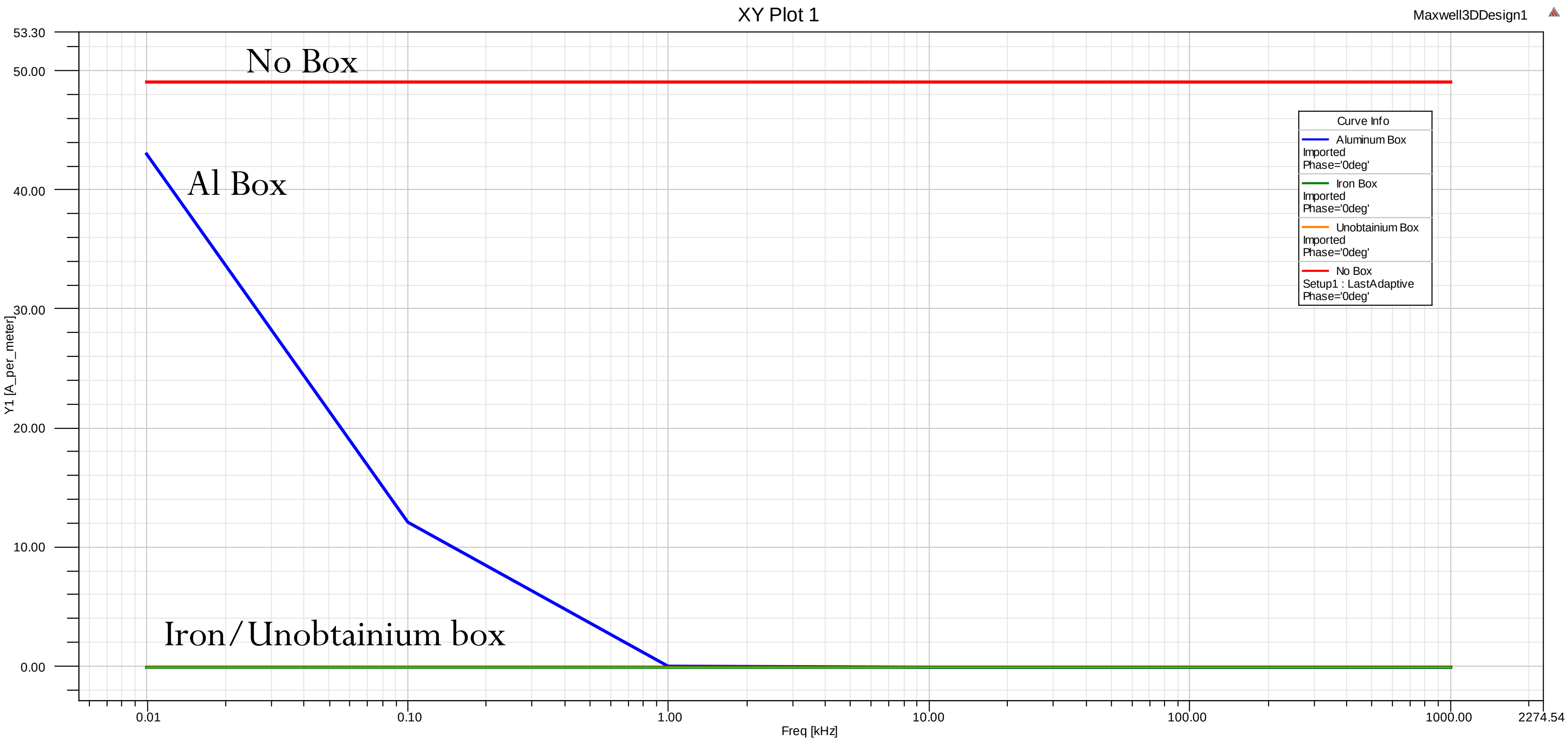
2.5 cm thick wall

Hypothetical Case

- There is a 5cm cube with a small amount of hollowed out material in the center
- There is a loop of current carrying wire at all frequencies surrounding the cube
- The cube is made of a particular material – the materials considered will be
  - Vacuum (no cube)
  - Aluminum
  - Iron
  - "Unobtainium" – has the same skin depth as iron except the relative permeability of the material is 1. but the relative conductivity is 688.

$$\delta = \frac{2.6}{\sqrt{f \mu_r \sigma_r}}$$

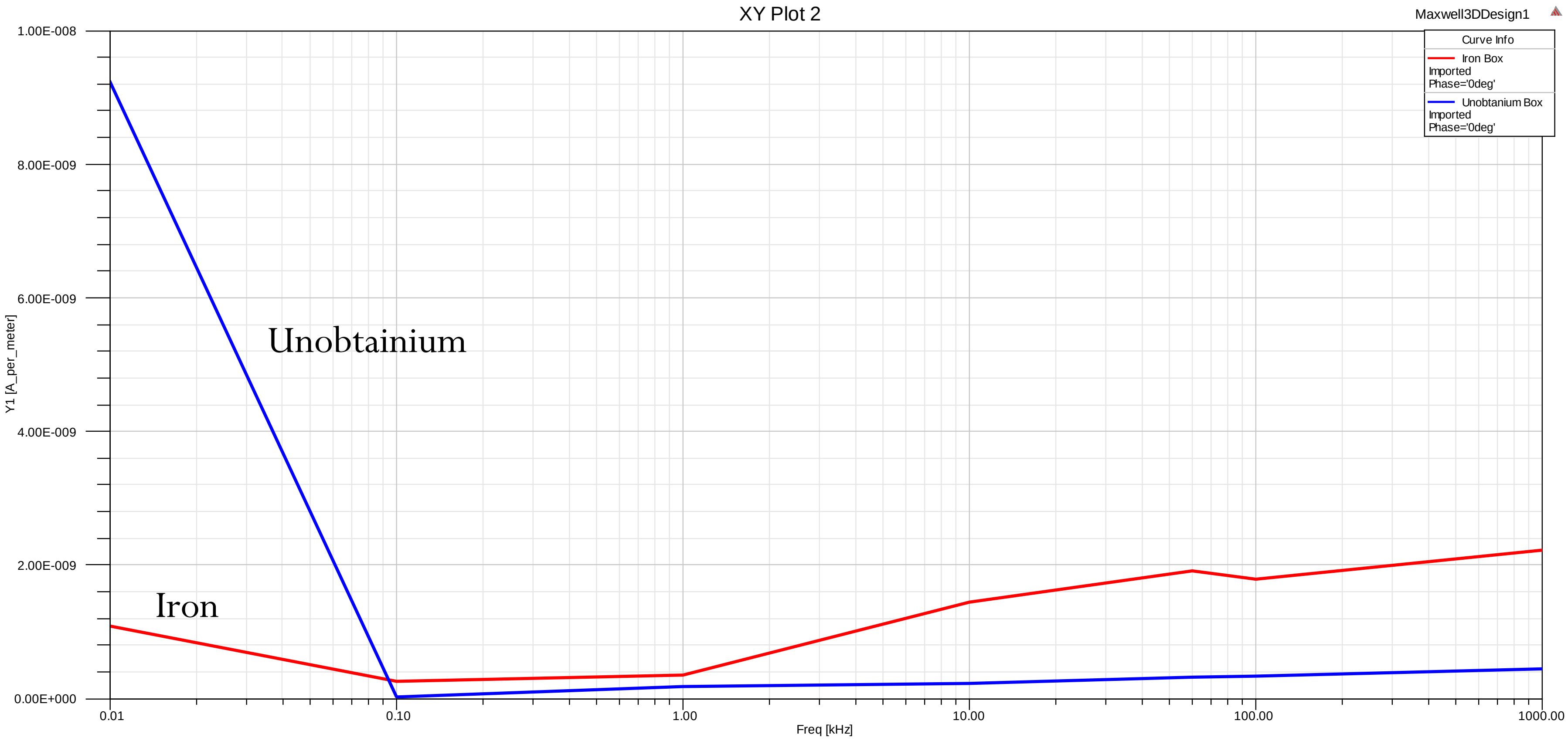
Magnetic Field Inside Box


No Box

Al Box

Iron/Unobtainium box

Iron vs. Unobtainium

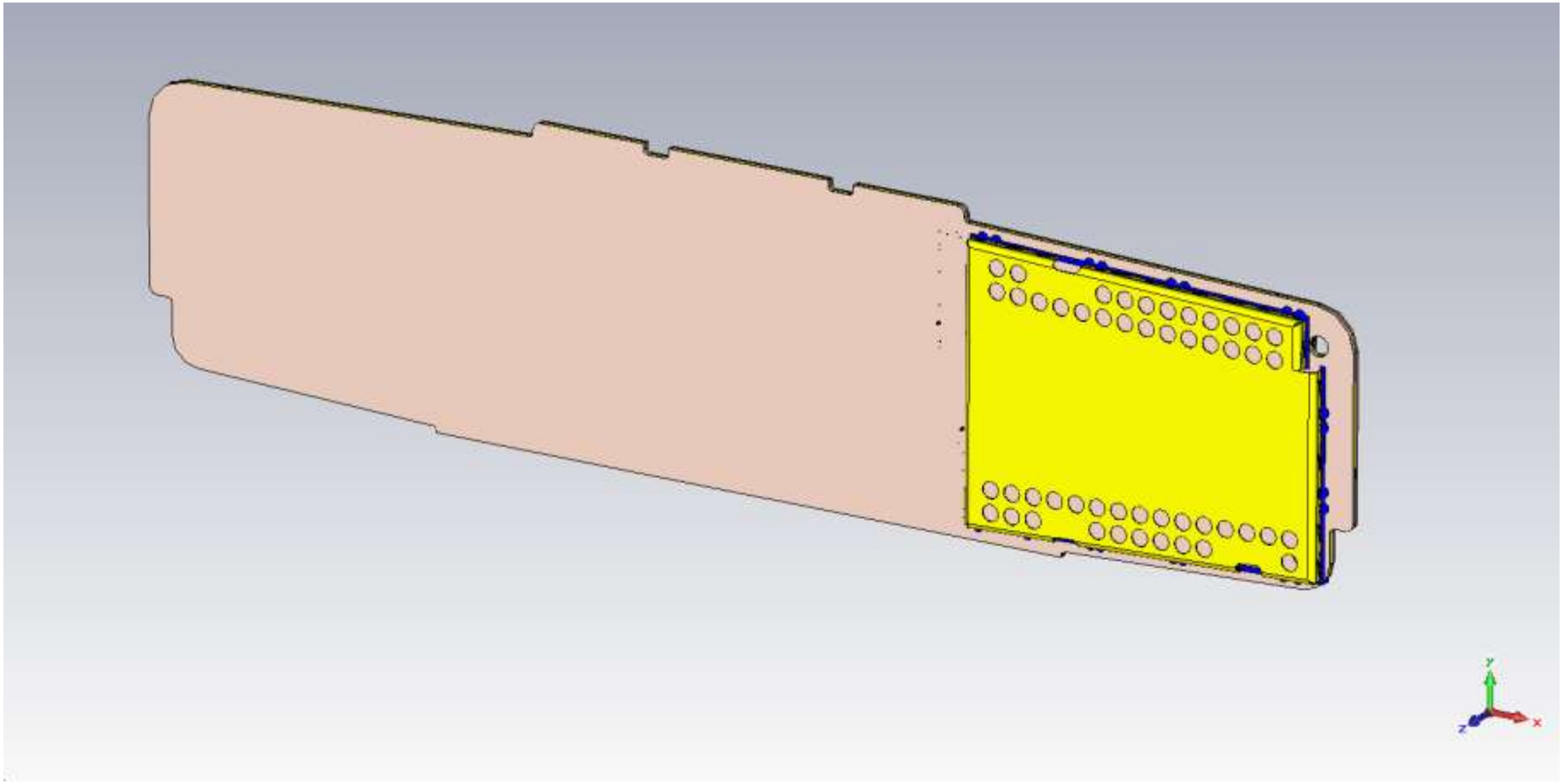


This suggests that permeability improves shielding beyond absorption loss below 100 Hz

