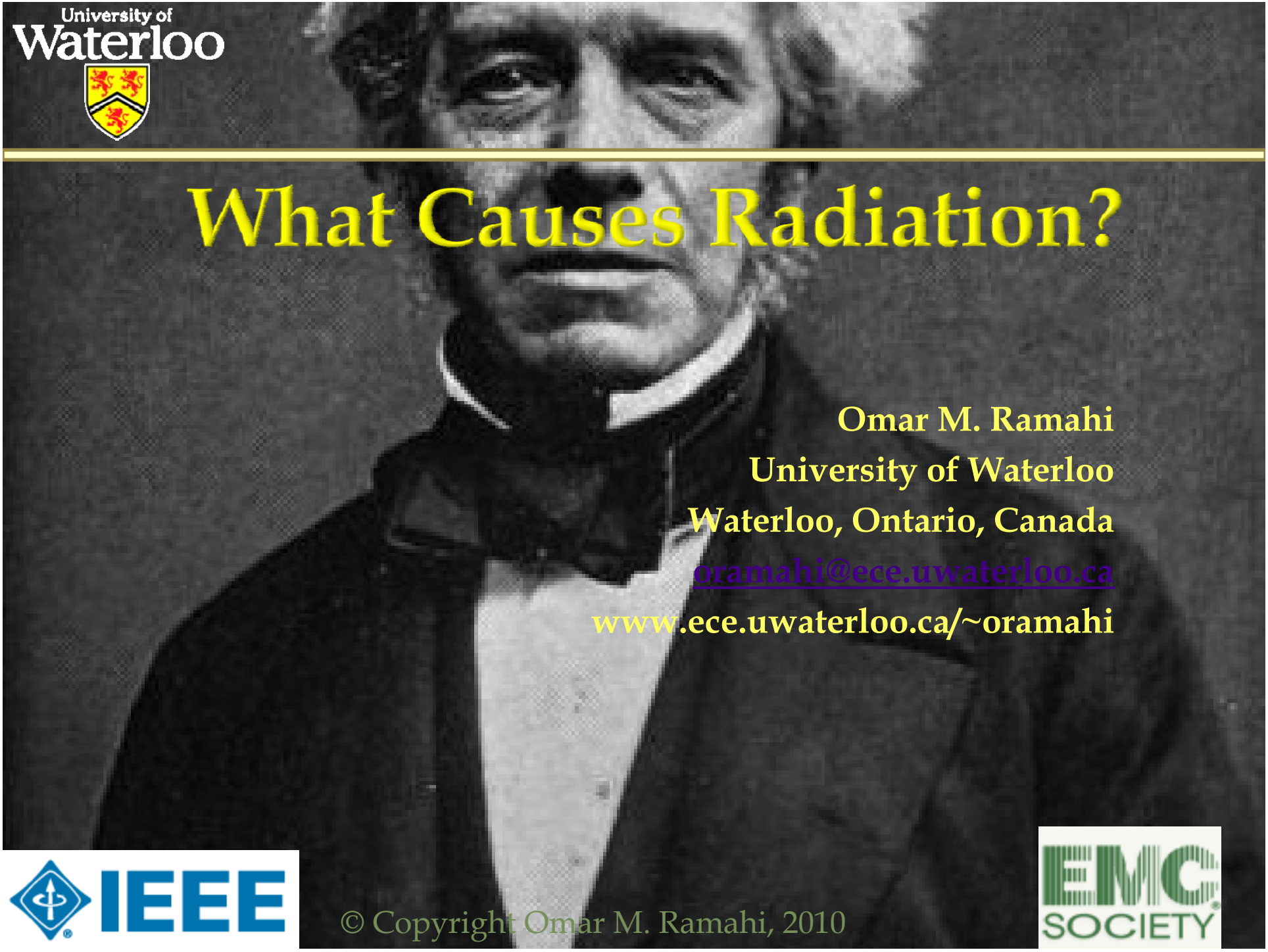

What Causes Radiation?

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University of Waterloo

gratitude… to many wonderful colleagues and brilliant graduate students who are too many to mention

…

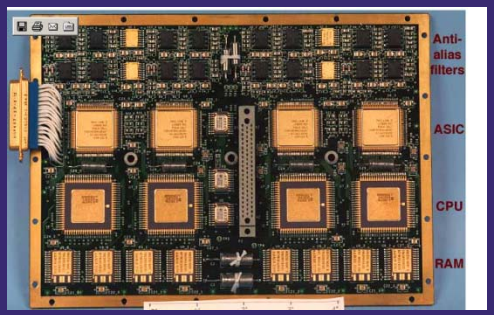
BUT SO GOOD NEVER TO FORGET!

IEEE

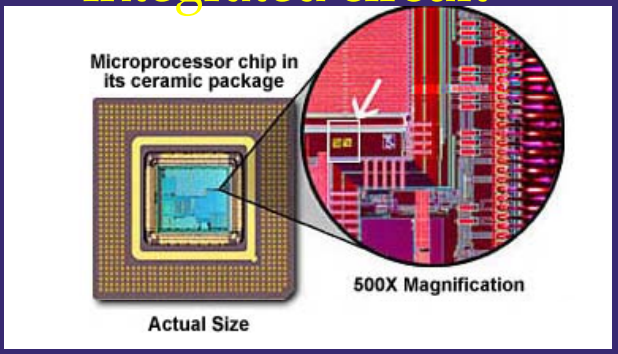
EMC SOCIETY

Source of Electromagnetic Noise

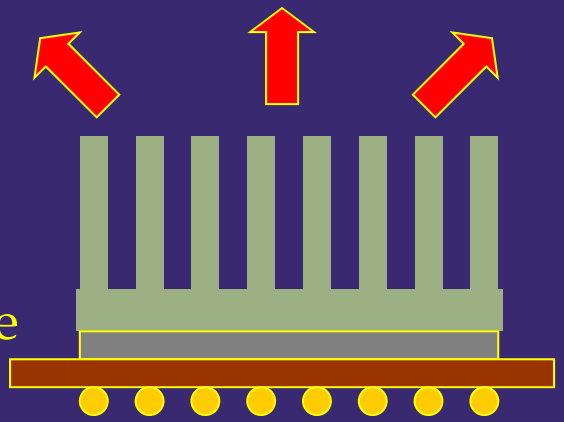
Printed circuit boards



Integrated circuit



Heat sink radiate electromagnetic energy at resonance mode



Chasses

University of Waterloo

What causes radiation?

Faraday's Law, full stop!

$$\int_{\mathrm{L}} E \cdot dl = -\frac{\partial}{\partial t} \int_{\mathrm{A}} \mathrm{B} \cdot \mathrm{dA}$$

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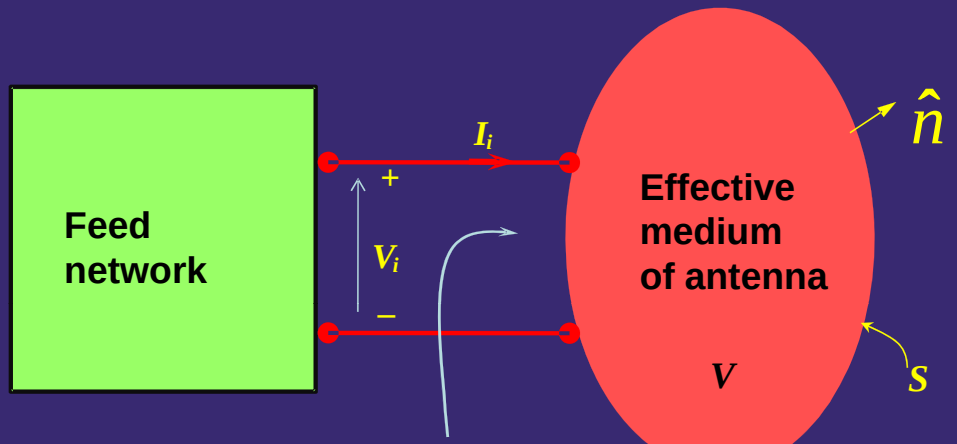
What about Maxwell's Equations?

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

A mathematical interpretation of Faraday's and other laws!

Impedance & Field Relations

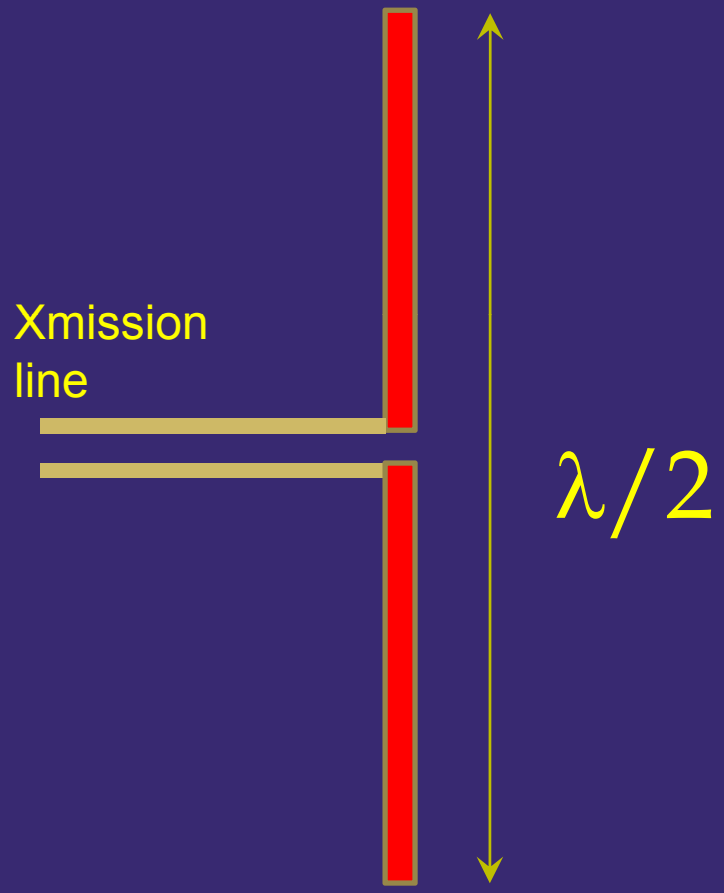


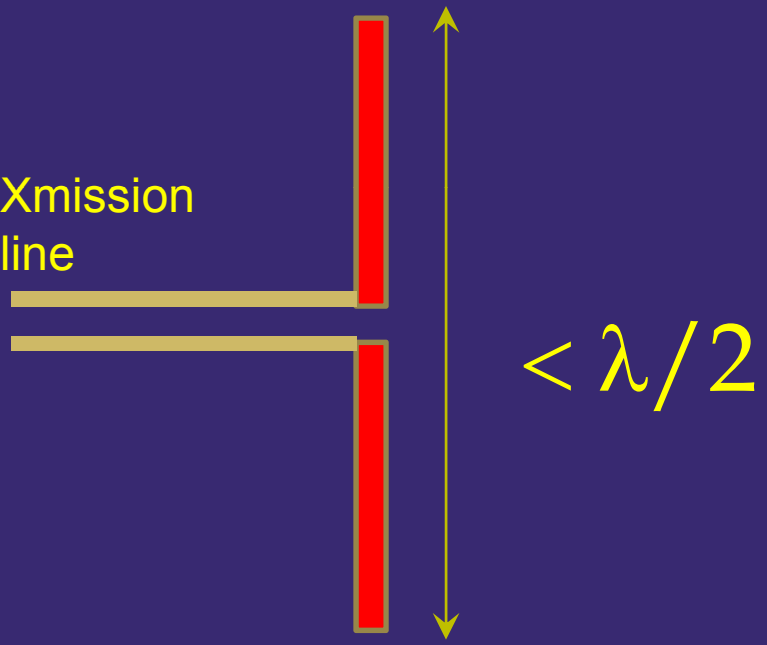
$$Z = V_i / I_i = R + jX$$

$$R = \frac{1}{|I_i|^2}\left[\mathrm{Re}\left\{\int_V (\mathbf{J}^* \cdot \mathbf{E})dv\right\} + 2\oint_A (\mathbf{S}\cdot\mathbf{n})da + 4\omega\,\mathrm{Im}\left\{\int_V (u_m - u_e)dv\right\}\right]$$

$$X = \frac{1}{|I_i|^2}\left[4\omega\,\mathrm{Re}\left\{\int_V (u_m - u_e)dv\right\} - \mathrm{Im}\left\{\int_V (\mathbf{J}^* \cdot \mathbf{E})dv\right\}\right]$$

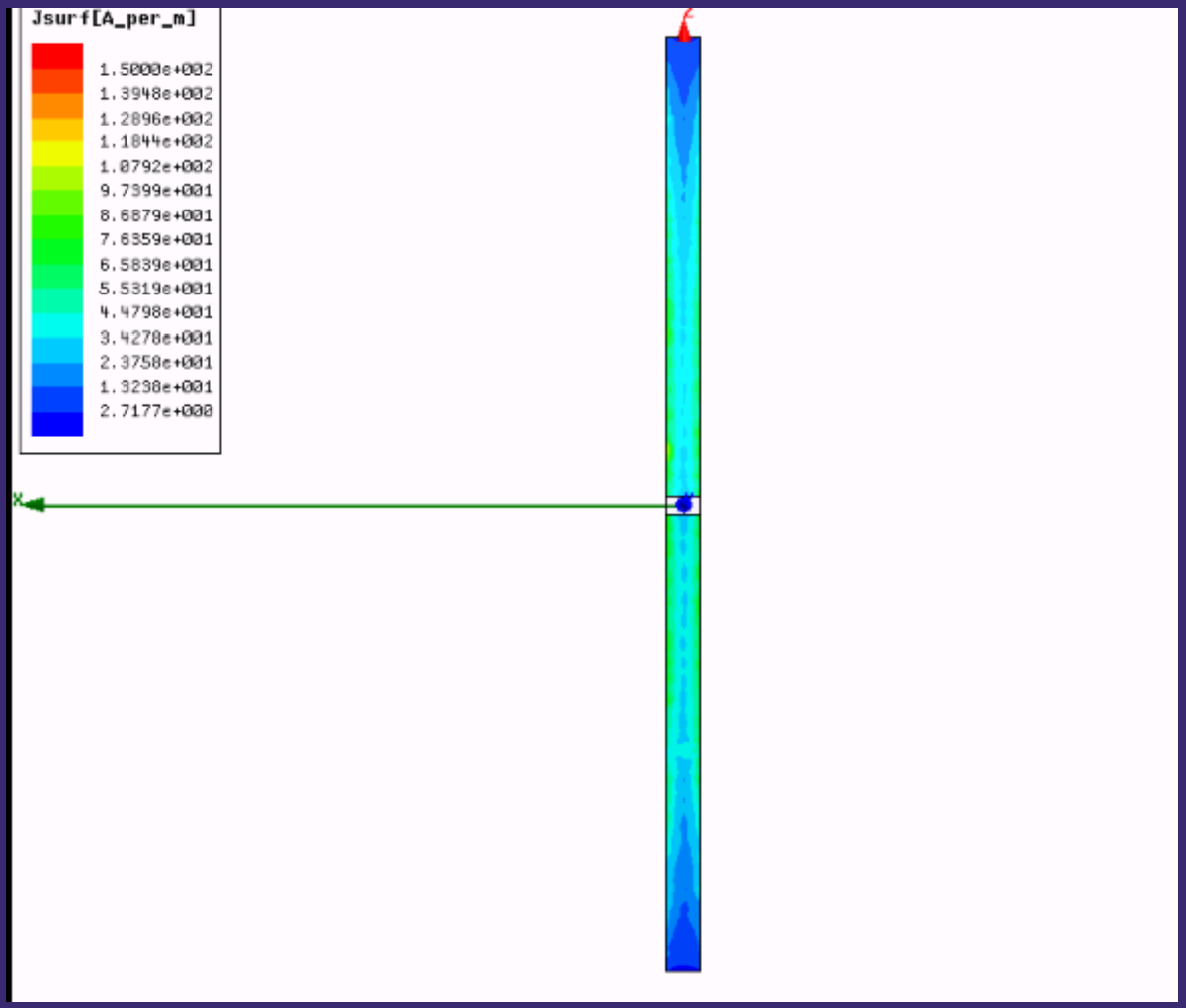
Dipole Antenna





Resonant antenna Non-resonant “antenna”

Dipole Antenna



Animation

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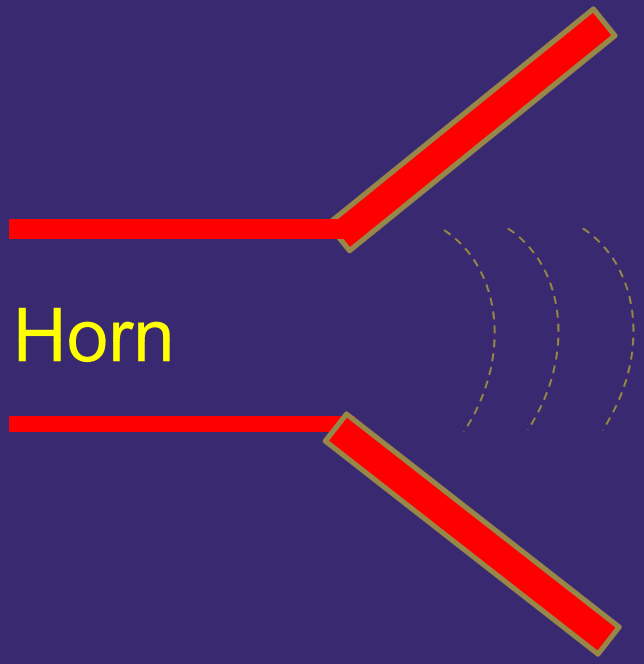
waveguides

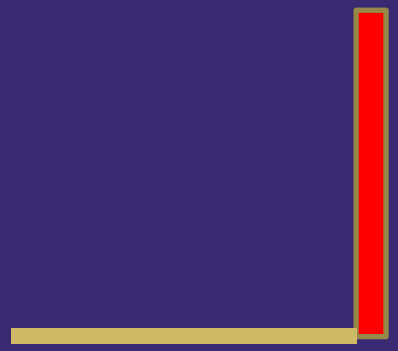
Flanged waveguide



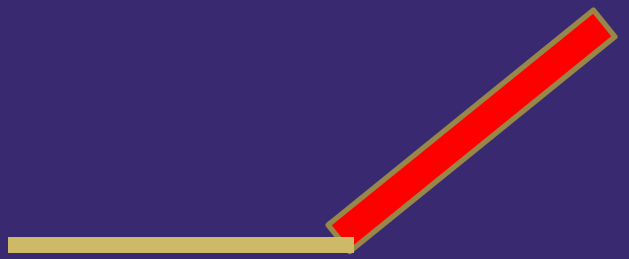
Horn

Open-Ended Waveguide

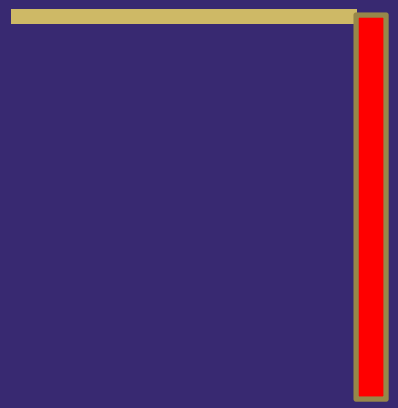
Flanged waveguide and Horn



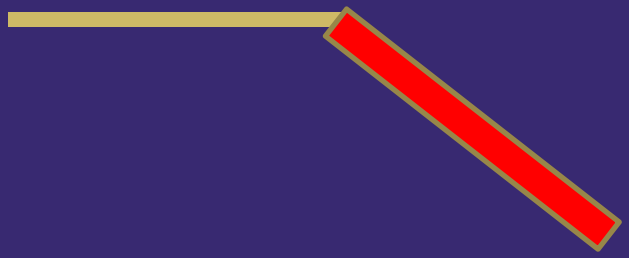
waveguide



waveguide

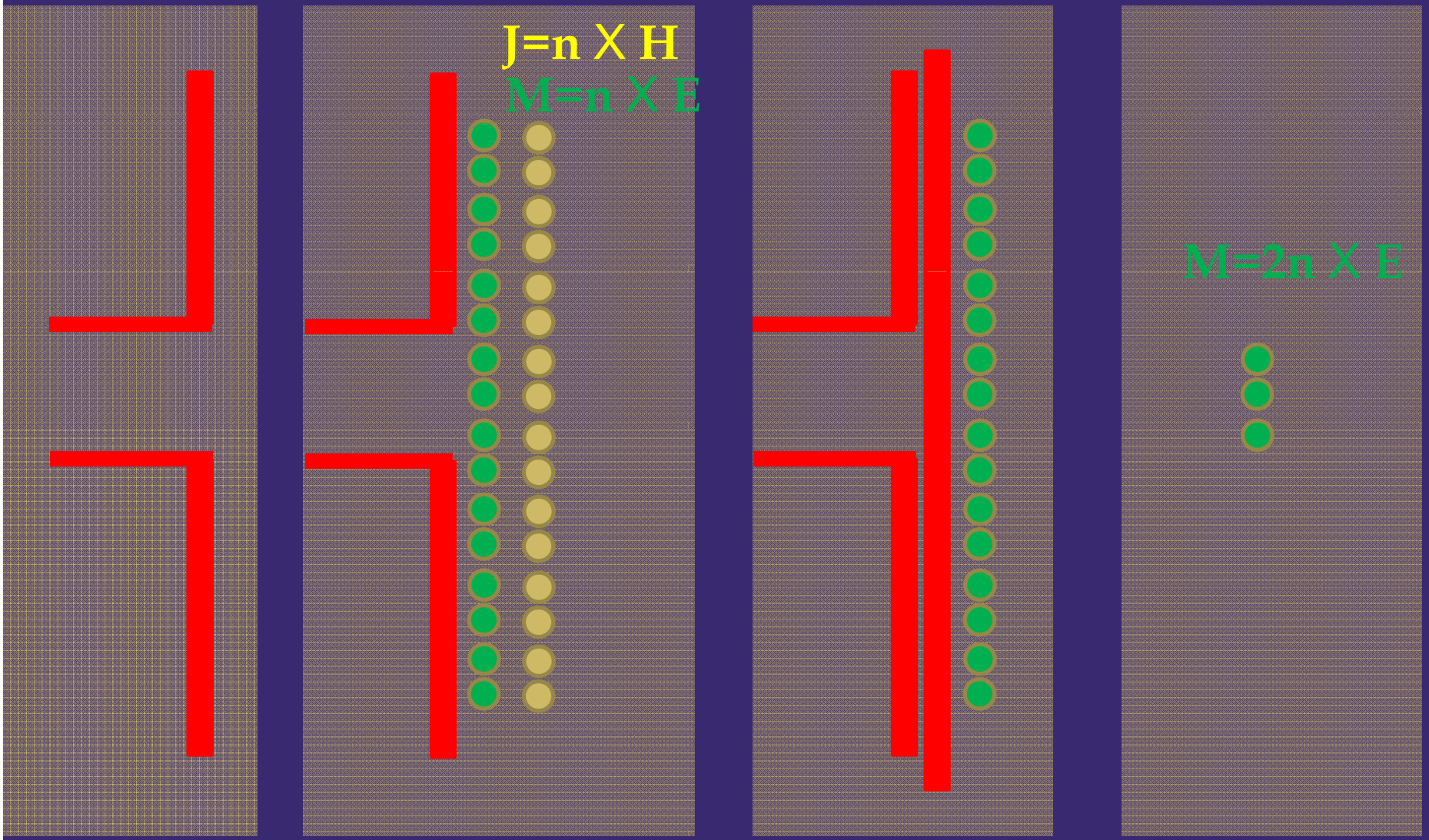


Flanged waveguide

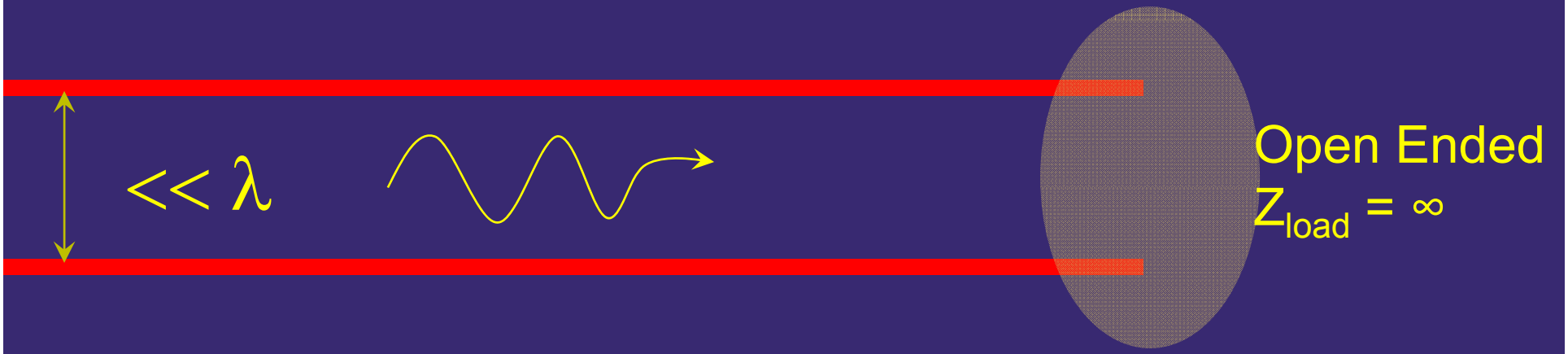


Horn

Flanged waveguide!



