Shielding and EMI for Wireless Circuits

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With much material from
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Introduction

EMI and unwanted coupling between components or systems is being addressed by improved grounding, balanced lines, wideband decoupling chokes, and local shielding.

The characteristics of local shielding are addressed in this talk, along with some other techniques for EMI mitigation, such as balanced lines, single point grounding, slotted ground planes, ferrite beads, and multiple bypassing.

EM simulation is an invaluable tool when assessing the effectiveness of these techniques. Moreover, the improved speed of simulation has led to surprising improvements in bypassing and grounding techniques.

Outline 1

Coupling and Radiation

- Differential and Common Mode Connections:
- Coupling Control techniques
- Crosstalk Between Microstrip Lines
- Radiation vs. Loop Area
- Isolation Techniques

Outline 2

Shielding

- Shielding Effectiveness and Wave Impedance; Shield Materials
- Effects of Slots and Holes in Shield
- Transfer Impedance as the Effectiveness Parameter

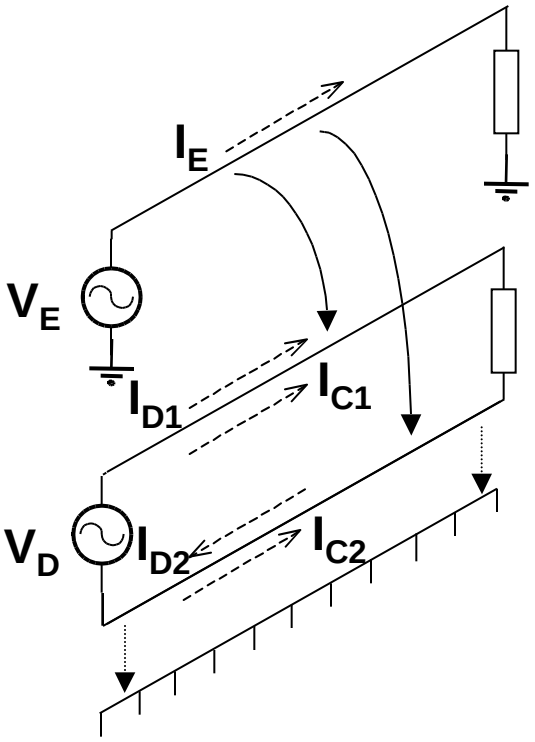
Grounding

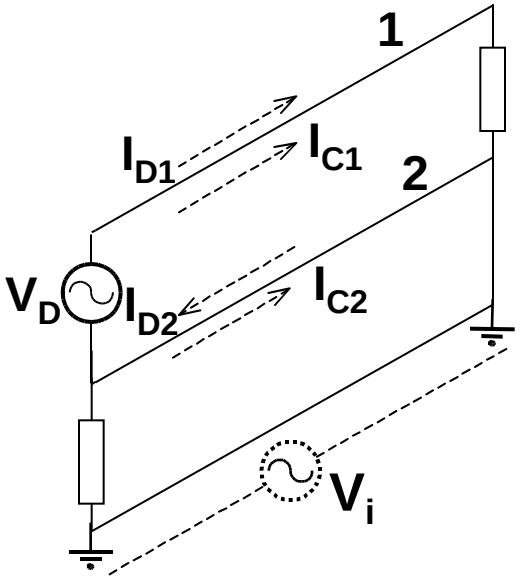
- Current Distribution Between Shield and Ground Plane
- Coupling Through Common Ground Inductance
- Ground Plane Discontinuities and Inductance Effects
- Choking off Ground Currents Filtering the Power Lines

Note: This presentation is based on material supplied by Anatoli Tsaliovitch, who takes no responsibility for the interpretation of these viewgraphs by the presenter. Those viewgraphs inserted by Allen Podell are marked in the lower left corner. We are grateful to Dr. Tsaliovitch for the use of his materials, and to Fotofabrication Corp. of Chicago for the data on their miniature folding shields.

Crosstalk and Ground Loops

Common Mode Sources





If current $I_{D1} = I_{D2}$, no common mode voltage drop. How is this done?