$$\mathcal{R} = \frac{l}{\mu A}$$

Effect of Apertures on EM Shielding

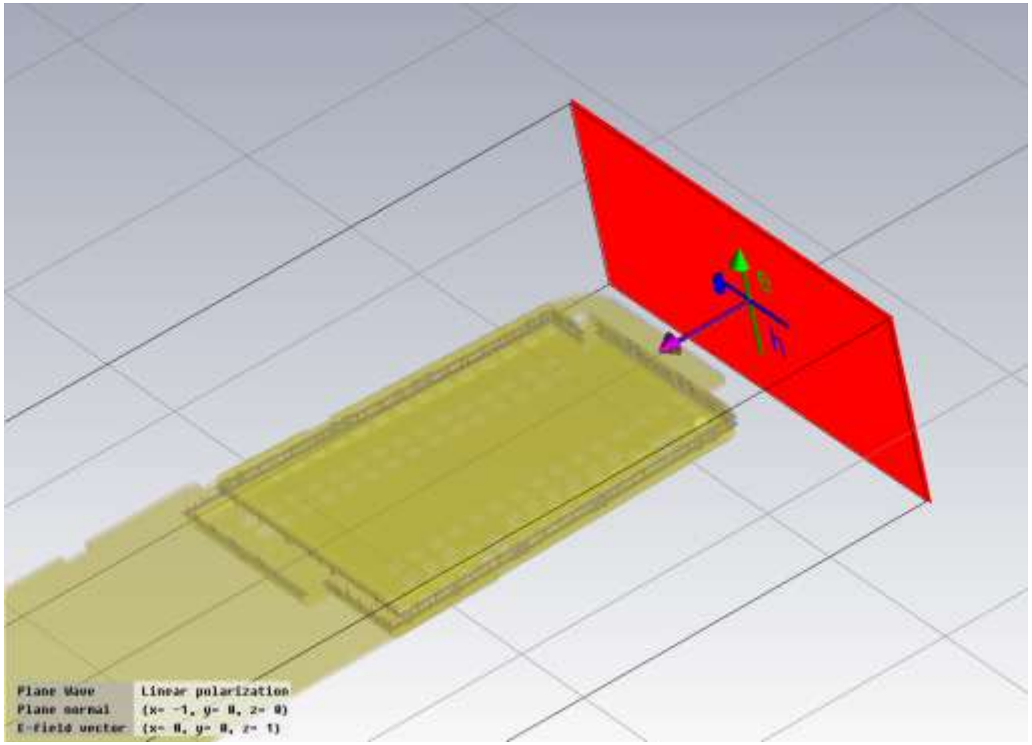
Model Setup



Principle of Reciprocity

- Most shields are passive
- The ability of a shield to stop an exterior field (immunity) is equal to its ability to stop an interior source (emissions)
- When determining shielding effectiveness, either an emissions or immunity case can be studied – whichever is more convenient
  - Typically, it's easier for physical measurement to measure emissions
  - Typically, it's easier for simulations to measure immunity

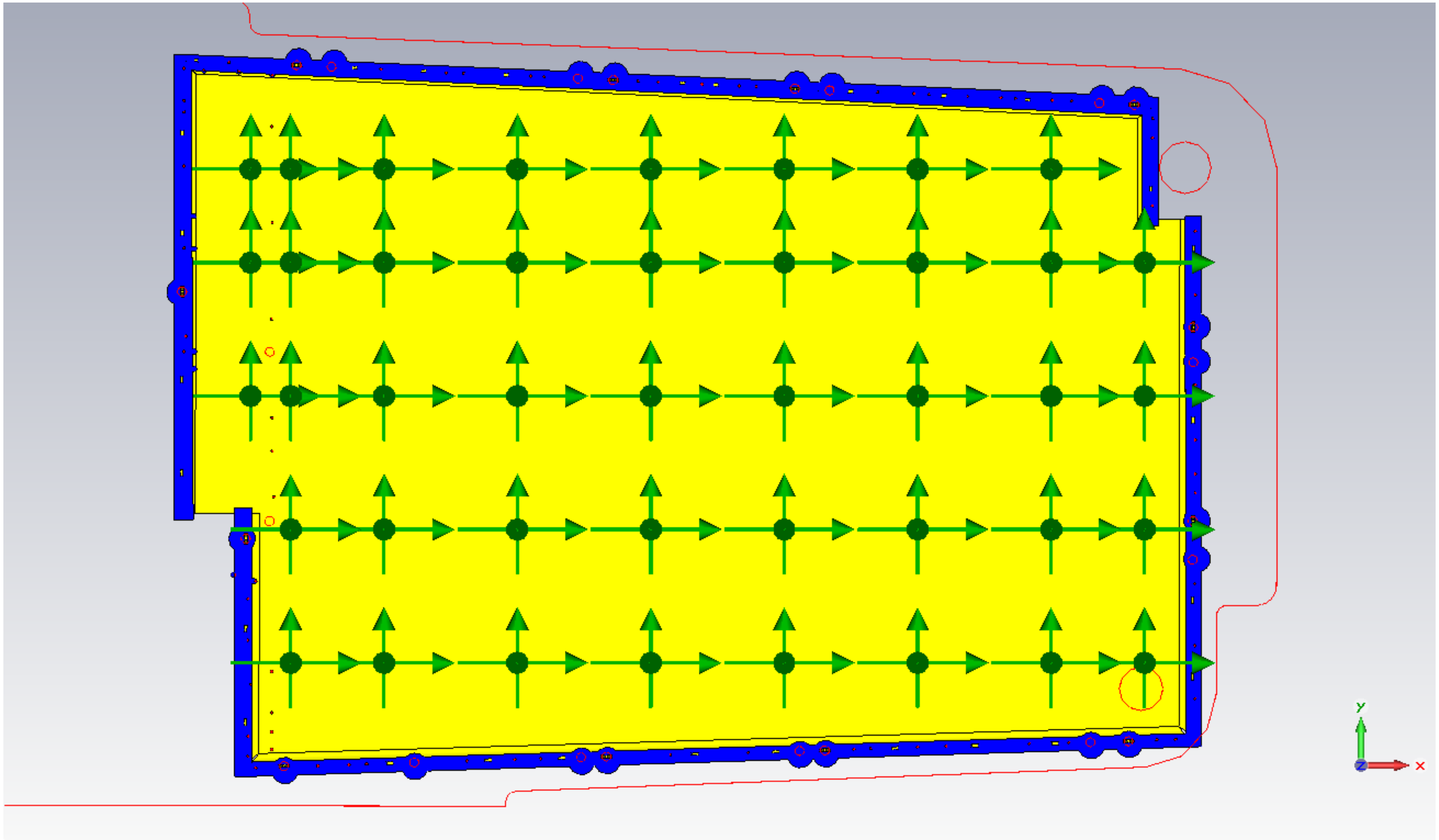
Model Excitation



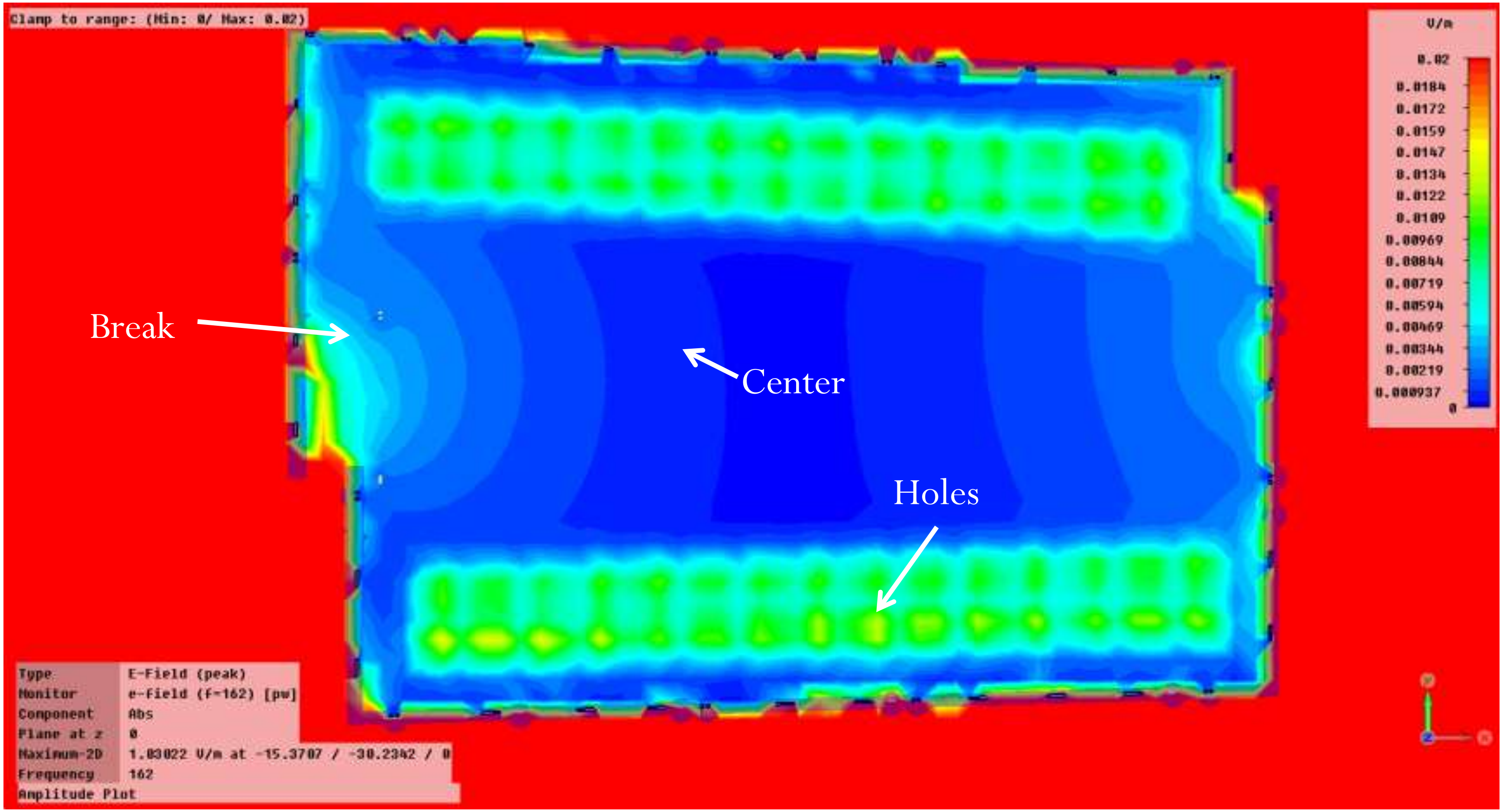
Plane Wave	Linear polarization
Plane normal	(x= -1, y= 0, z= 0)
E-field vector	(x= 0, y= 0, z= 1)

X Direction

Probe Locations
Height is at PCB Outer Layer Level



Electric Field (X Plane Wave) at 162 MHz



Clamp to range: (Min: 0/ Max: 0.02)