Consider a TEM wave 377Ω Xmission line



Expect full reflection!
Maximum Impedance Missmatch!

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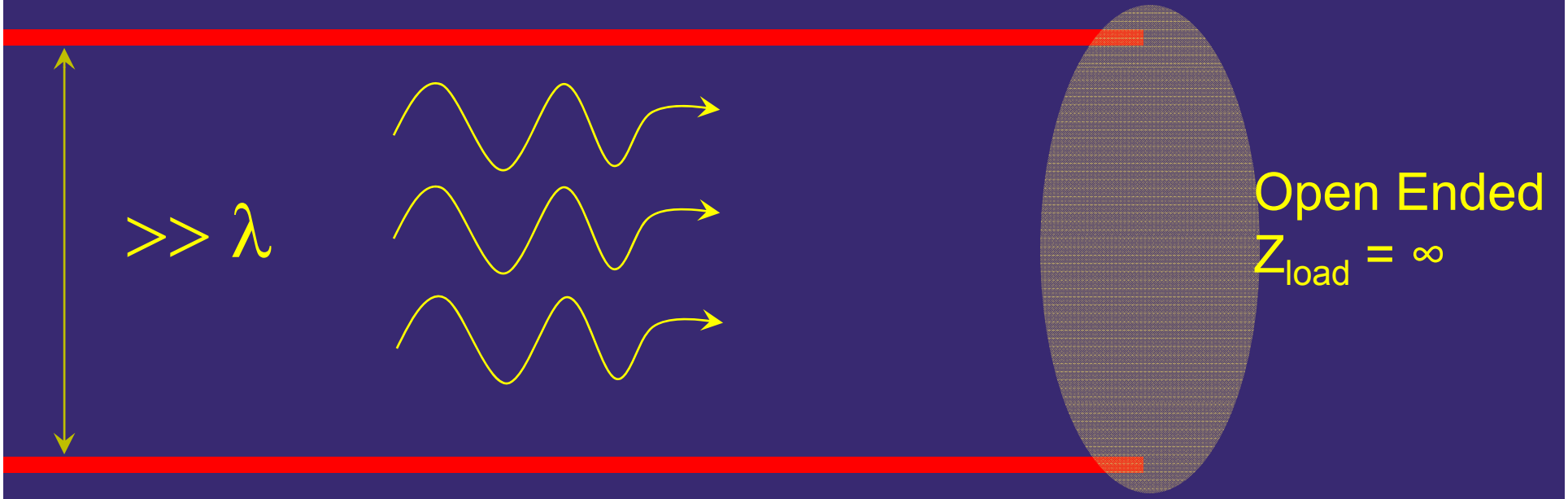
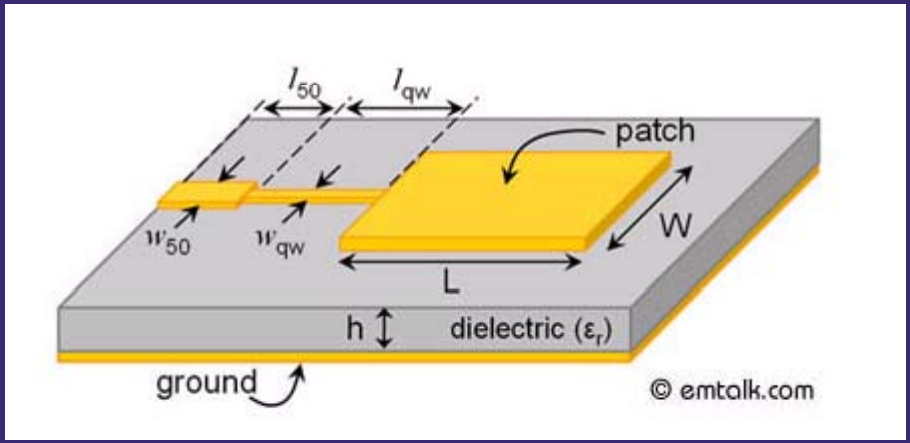
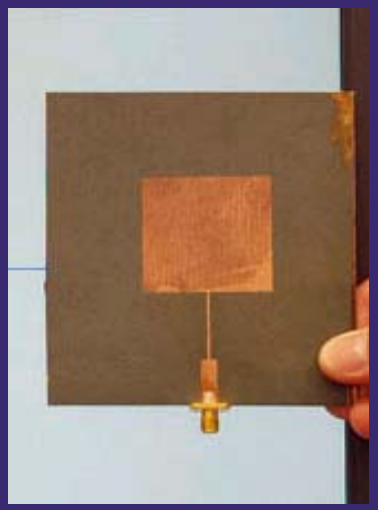
Consider a much wider Xmission line



Wave impedance is defined locally
And varies over the cross section…
Hence, radiation is possible!

The Invincible μstrip Patch Antenna





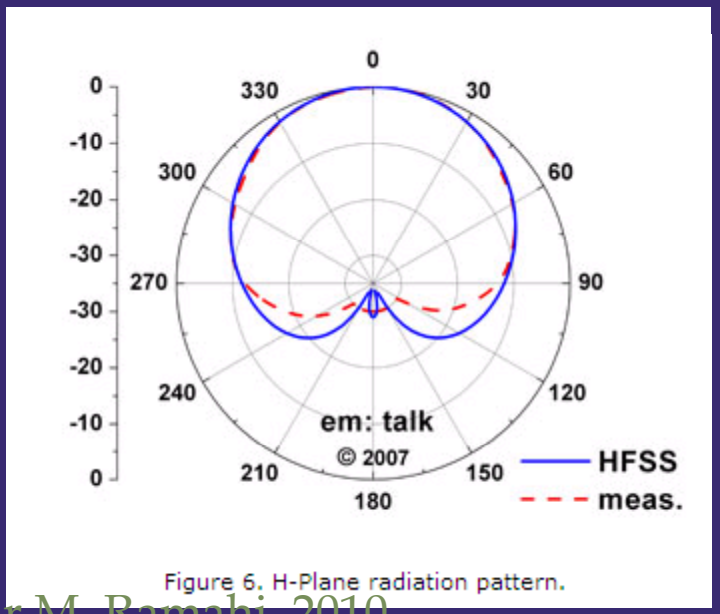
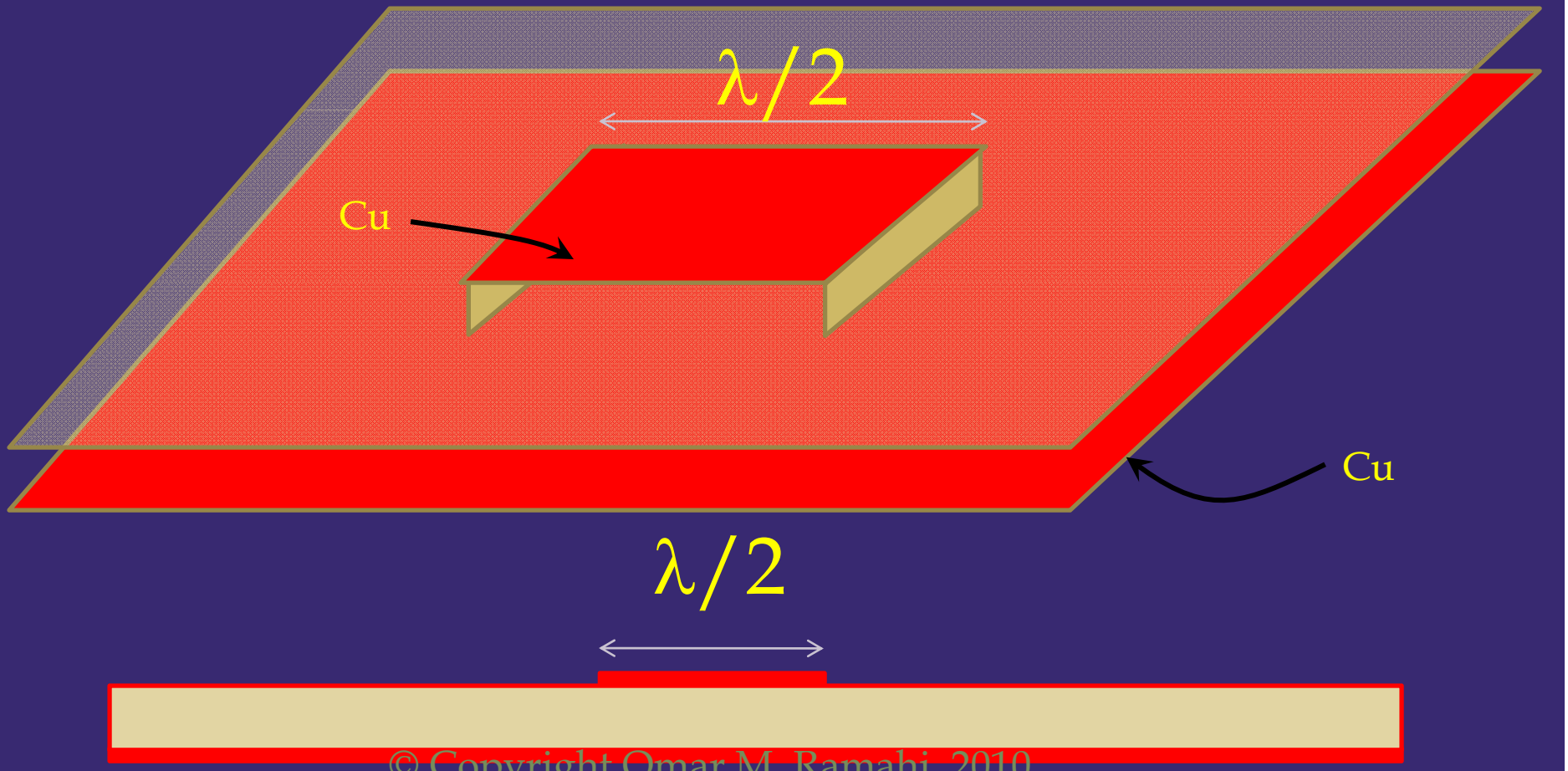
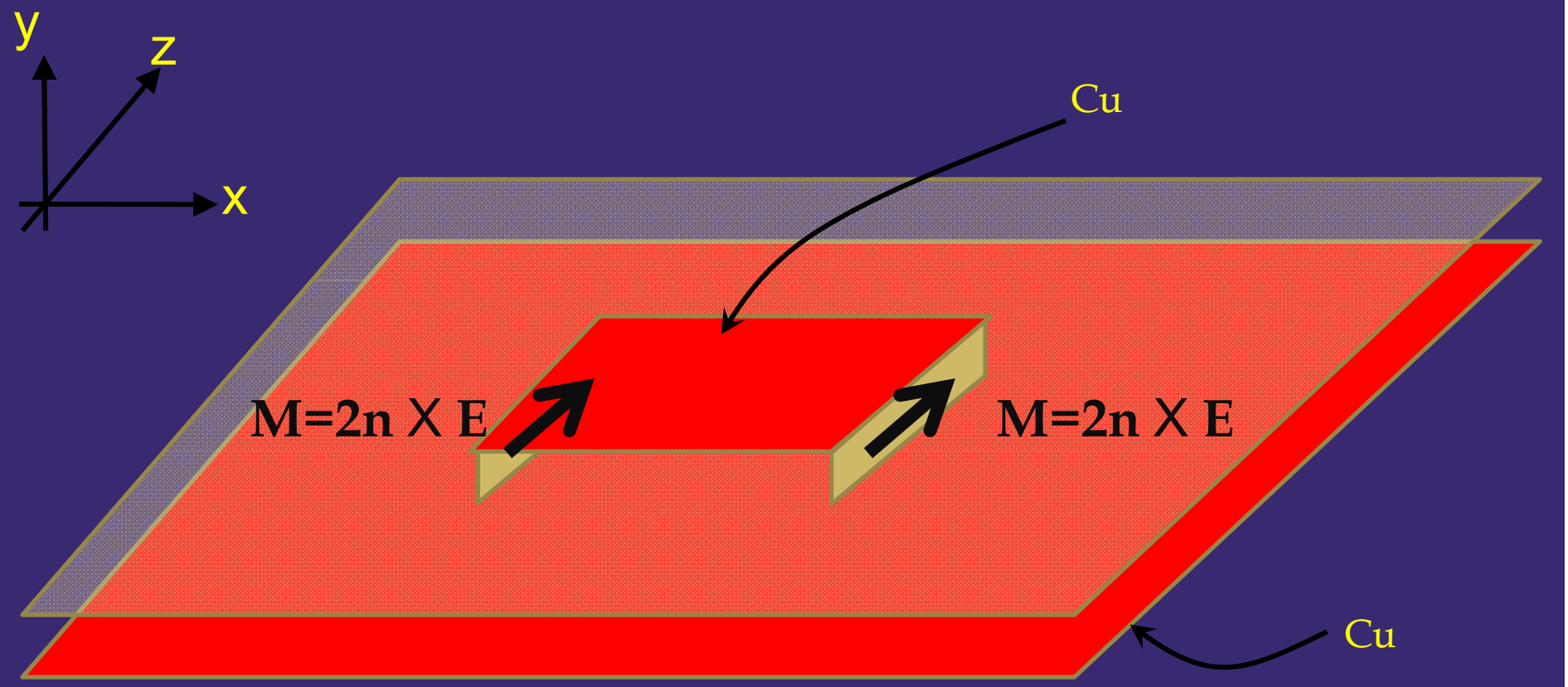


Figure 6. H-Plane radiation pattern.