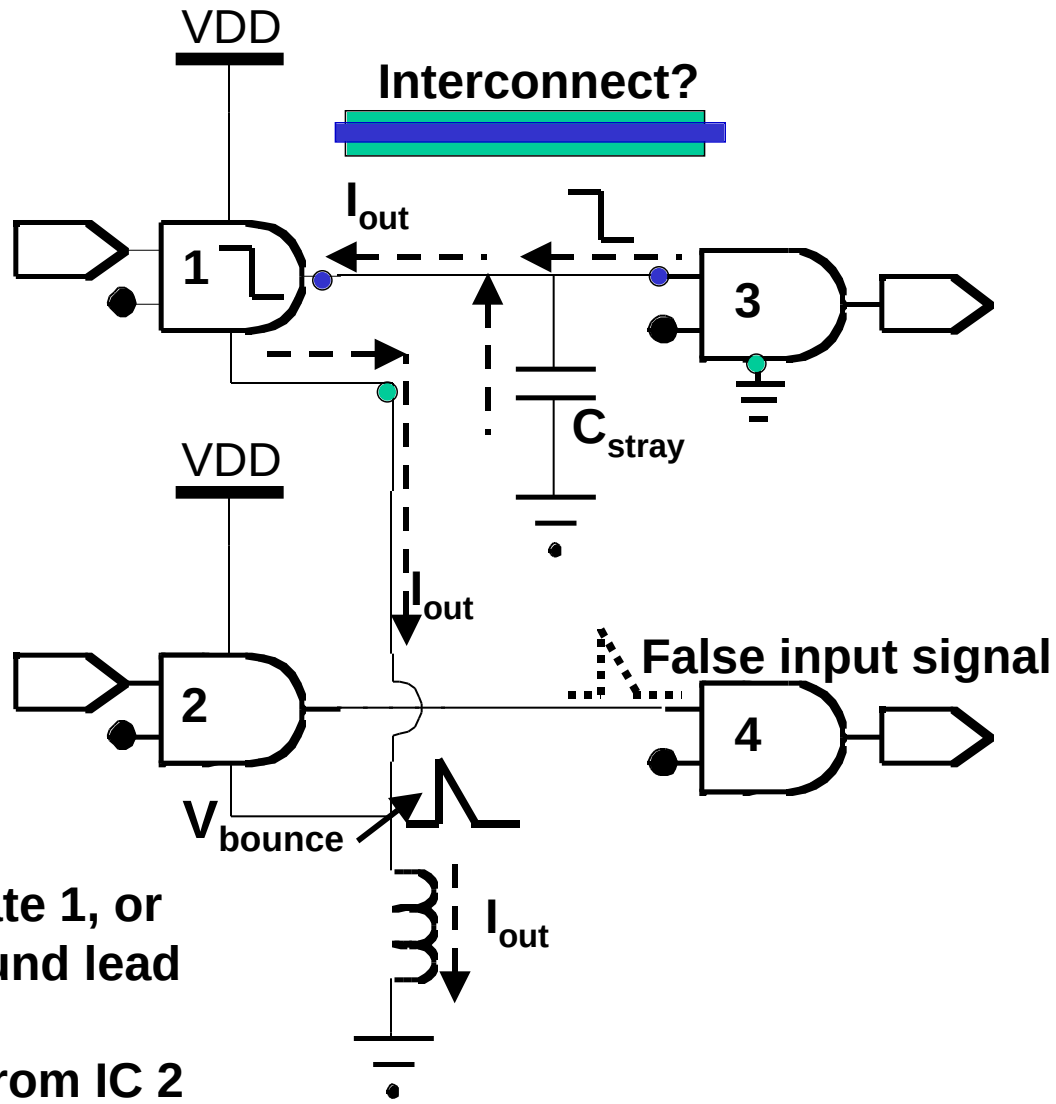
$I_1 = I_{C1} + I_{D1}$, $I_2 = I_{C2} - I_{D2}$

Crosstalk and Induction

Ground Loops

Coupling Through Common Lead Inductance-Ground Loops

When the output of gate 1 goes negative, a low impedance appears between the output of gate 1 and its ground pin discharging Cstray and the input capacitance of gate 3 through the common ground lead inductance, creating a false input signal to gate 4



Solution:
1- Reduce loading on gate 1, or
2- Reduce common ground lead inductance, or
3- Run a direct ground from IC 2 to IC 3 or 4