Break

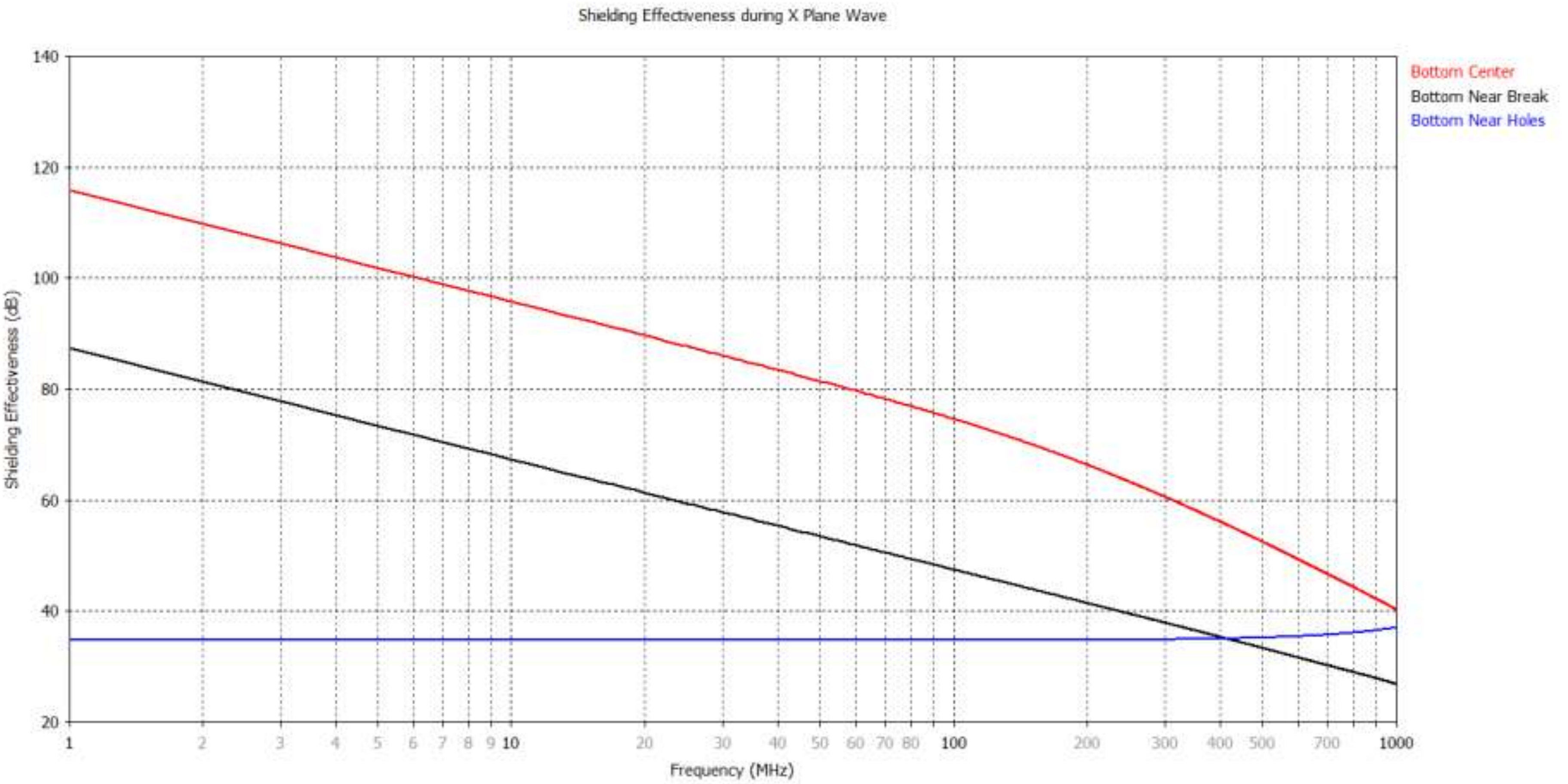
Center

Holes

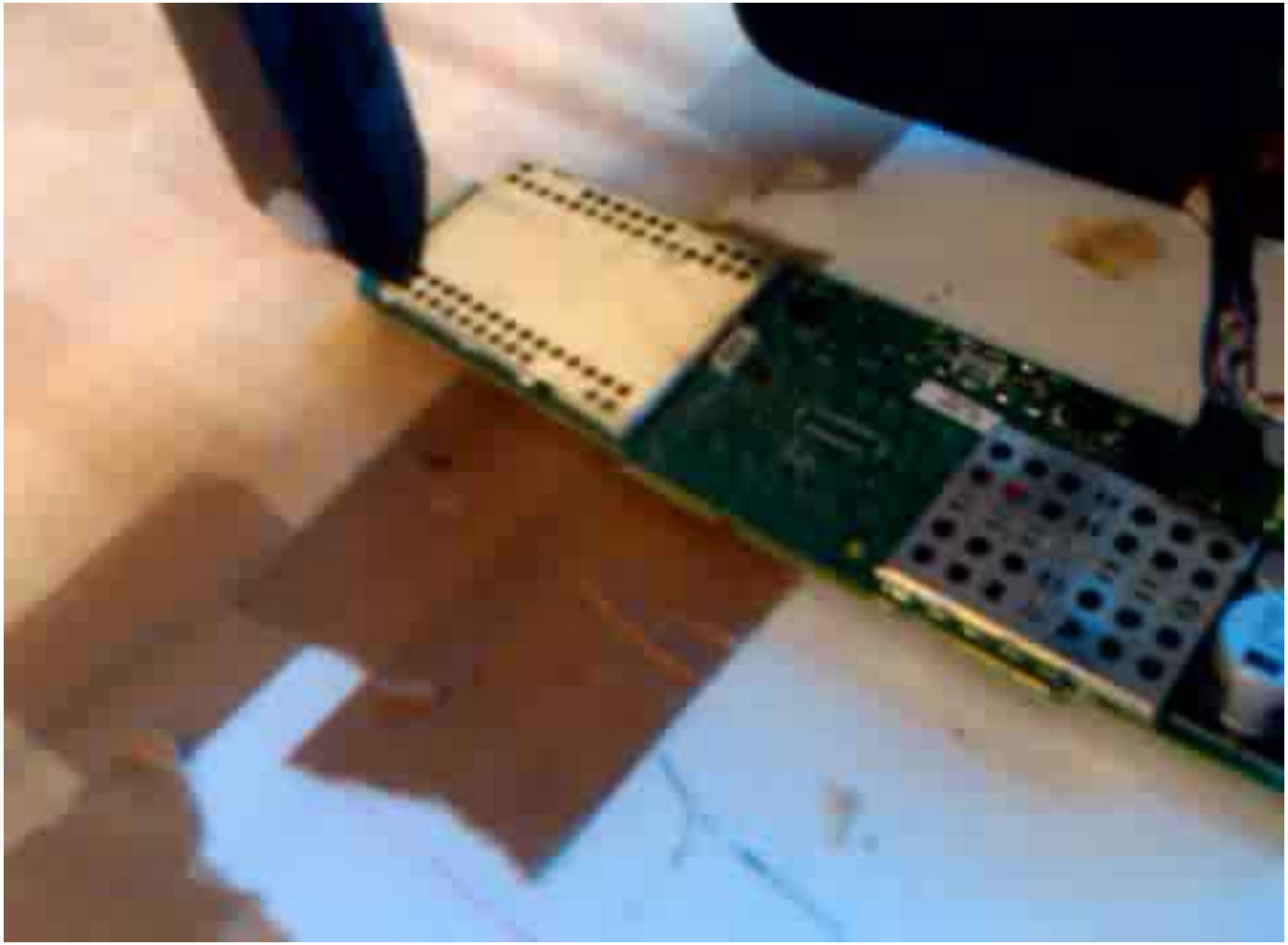
Type	E-Field (peak)
Monitor	e-Field (f=162) [pw]
Component	Abs
Plane at z	0
Maximum-2D	1.03022 V/m at -15.3707 / -30.2342 / 0
Frequency	162