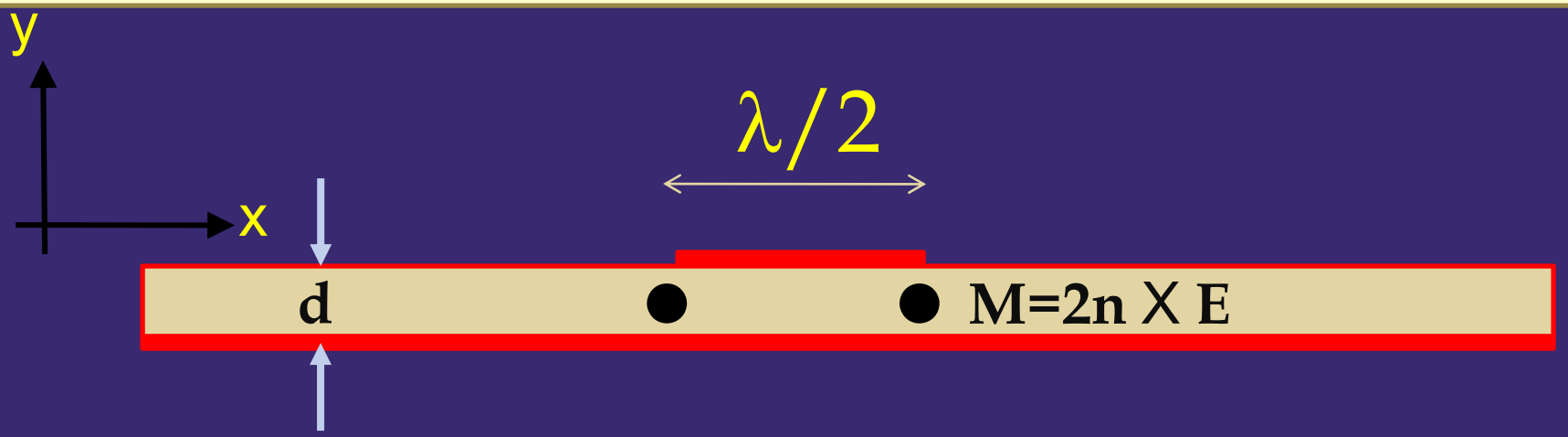
The Invincible μstrip Patch Antenna

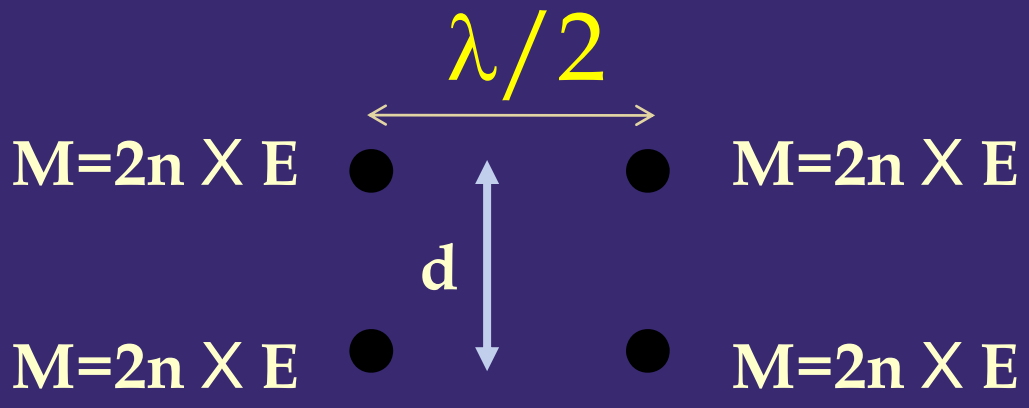


The Invincible μstrip Patch Antenna



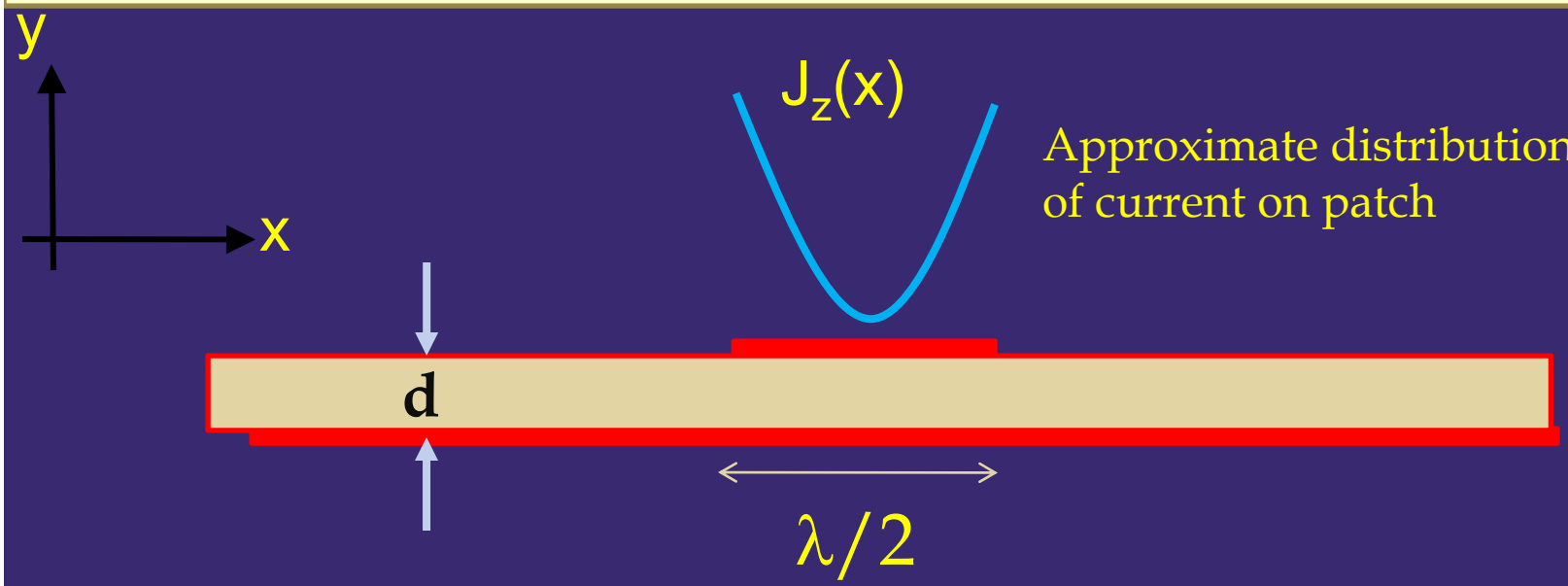
A Good Model to Predict Radiation

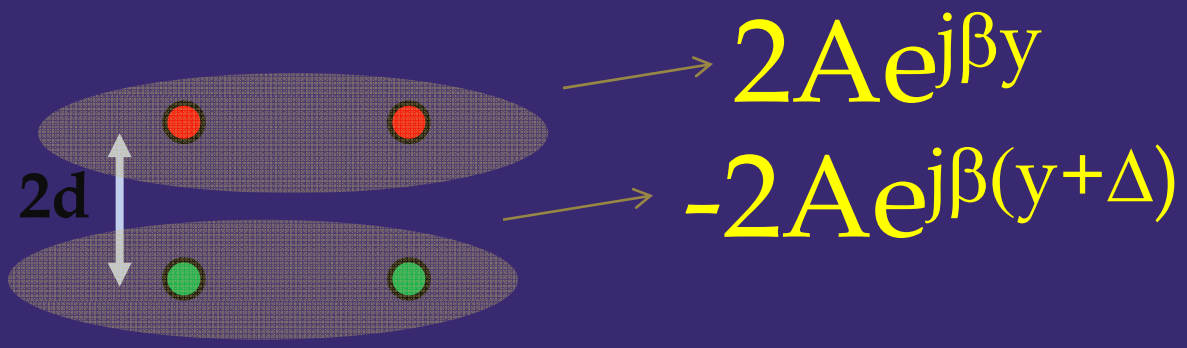




But…. It is just a *model!*

A Good Model to Predict Radiation





Bottom Line: Current on Cu causes radiation

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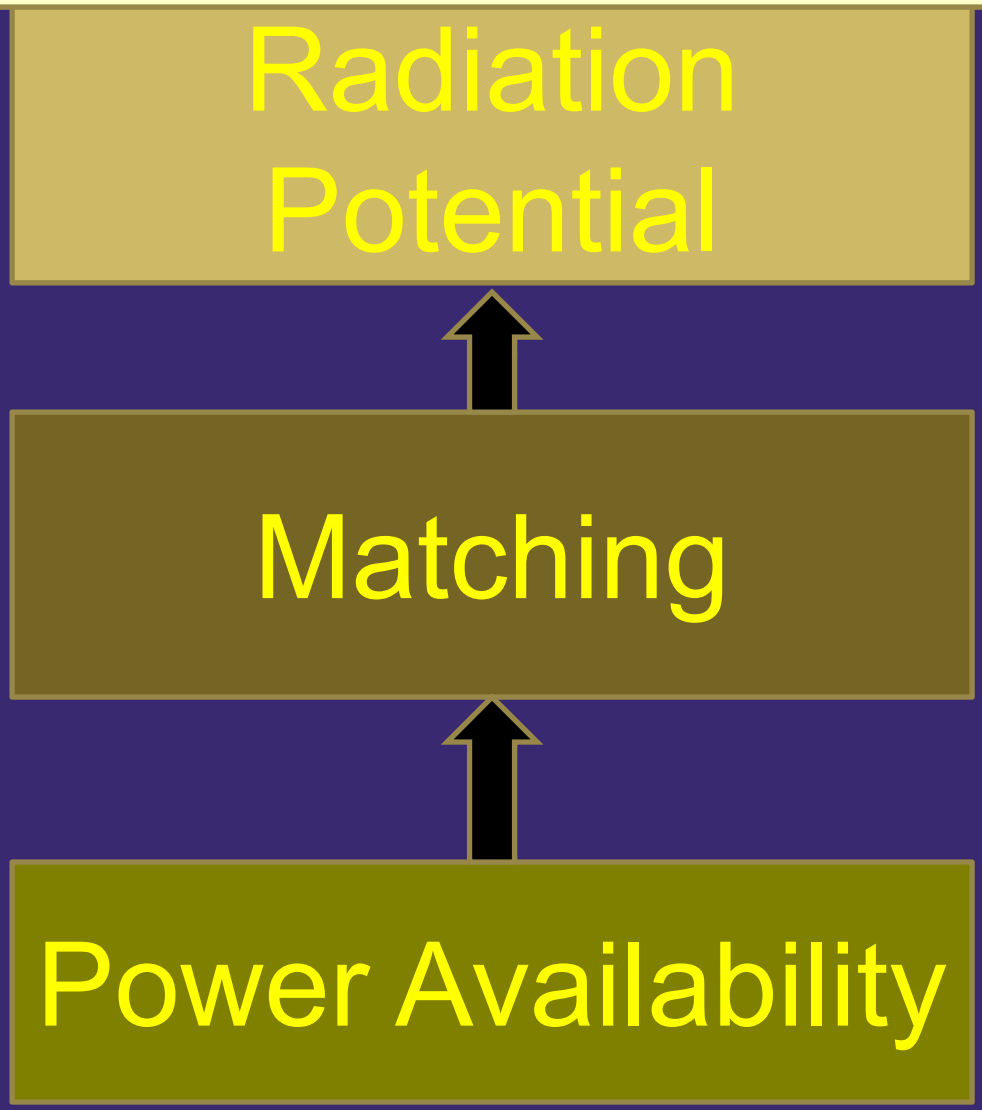
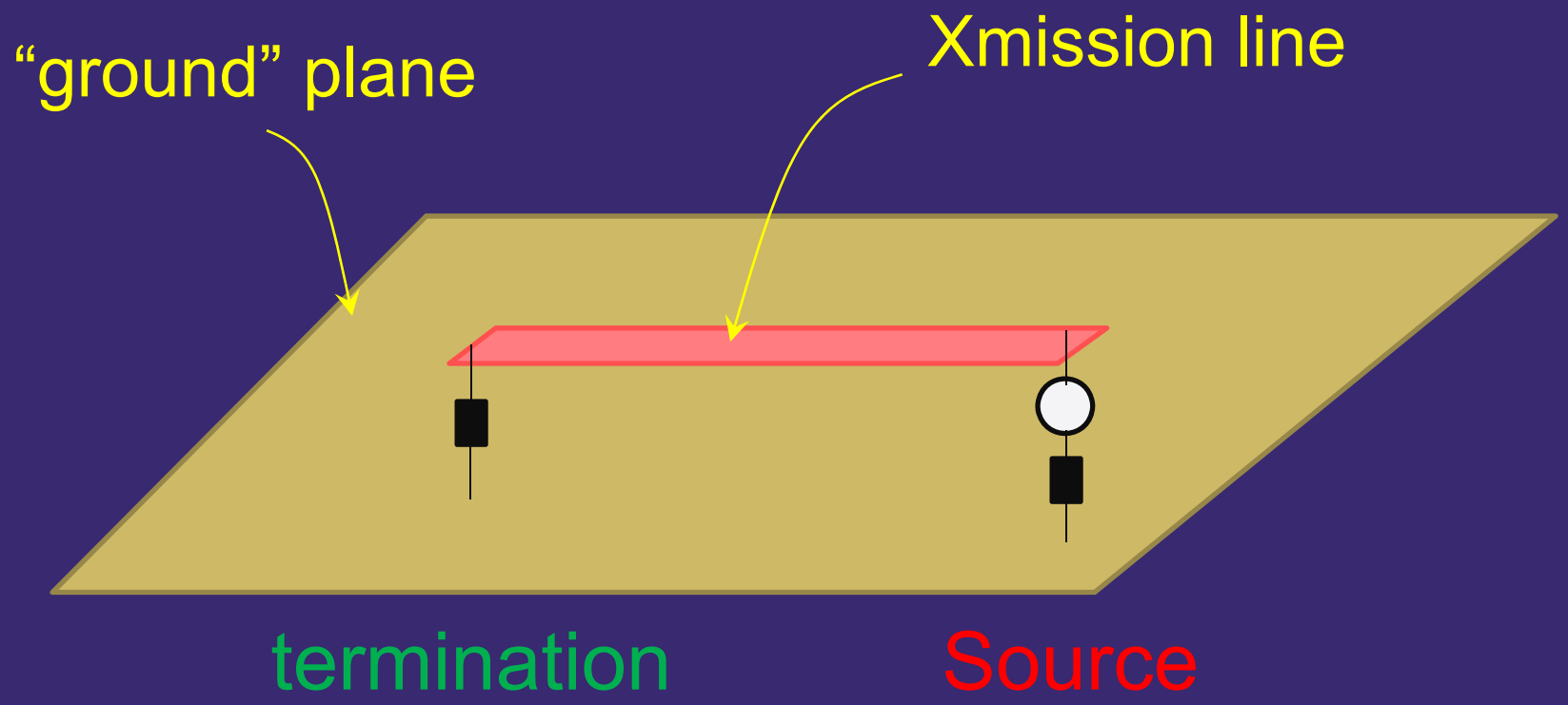
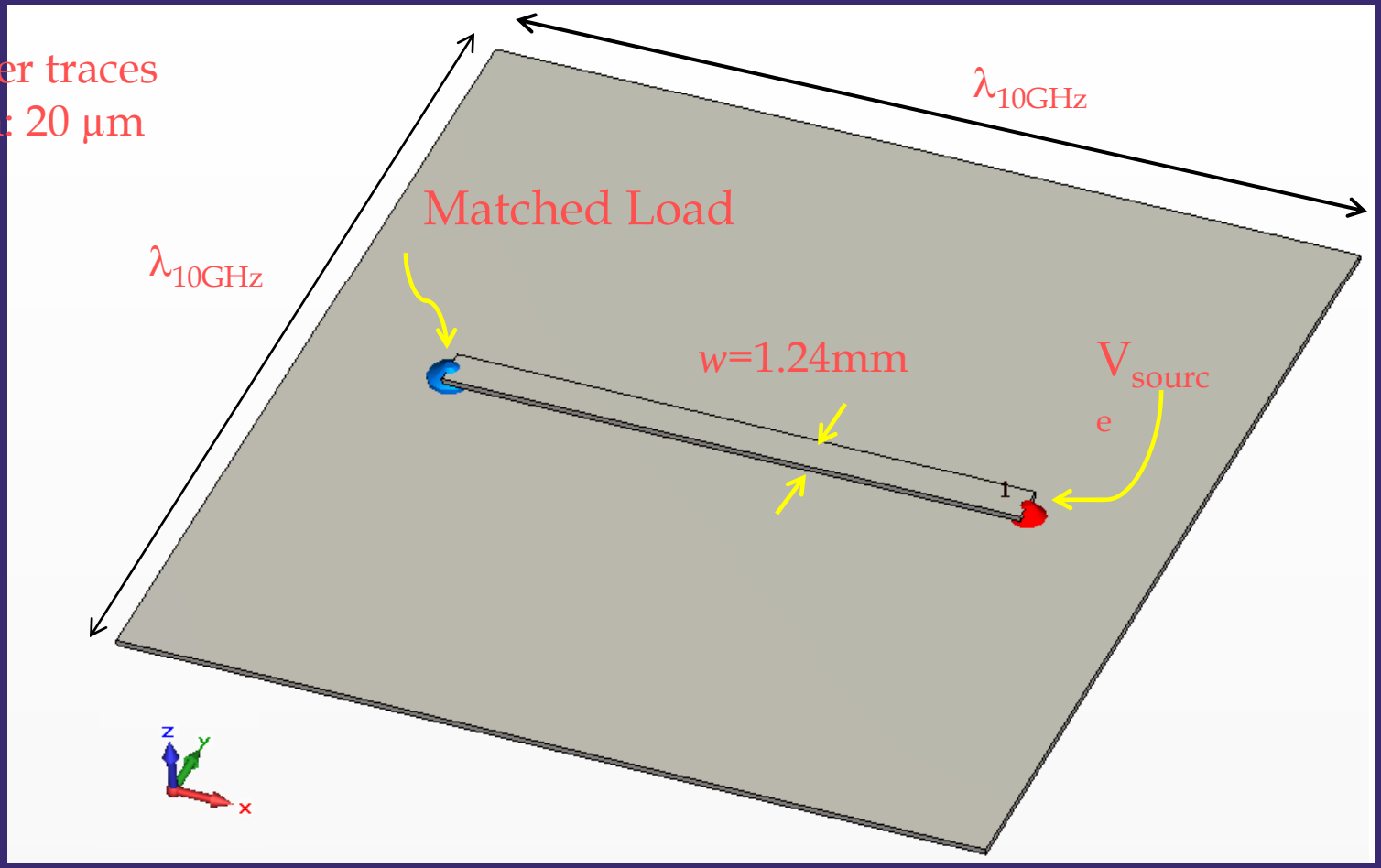




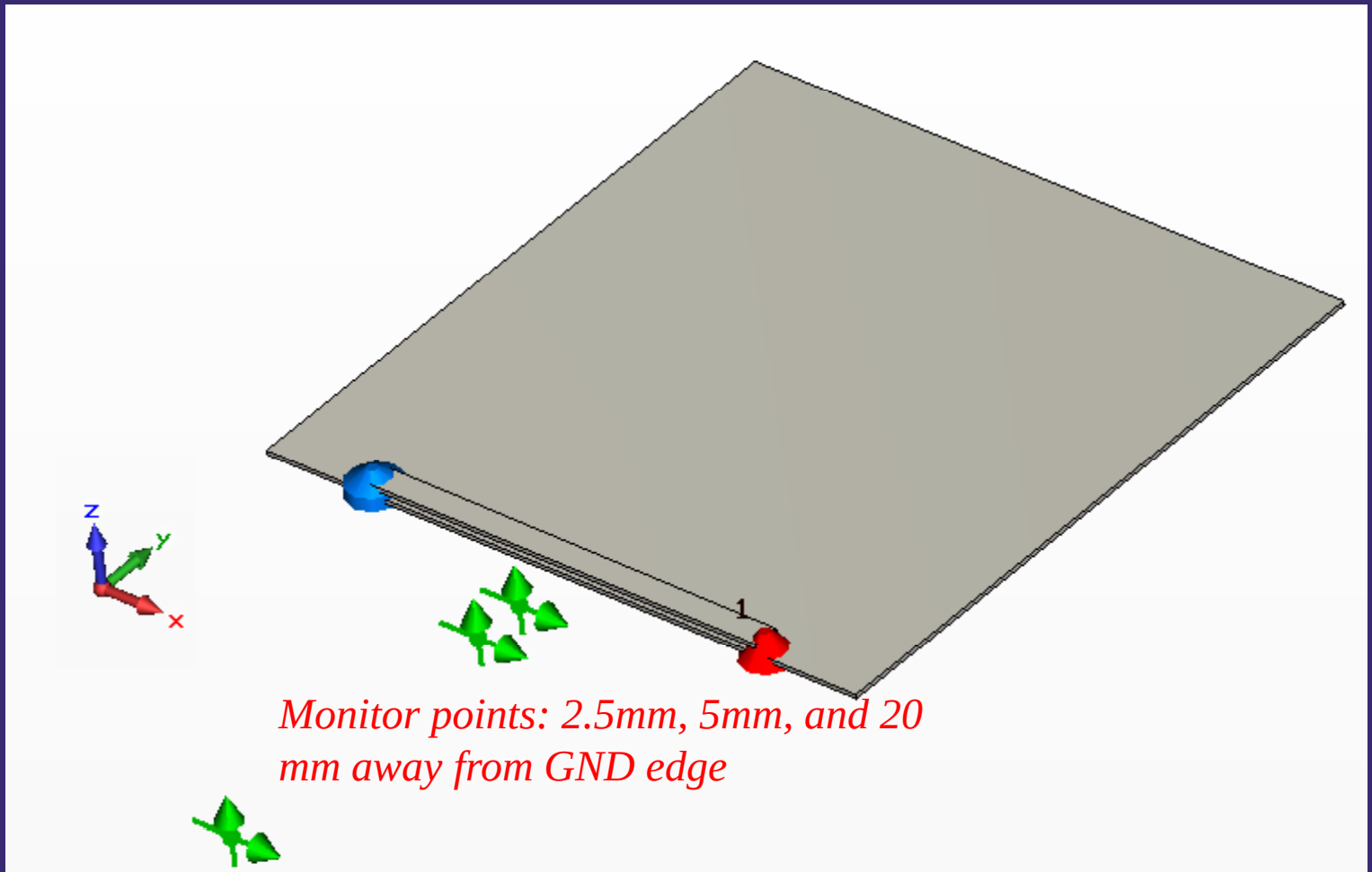
Single-ended (SE) TL segment on top of GND plane

Copper traces width: 20 μm



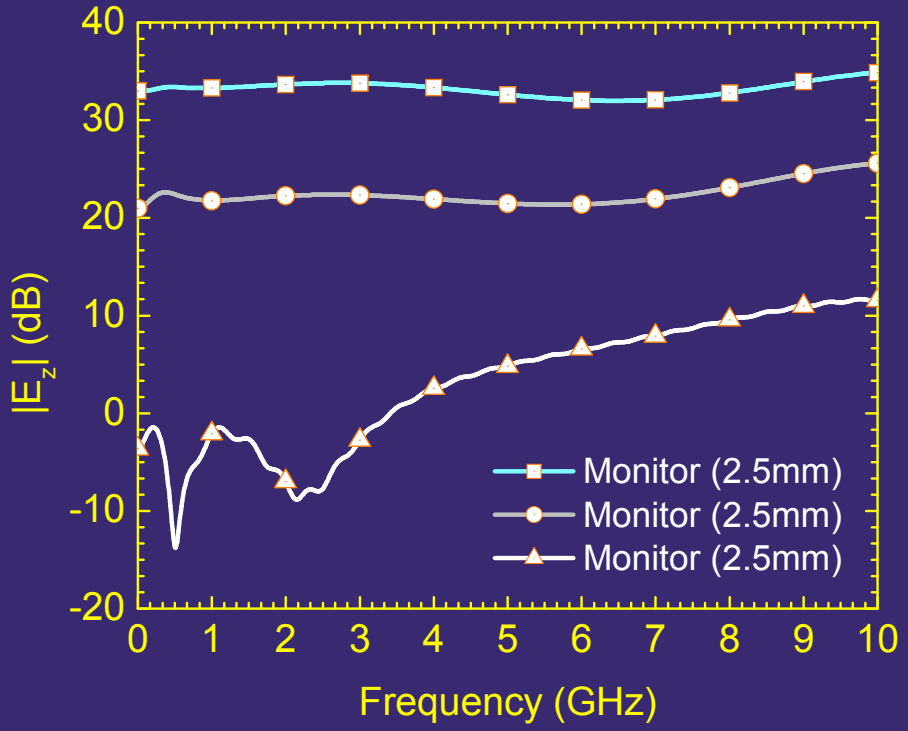
h=0.254mm

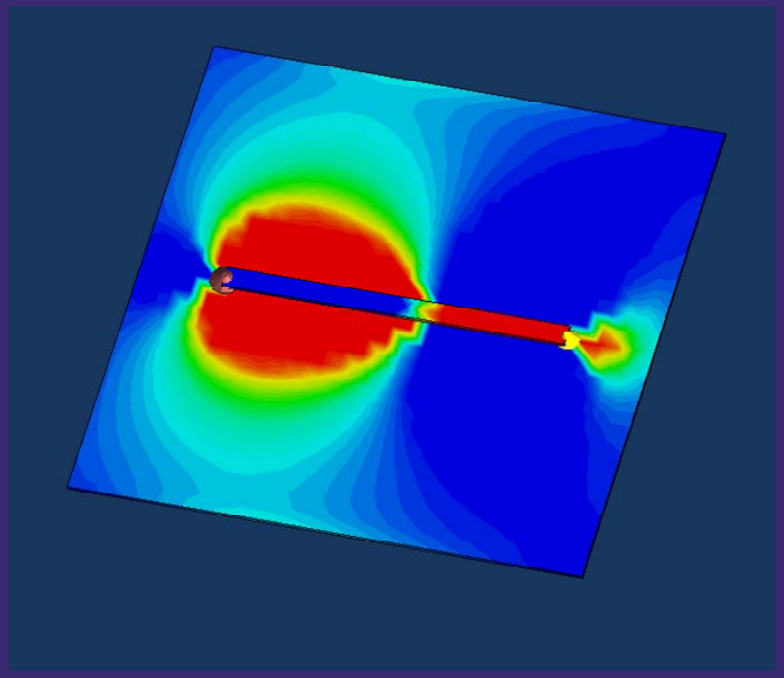
Field Monitors



Monitor points: 2.5mm, 5mm, and 20 mm away from GND edge

Case III: at center of GND





Monitor: Ez

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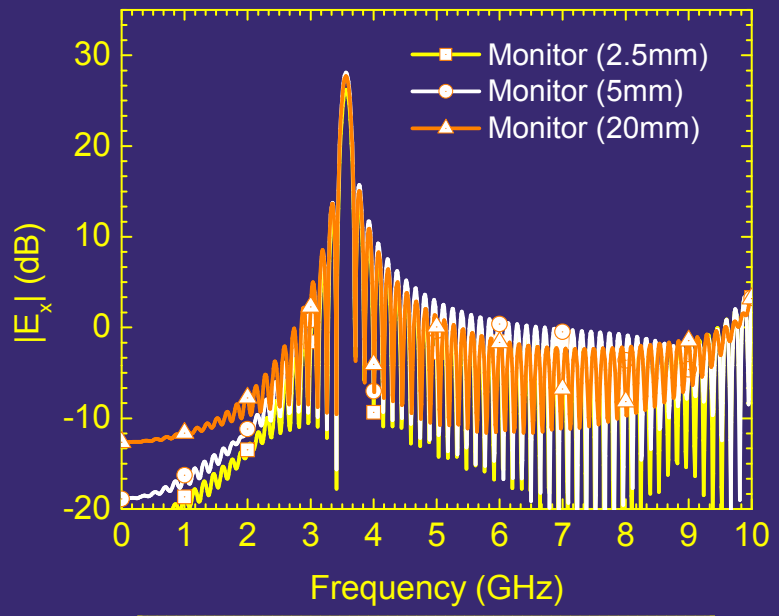
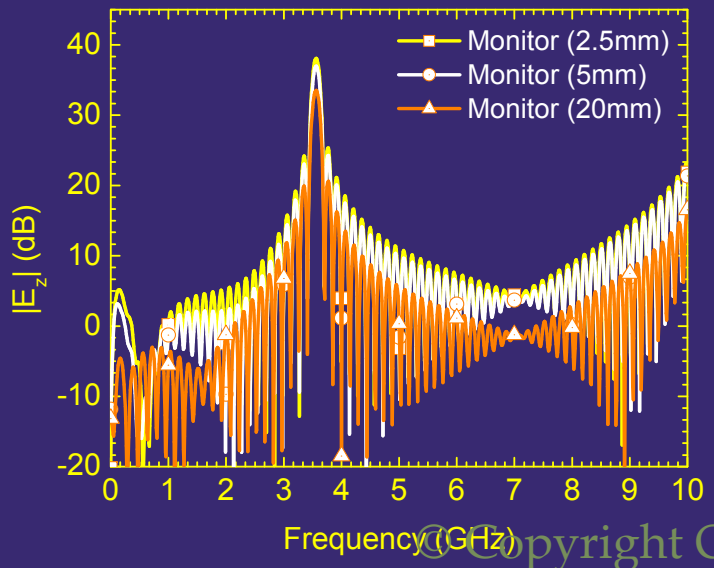
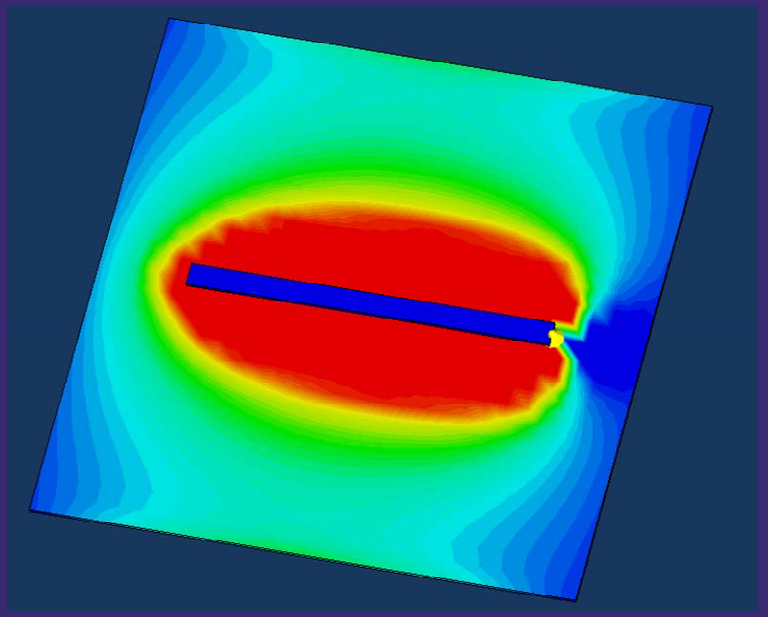
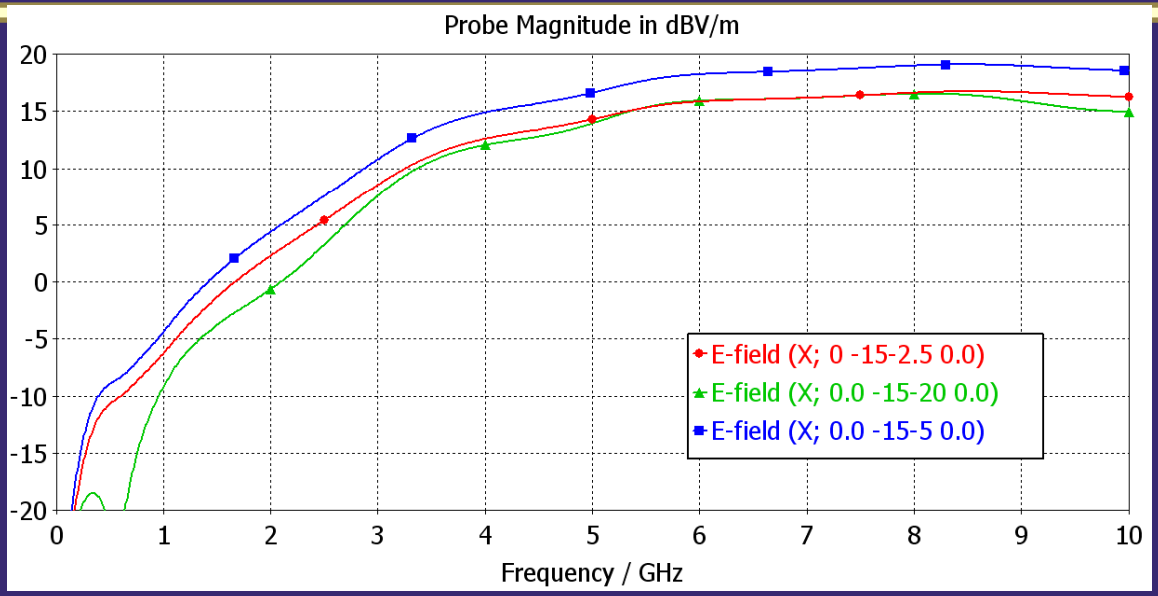


