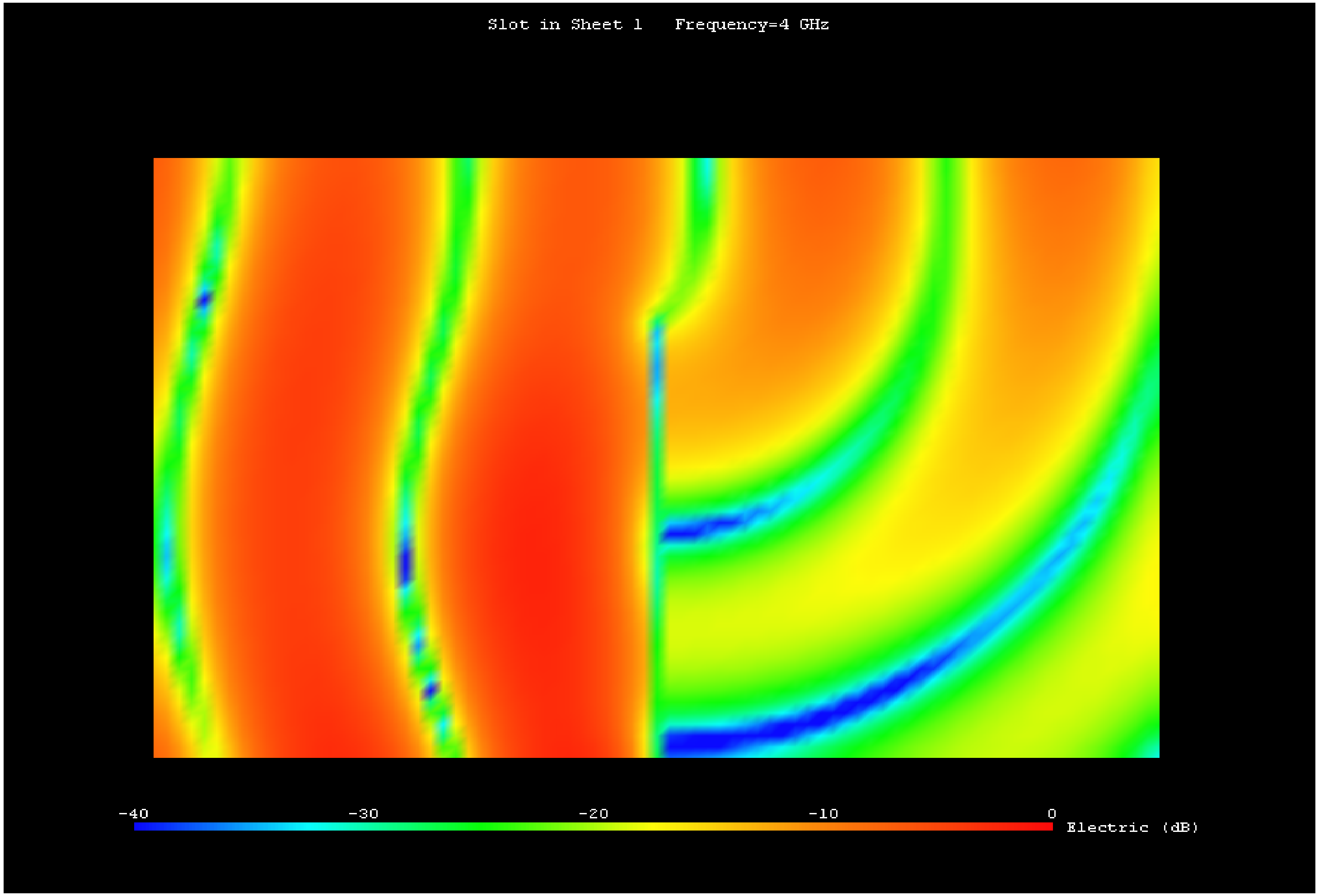
Screening

Keeping the “baddies” out

Scope of Topic

- A screen reduces transmission of Electric or/and Magnetic Fields
- Complete blocking is unlikely
- Effectiveness depends on wave impedances
  - Near field/far field
- EM fields are not blocked completely by a partial shield

Partial Shield



What Happens at an interface?

- Some energy is transmitted
- Some energy is reflected
- If edges exist, energy will creep round them
- If slots, or holes, exist energy will flow through them
  - Dependent on dimensions and frequency

Topics

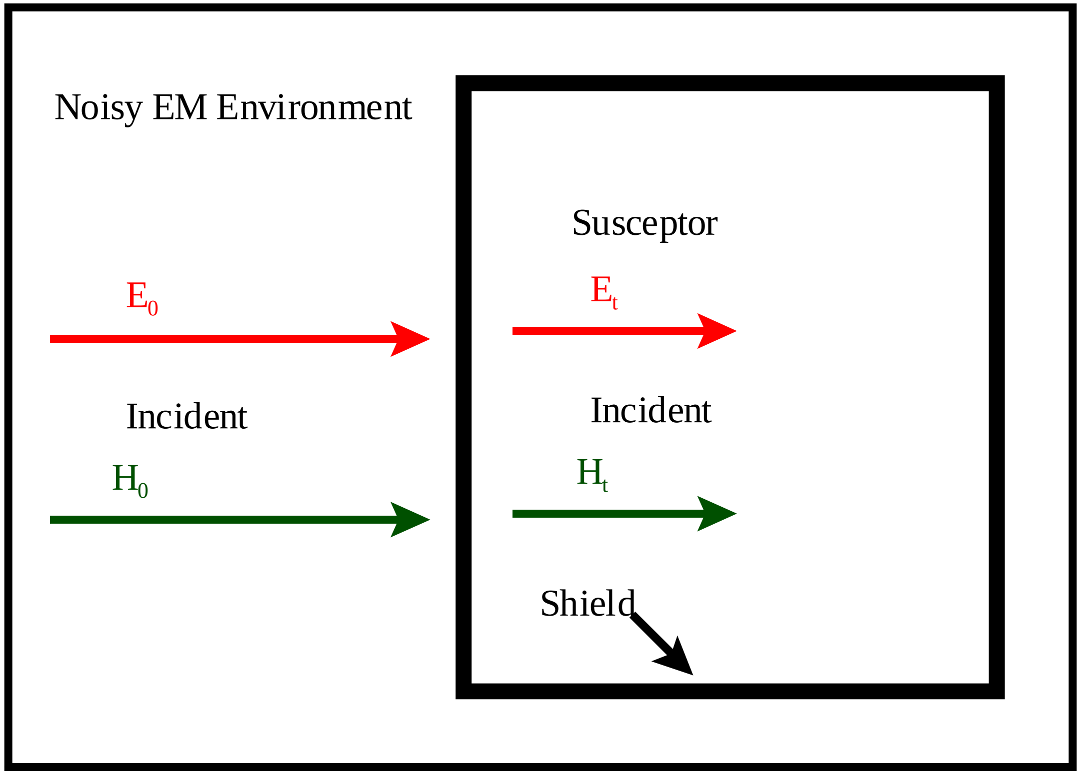
- Consider hermetic sealed containers
- Look at apertures and their behaviour
- Produce simple equations to model their behaviour
  - Shielding Effectiveness

Hermetic Shield

- Shielding Effectiveness

$$S = 20\log\left(\frac{E_0}{E_t}\right) \quad dB$$

$$S = 20\log\left(\frac{H_0}{H_t}\right) \quad dB$$



Shield Materials and Mechanisms

- Partial reflection at the surface
  - Reflection loss
- Internal losses
  - Attenuation
- Generally require magnetic material to shield magnetic fields
- Eddy currents can be used in non-magnetic materials
  - Require high frequencies

Shield Materials and Mechanisms

- Purely conductive shields shield
  - Electric Fields
    - Partial reflection at surface
    - Absorption
    - Multiple reflections
  - Magnetic fields at high frequencies –
    - IF the screen is thick