Amplitude Plot

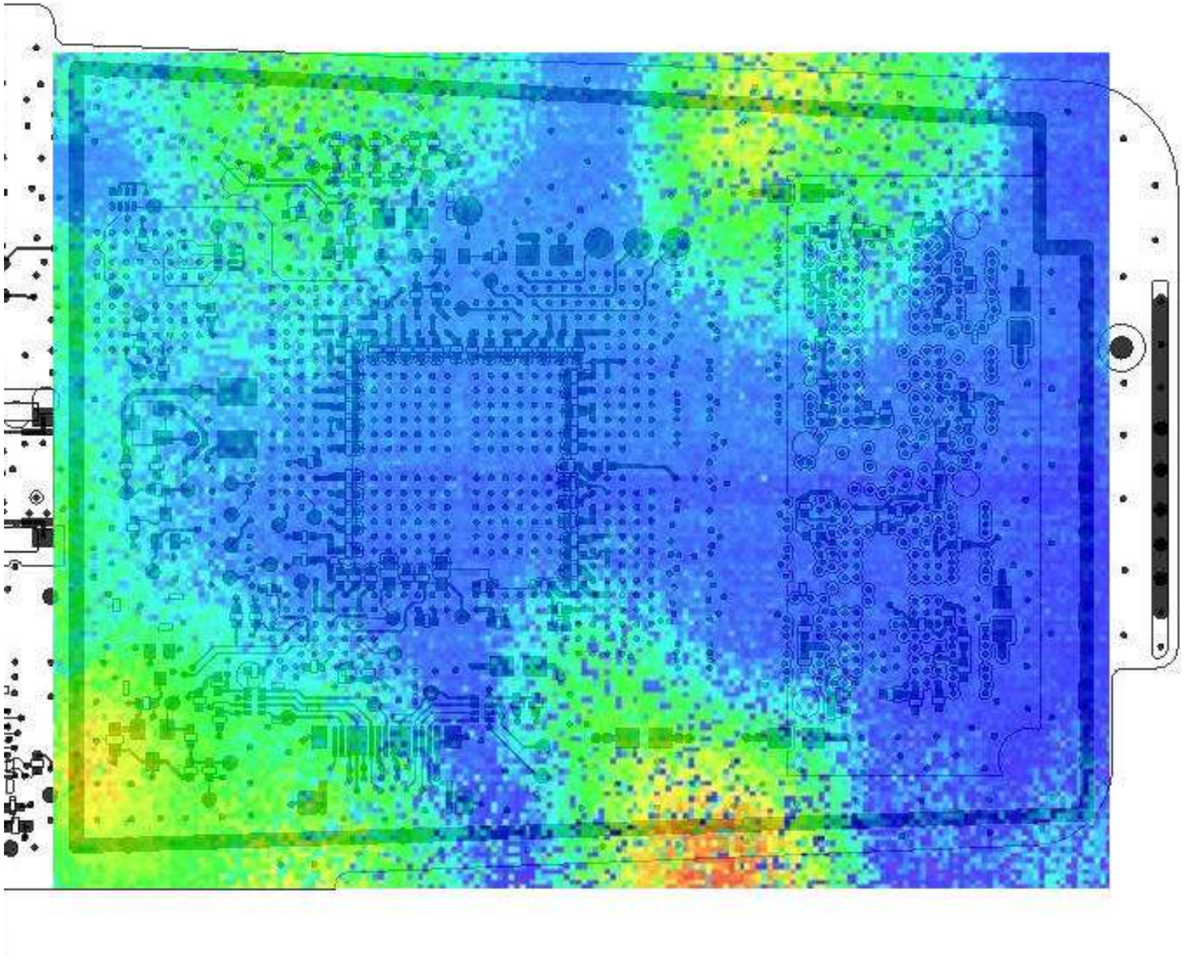
Shielding Effectiveness over Frequency



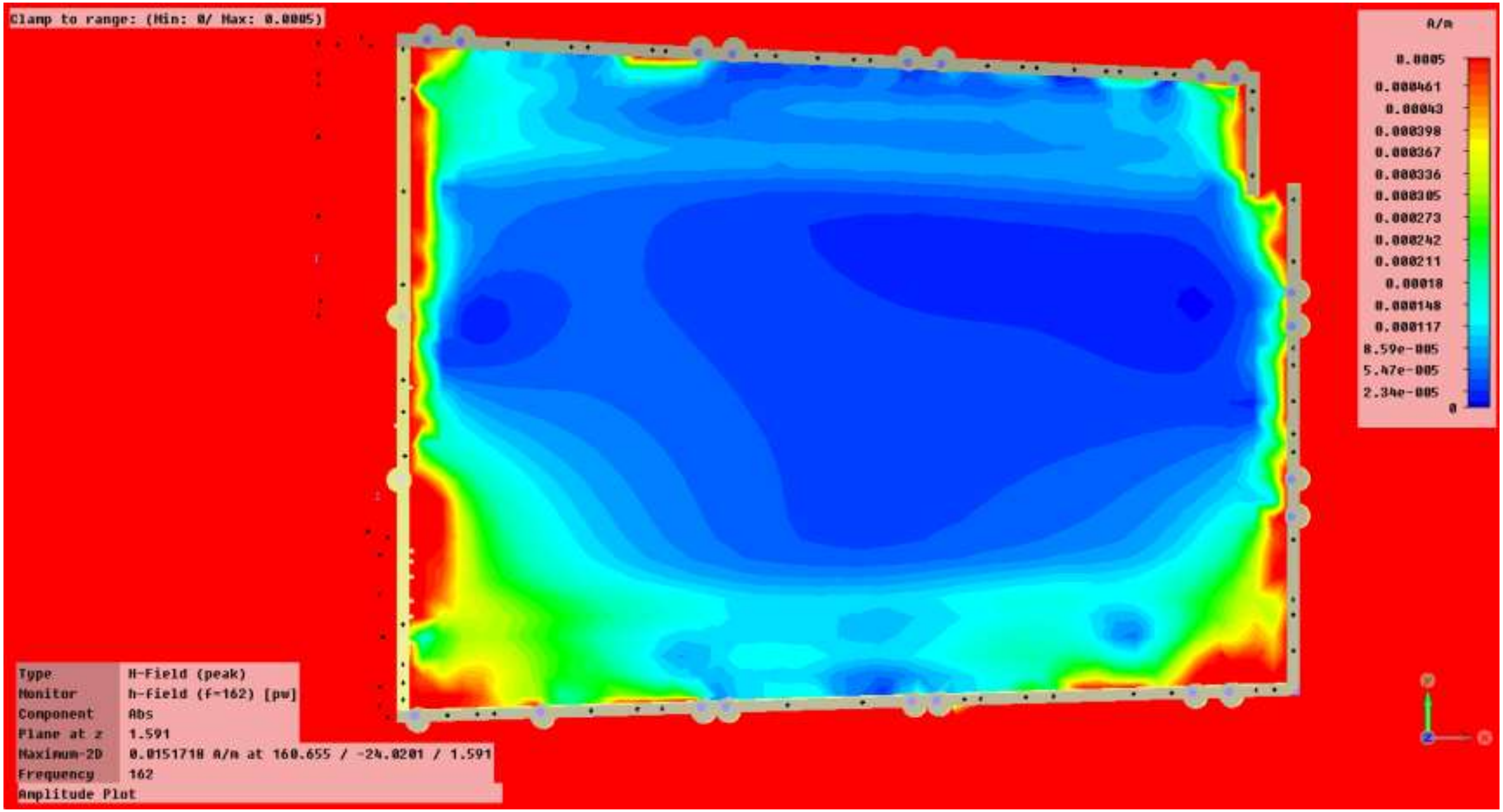
H field Scanner



Laboratory Measurement Showing H field Product Emissions at 162 MHz



H Field Plot at 162 MHz
X Plane Wave

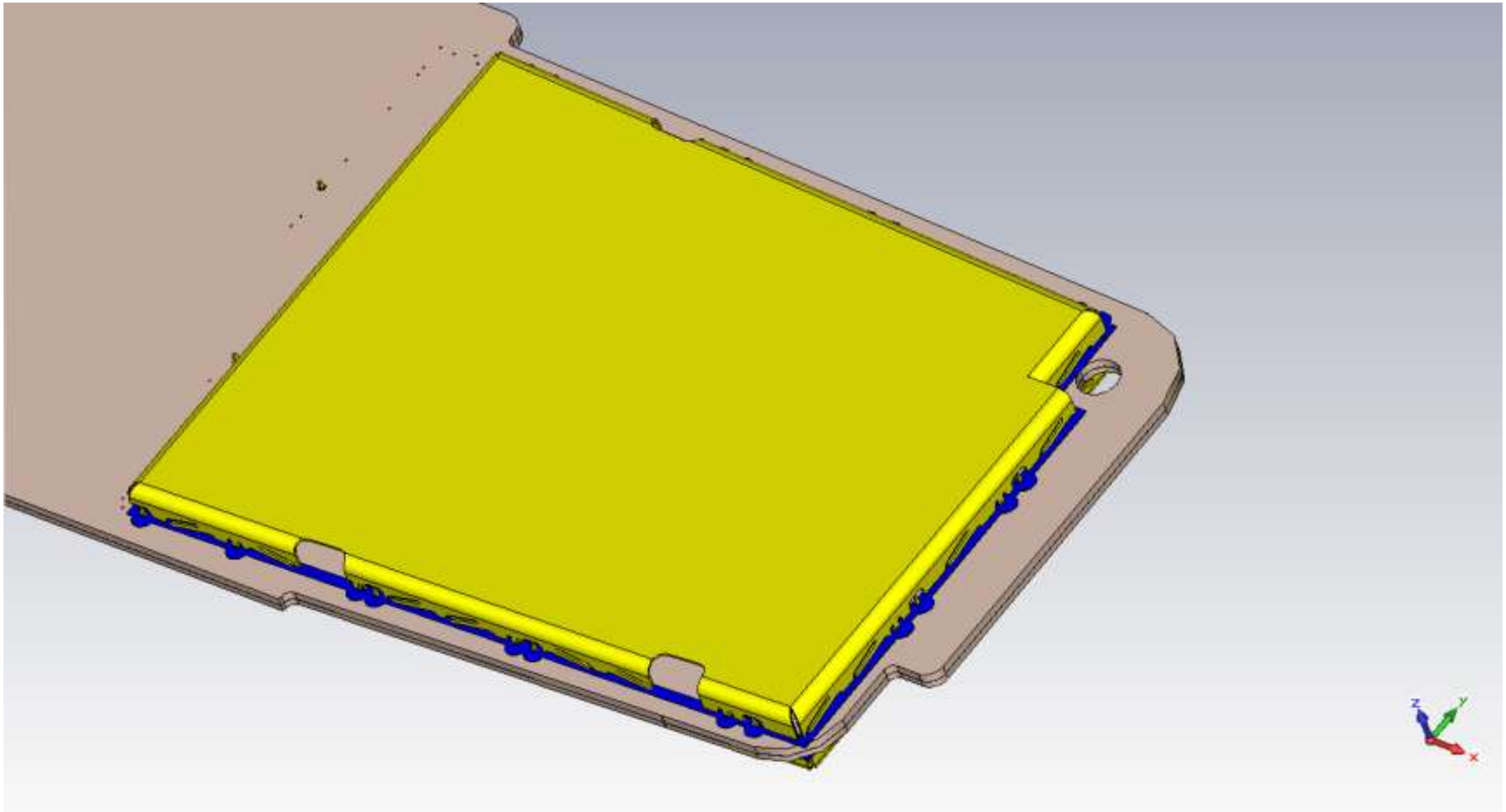


Clamp to range: (Min: 0/ Max: 0.0005)

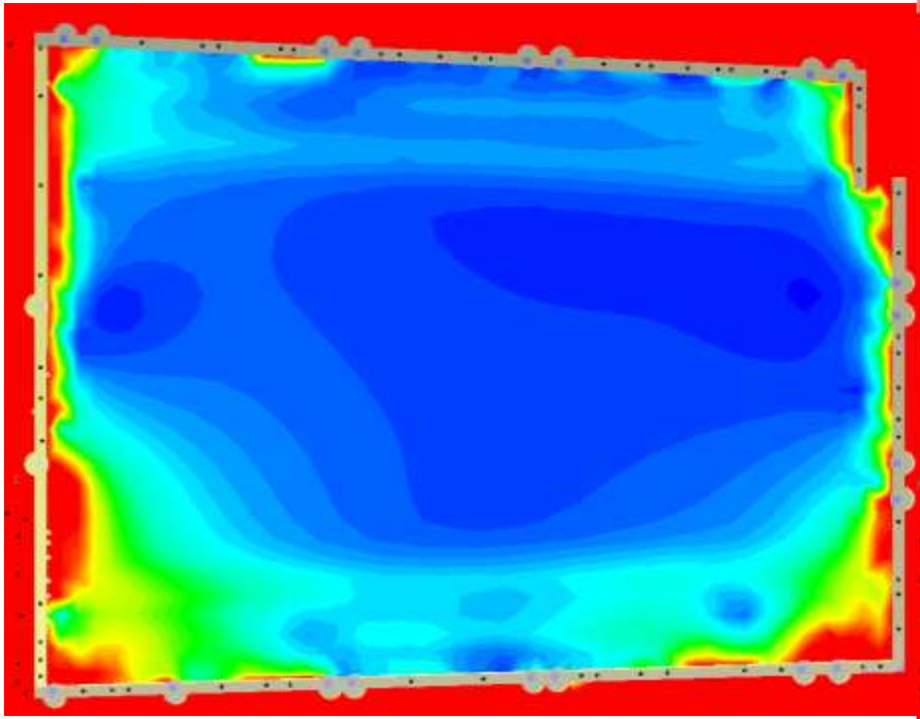
Type	H-Field (peak)
Monitor	h-Field (f=162) [pw]
Component	Abs
Plane at z	1.591
Maximum-2D	0.0151718 A/m at 160.655 / -24.0201 / 1.591
Frequency	162