Reducing Unwanted Coupling

Capacitive coupling

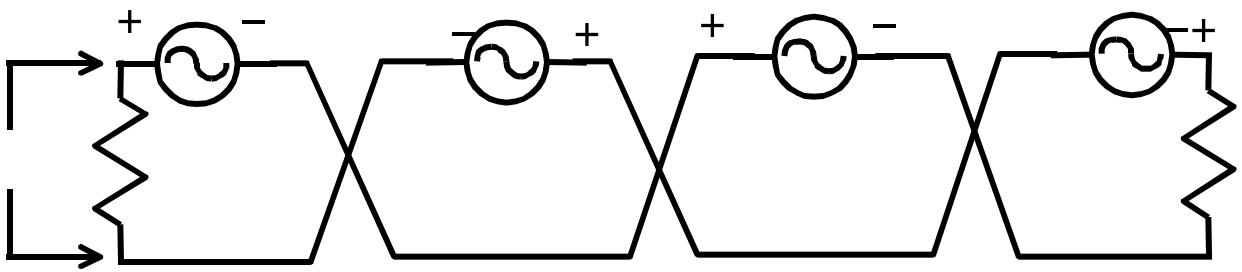
$$Vn = V1 * C12 / (C12 + C2g)$$

Magnetic coupling

$$Vn = j\omega BA \cos\Theta$$

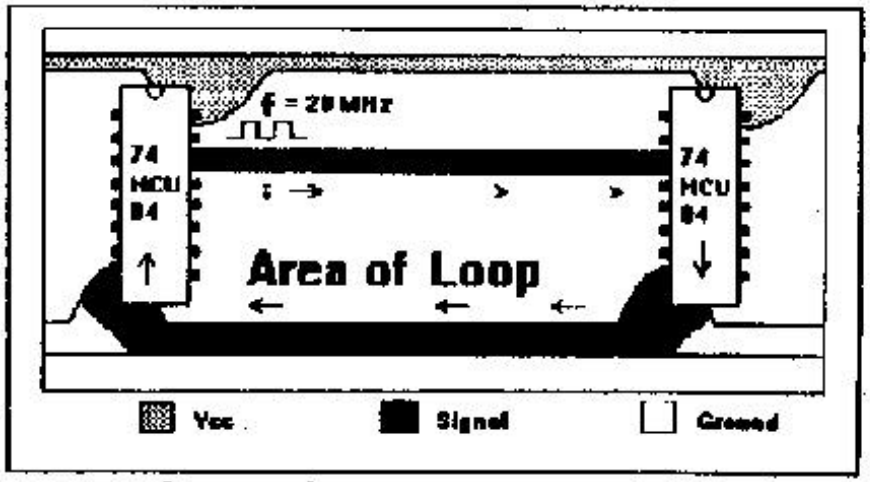
- **Reduce circuit length (E) and area (M)**
- **Bring direct and return paths closer**
- **Place single-ended circuits closer to ground plane**
  - **Use balanced twisted pairs, or crossed PC traces**