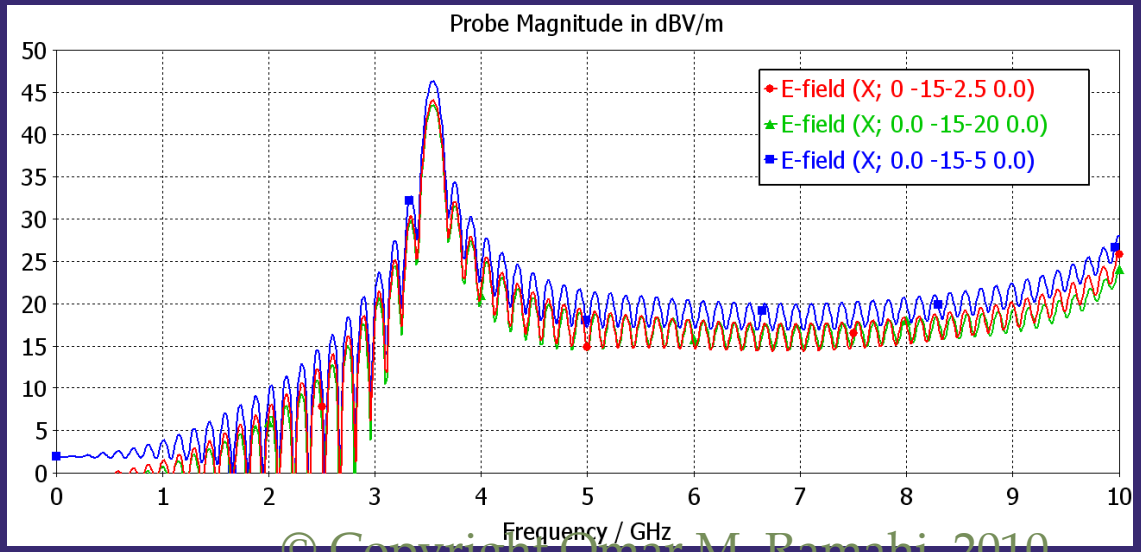




Case I: Line at edge

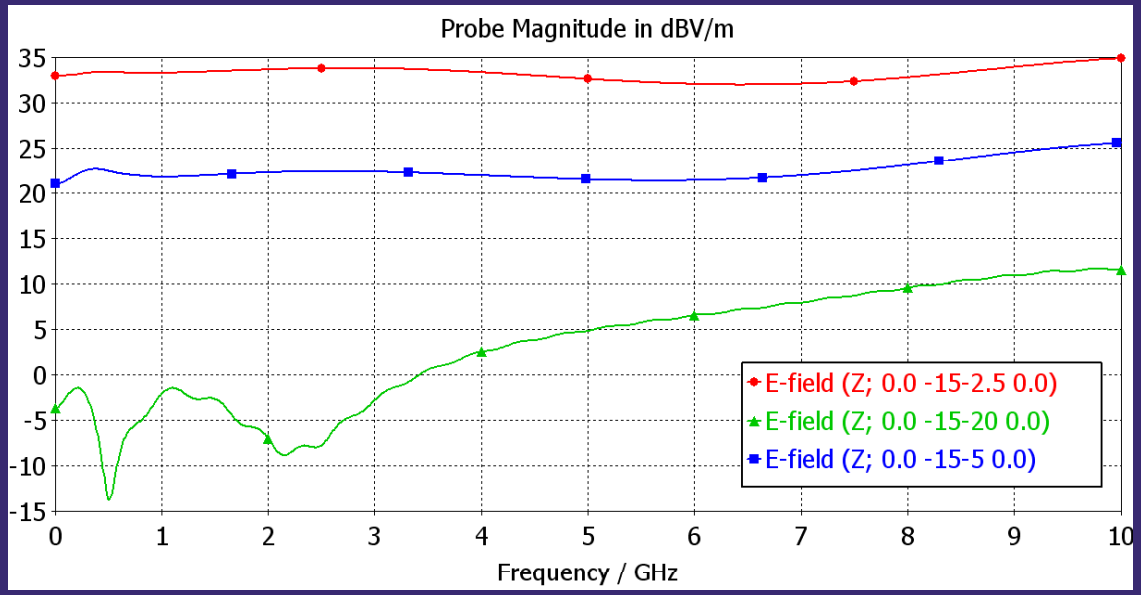


Matched

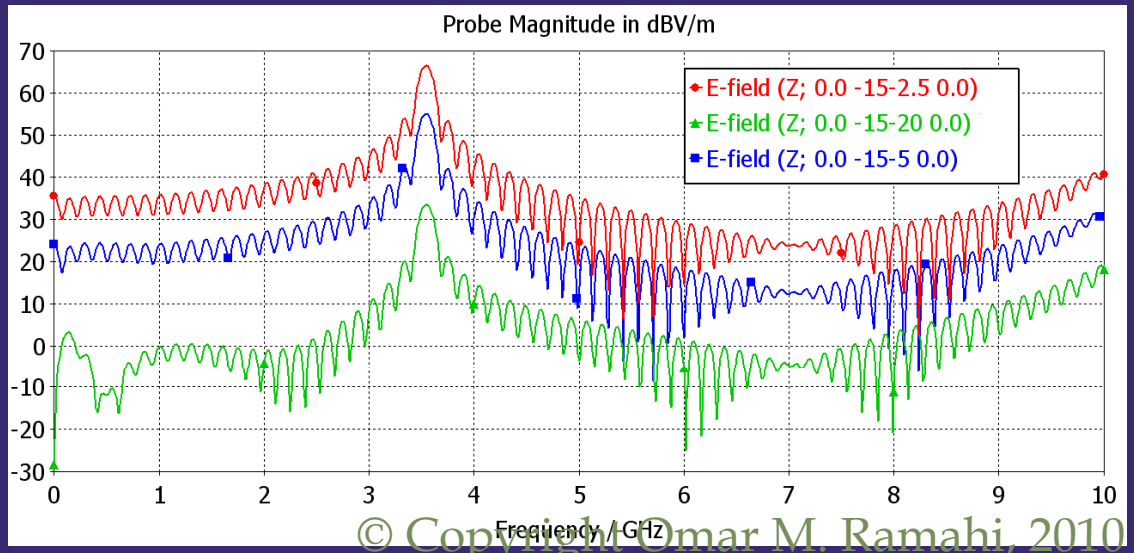


Open

Case I: Line at edge

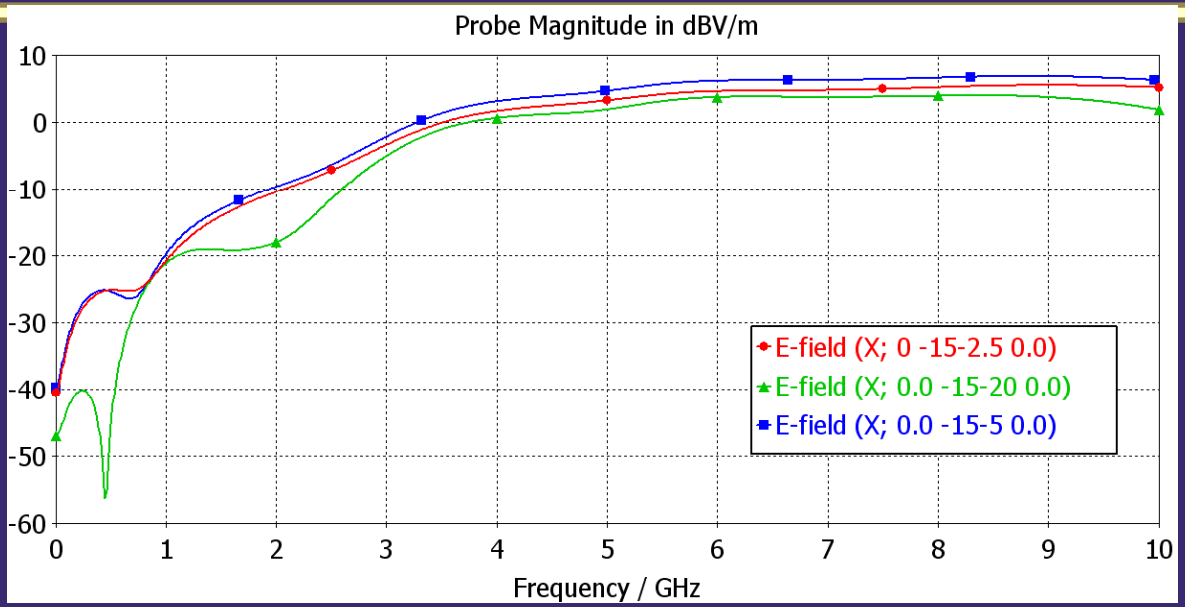


Matched

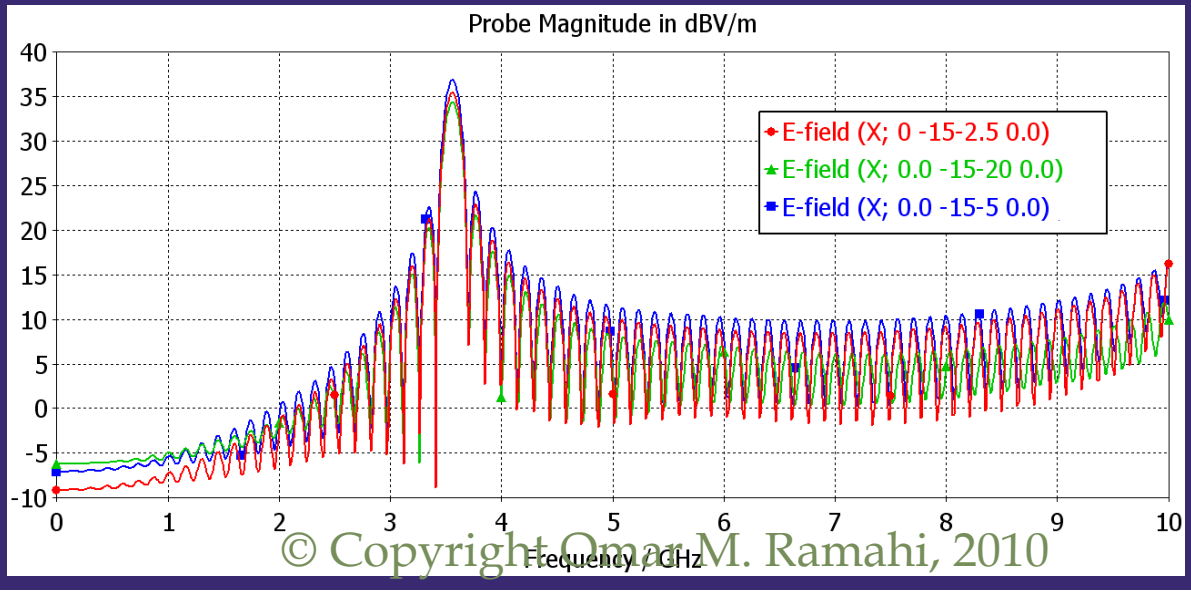


Open

Case II: 5 mm inside away from edge of GND

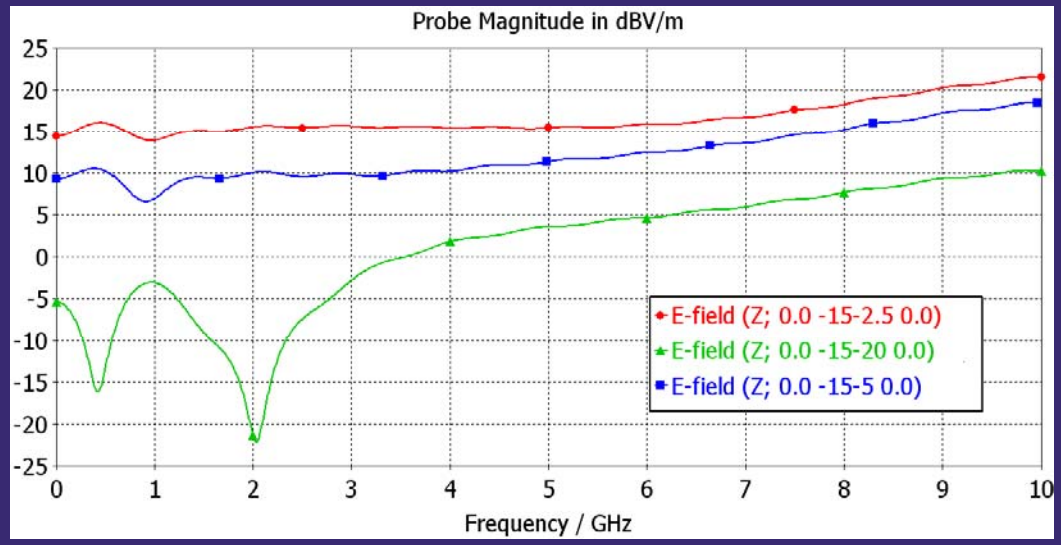


Matched

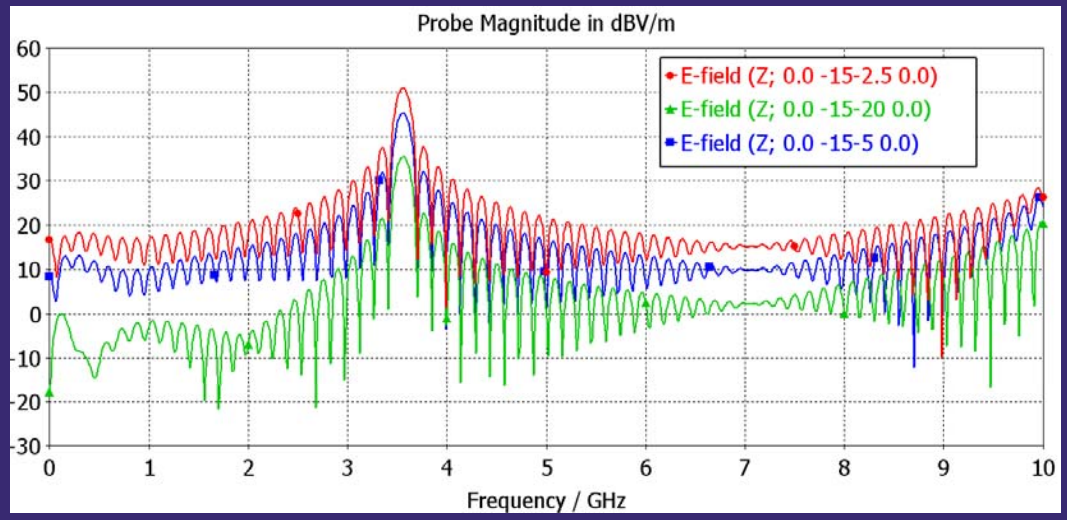


Open

Case II: 5 mm inside away from edge of GND

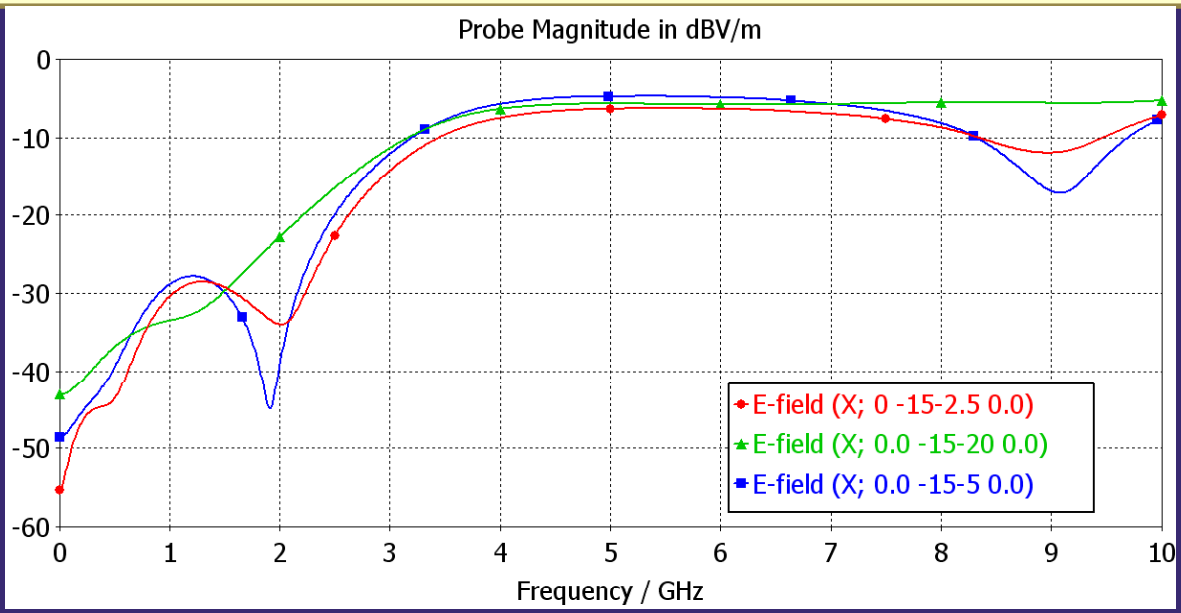


Matched

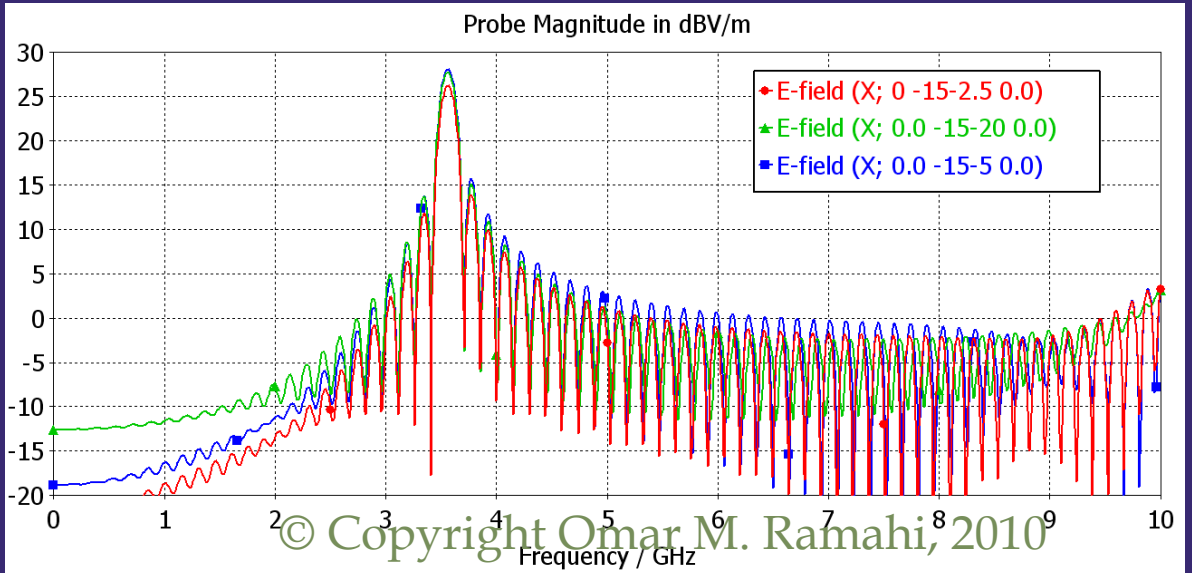


Open

Case III: at center above GND

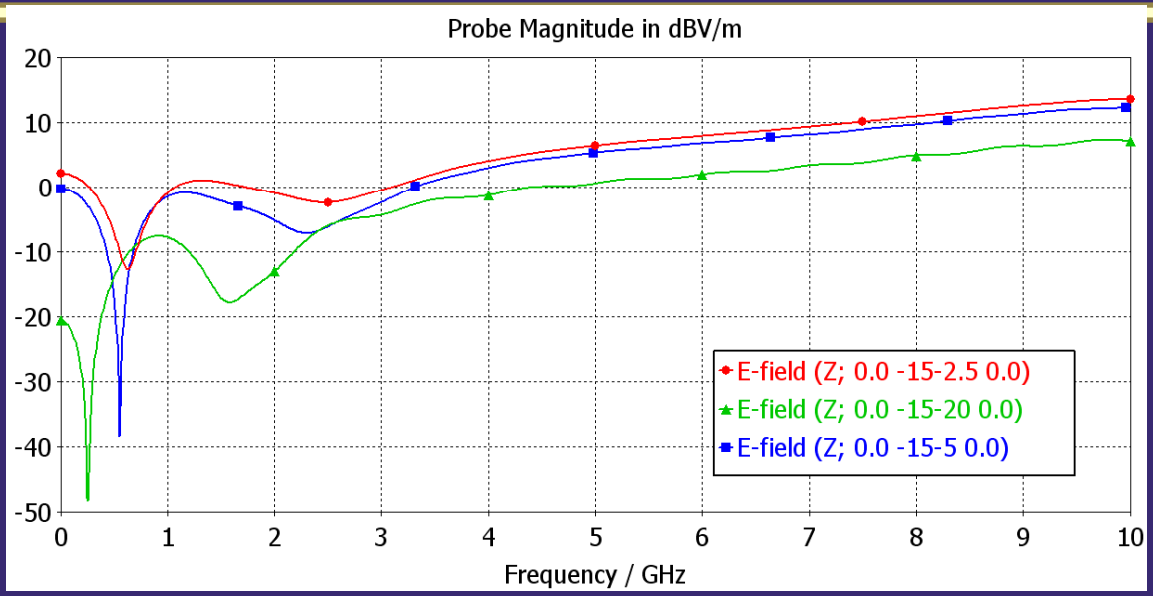


Matched

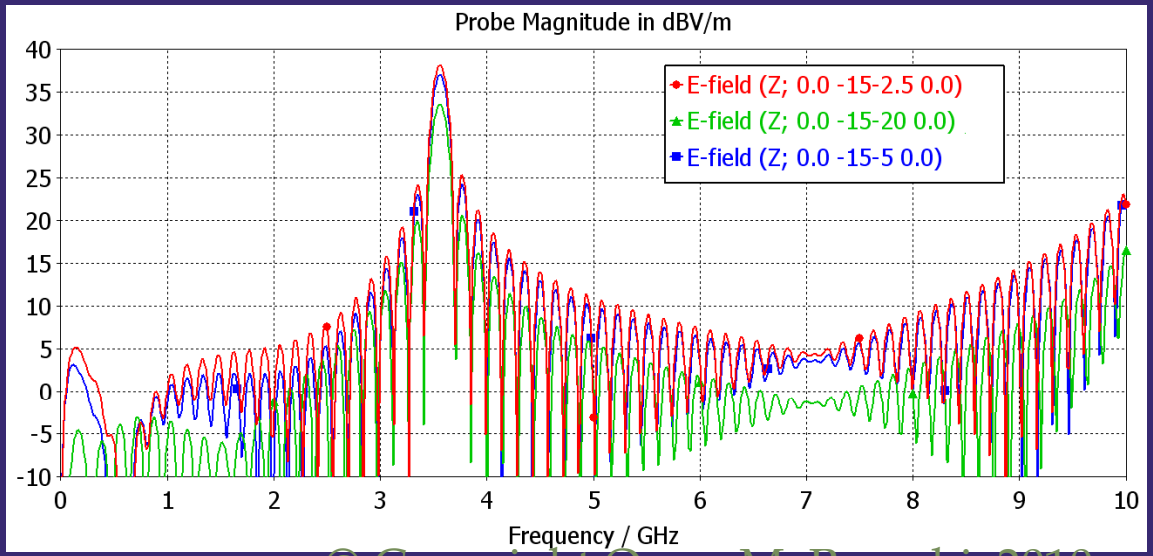


Open

Case III: at center of GND



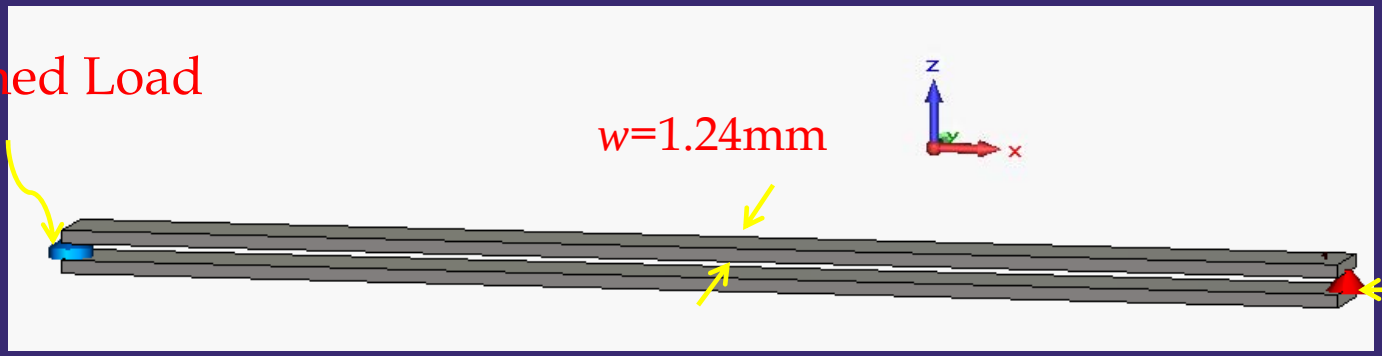
Matched



Open

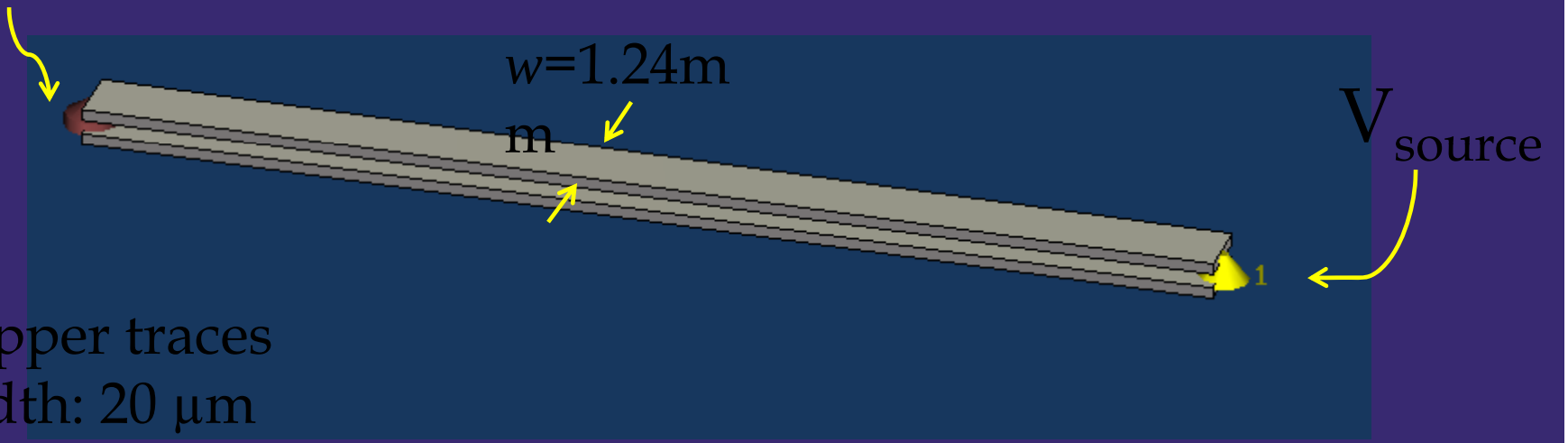
Single-ended (SE) Stripline