Amplitude Plot

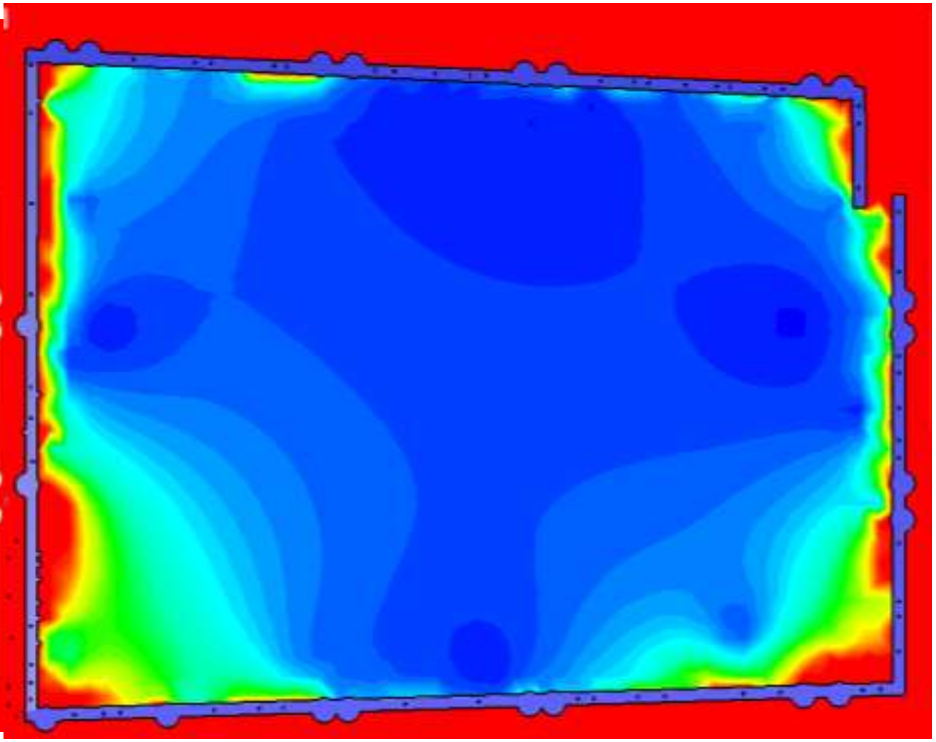
Vent Holes Removed



H Field Plot at 162 MHz
X Plane Wave

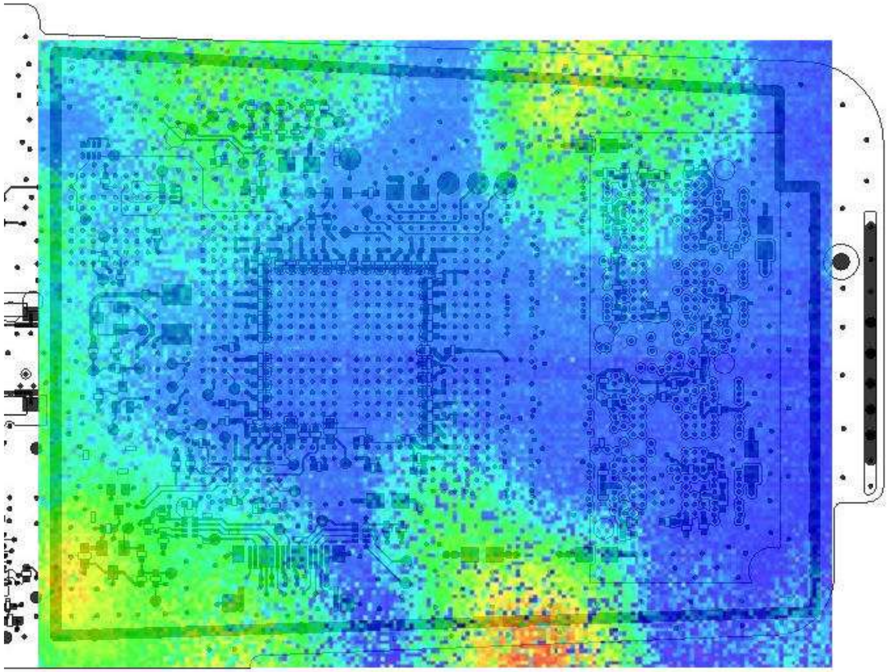


Model with Vents

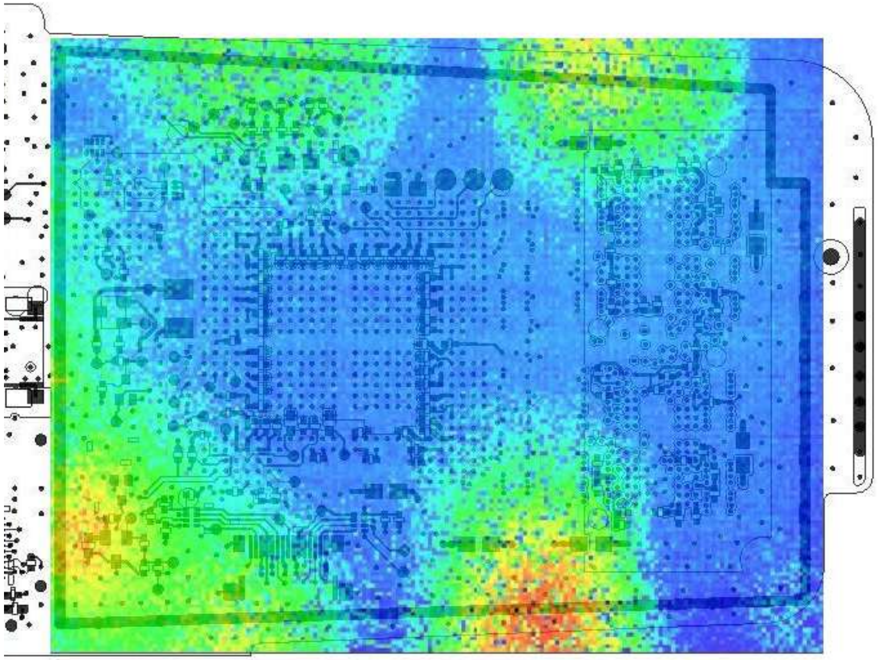


Model Without Vents

H Field Laboratory Measurement At 162 MHz

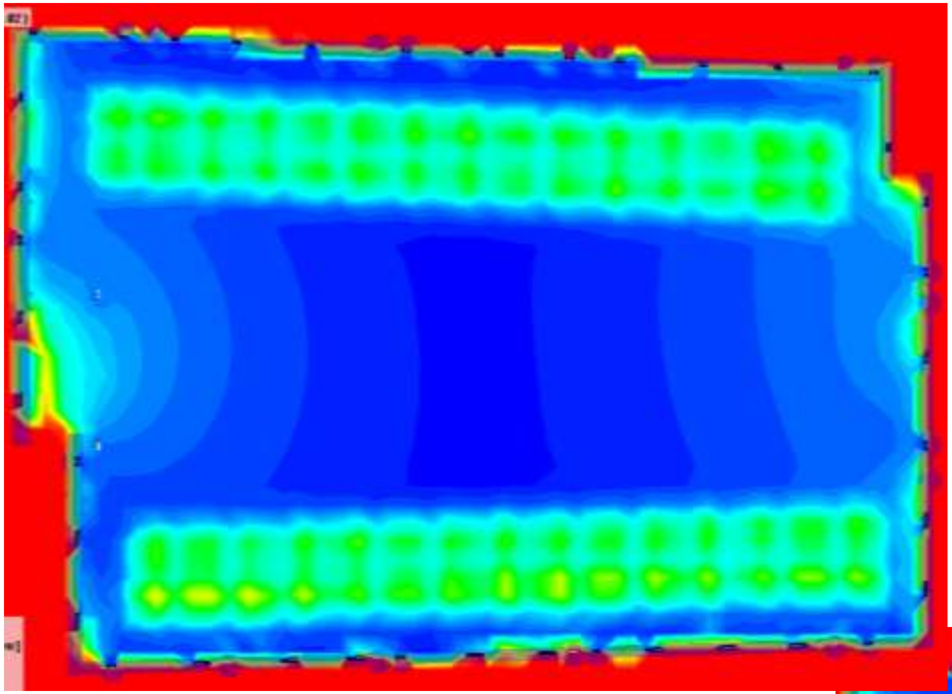


Measured With Vents

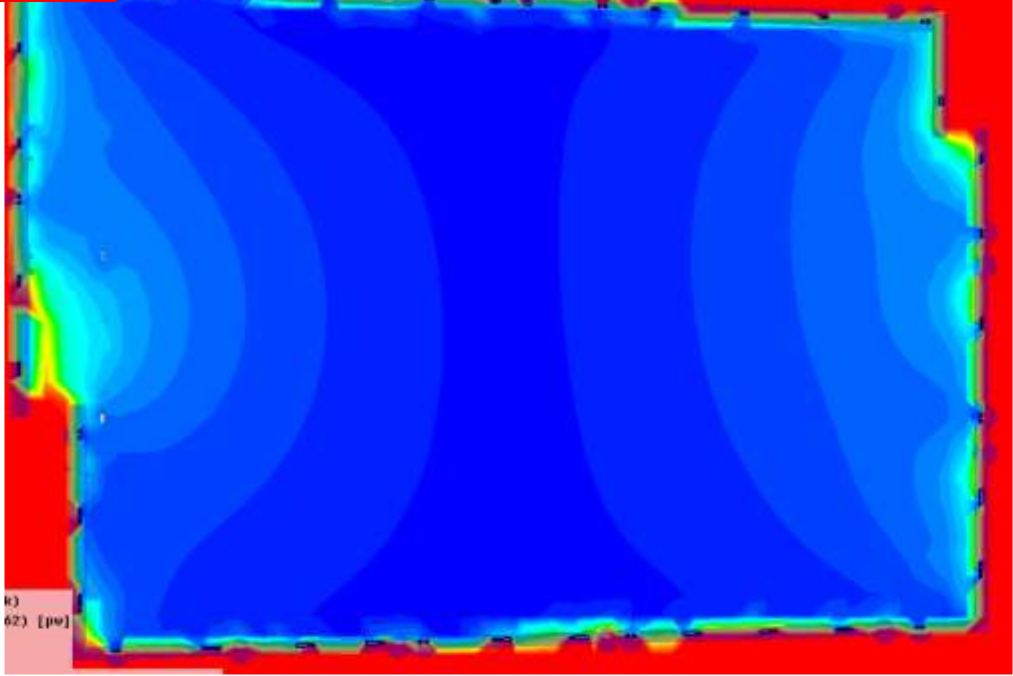


Measured Without Vents

E Field Plot
At 162 MHz



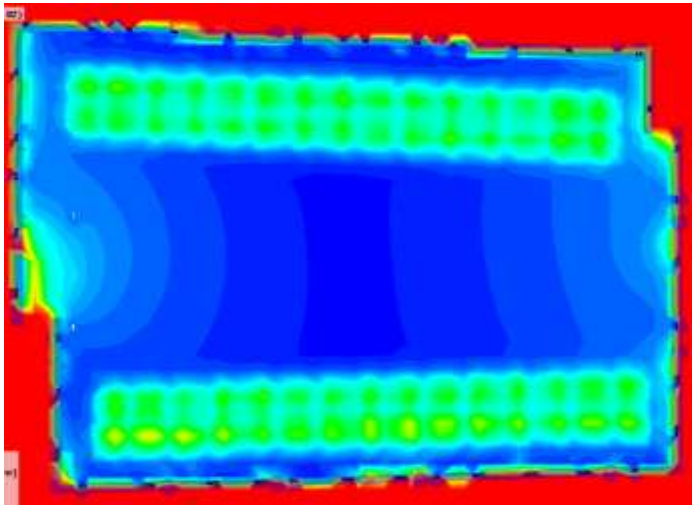
With Vents



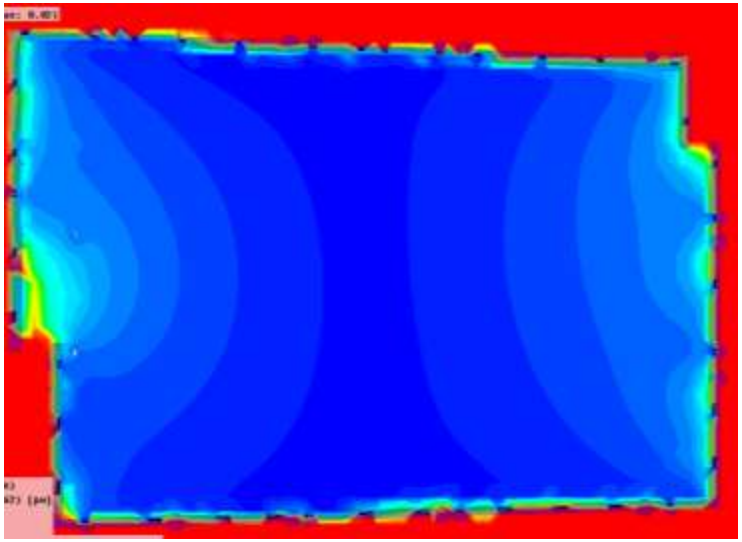
Without Vents

Shield Apertures

- Electrically small apertures reduce electric field shielding when the source/receiver is close to the aperture
- This demonstration shows that apertures of a certain nature can impact electric field shielding but not magnetic field shielding