Vt = Vn - Vn + Vn - Vn = 0

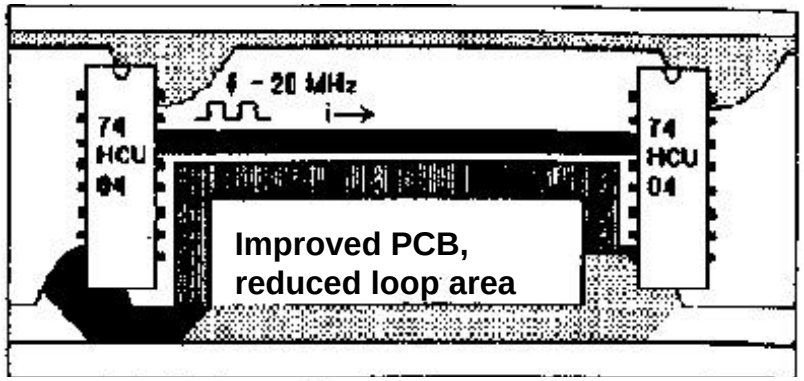


- **Isolate circuits: Separation/Shielding**

PWB Radiation vs Loop Area

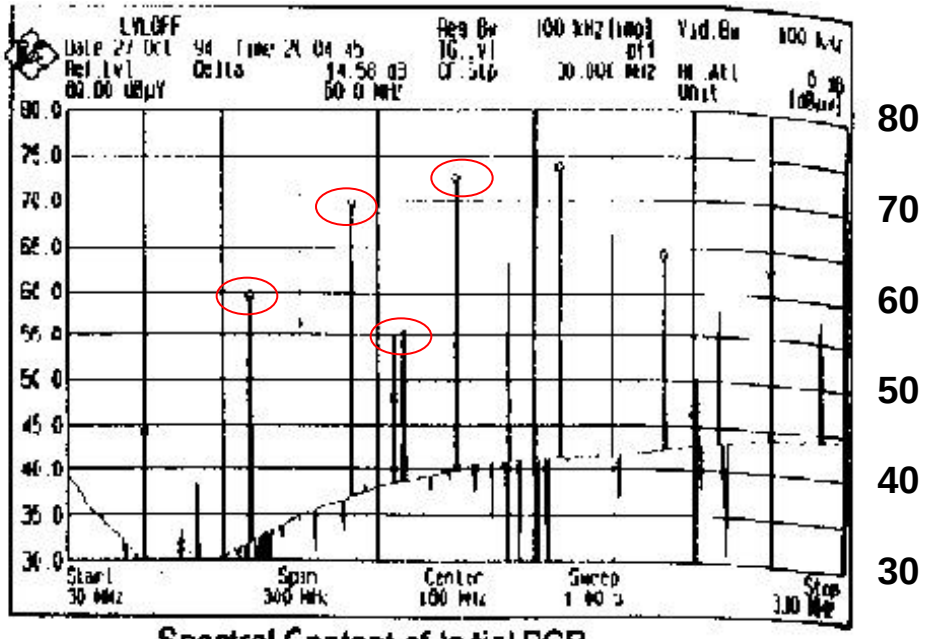


Original PCB - Condition 1

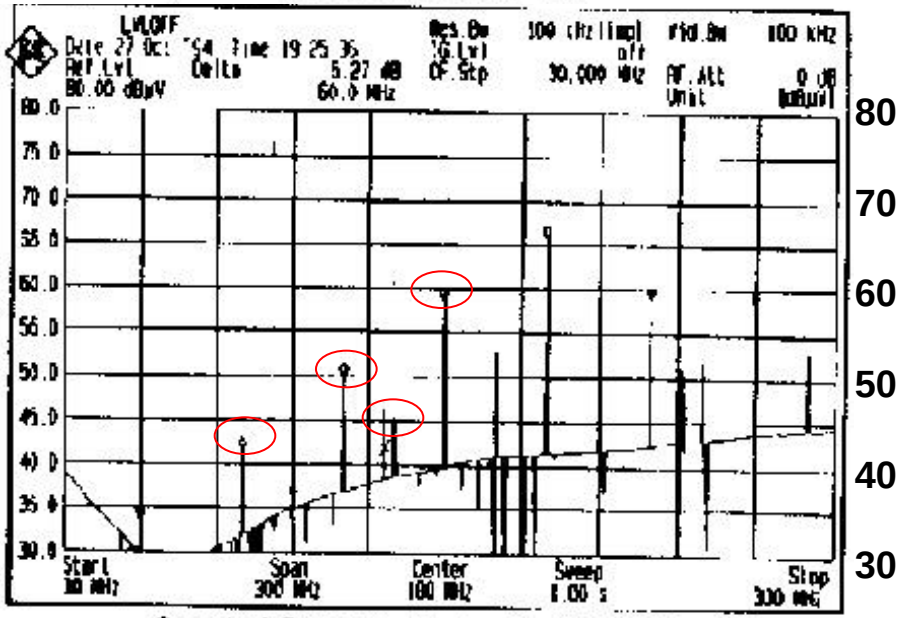


$$E_\theta = \frac{120\pi^2 I}{r}\frac{A}{\lambda^2}\sin\theta$$

F.J.Tilley, IEEE EMC-95

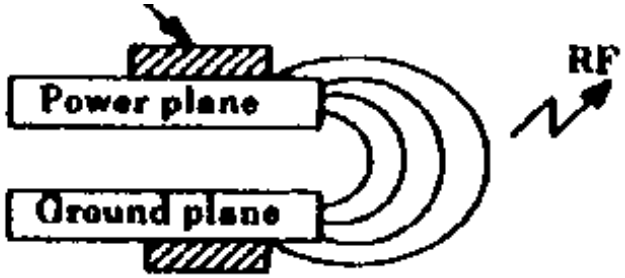


Spectral Content of Initial PCB

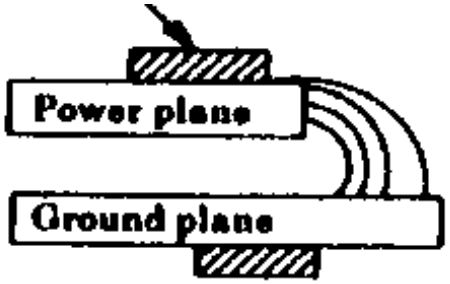


Spectral Content with the Modified Return Line

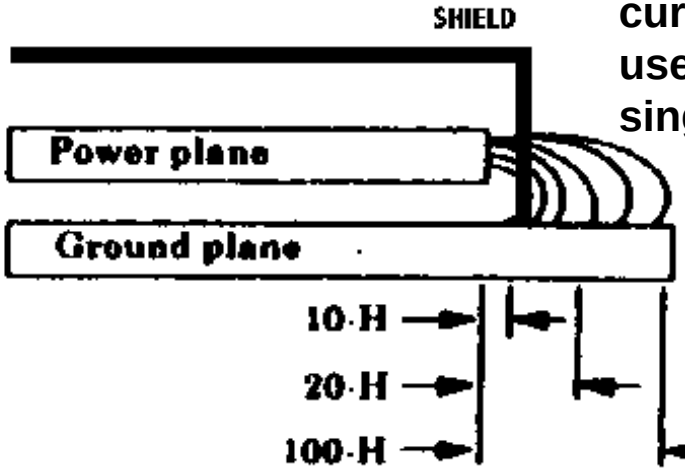
The 20H Rule vs. Shielding



RF currents fringing between the power and ground planes at the edge of the board.
RF emissions occur.



RF currents do not fring from edge of board. RF currents have a return plane to couple to.
RF emissions do not occur.