Copper traces
width: 20 µm



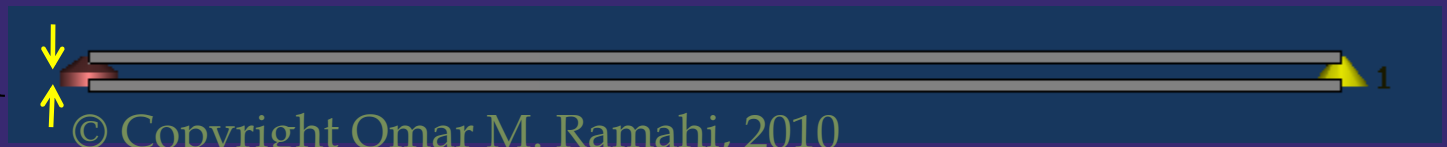
Single-ended (SE) Parallel Stripline

Matched Load



Copper traces
width: 20 µm

h=0.254mm



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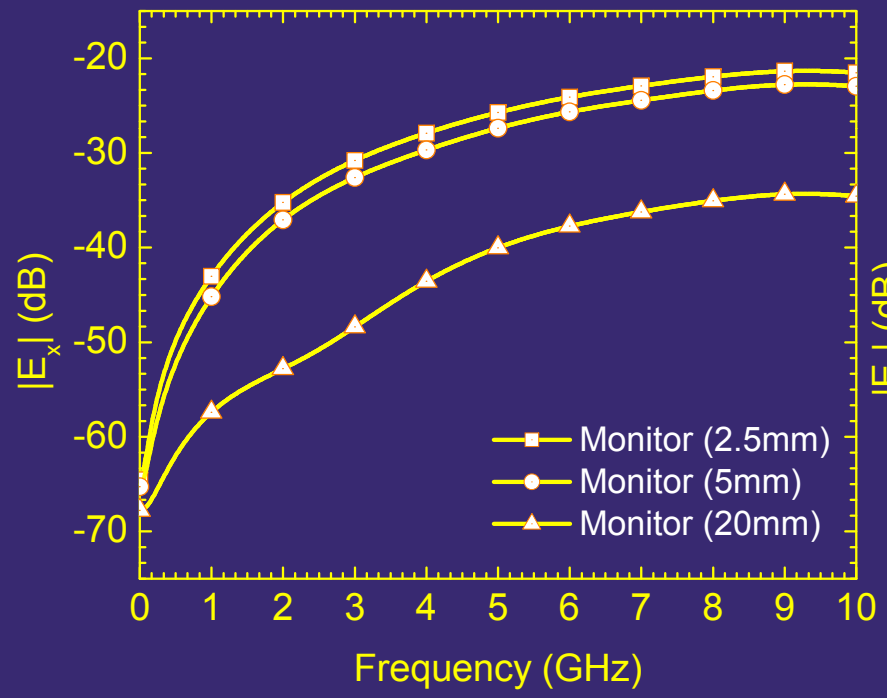
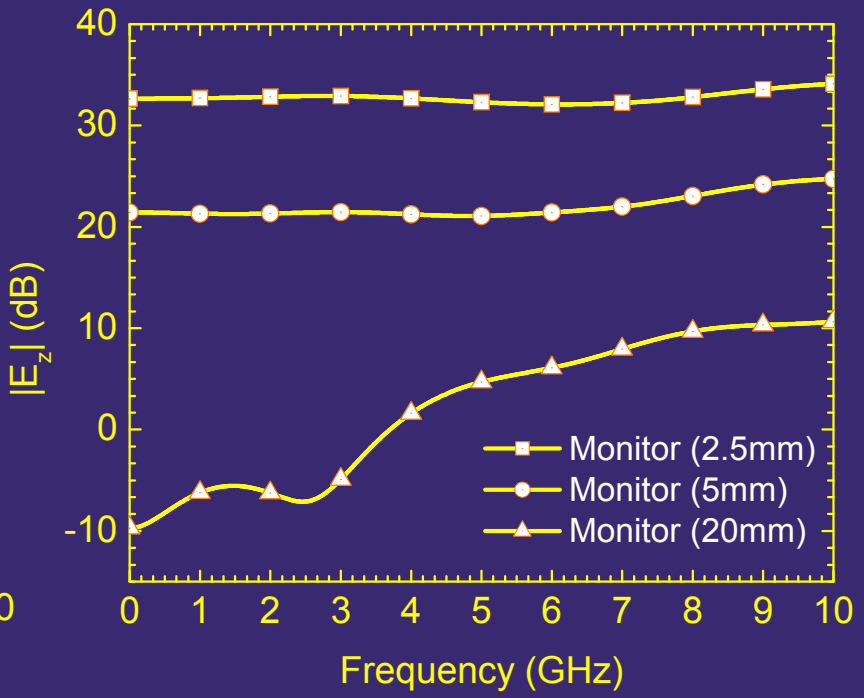


Monitor: Ex



Monitor: Ez

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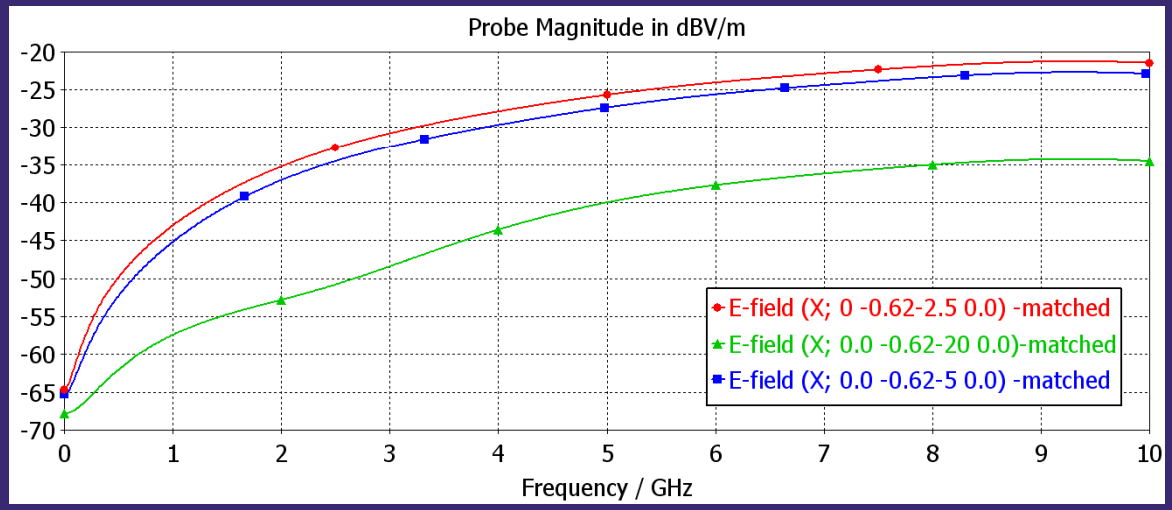
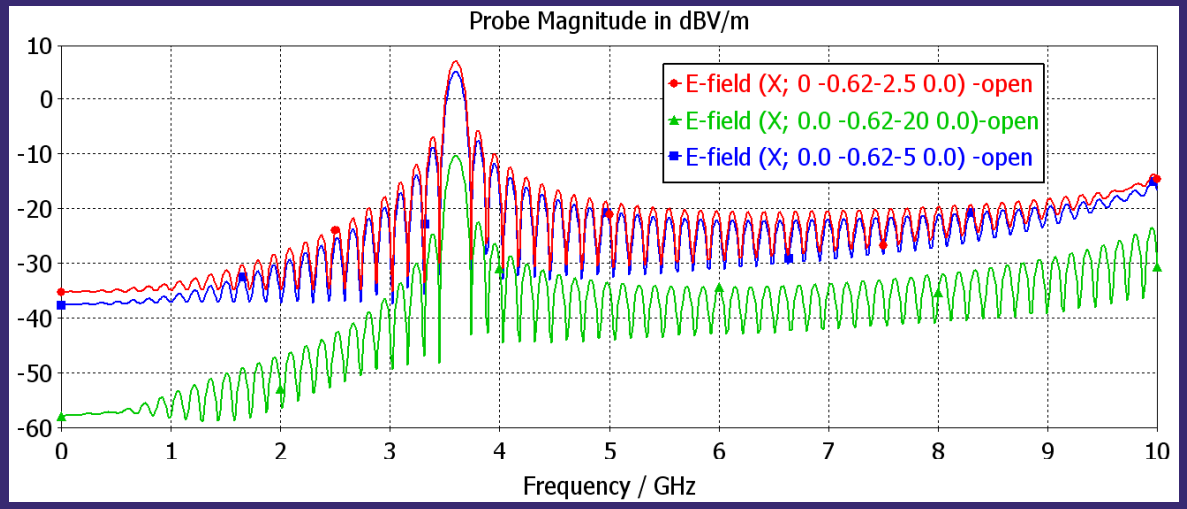
Monitor: Ex



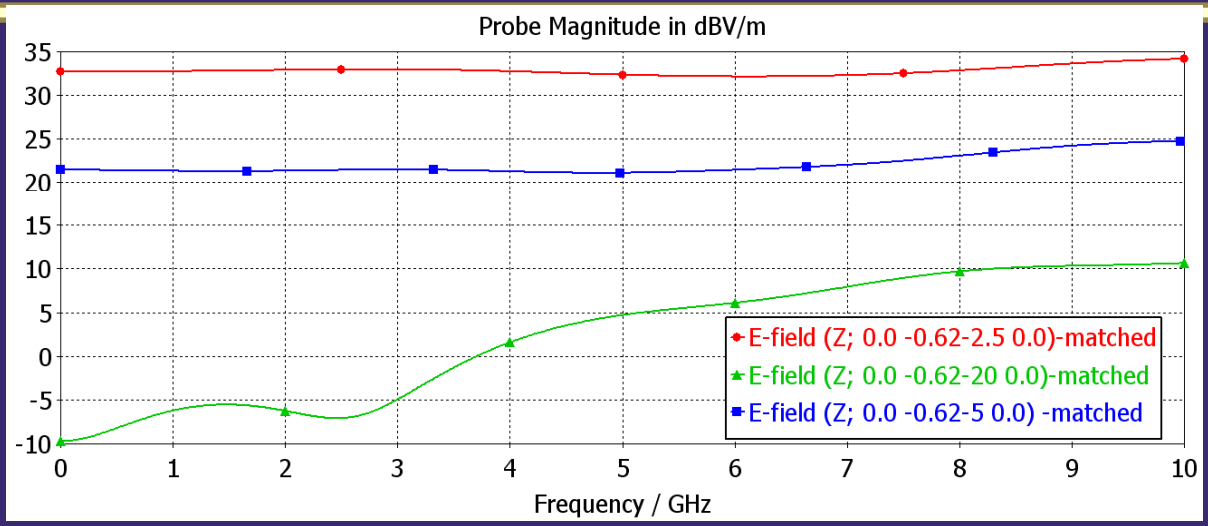
Matched



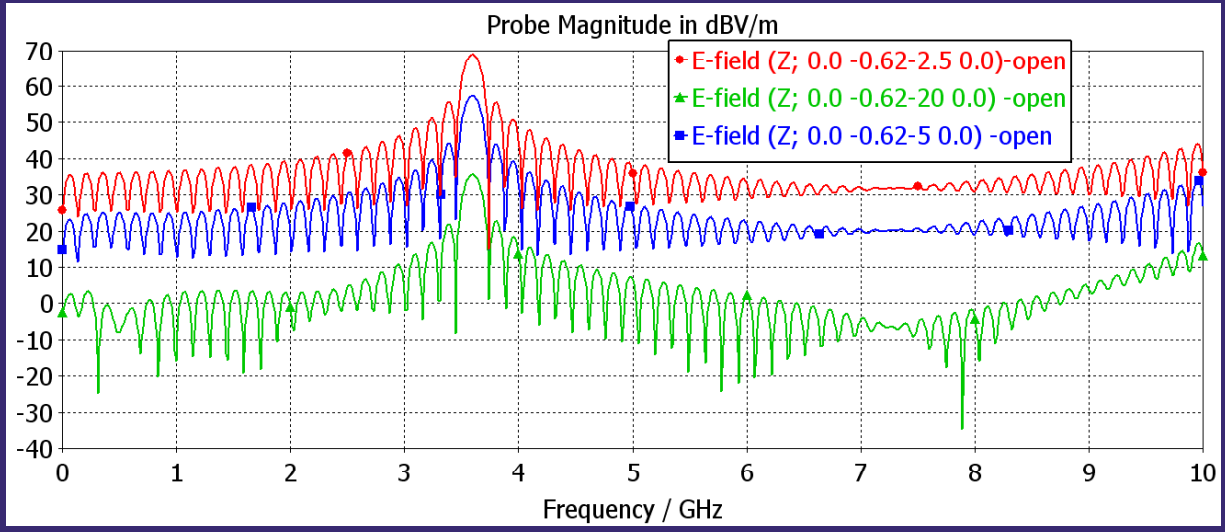
Open

University of Waterloo

Monitor: Ez



Matched



Open

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The Mysterious Aperture

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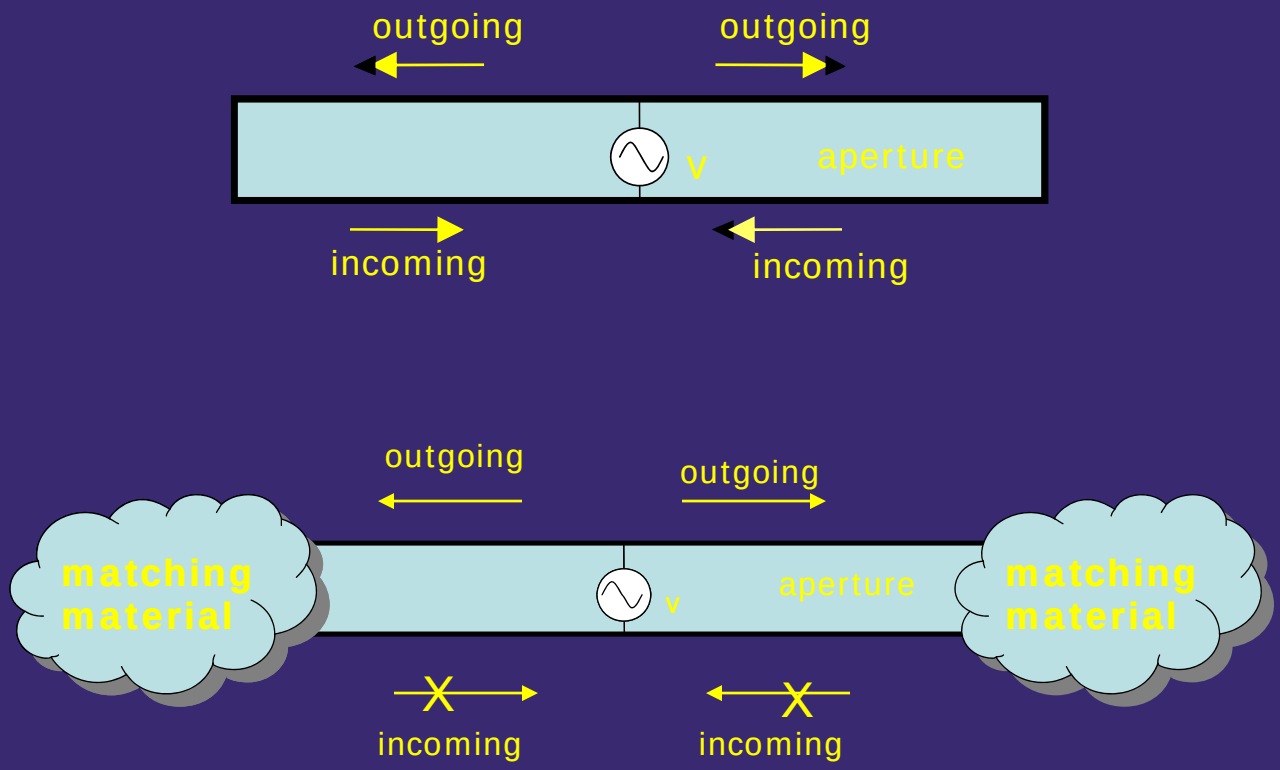
Shielding wall with opening for audio speaker