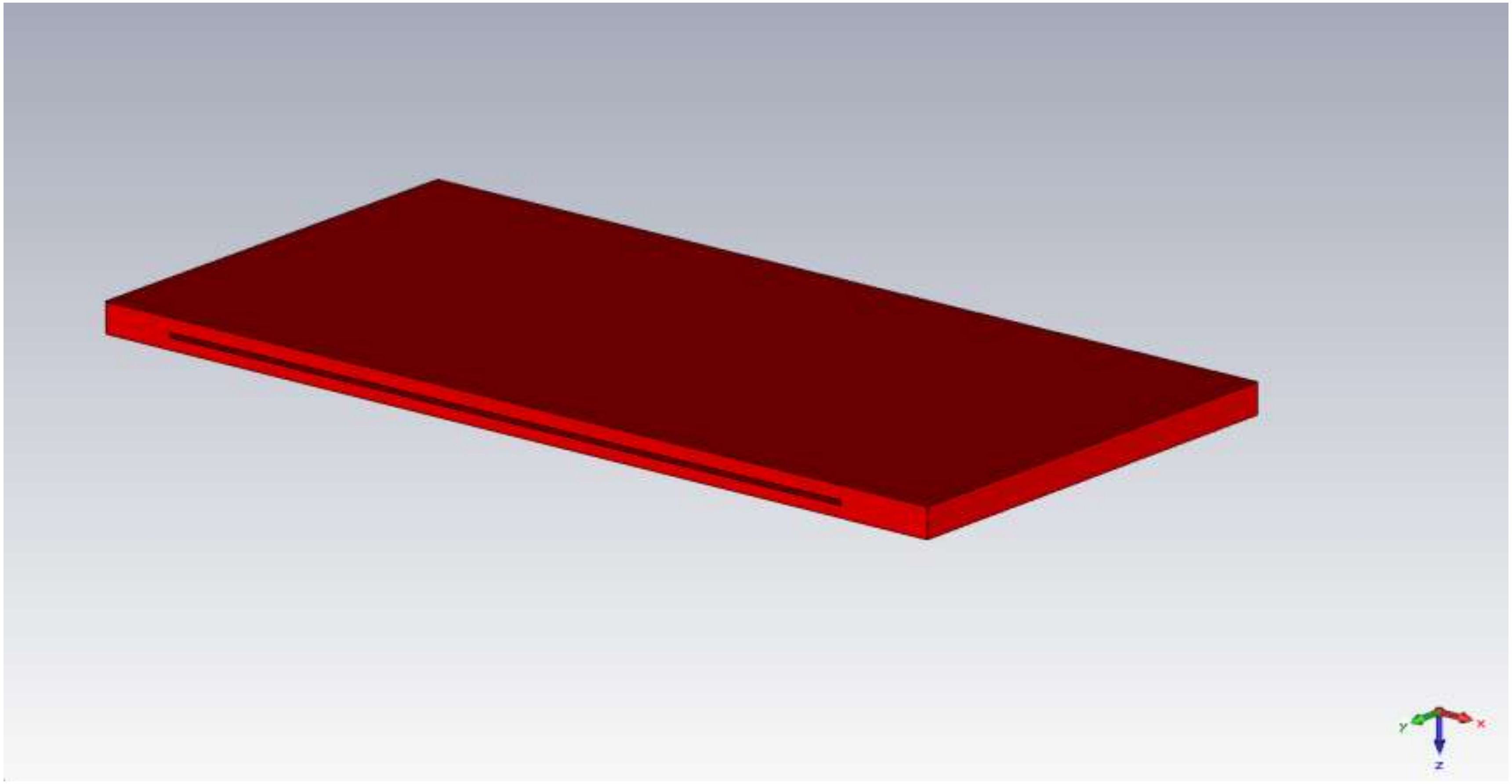


E field With Vents

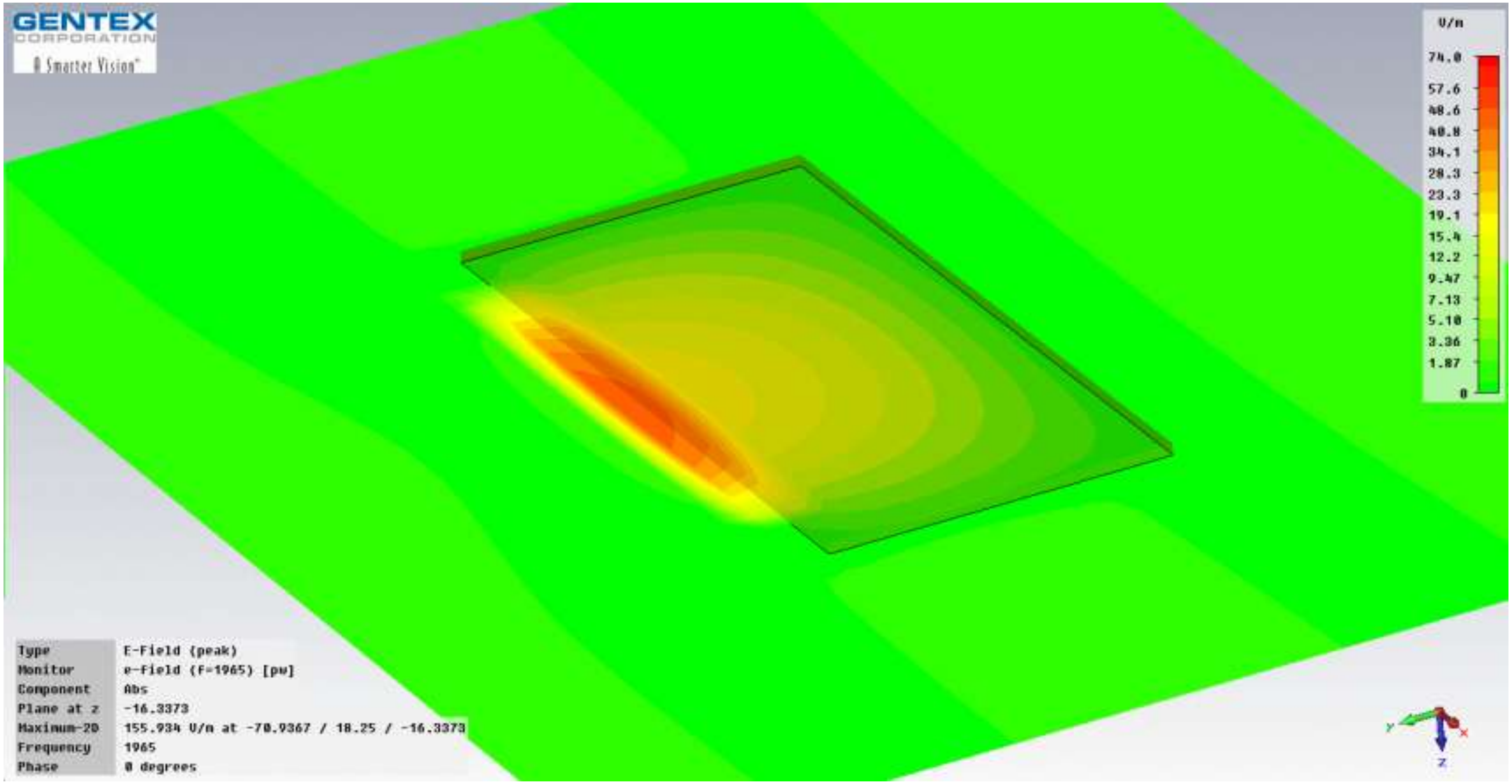


E Field Without Vents

Slots

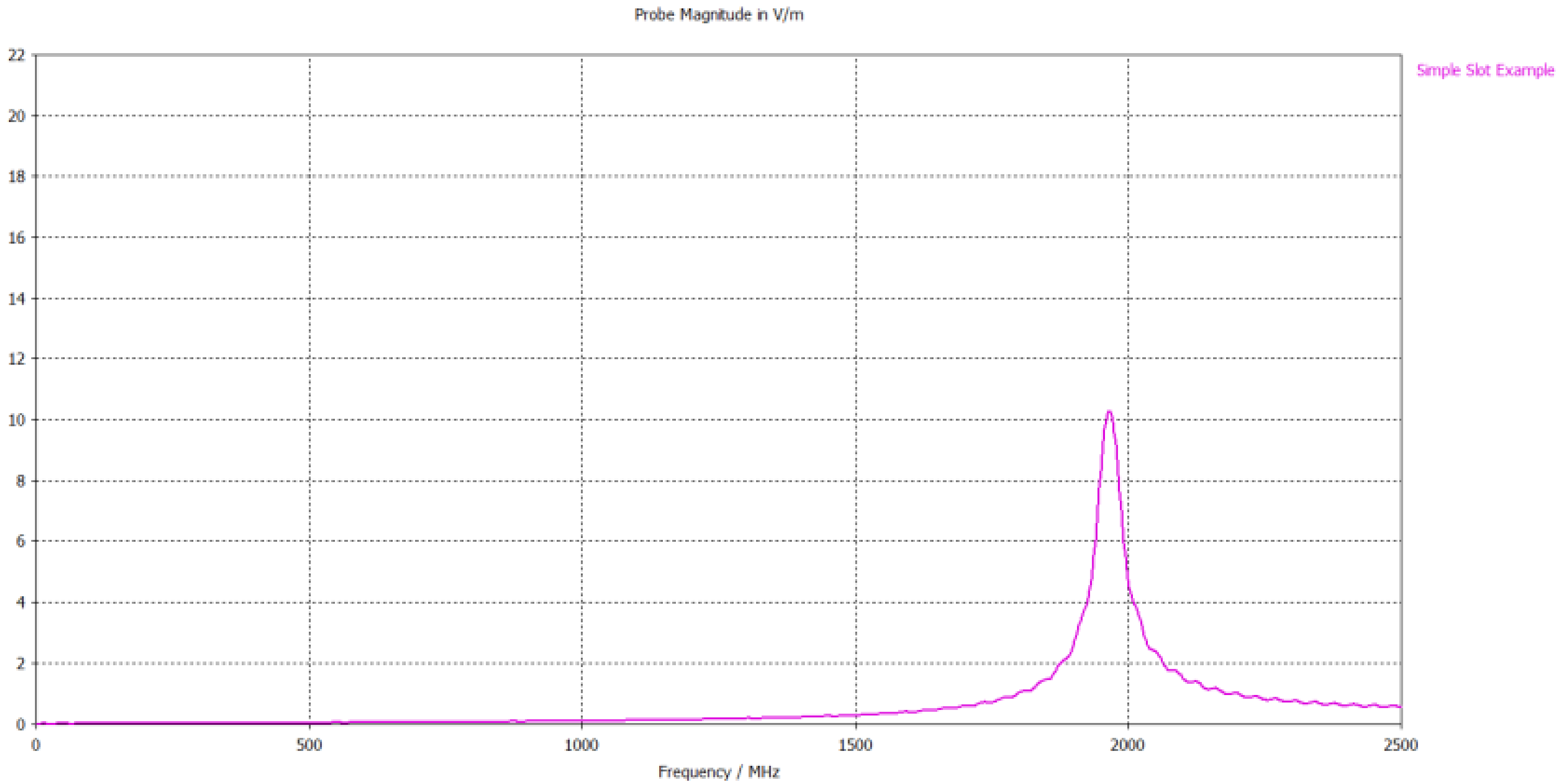


Simple Radiation Pattern



Type	E-Field (peak)
Monitor	e-Field (f=1965) [pw]
Component	Abs
Plane at z	-16.3373
Maximum-2D	155.934 V/m at -70.9367 / 18.25 / -16.3373
Frequency	1965
Phase	0 degrees

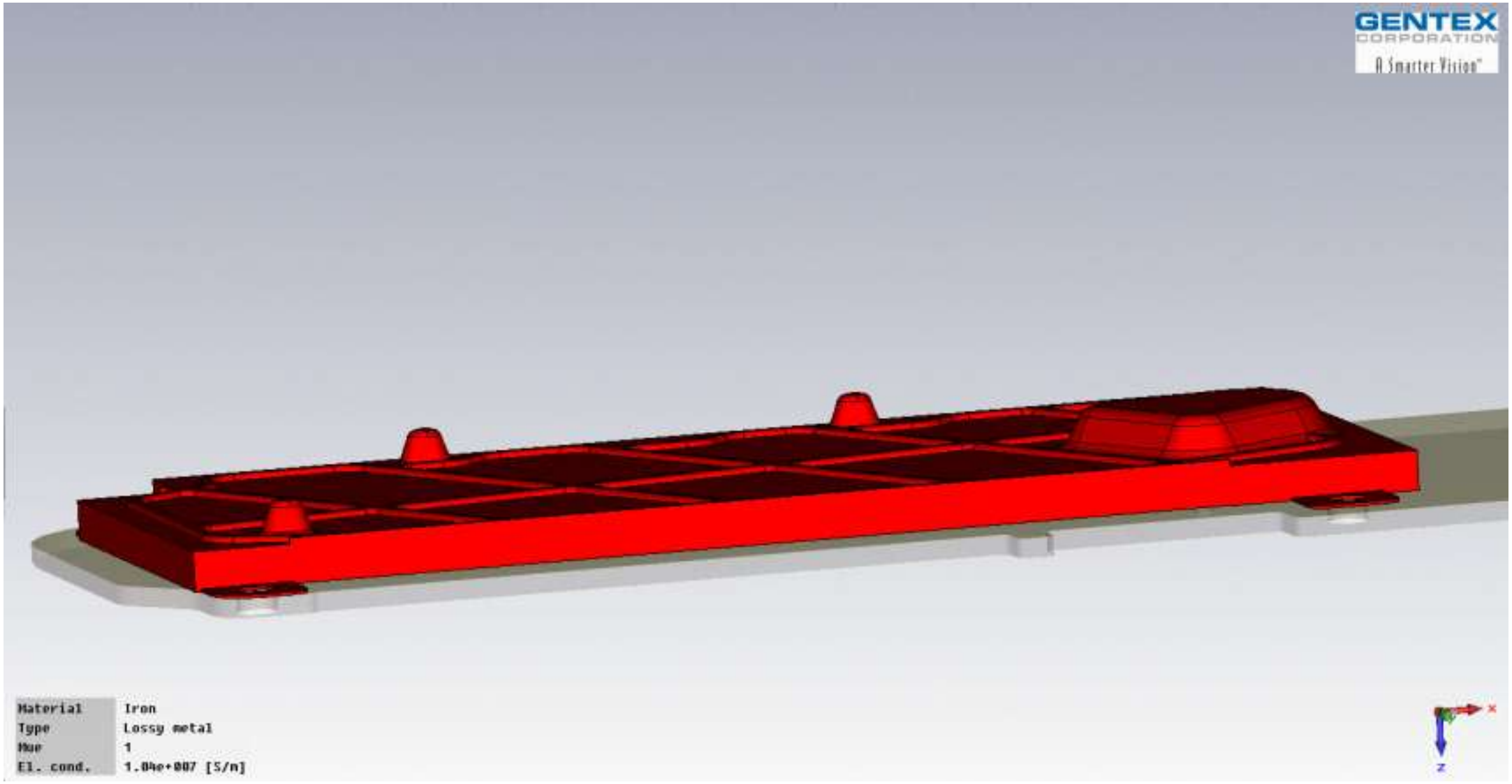
Simple Slot Graph



Slots

- Slots can be created in a shield through several ways
  - If two metallic surfaces are touching but not pressed together, there is a poor connection between these two surfaces
  - Seams
  - Lids
  - Gaskets
  - Paints
- A shield connection should NOT be through a screw!