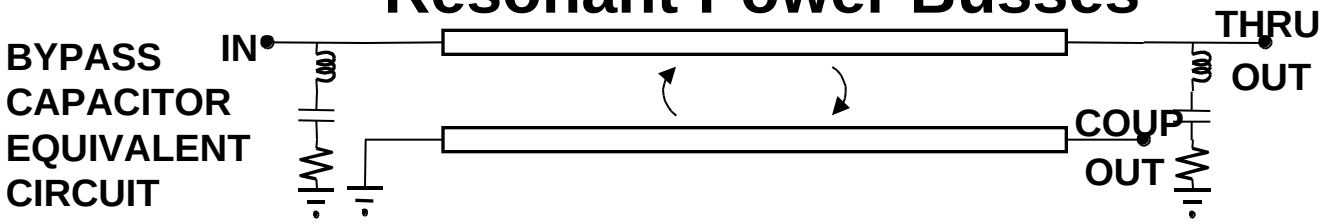


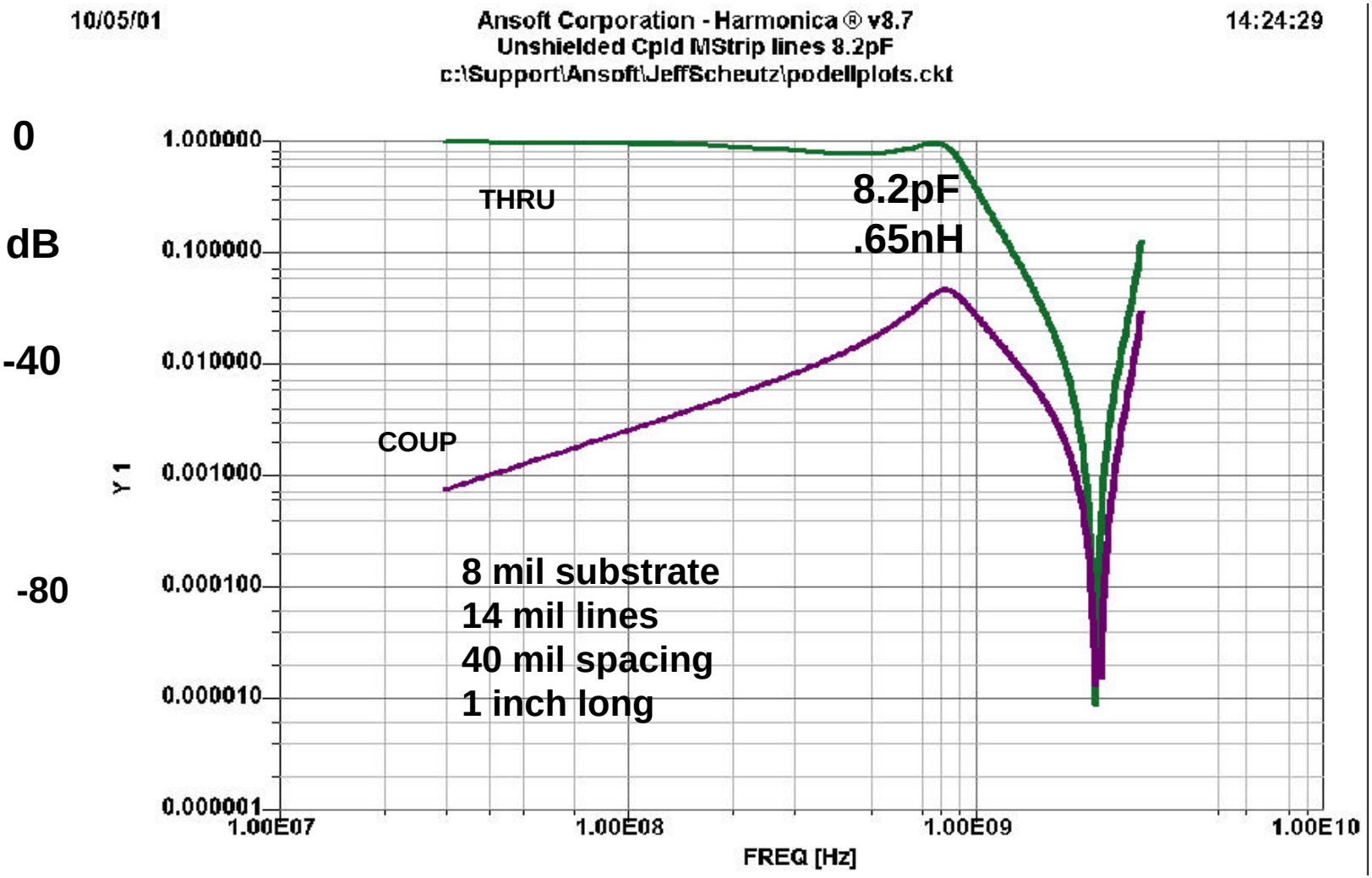
Flux Boundary Display

Note: Far field and size are reduced,and current now flows in the shield. So, don't use the shield for a ground return, think single point parallel ground.

(AFP)