Total Shielding Effectiveness

$$S = R + A + B \quad dB$$

- R is Reflection Loss
- A is Absorption Loss
- B accounts for internal reflections
  - Ignore if A>10dB

Shielding Effectiveness

- Depends on Wave Impedance and Characteristic Impedance of Shield
  - Require an impedance mismatch
- Generally, for any medium

$$Z = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$$

- where the conductivity

$$\sigma = \sigma_r \sigma_{Cu}$$

Shielding Effectiveness

- Insulators $\sigma << \omega\varepsilon$ so $Z = \sqrt{\frac{\mu}{\varepsilon}} = 377\Omega$

- Good Conductor $\sigma << \omega\varepsilon$
- Shield Impedance

$$|Z| = \sqrt{\frac{\omega\mu}{\sigma}}$$

$$\mu_0 = 4\pi x 10^{-7} \quad Hm^{-1} \qquad \sigma_{Cu} = 5.28 x 10^{7} \quad Sm^{-1}$$

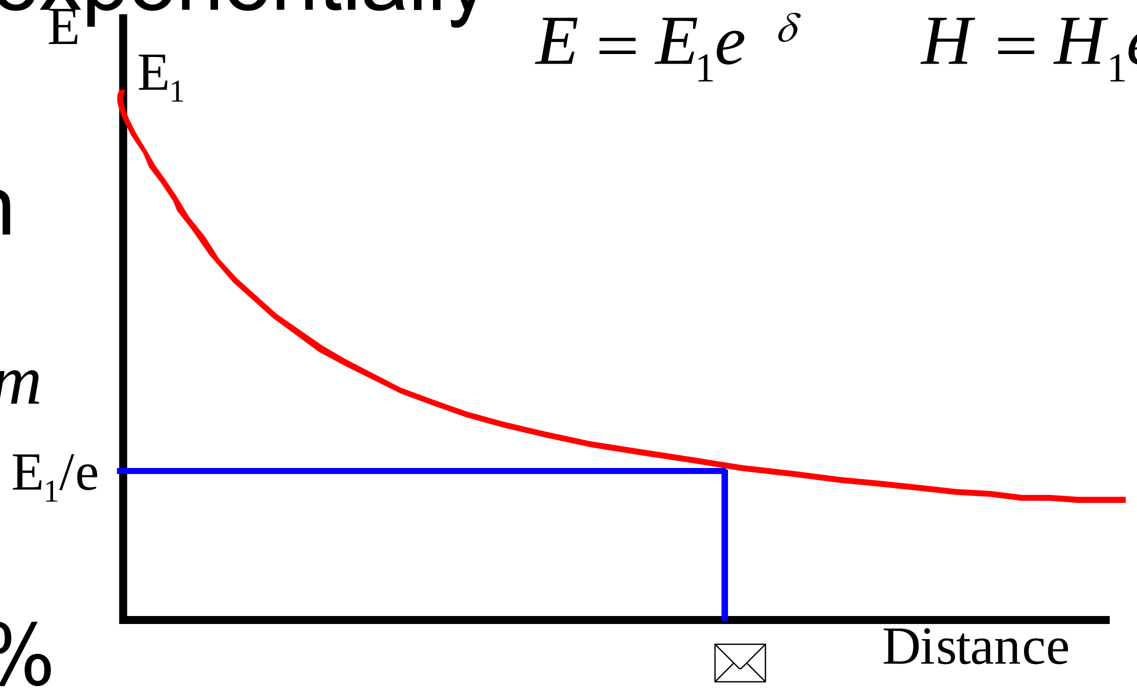
Some Common Screening Materials

Material	σ_r	μ_r	$\lvert Z_s \rvert$ (Ω)
Copper	1	1	$3.68 \times 10^{-7}\sqrt{f}$
Aluminium	0.61	1	$4.71 \times 10^{-7}\sqrt{f}$
Steel	0.1	1000+	$3.68 \times 10^{-5}\sqrt{f}$

Absorption Loss

- TEM wave in a lossy medium loses amplitude exponentially

$$E = E_1 e^{-\frac{x}{\delta}} \qquad H = H_1 e^{-\frac{x}{\delta}}$$



- Skin Depth

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

- 1/e = 36.8%

Typical Values for Skin Depth (cm)

Frequency			
50Hz	0.933	1.195	0.12
1kHz	0.201	0.269	0.027
1MHz	0.0066	0.0085	0.0009