Base Line Shield

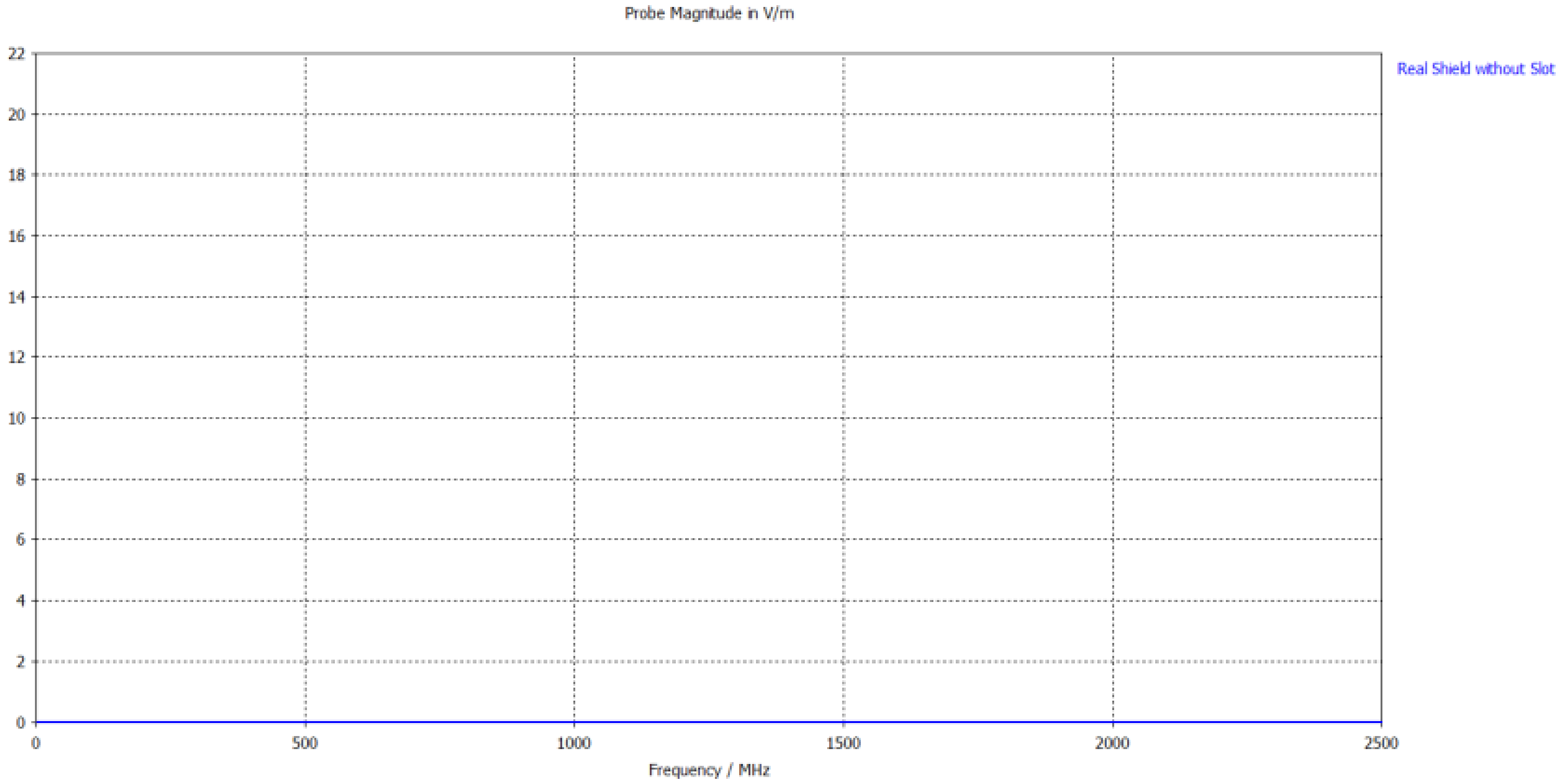


Material	Iron
Type	Lossy metal
Mue	1
El. cond.	1.04e+007 [S/m]

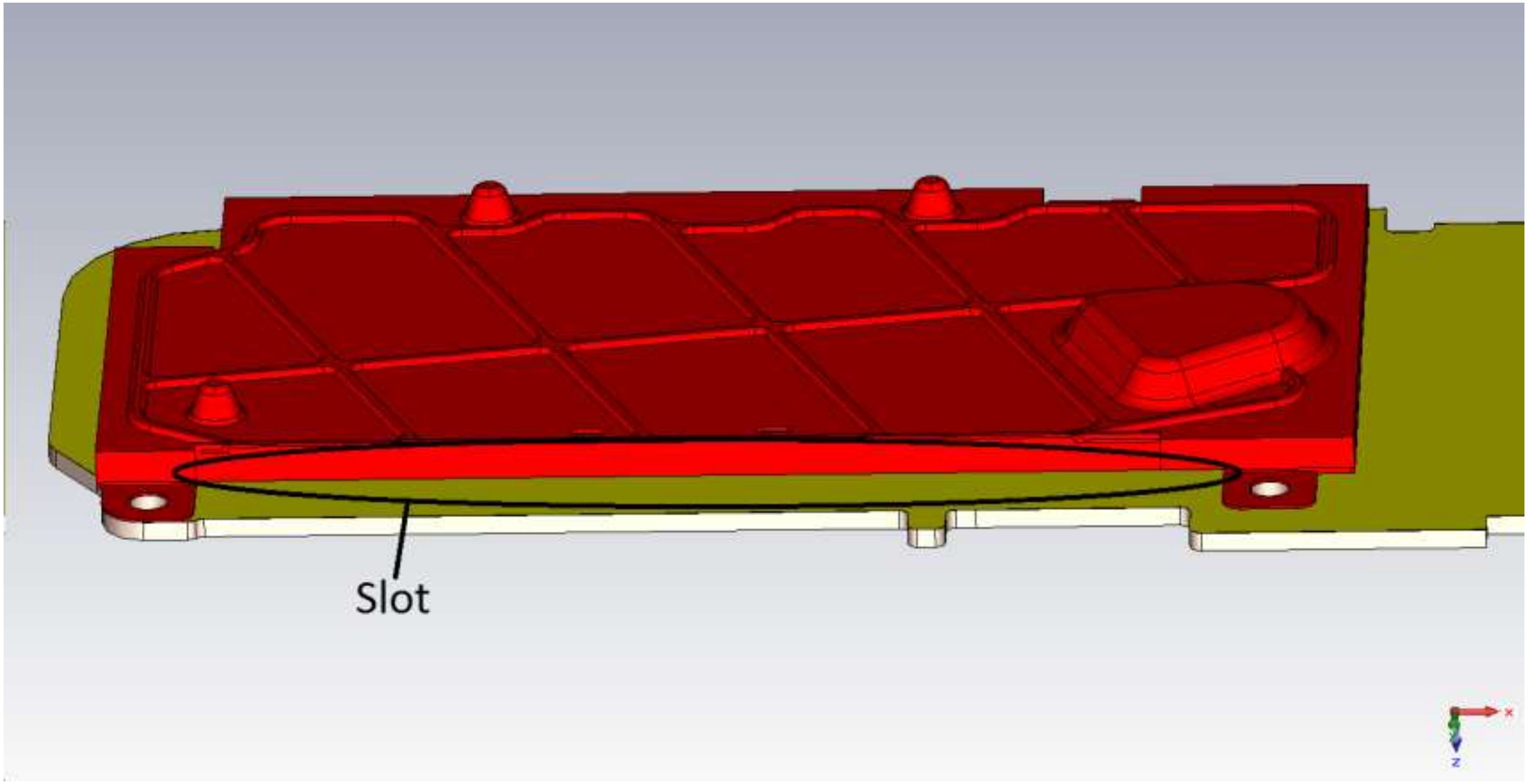
Applied EMI Wave

```
Type          E-Field
Monitor       e-field (t=0.0005..0.0015(0.00001)) [pw]
Component     Abs
Plane at z    -14.7551
Maximum-2D    1.69537 V/m at -52.3732 / 27.475 / -14.7551
Sample        1 / 101
Time          0.0005
```