Opening for air ventilation

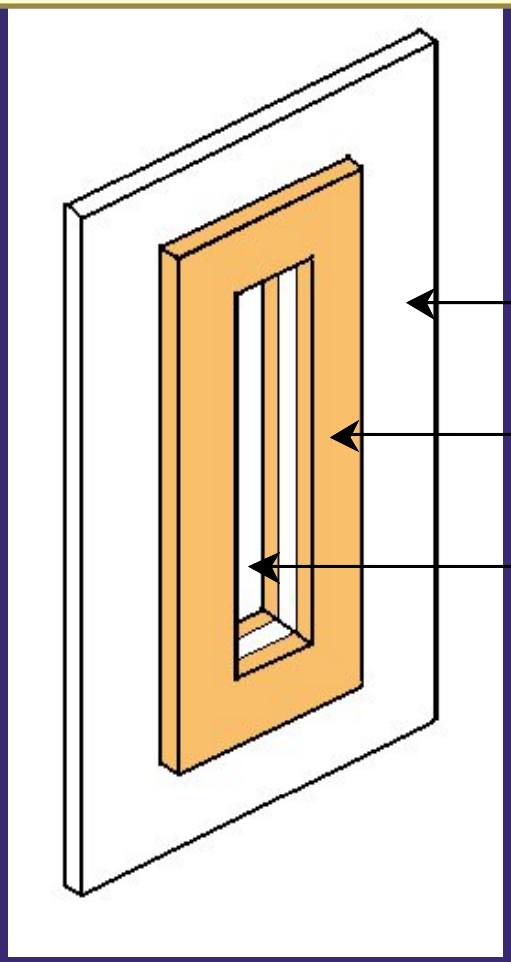
Opening for mounting display

Shielding chassis with aesthetics design

Transmission Line Interpretation of Apertures



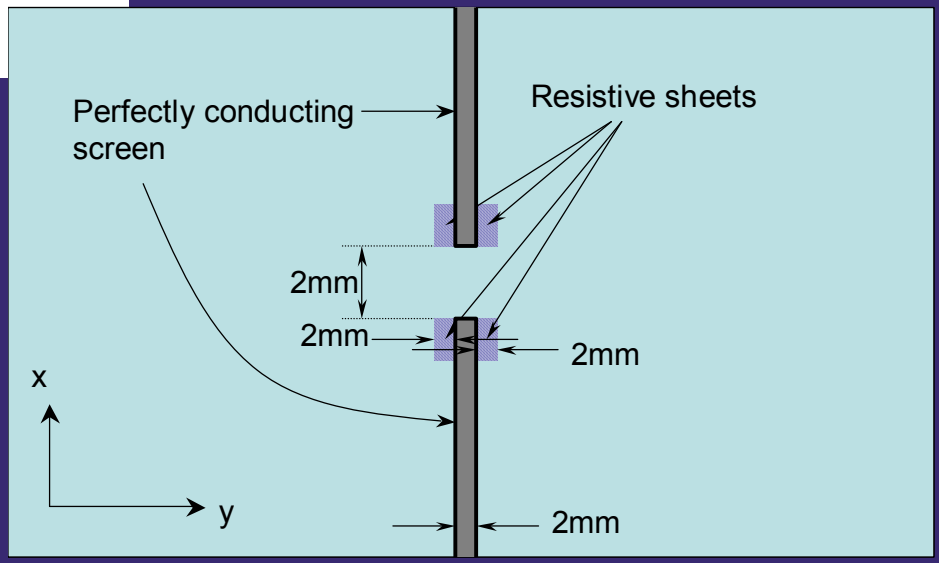
"Loaded" Aperture



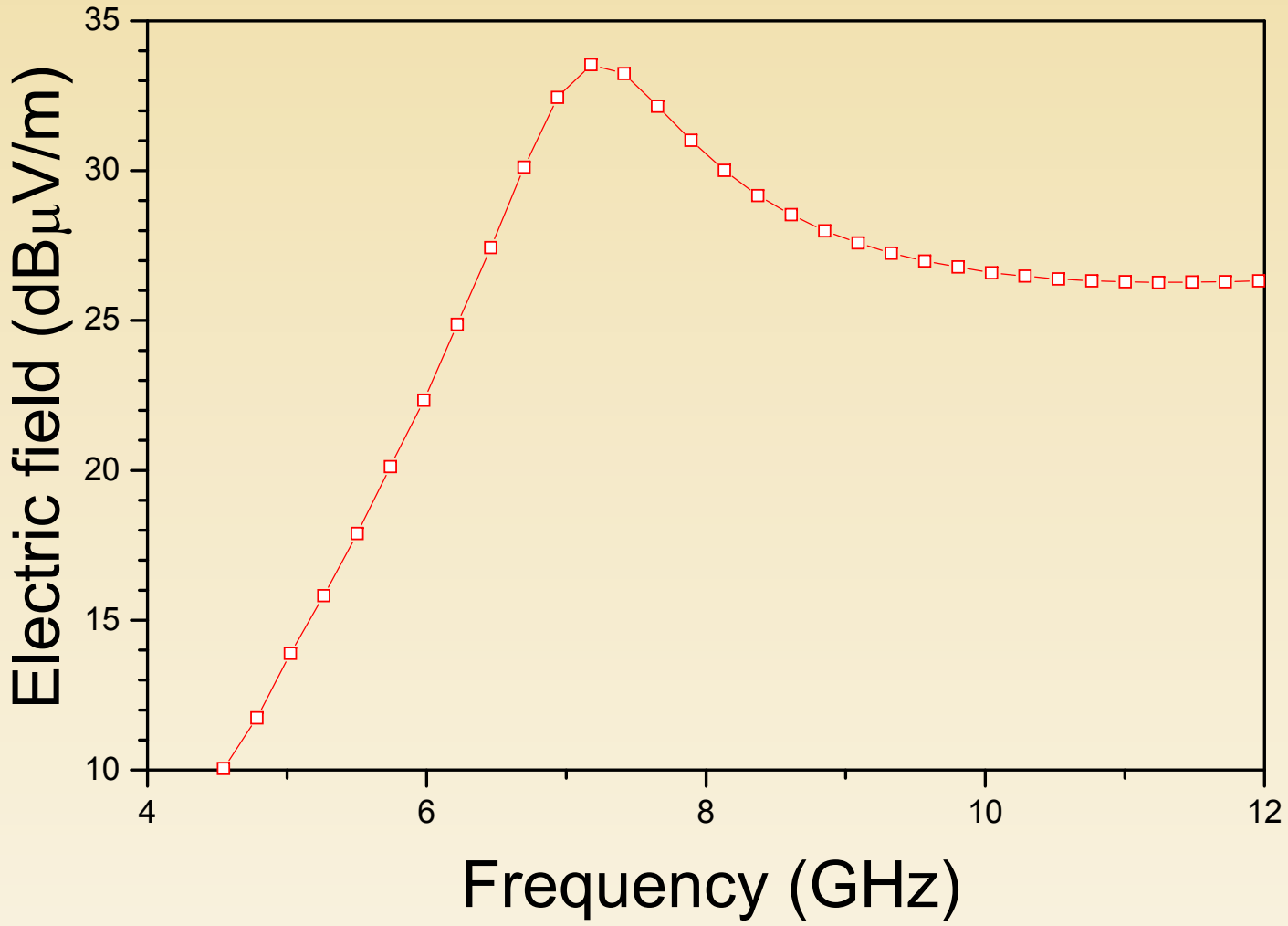
Infinite perfectly conducting screen

Resistive sheet

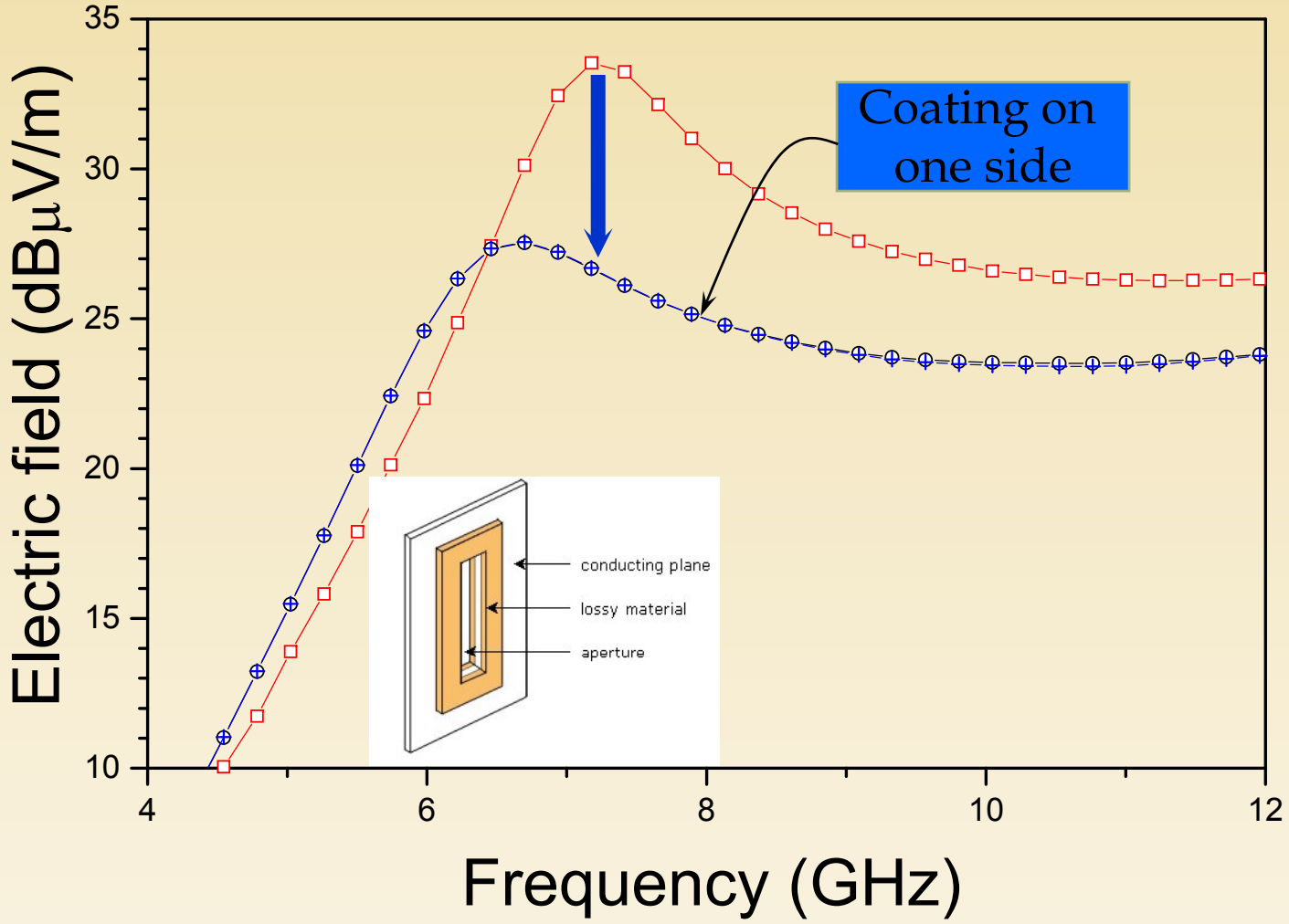
aperture



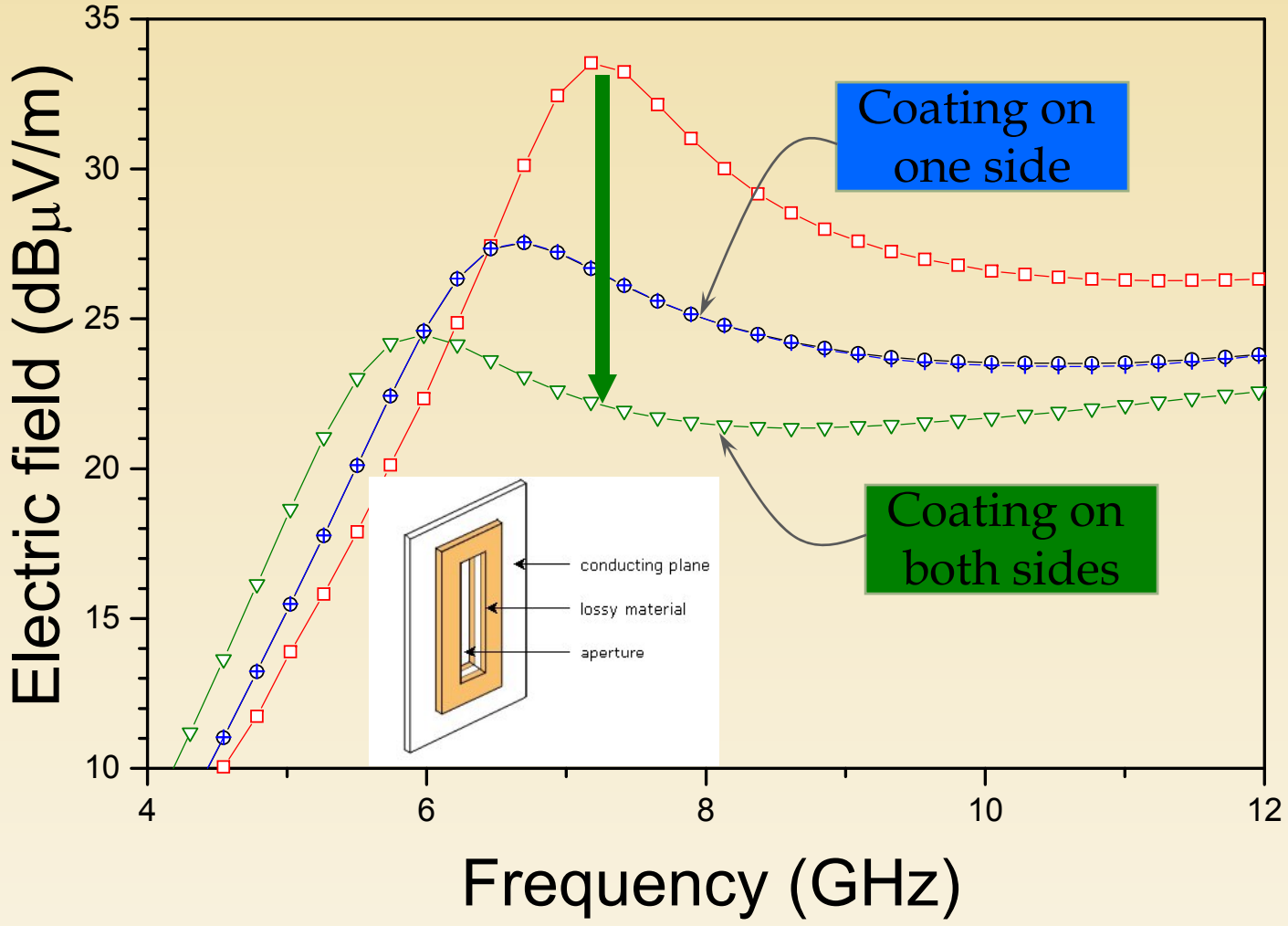
Aperture without Coating



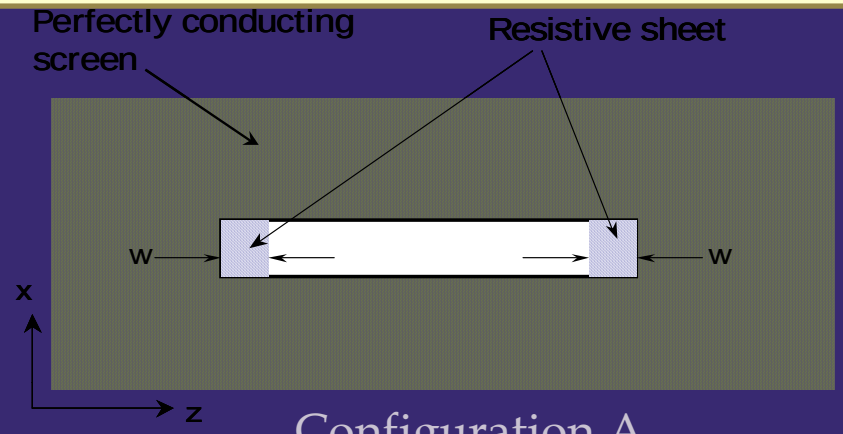
Reduction of Radiated Field at Resonance



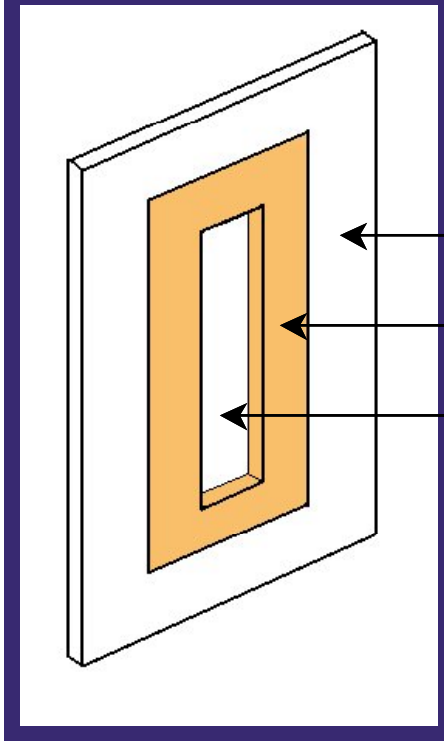
Reduction of Radiated Field at Resonance