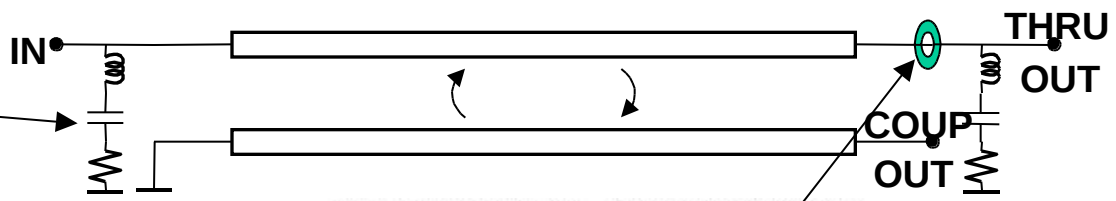
Resonant Power Busses





Resonant Power Busses

100 pF NPO BYPASS CAPACITOR EQUIVALENT CIRCUIT

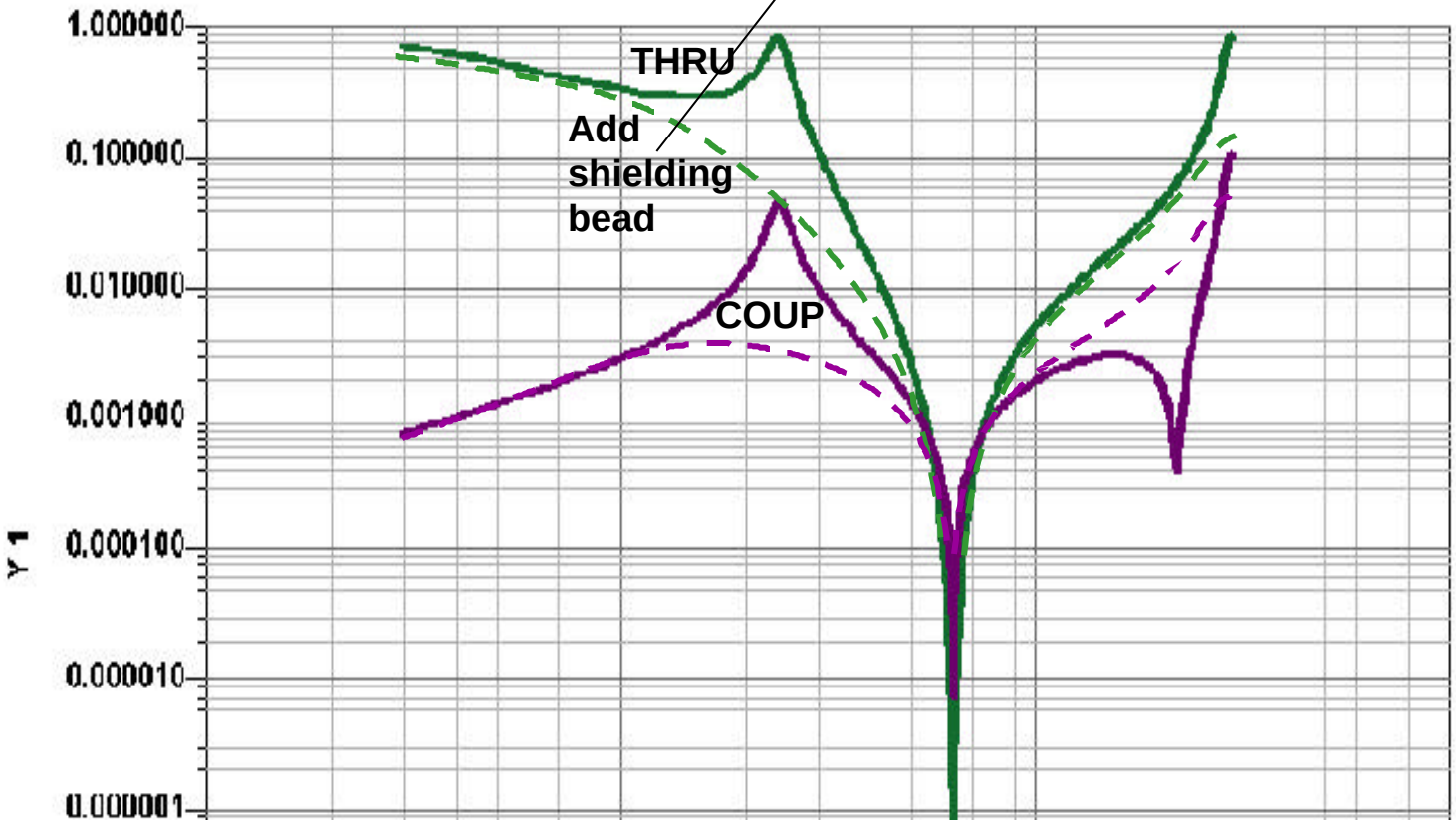


10/05/01

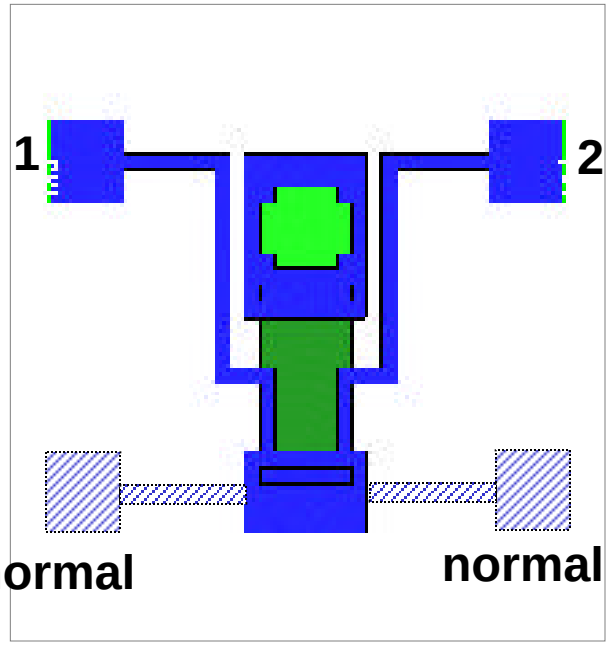
Ansoft Corporation - Harmonica® v8.7
Unshielded Cpld MStrip lines 100pF
c:\Support\Ansoft\JeffSchcutz\podcllplots.ckt