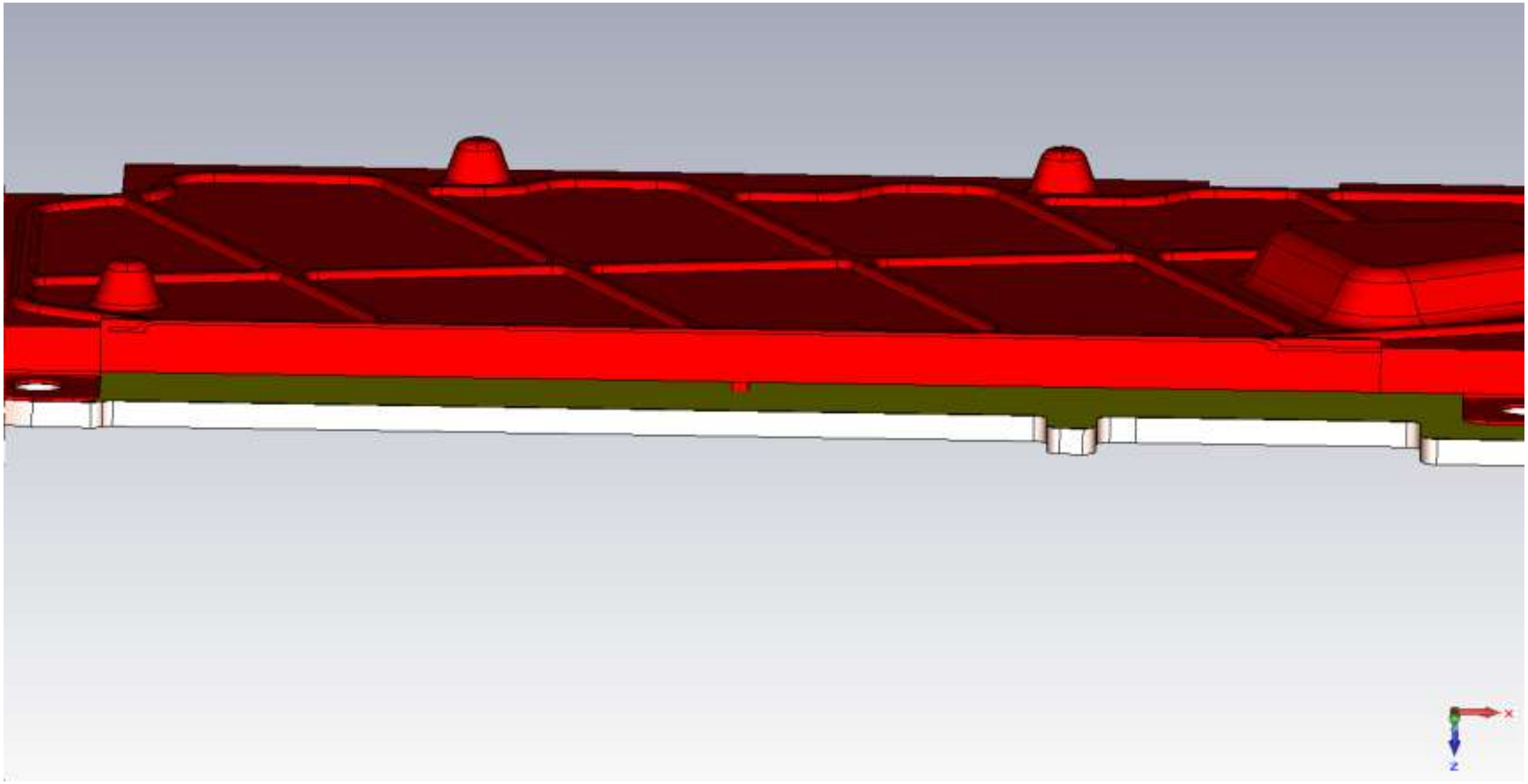
Real Shield without Slot Graph



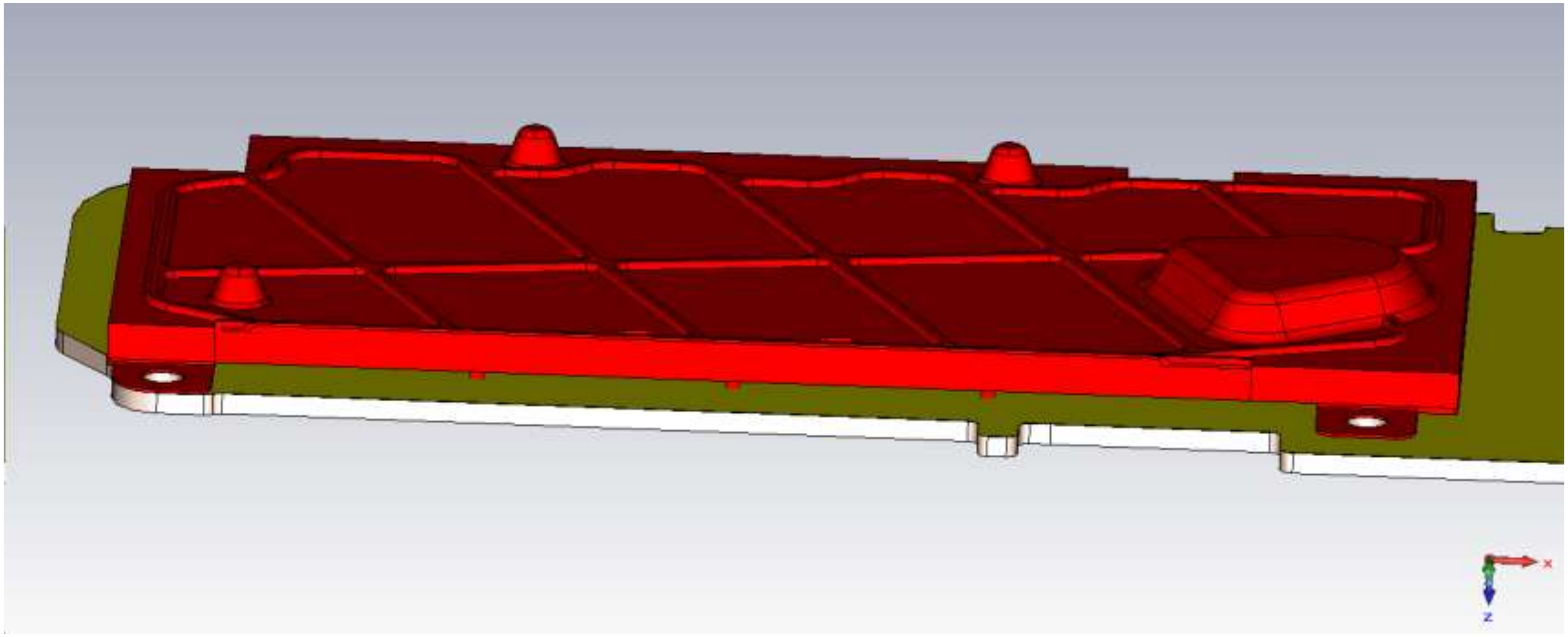
Real Shield with Slot



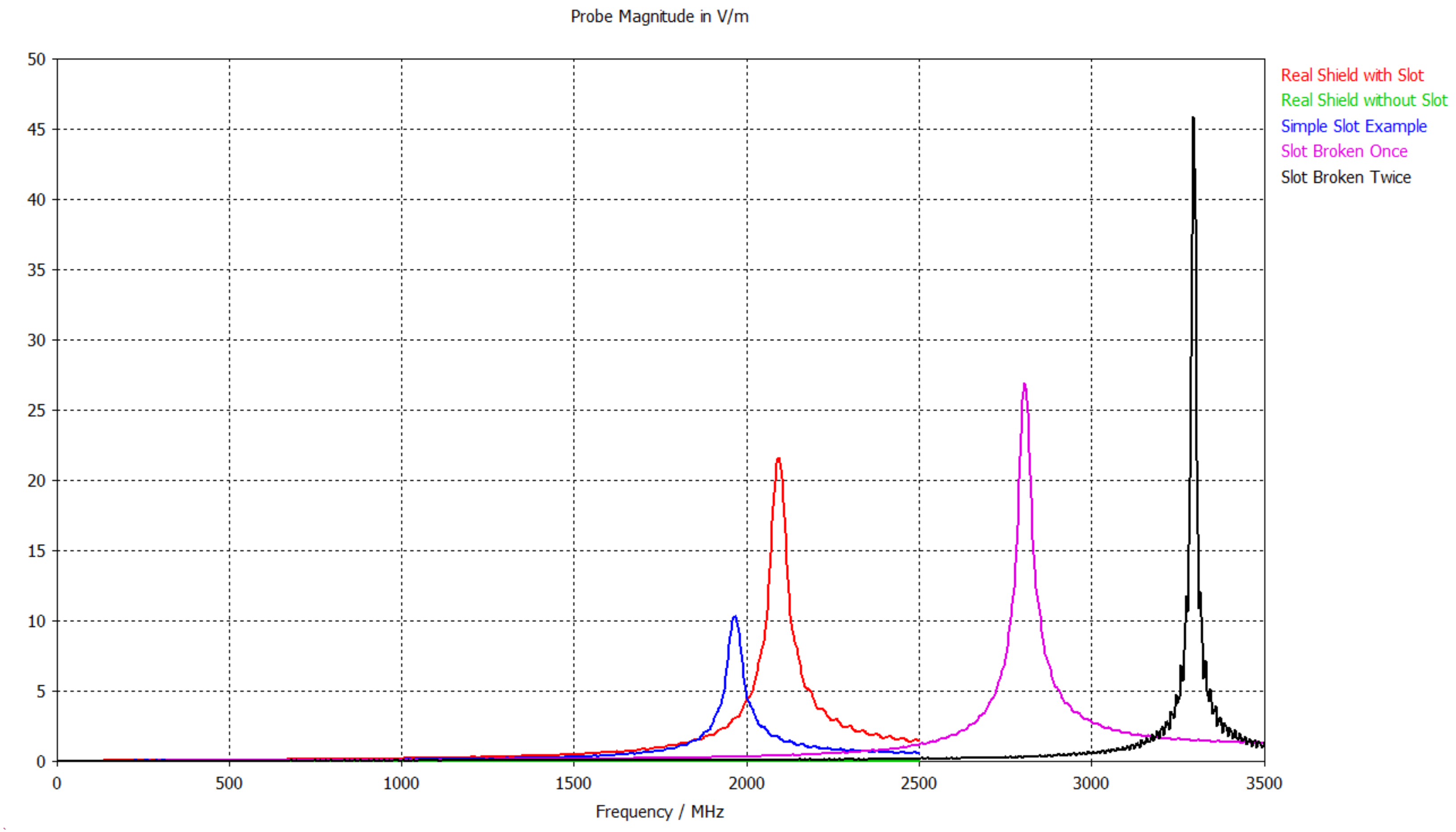
Slot Broken in Two



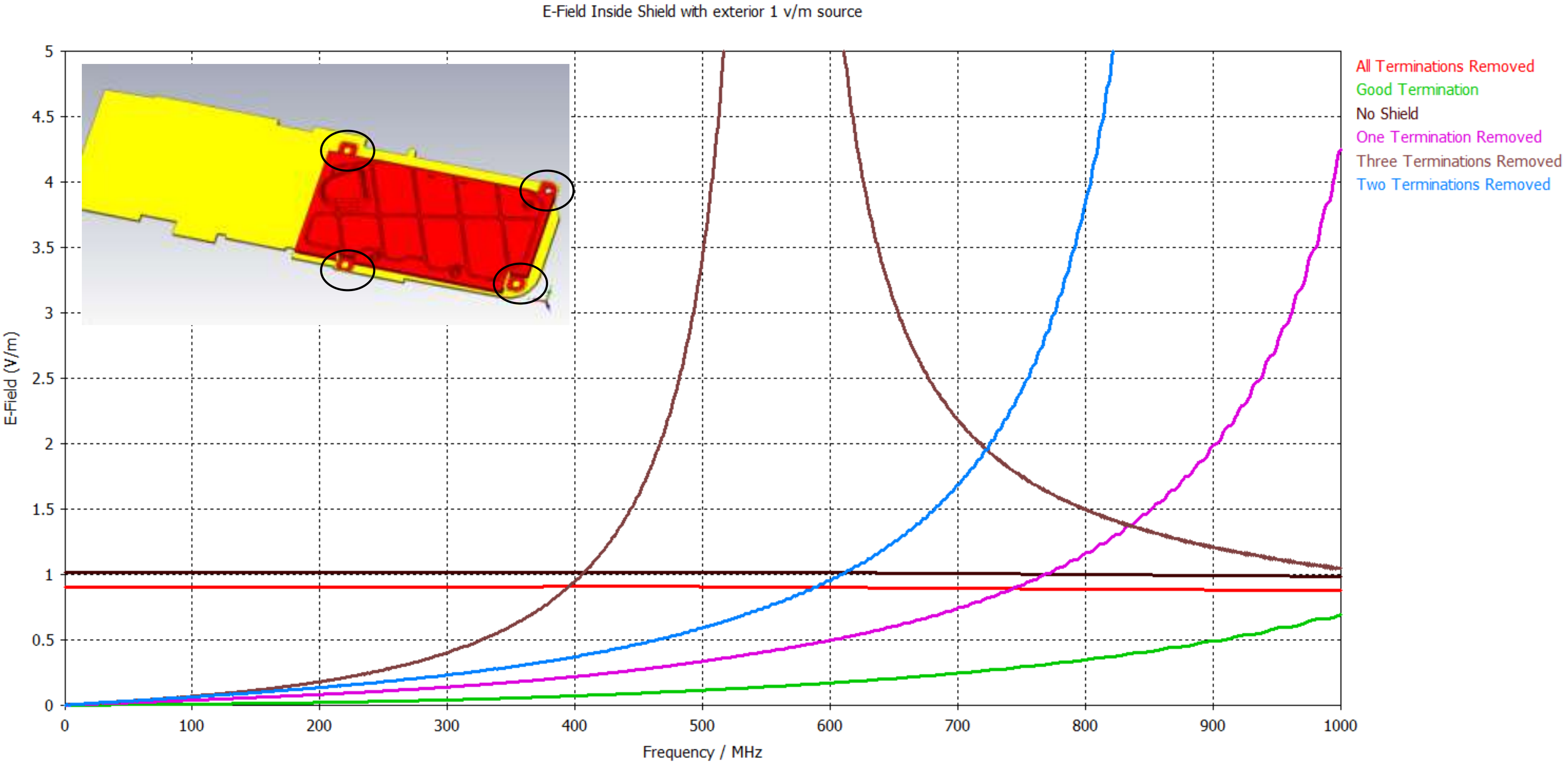
Slot Broken in Four



Summary Graph

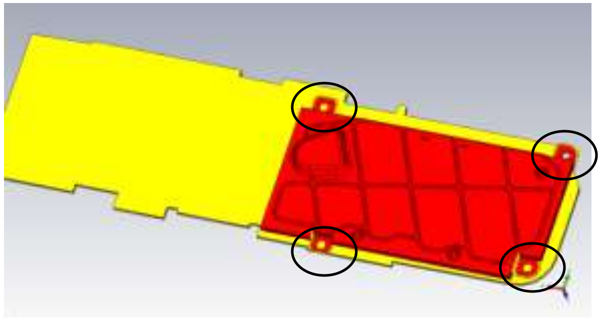


Simulation of a PCB shield with various lifted terminations:



PCB Shield Terminations

- Slot antennas are created between shield termination points
- Fewer shield terminations may be easier to install but may create resonant conditions at critical frequencies
- Shields reduce the fields at lower frequencies with a risk of creating resonance at higher frequencies



What Makes an Effective Shield?

Static Electric Field

?

Static Magnetic Field

?

Low Frequency Electric Field

?

Low Frequency Magnetic Field

?

High Frequency Electromagnetic Field

?

What Makes an Effective Shield?

Static Electric Field	Static Magnetic Field	Low Frequency Electric Field	Low Frequency Magnetic Field	High Frequency Electromagnetic Field
Same Potential as Victim Circuit	High Permeability Material	High Conductivity Material	Thick Material (compared with skin depth)	Small Apertures (compared to wavelength)