Absorption Loss through a Shield

- Express E_t in terms of the exponential reduction

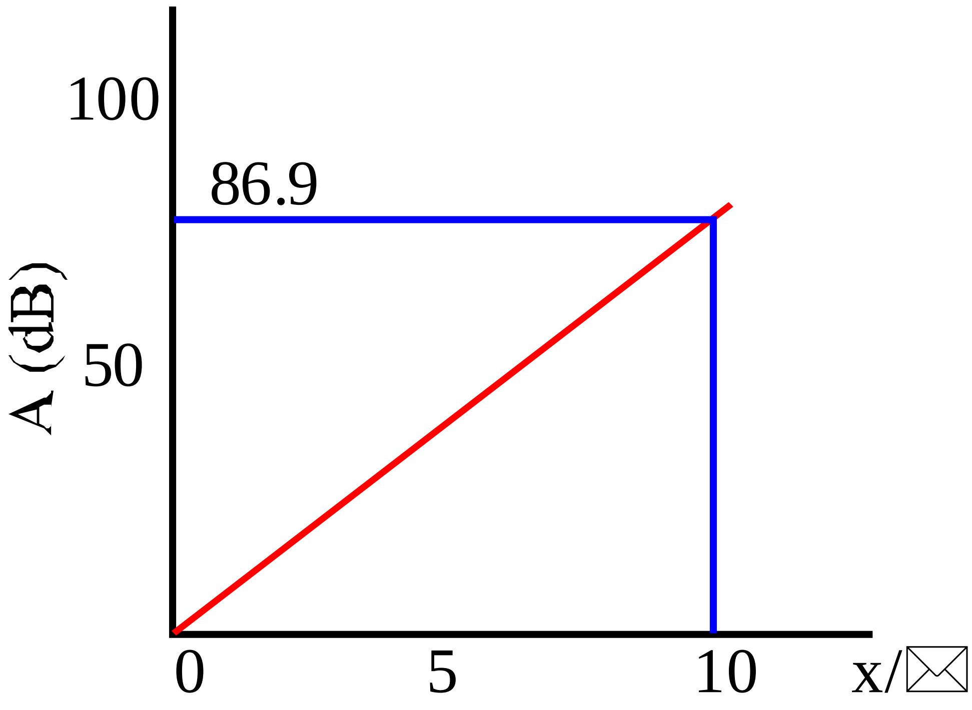
$$A = 20\log\frac{E}{E_1}$$

$$A = 20\log\left(e^{-\frac{x}{\delta}}\right)$$

$$A = 20\frac{x}{\delta}\log e$$

Absorption Loss through a Shield

$$A = -8.69\frac{x}{\delta} \qquad dB$$

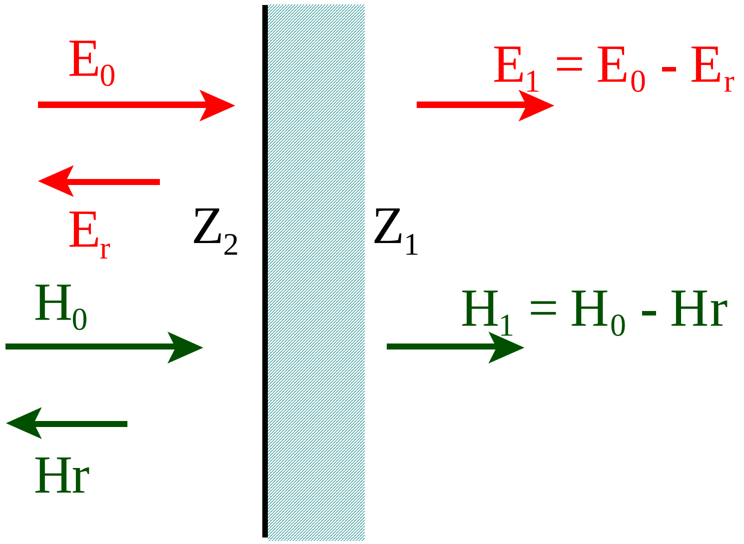


- Loss is proportional to plate thickness
- True for E and H

Reflection Loss

- Relates to Reflection Coefficient.
- Normal Incidence

$$\frac{E_r}{E_0} = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$



$$\frac{E_1}{E_0} = \frac{2Z_2}{Z_1 + Z_2}$$

$$\frac{H_1}{H_0} = \frac{2Z_1}{Z_1 + Z_2}$$

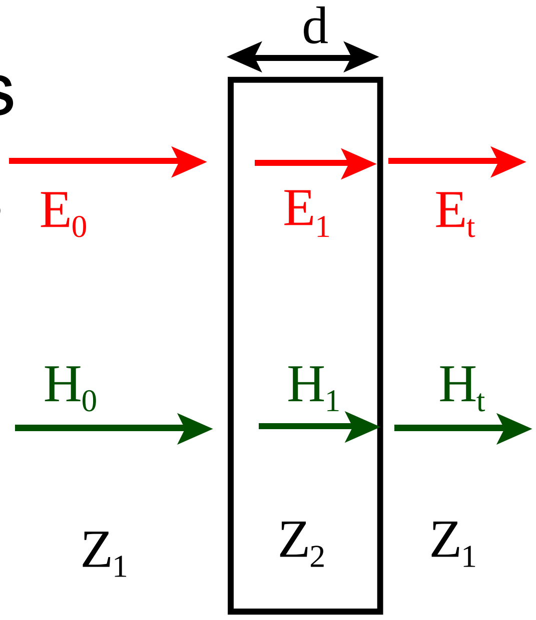
Reflection Loss Through a Plate

- Two Boundaries
  - Combine two equations
  - Ignore Absorption Loss

$$\frac{E_t}{E_1} = \frac{2Z_1}{Z_1 + Z_2}$$

$$\frac{E_t}{E_0} = \frac{4Z_1 Z_2}{(Z_1 + Z_2)^2}$$

$$\frac{H_t}{H_0} = \frac{4Z_1 Z_2}{(Z_1 + Z_2)^2}$$



Absorption Loss

- Model as an exponential

  $$L_A = e^{-\gamma d}$$

- Only applies to second reflection loss term
- Exponential is used to account for multiple reflections in sheet

Electric Fields

- Wave impedance is high
- Shield impedance is low
- Substituting Z_w and Z_s gives

$$\frac{E_t}{E_0} = \frac{4Z_w Z_s}{(Z_w + Z_s)^2} \approx \frac{4Z_s}{Z_w}$$

$$R = 20\log\left(\left|\frac{Z_w}{Z_s}\right|\right) \quad dB$$

Plane Waves

- Similar picture to E fields
- Wave Impedance is 377Ω
- Shield Impedance is very low
- In both cases
  - Virtually all reflection occurs at first interface
  - Thin conducting shield is normally sufficient

Magnetic Fields

- Wave Impedance is low
- Shield Impedance is low
- Reflection from interface is low
- Require absorption to attenuate magnetic fields
- Usually use magnetic materials with high permeability to increase the shield impedance

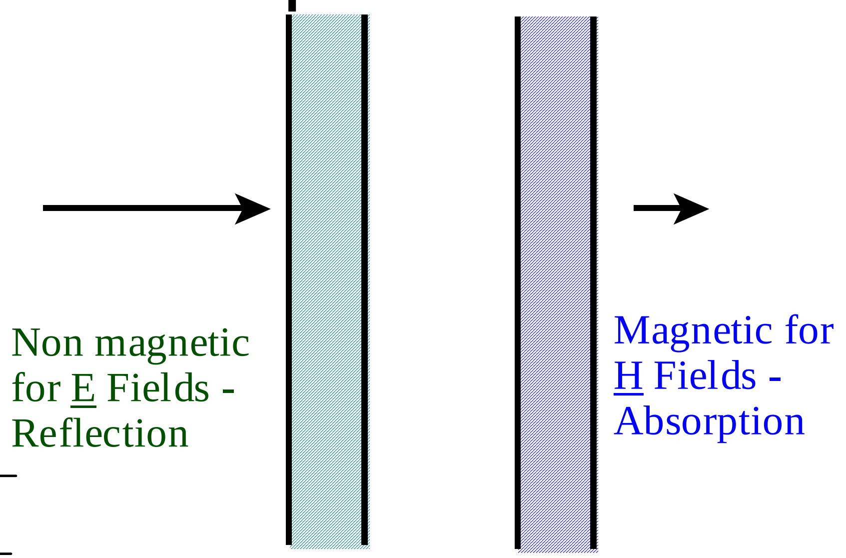
Composite Fields

- Use twin shield to solve the problem
- Magnetic Shield
  - High permeability
  - Increases Z_s

$$Z_s = \sqrt{\frac{\omega\mu}{\sigma}}$$

$$\delta = \sqrt{\frac{2}{\omega\mu\varepsilon}}$$

  - Reduces δ
  - Increases Absorption



Seams and Holes

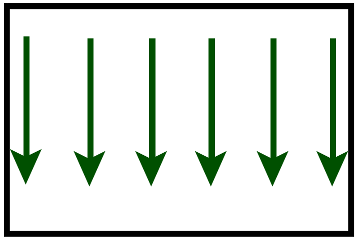
- Always present
  - Access
  - Cables
  - Ventilation
- Leakage dominates propagation through the case
- Concentrate on the seams and holes

Seams and Holes

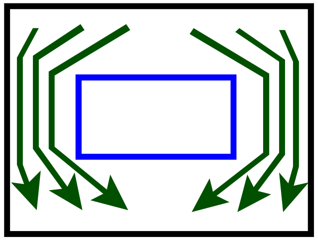
- Magnetic fields are better “escape artists”
  - They leak more through seams and holes
- Leakage depends on
  - Maximum linear dimension of the hole
  - Aperture wave impedance
  - Frequency of the source

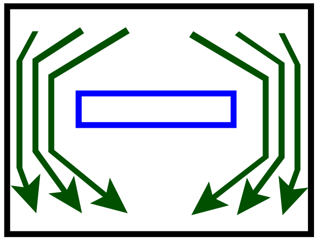
Shielding Mechanism

- Eddy currents in shield
- Undistorted

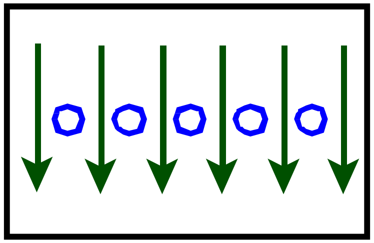


- Slots distort currents



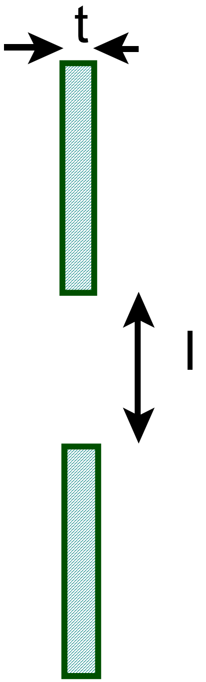


- Holes improve the problem



Slot Antenna

- Allows development of simple method for handling slots/holes
- Applies to thin shields t < l
- Efficient radiator for t = λ/2
- For narrow slots the perimeter is 2λ.