Other Loading Material Configurations



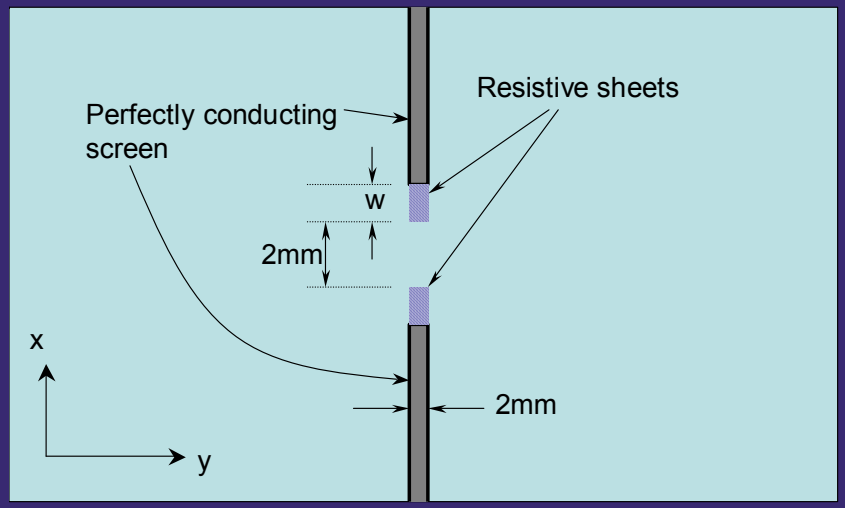
Configuration A



Infinite perfectly conducting screen

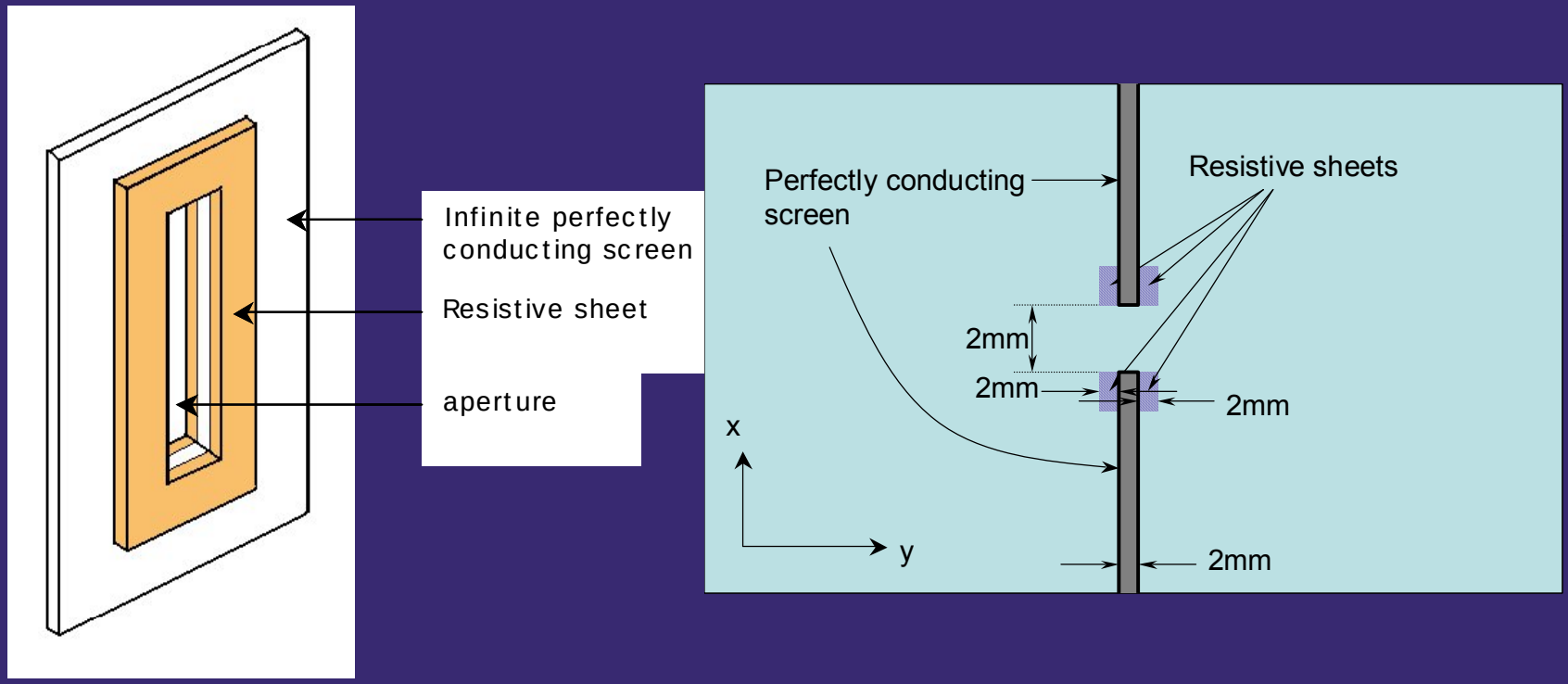
Resistive sheet

aperture



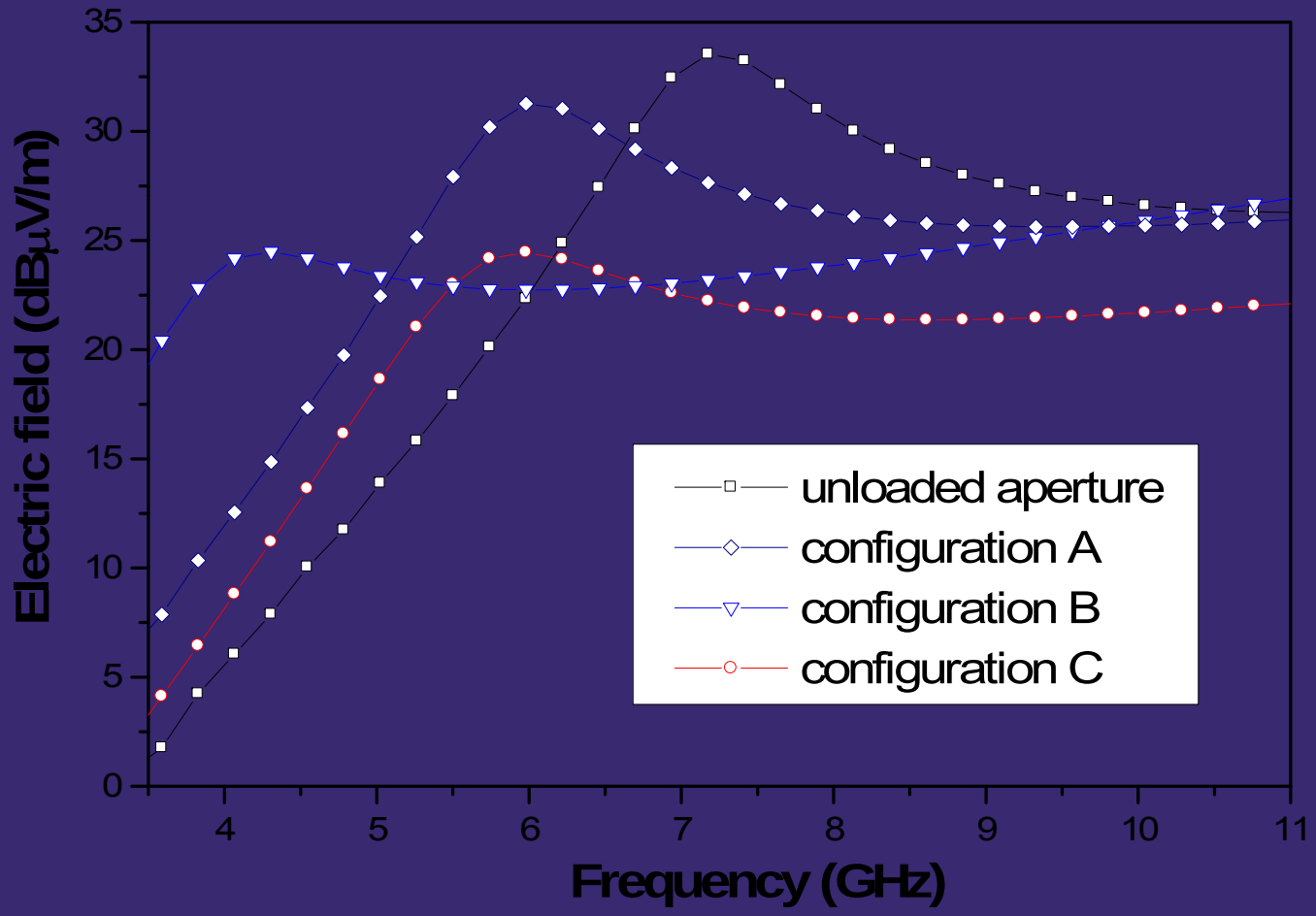
Configuration B

Loading Material Configuration C

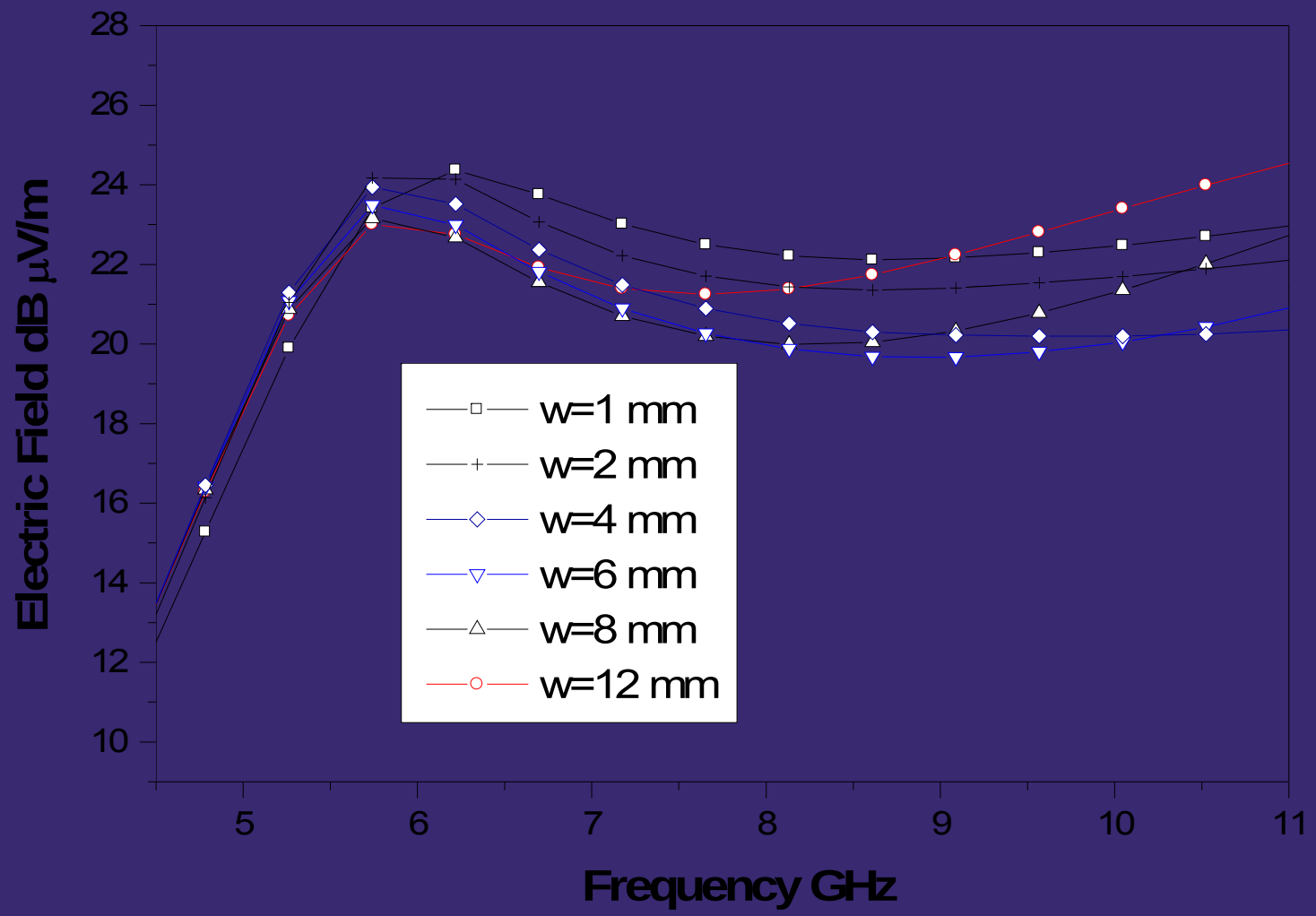


Configuration C

Radiation Mitigation with Loading Configurations



Radiation Mitigation with Loading Width

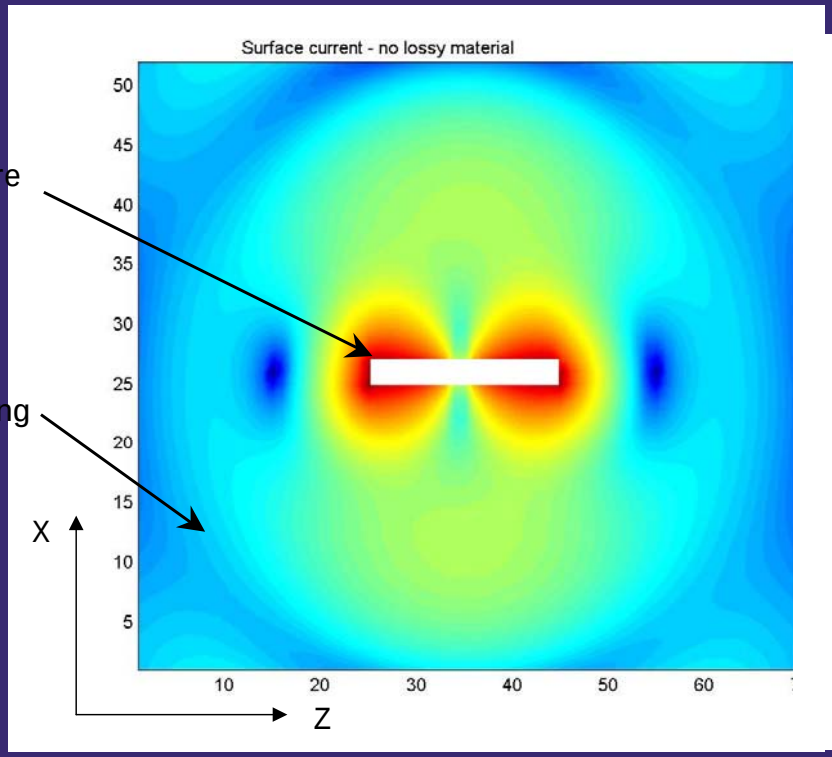


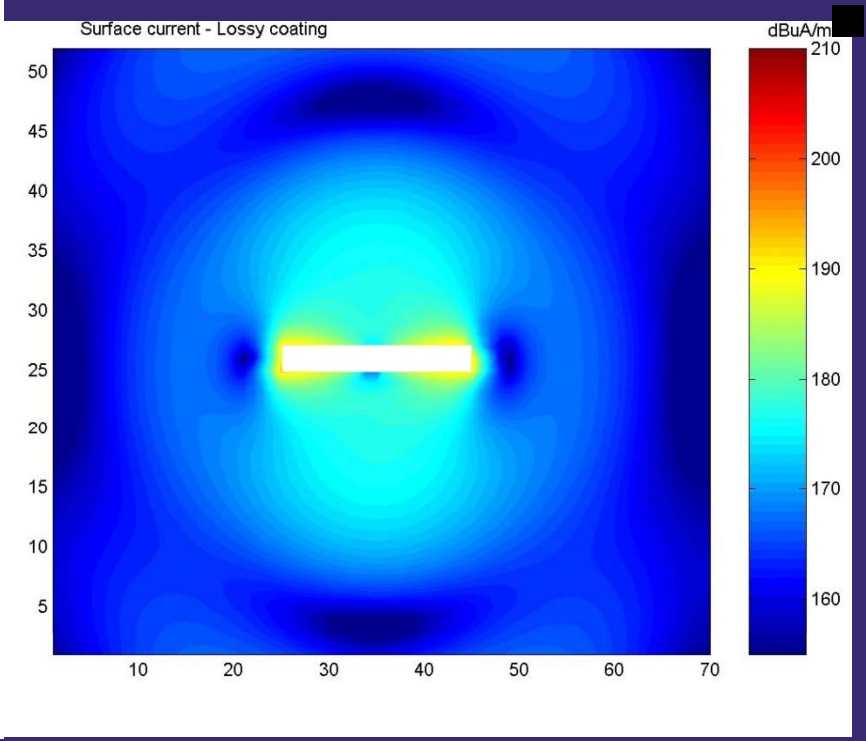
ε_r =4, and σ =5 $Ohm^{-1}m^{-1}$

Surface Current before and after loading

No Loading

Loading of ε_r= 4, σ=5, and width=6mm





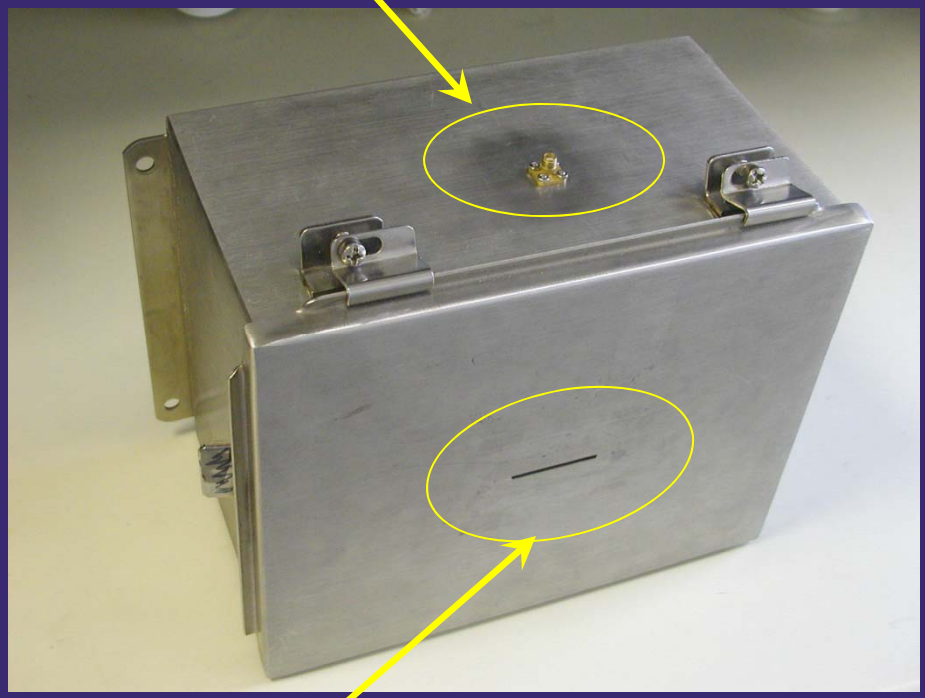
Before **After**

Surface current is the culprit!

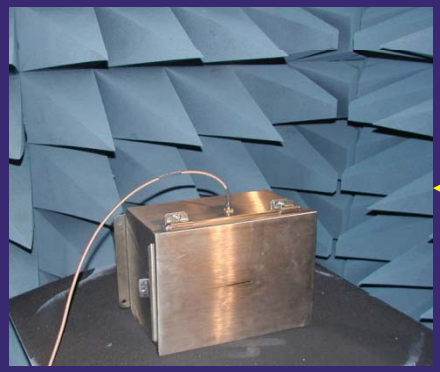
Experimental Study:

Material used:

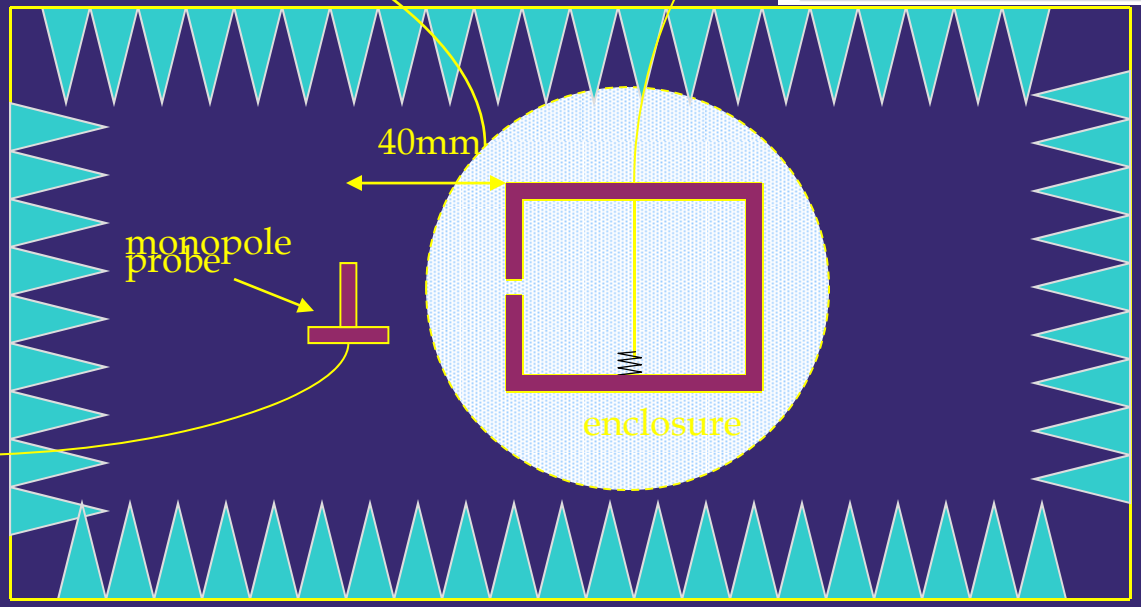
- Emerson & Cuming
  VF30 ε_r'=37 @8.6GHz,
  σ=2-20 s/m
- Emerson & Cuming
  MCS μ_r'=2, μ_r''=2.5, ε_r'=37



Radiation Measurements

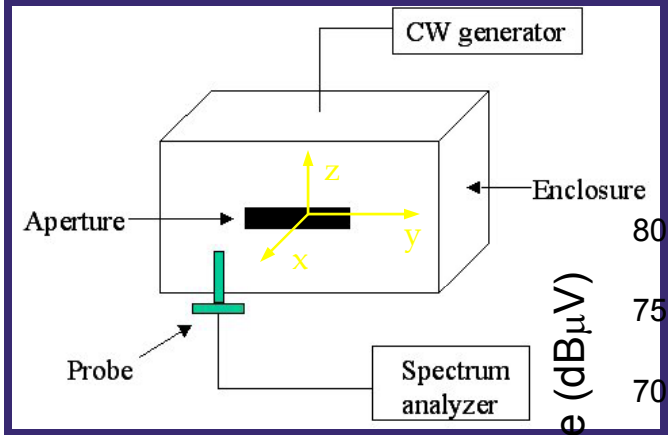


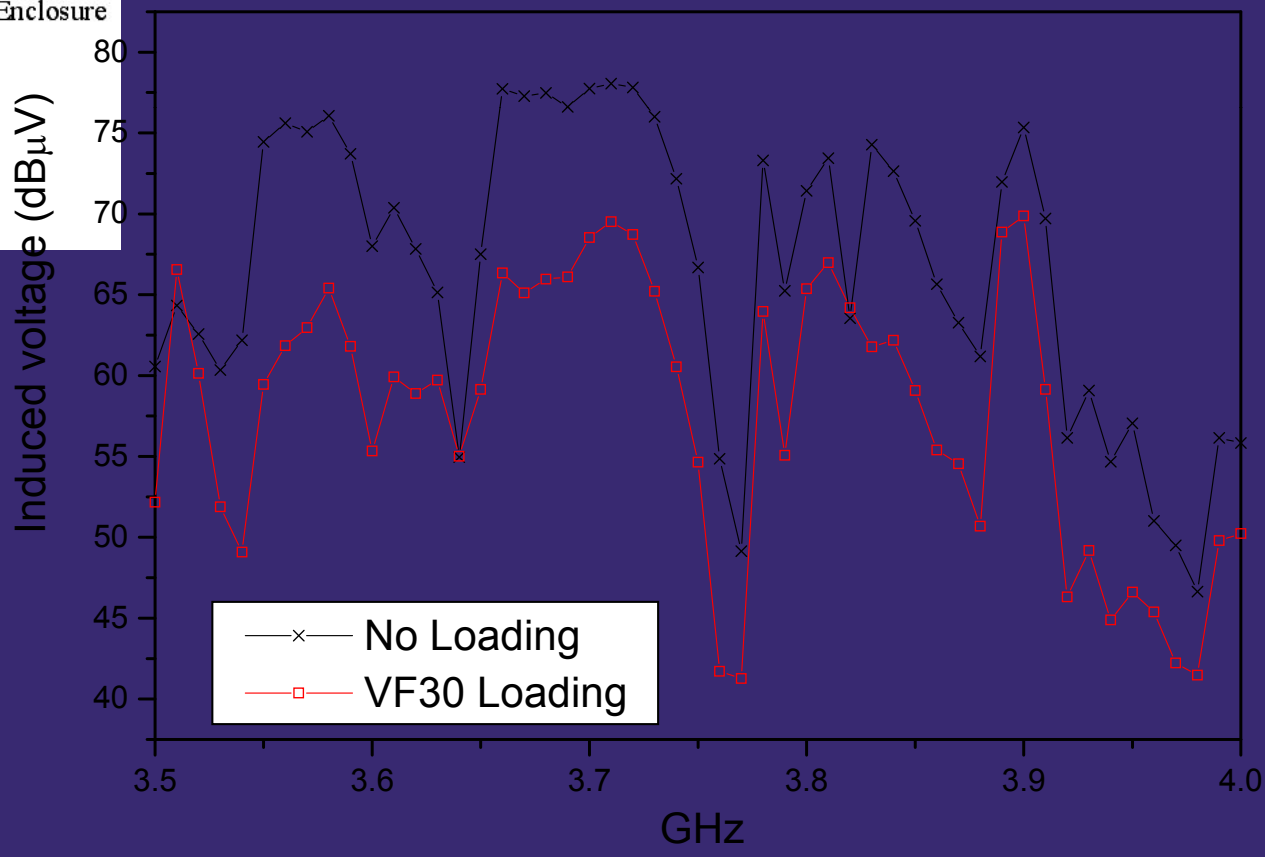
continuous
wave generator



Spectrum analyzer

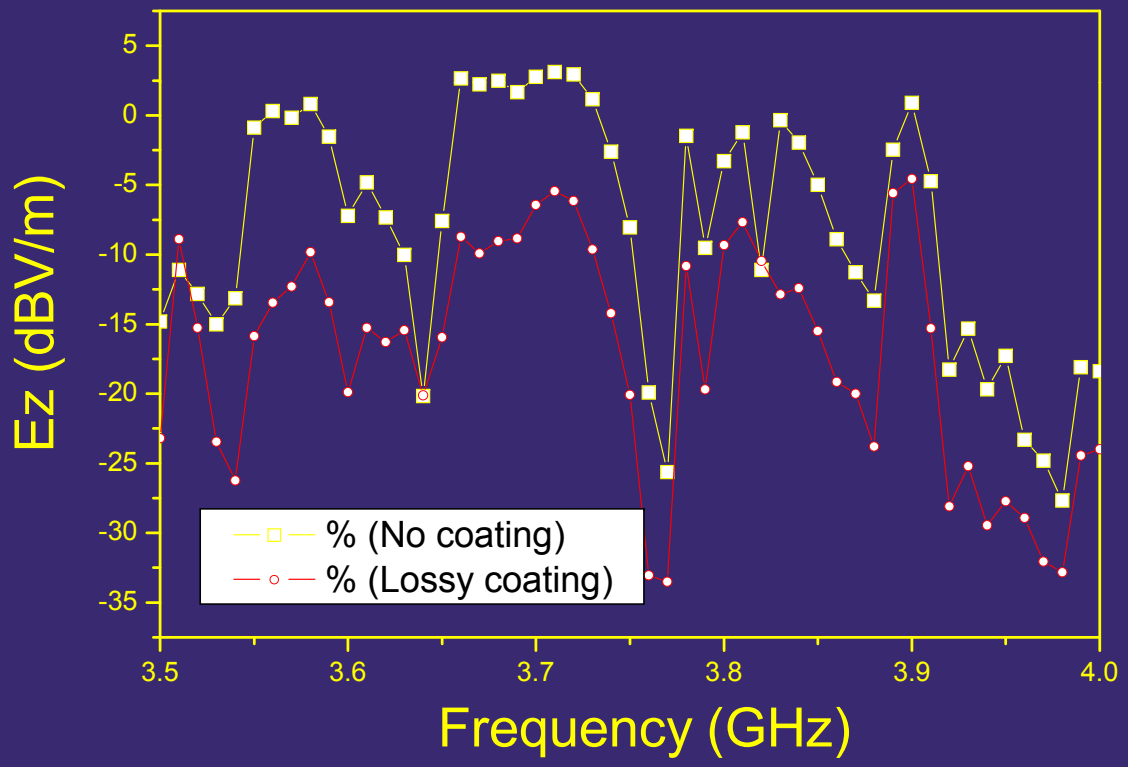
Radiation Measurement with VF30 Loading



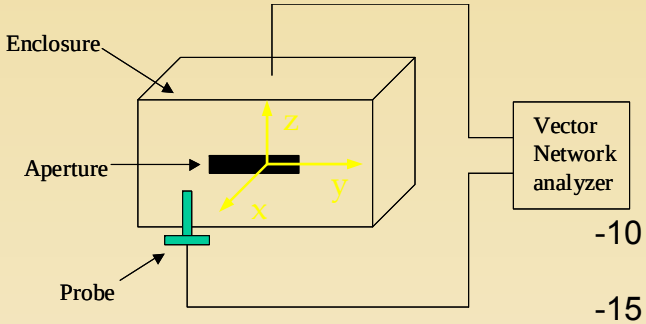


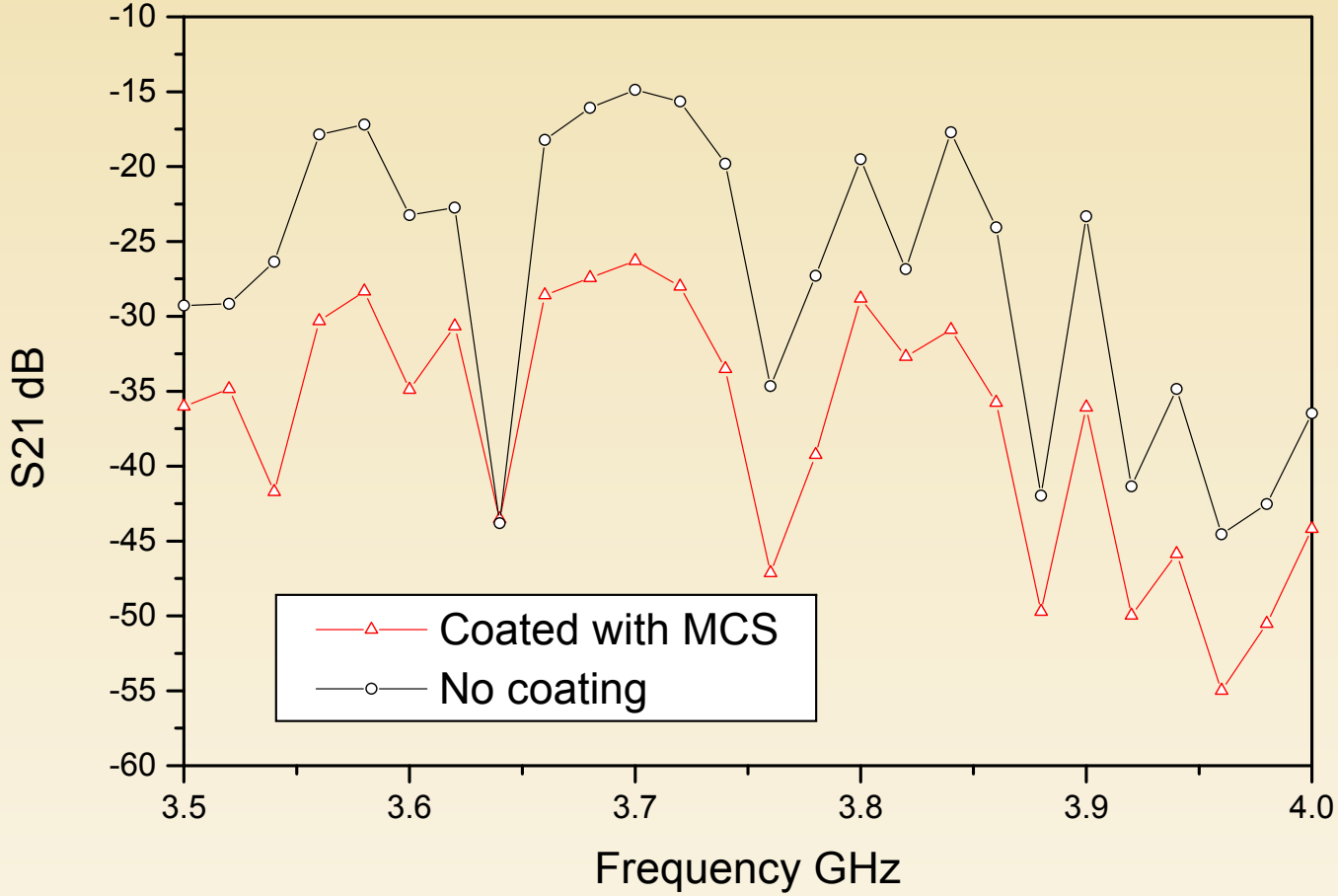
Electric Field Calculation with VF30 Loading