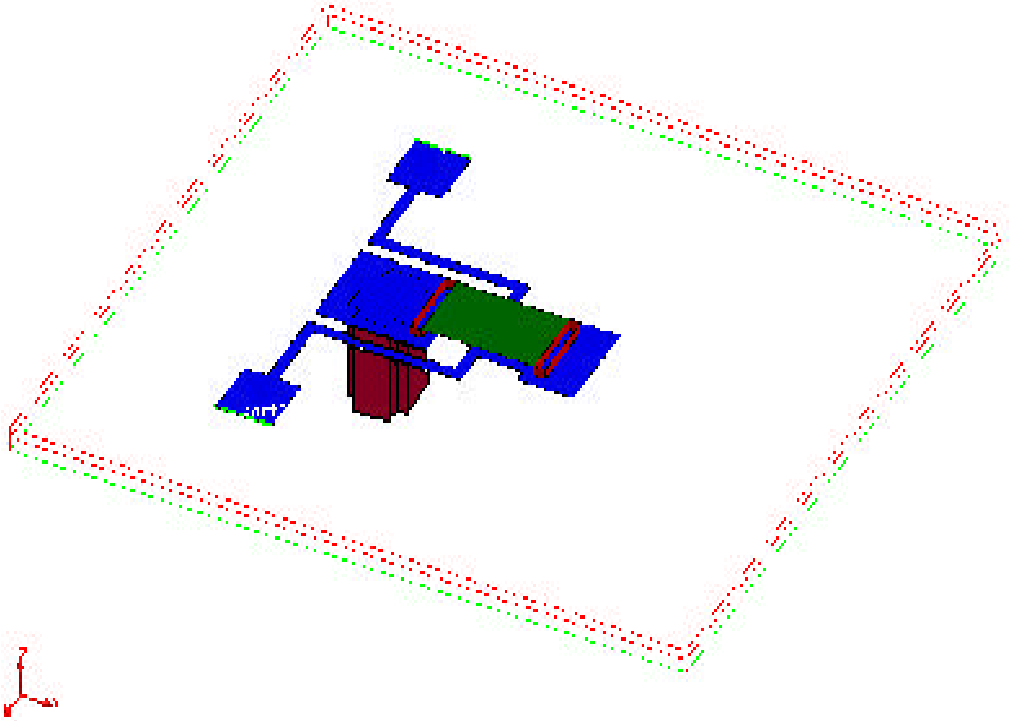
14:30:05

Trans-
mission
0
dB
-40
-80



Improved .01uF bypassing by moving power buss





Frequency (GHz)	DB(|S[1,2]|) normal	DB(|S[1,2]|) Bypassx
1	-15.6	-20.7
2	-10.1	-15.5
4	-5.7	-11.8

Improved Power Buss

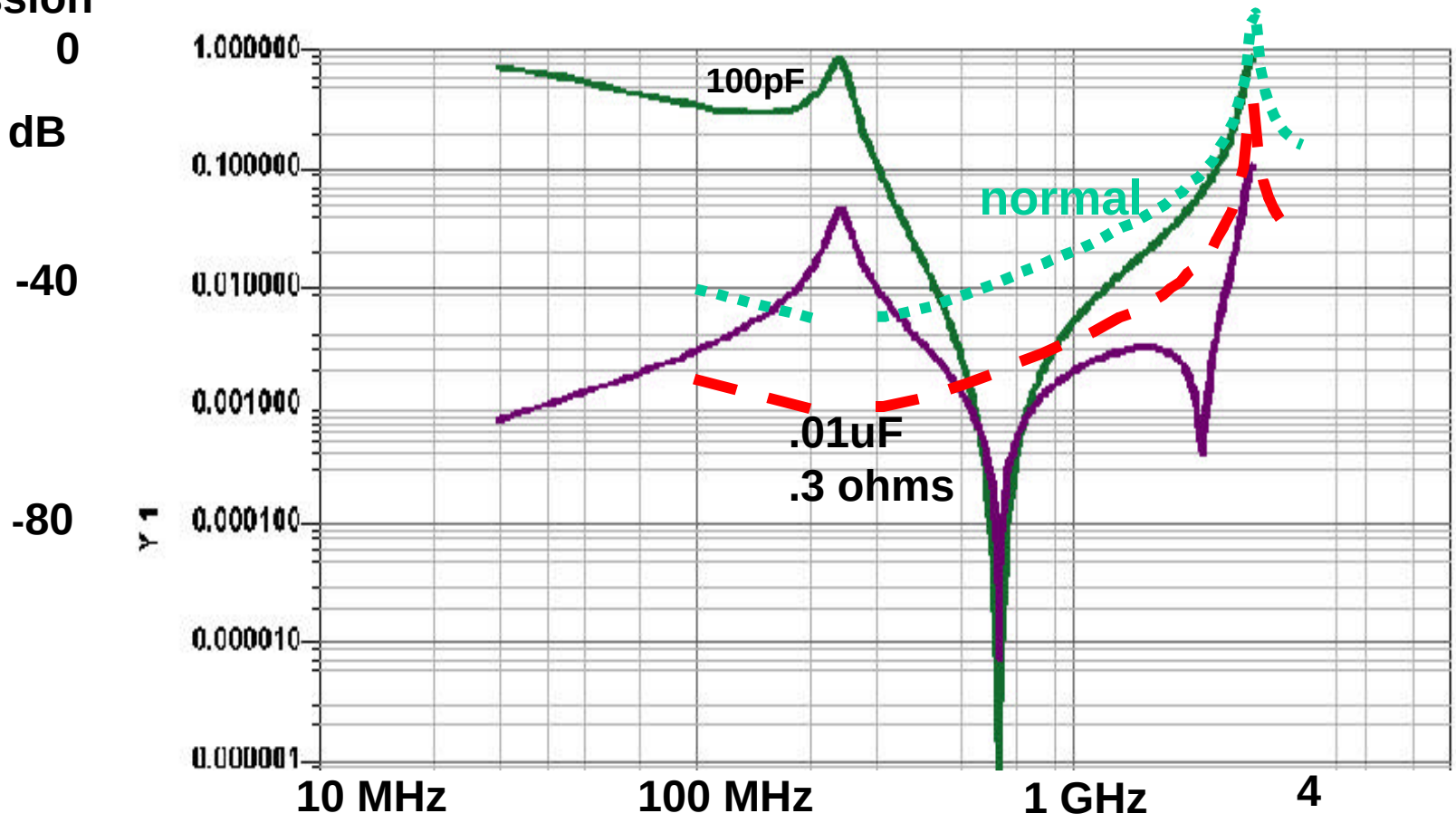
100 pF NPO BYPASS CAPACITOR EQUIVALENT CIRCUIT