Circular Aperture

- Treat as an aperture antenna

$$G = \frac{4\pi A}{\lambda^2} \quad = \quad \left(\frac{2\pi r}{\lambda}\right)^2$$

- Substituting for the area
- Magnetic fields tend to penetrate the aperture

Shield Effectiveness

- P_1 is power transmitted with no shield present
- P_2 is power transmitted with shield present (including hole)

$$S = 10\log\left(\frac{P_1}{P_2}\right) \quad dB$$

- Gain is P_2 / P_1 so

$$S = 20\log\left(\frac{\lambda}{2\pi r}\right) \quad dB$$

  - Circular hole
  - Reflection loss at the hole

Multiple Holes

- For n holes

$$G \approx n\left(\frac{2\pi r}{\lambda}\right)^2$$

- giving

$$S = 20\log\frac{1}{\sqrt{n}}\left(\frac{\lambda}{2\pi r}\right) \qquad dB$$

Narrow Slot

- Leakage related to maximum length

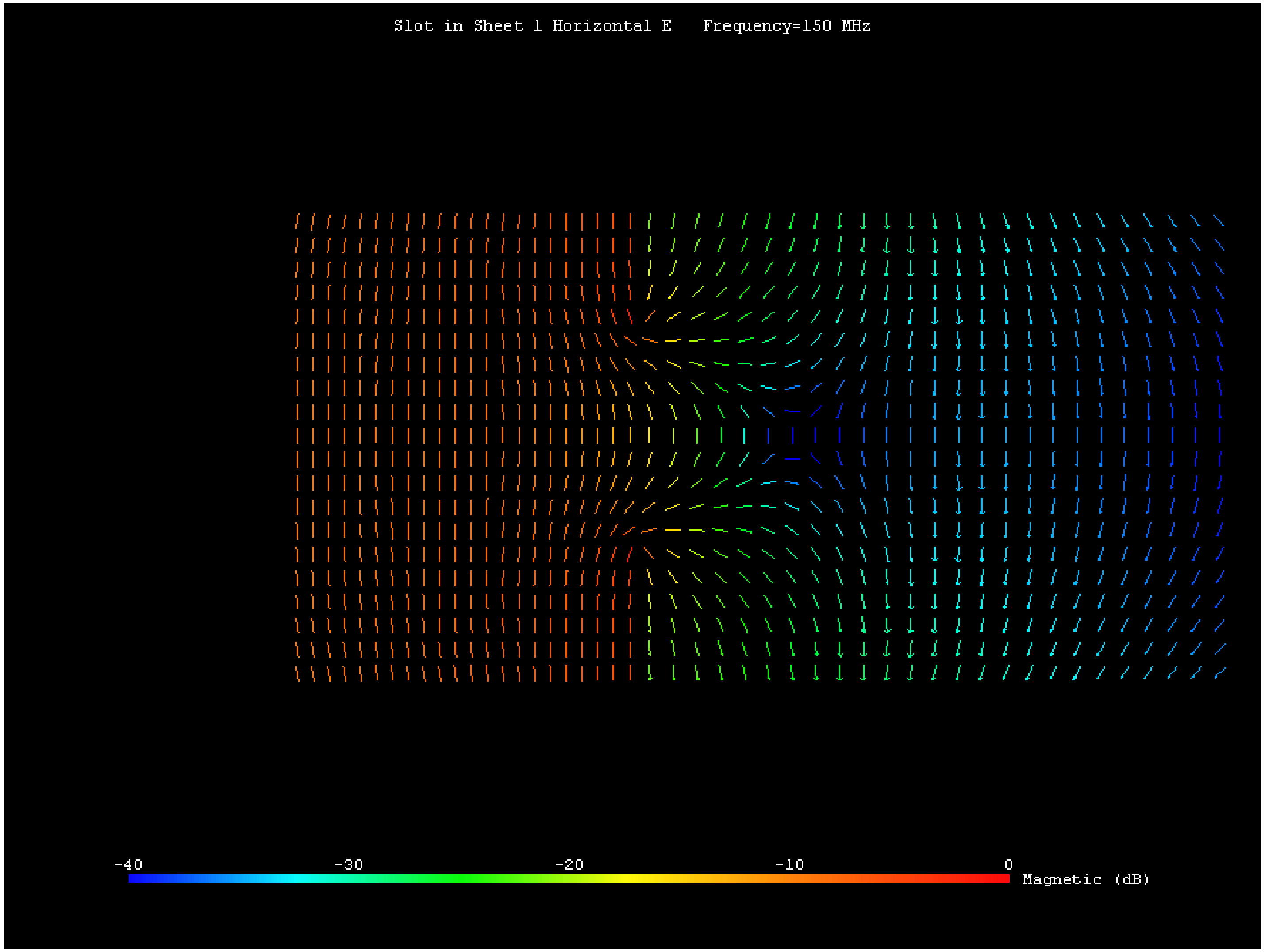
$$S = 20\log\left(\frac{\lambda}{2l}\right) \quad dB$$

- For thin shields
  - l < λ/50
- S = 28dB
- Power ratio is 630

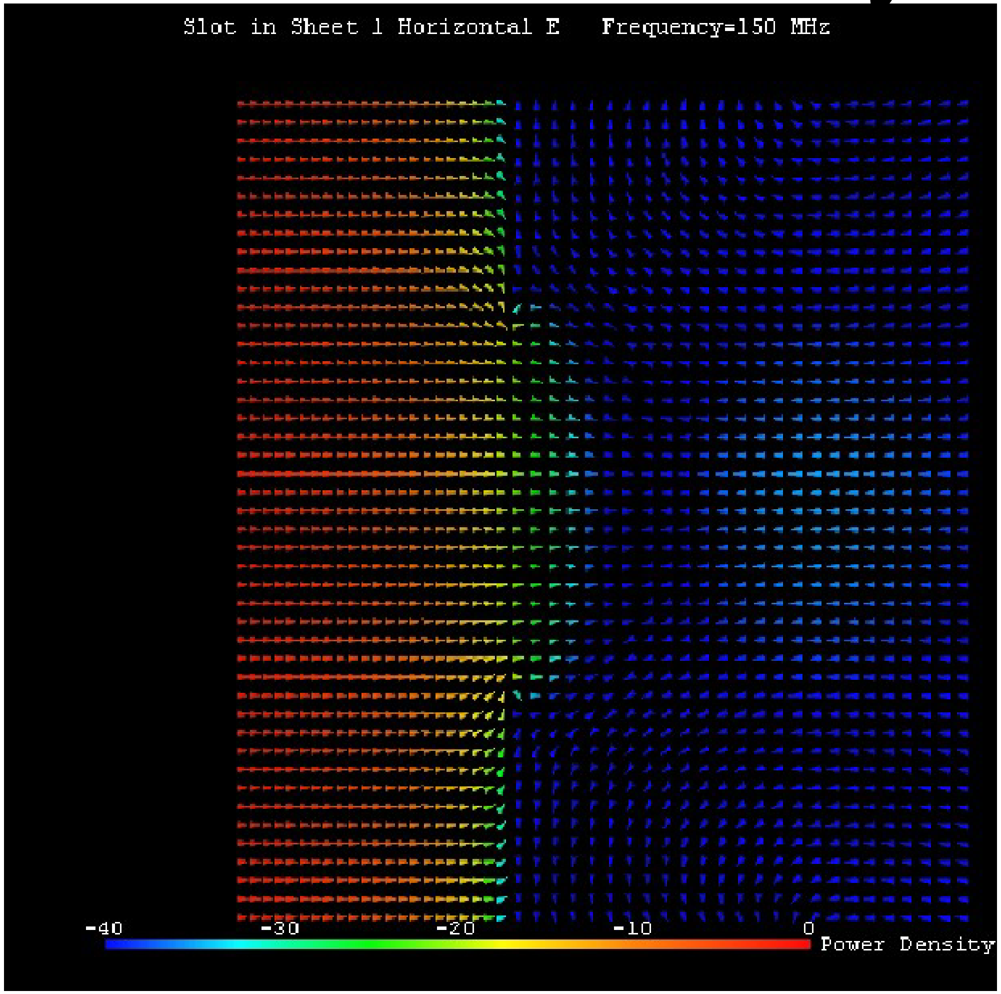
Rectangular Slot

- 40mm x 20mm
- E field aligned with 40mm side
- 3.7GHz resonant frequency
- Fields at 150MHz, 2.4GHz and 14GHz