Electric field equals induced voltage times antenna factor *AF*

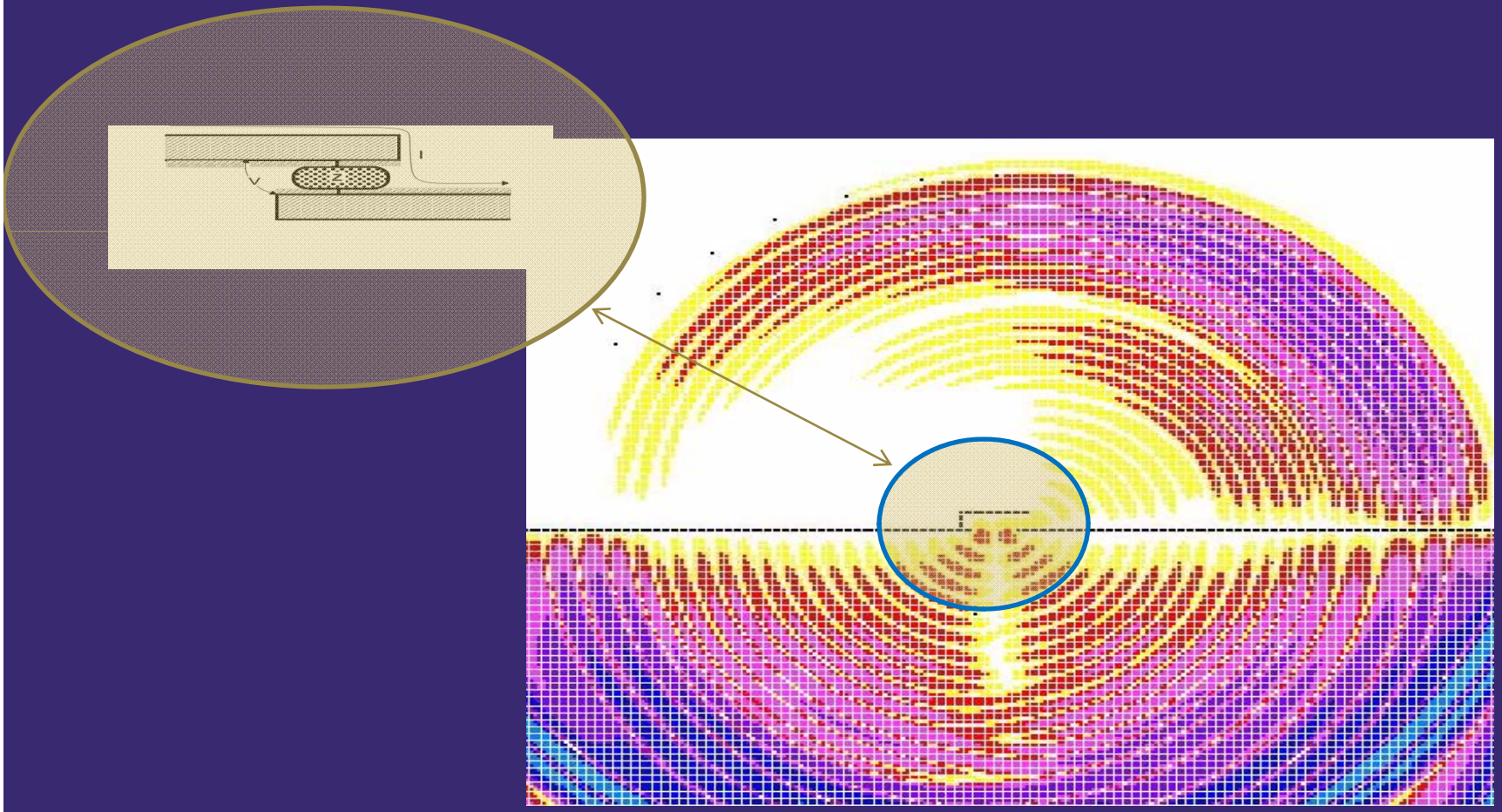


S_{21} Measurement with MCS Loading

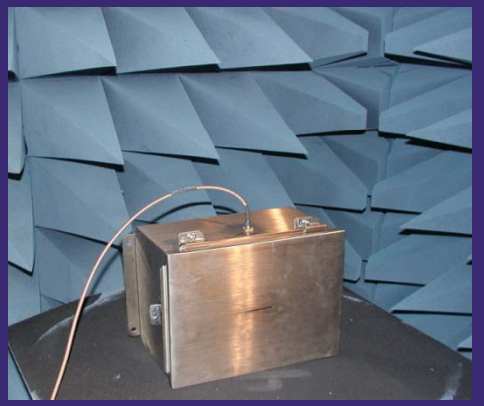


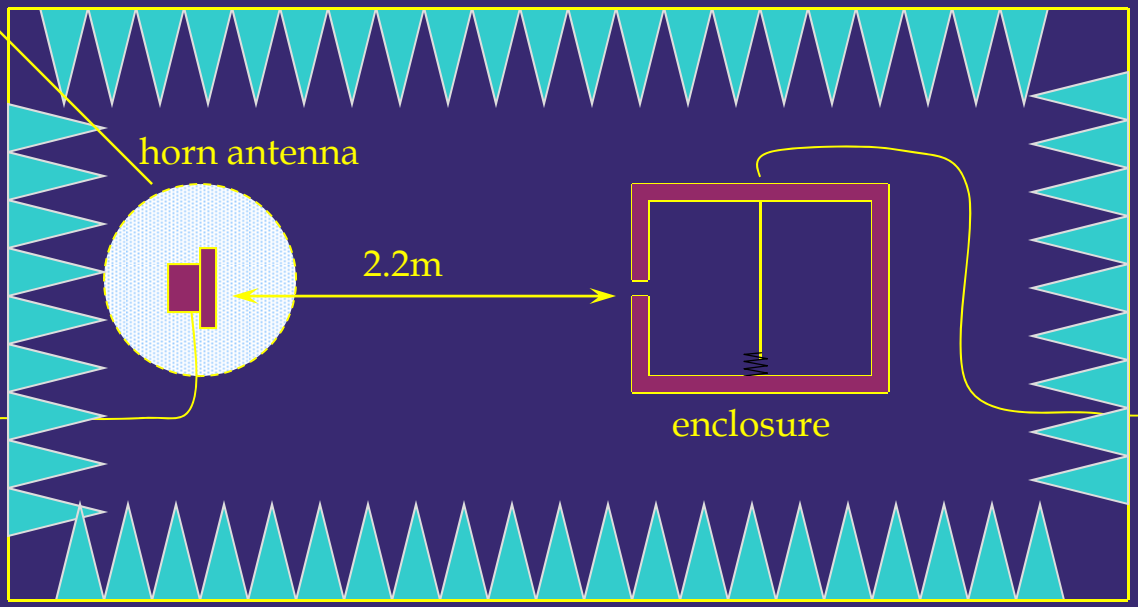


Finite-Impedance



Radiation Susceptibility Measurements

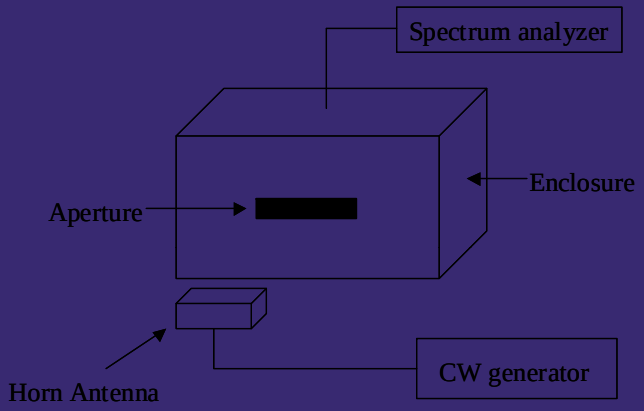


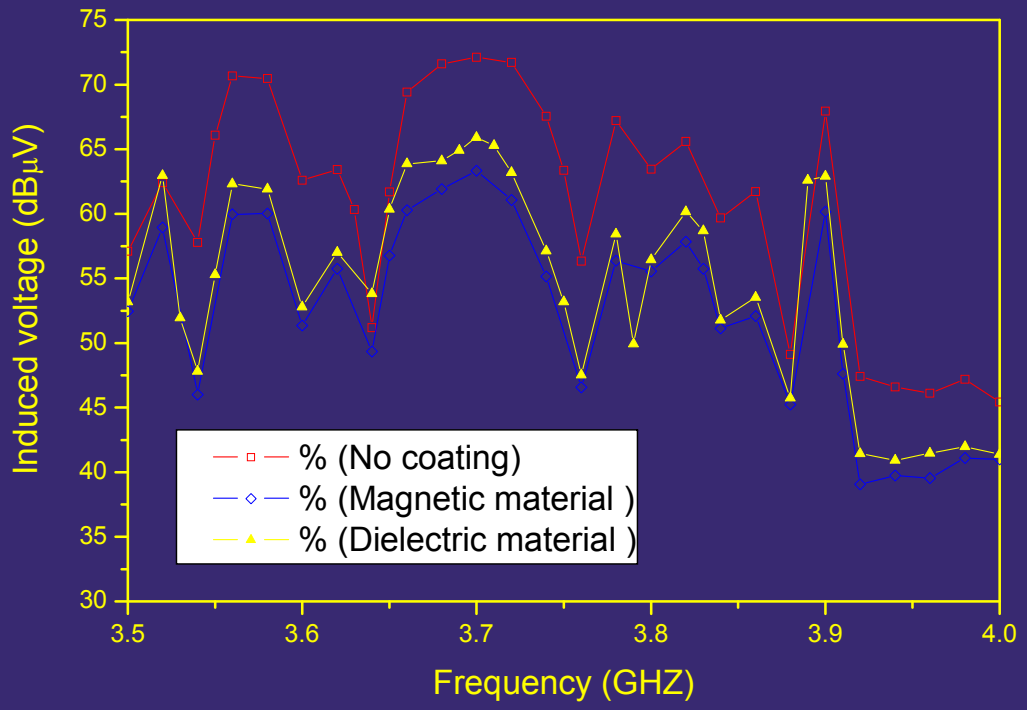


continuous wave generator

spectrum analyzer

Susceptibility Test with Different Material





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If J on surface of the box causes radiation

would radiation be eliminated if J=0 on surface?

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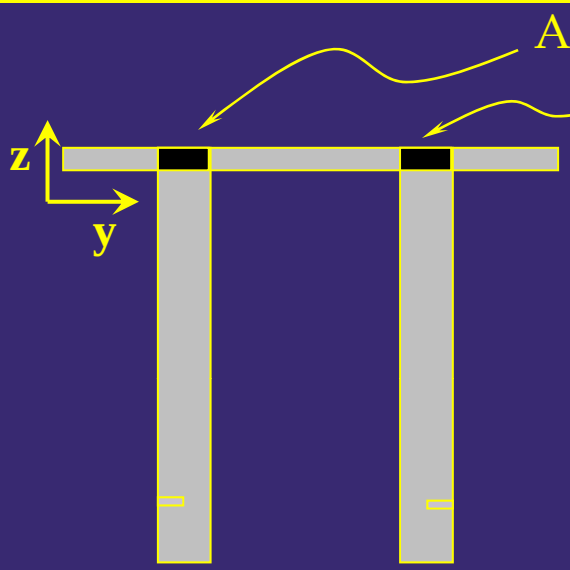
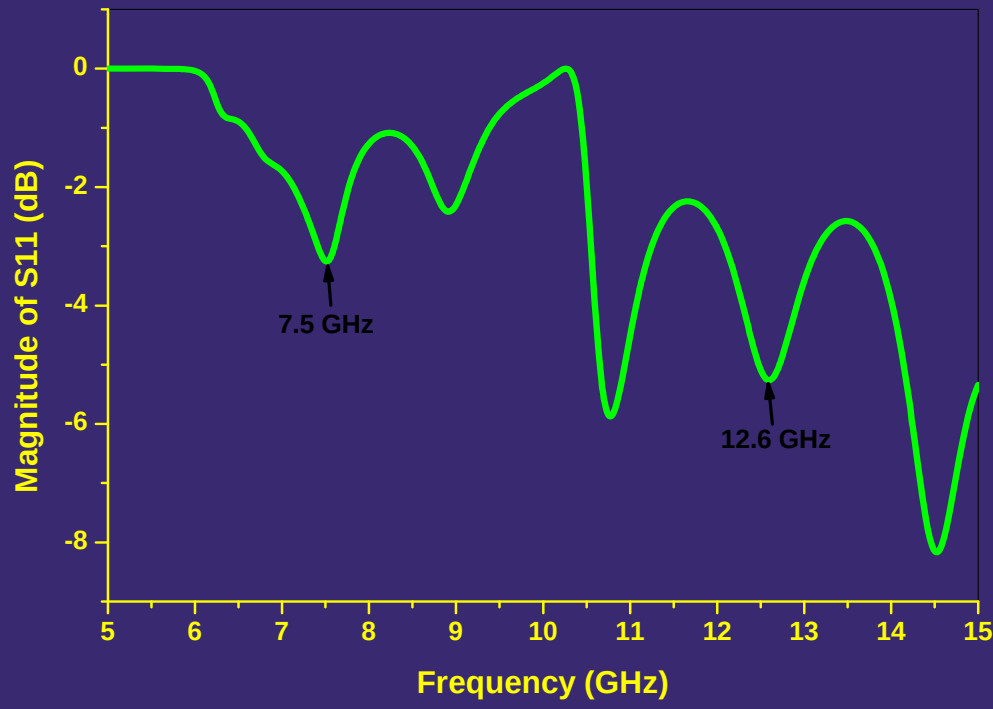
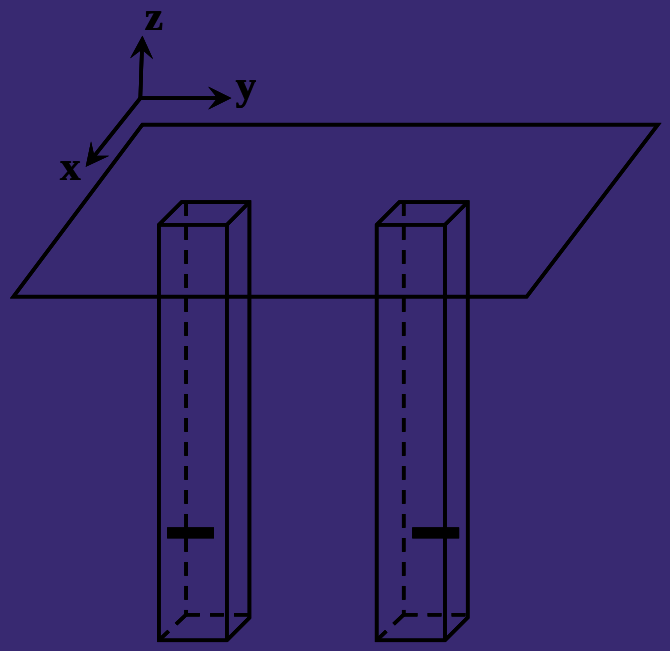
Animation: Aperture in screen

"Apertures" vs. "Patches/lines"

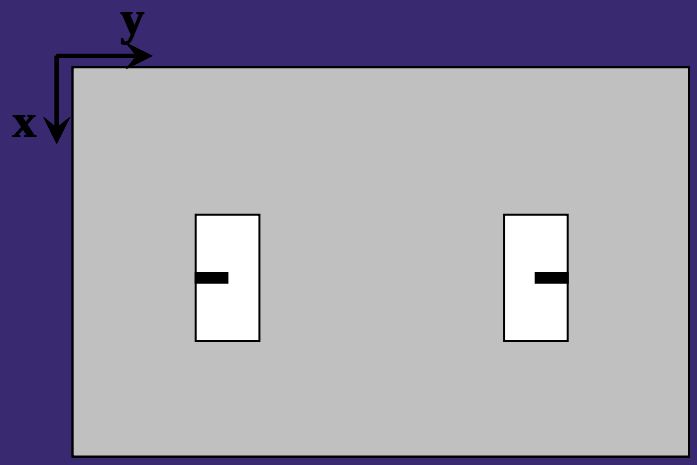




Cavities or Antennas Sharing Common Ground

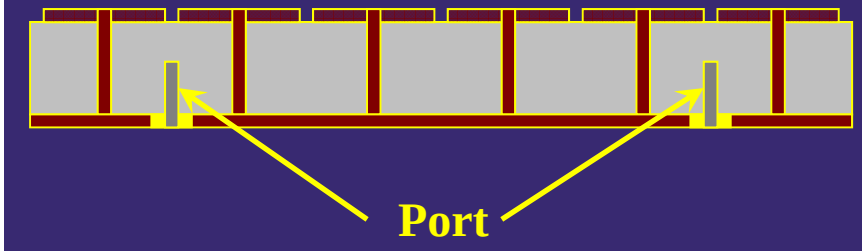


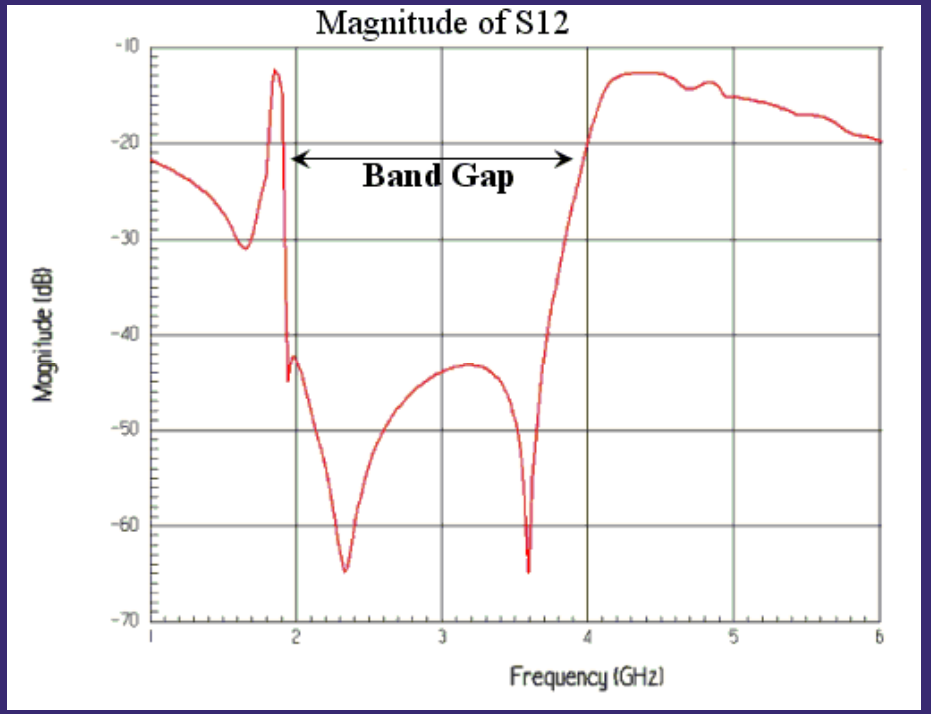
Perspective view



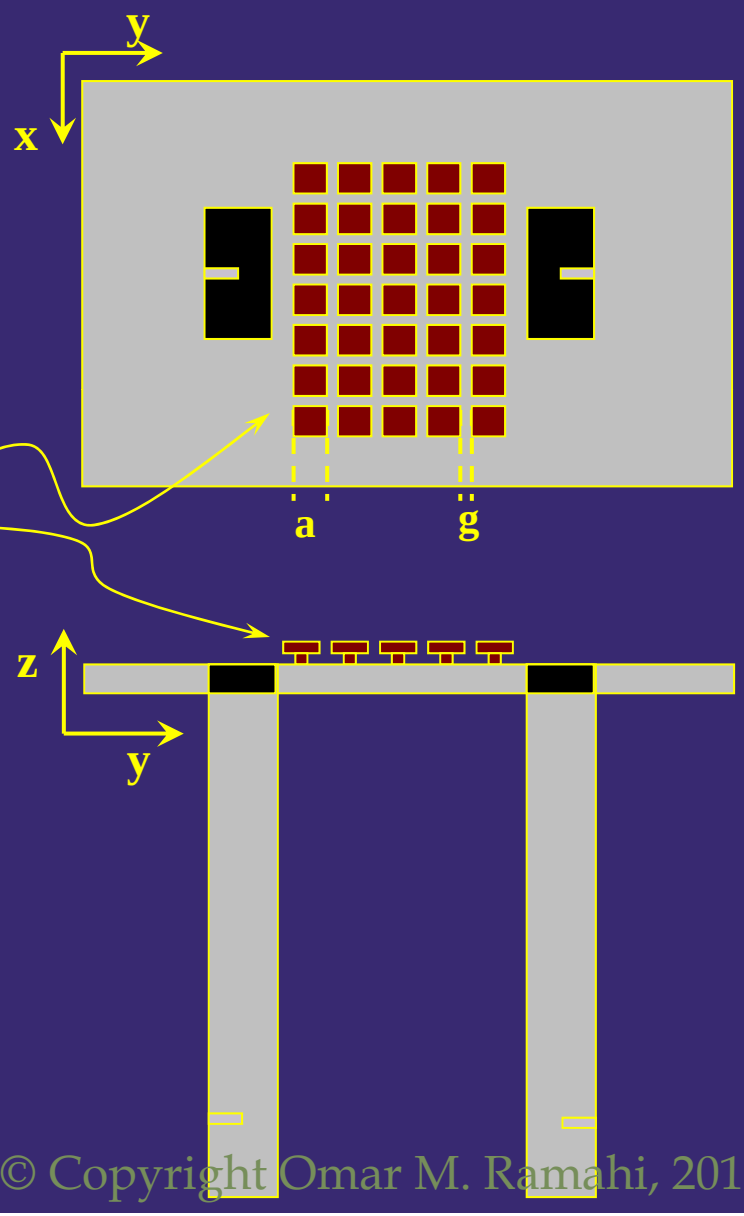
Top view

Design of EBG structure using S-parameters simulation





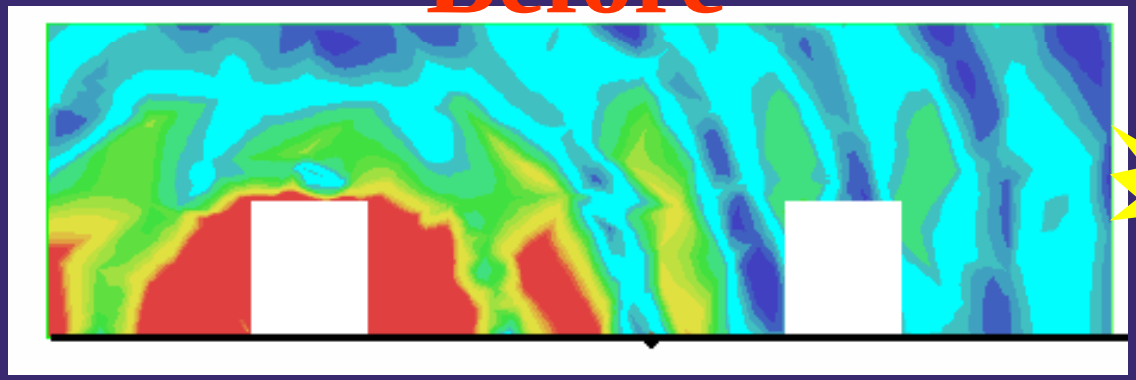
Effect of EBGs on Coupling



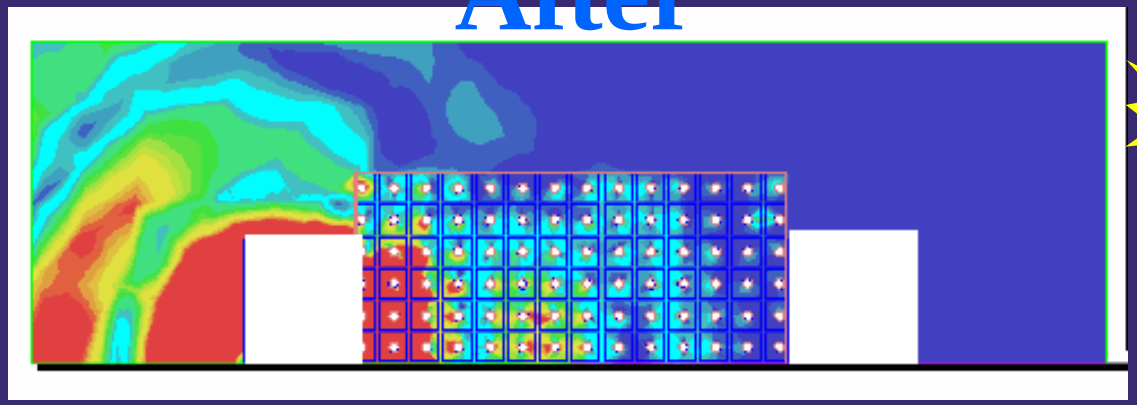
EBG Surface
Placed between
antennas

Surface Current Density at 12.6 GHz on Common Ground

Before



After



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Animation
Aperture with resistive sheet

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Animation
Aperture with EBGs

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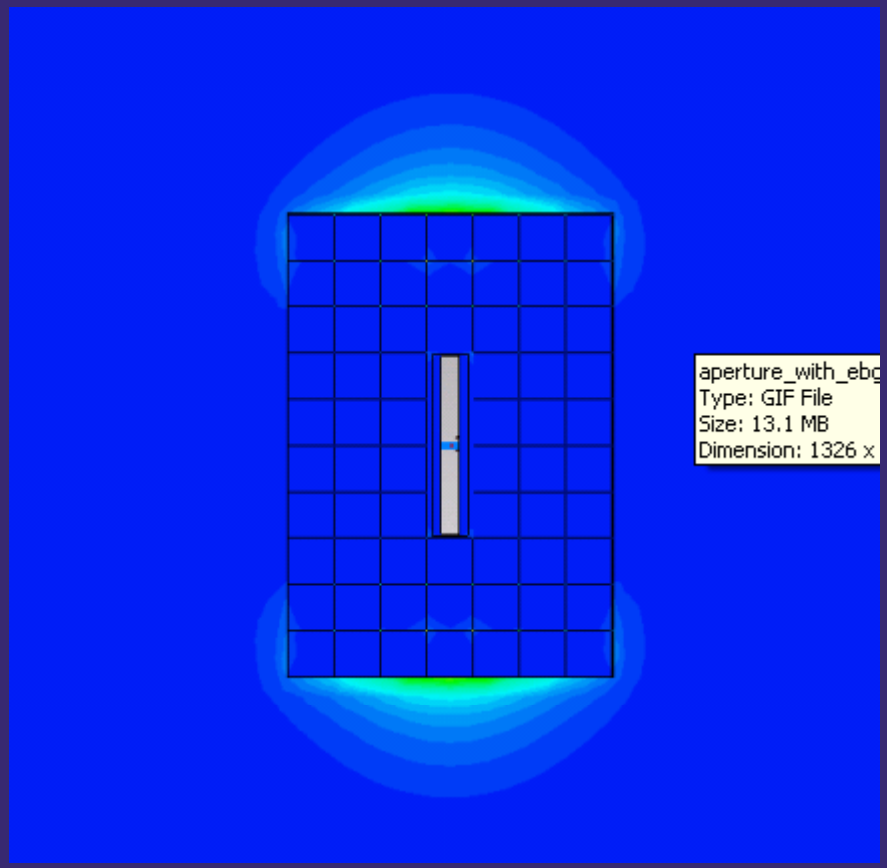

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If we can directly determine electrical currents, we should easily determine what radiates
Or how to stop it from radiating!