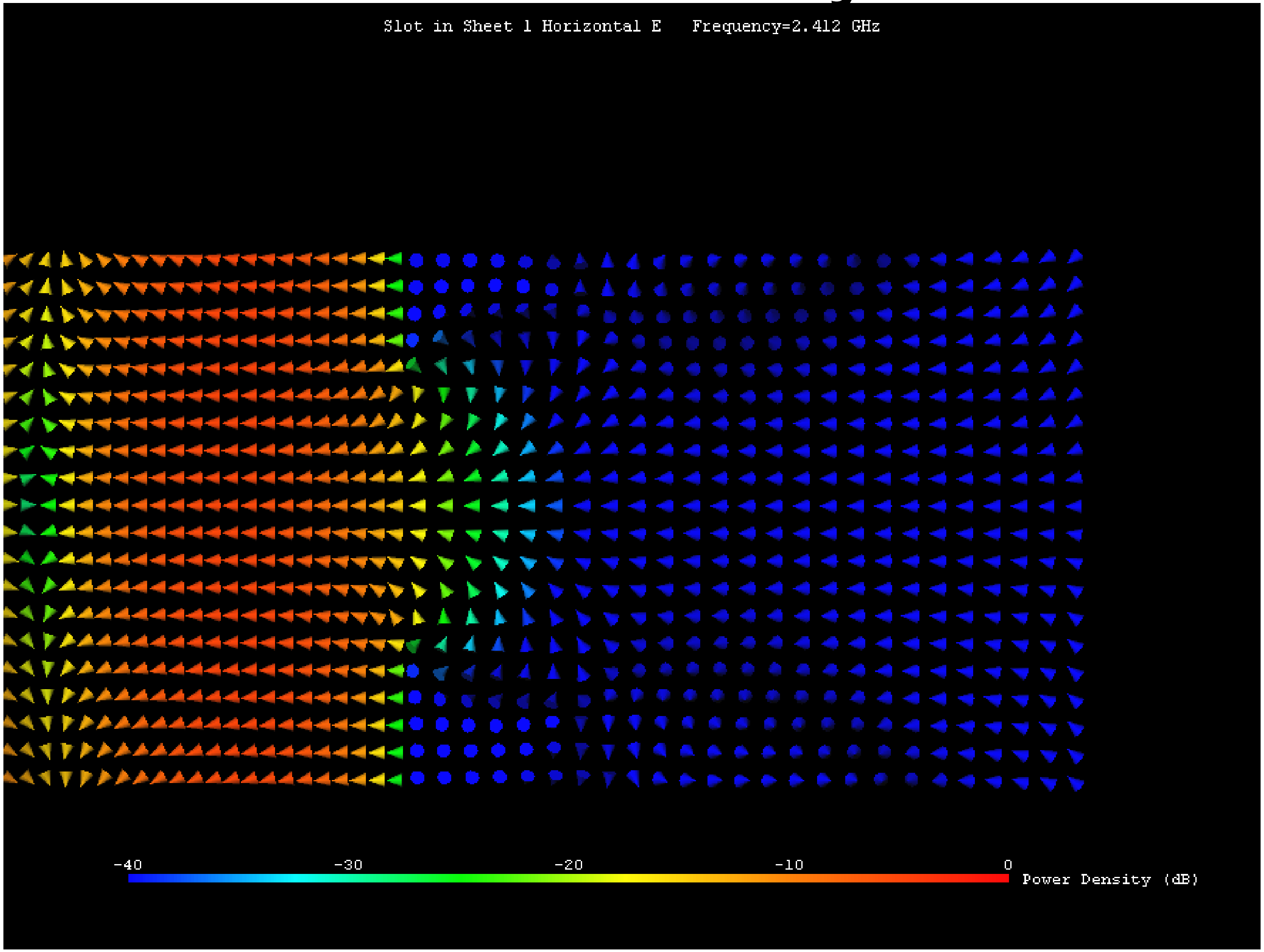
150MHz Magnetic Field



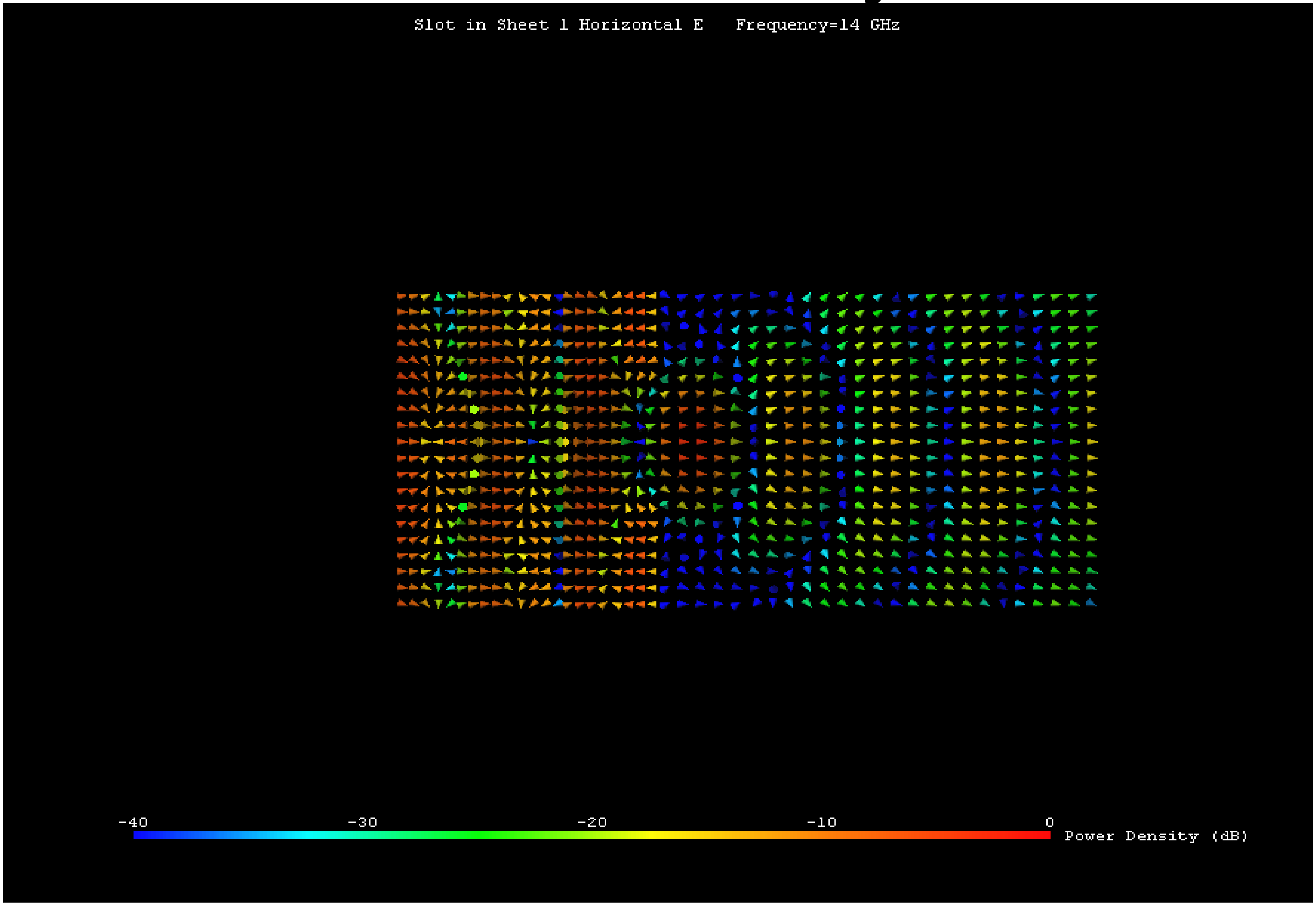
150MHz Power Density



2.4GHz Power Density

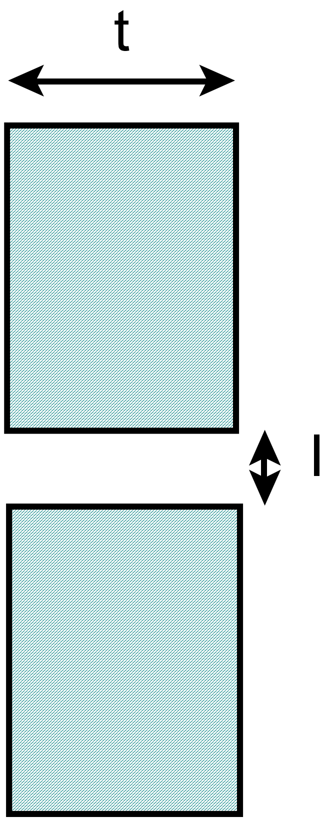


14GHz Power Density



Thick Shields

- Defined by t > l
- Aperture acts a a waveguide
- If aperture dimension is less than λ/2 screening will be good
- Cut-off wavelength for narrow slot $\lambda_c = 2l$
- Cut-off is not complete



Thick Shields

- Cut-off frequency in air

$$f_c = \frac{c}{\lambda_c} = \frac{1.57x10^7}{l}$$

- Below f_c the mechanism is waveguide loss
- Attenuation of the form

$$H = H_0 e^{-\alpha x}$$

- For f << f_c

$$\alpha \approx \frac{\omega}{c} \frac{f_c}{f}$$

Thick Shields

- Shielding effectiveness

$$S_{wg} = 20\log\left(\frac{H_{entry}}{H_{exit}}\right) = 20\log\left(e^{\alpha t}\right)$$

$$S_{wg} = 20\alpha t \log(e) = 8.69\alpha t \qquad dB$$

- Note similarity to absorption loss in solid plate

$$S_{wg} \approx 8.69\frac{2\pi f}{c}\frac{c}{2l}\frac{1}{f}t = 27.2\frac{t}{l} \qquad dB$$

Thick Shields

- Note
  - frequency independence
  - $f << f_c$
- Total Shielding Effectiveness

$$S = 20\log\left(\frac{\lambda}{2l}\right) + 27.2\frac{t}{l} \qquad dB$$

Reflection **Absorption**

Thick Shields

$$\lambda_c = 1.7d$$

- Circular Hole t > d

$$f_c = \frac{c}{\lambda_c} = \frac{1.75x10^7}{d} \quad in \quad air$$

$$\alpha = \frac{\omega}{c}\frac{f_c}{f} = \frac{2\pi f}{c}\frac{c}{1.7d}\frac{1}{f} = \frac{3.7}{d}$$

- giving

$$S_{wg} = 8.69\frac{3.7}{d}t = \frac{32t}{d} \quad dB$$

Thick Shields

- Total Shielding Effectiveness

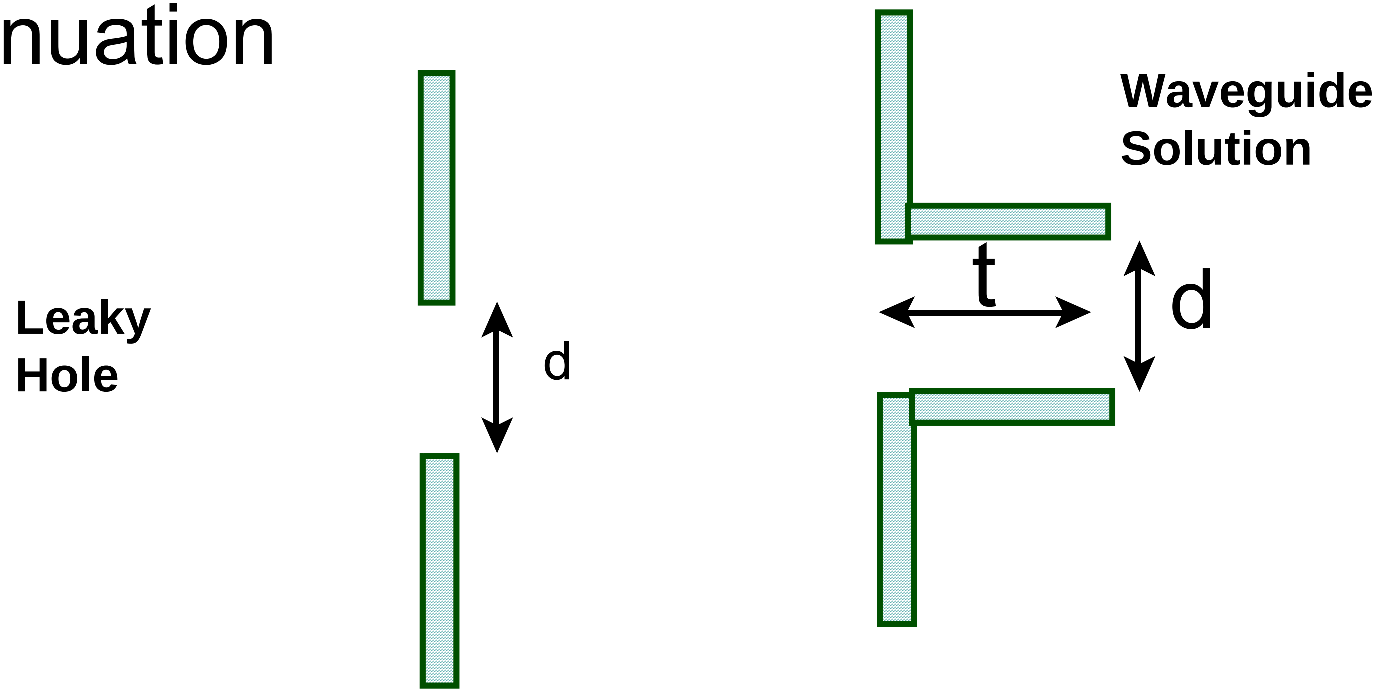
$$S = 20\log\left(\frac{\lambda}{\pi d}\right) + \frac{32t}{d} \qquad dB$$

Reflection **Absorption**

- If $\lambda = 5\lambda_c$ and t = 2d
- S = 8.65 + 64 dB
- Waveguide absorption is far more effective

Handling a hole for cable entry

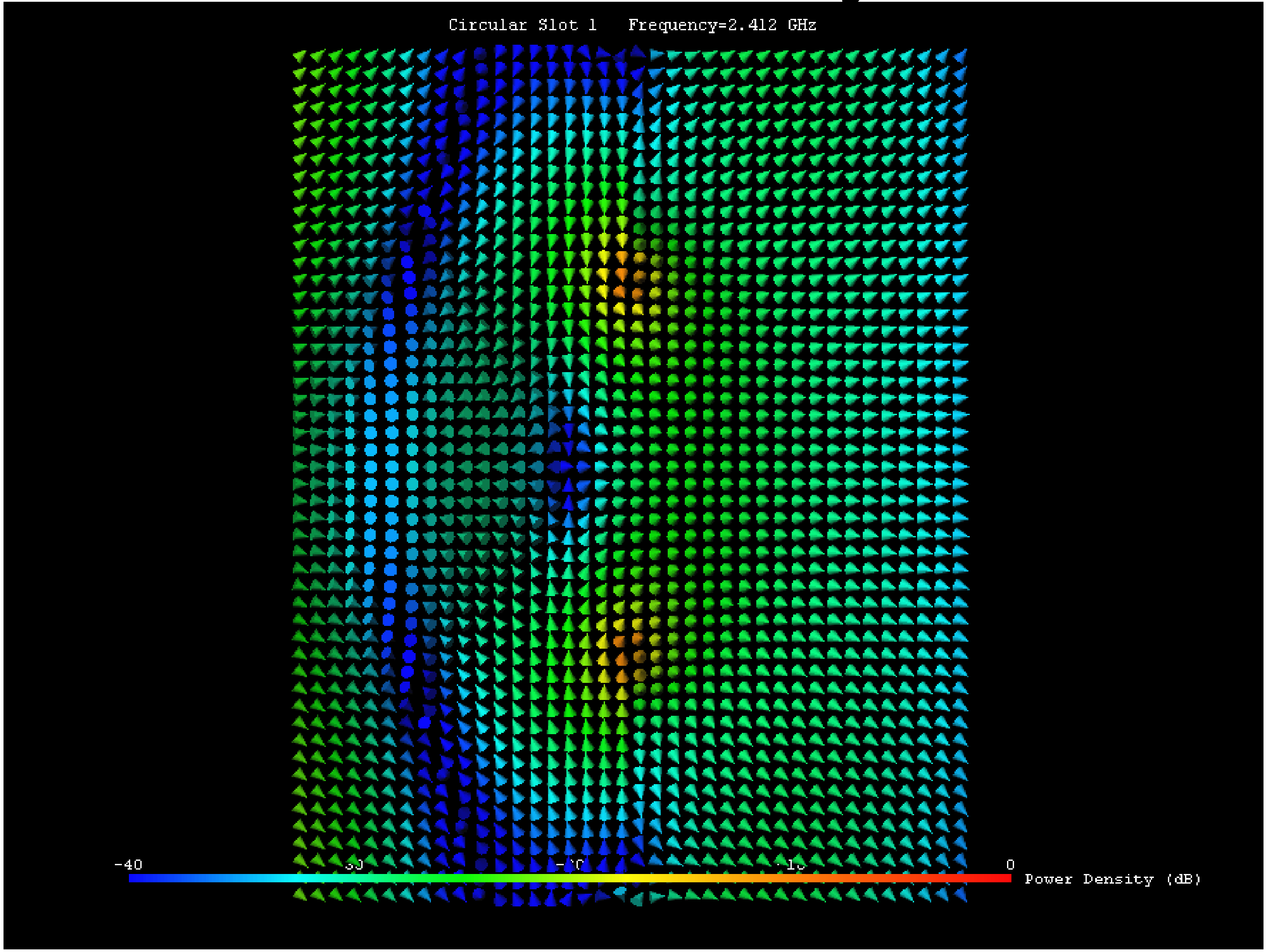
- The best technique is to increase shielding effectiveness by adding waveguide attenuation



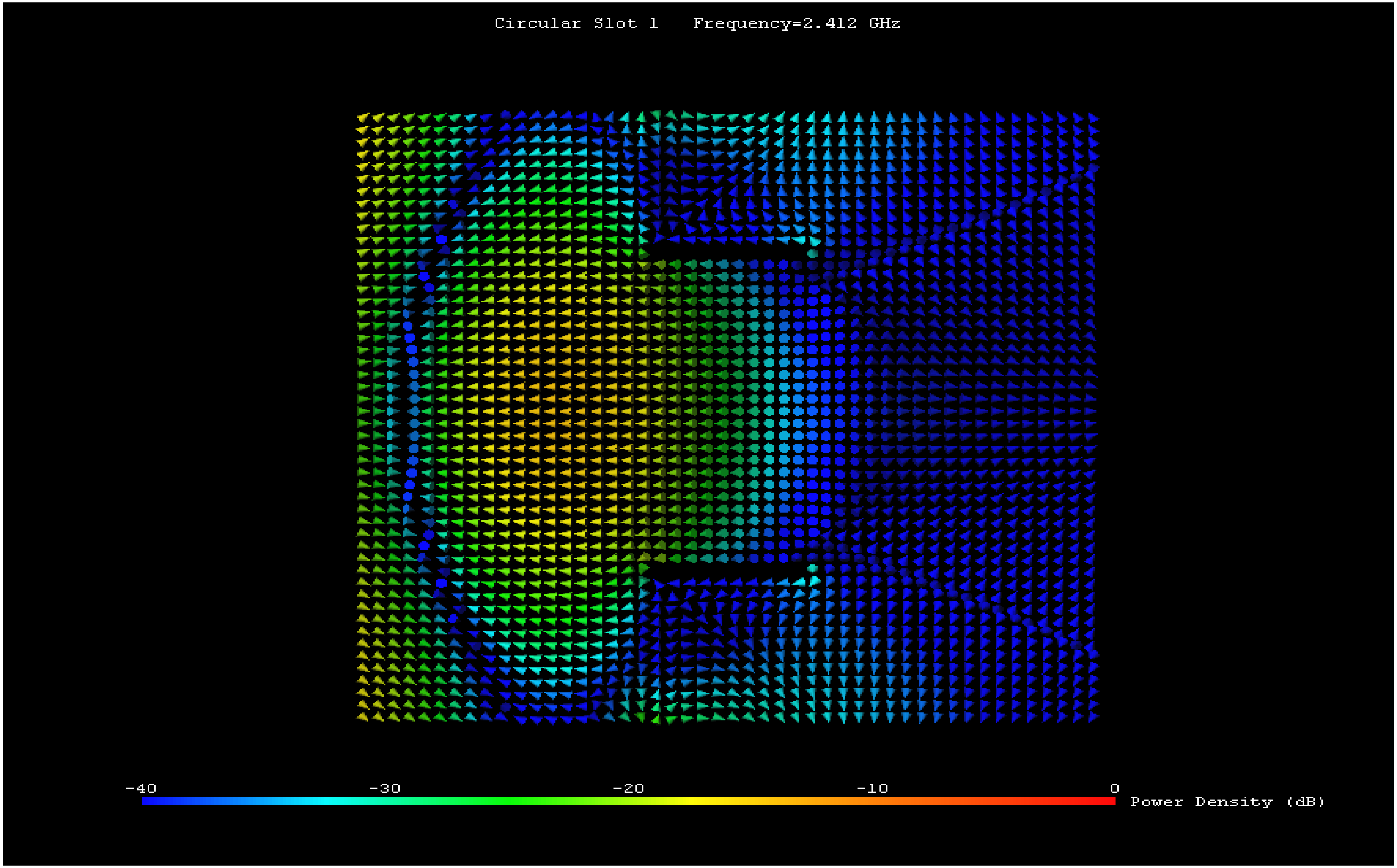
Circular Apertures

- Radius 25mm
- Radius 25mm with 20mm tube extension

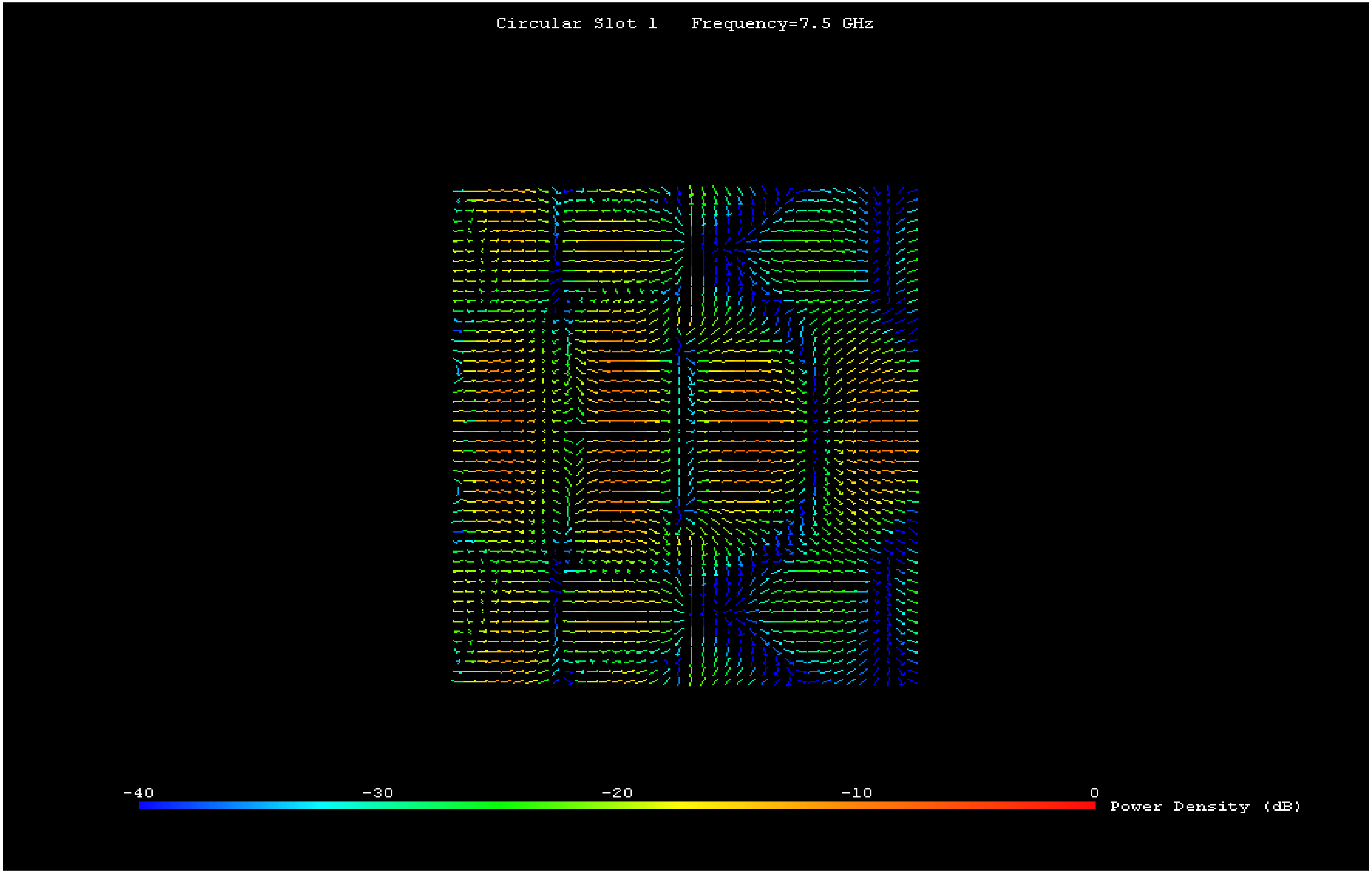
2.4GHz Power Density



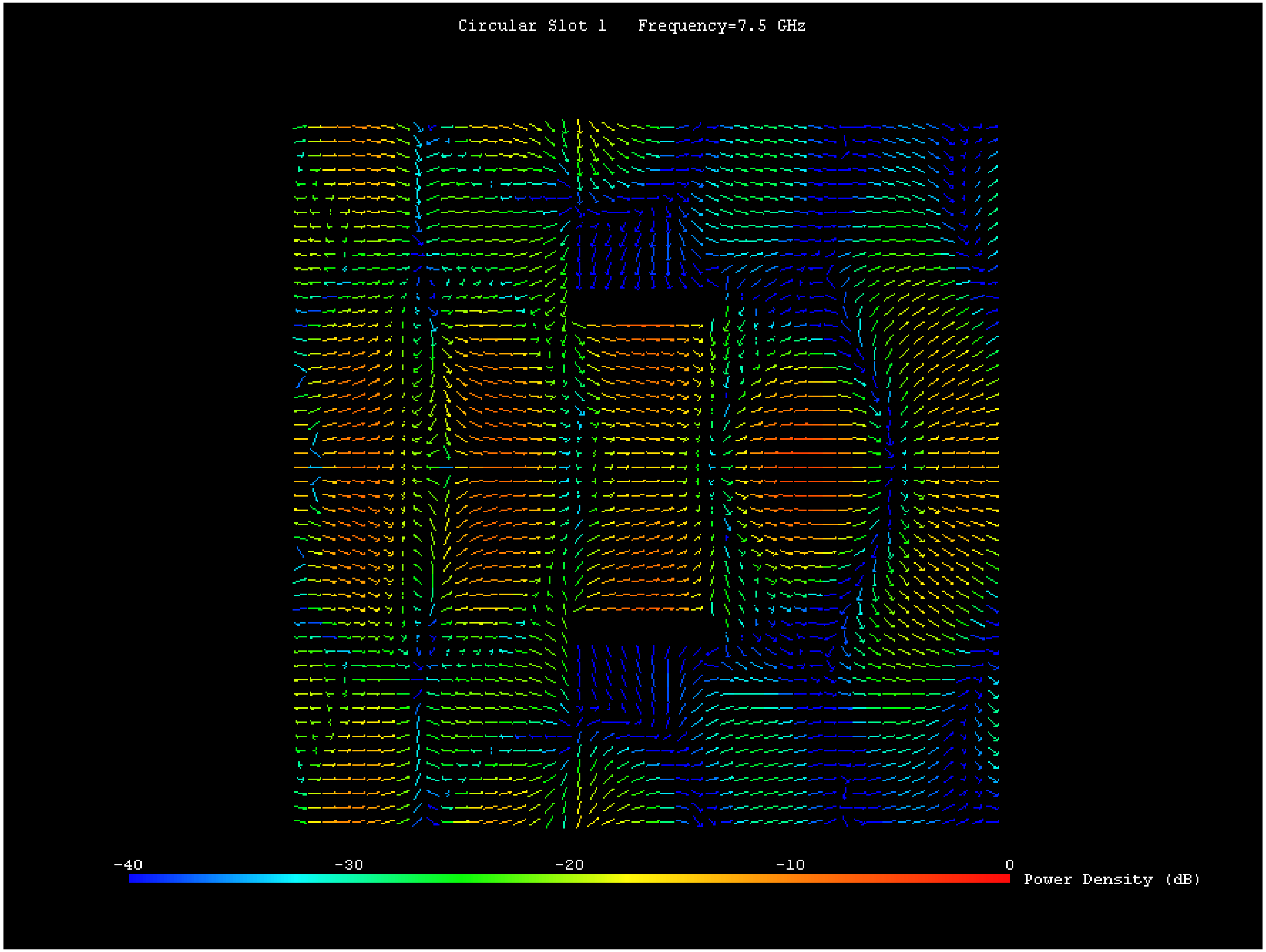
2.4GHz + 20mm tube



7.5GHz Power Density



7.5GHz + 20mm tube



Approach to the problem

- Find field strength at the shield
- Know what type of field and shield you have
- Apply shielding factor
- Apply inverse square law to get field strength some distance away from the shield

Summary

- Shielding can be achieved for all types of EM fields
- Simple equations have been derived from the basic theory
- Holes and seams cause significant problems with shielding