10/05/01

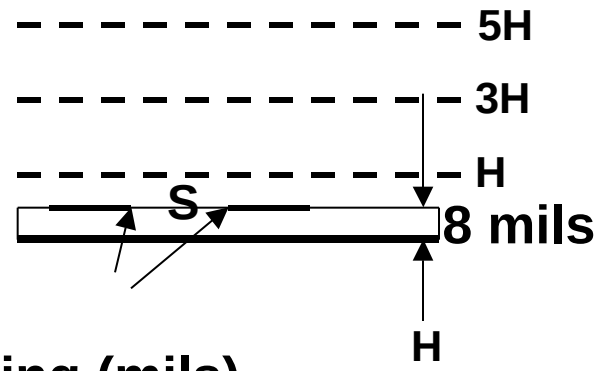
Ansoft Corporation - Harmonica® v8.7
Unshielded Cpld MStrip lines 100pF
c:\Support\Ansoft\JeffSchcutz\podellplots.ckt

14:30:05

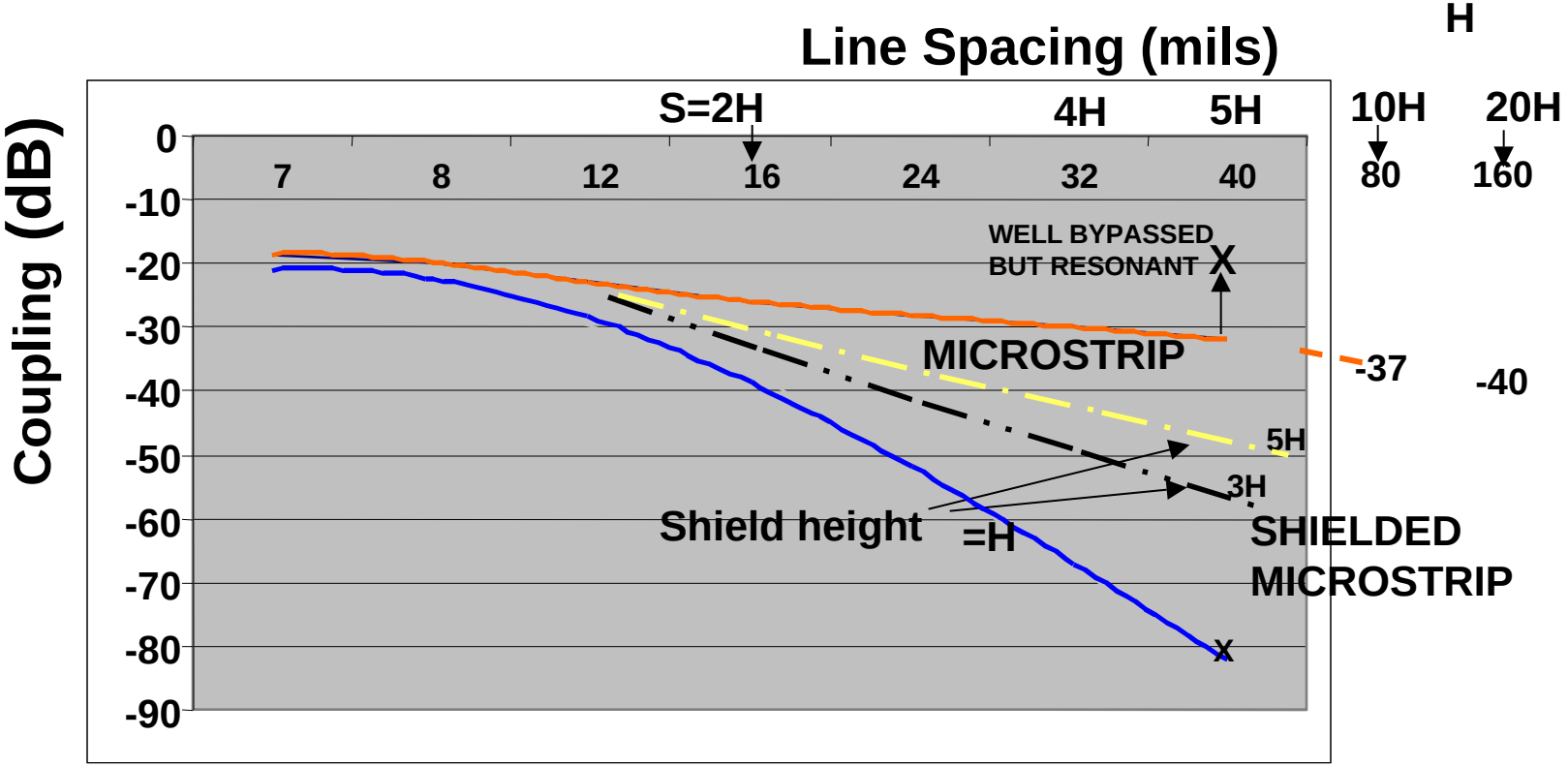
Trans-mission



Microstrip Coupling- Effect of Shield Height

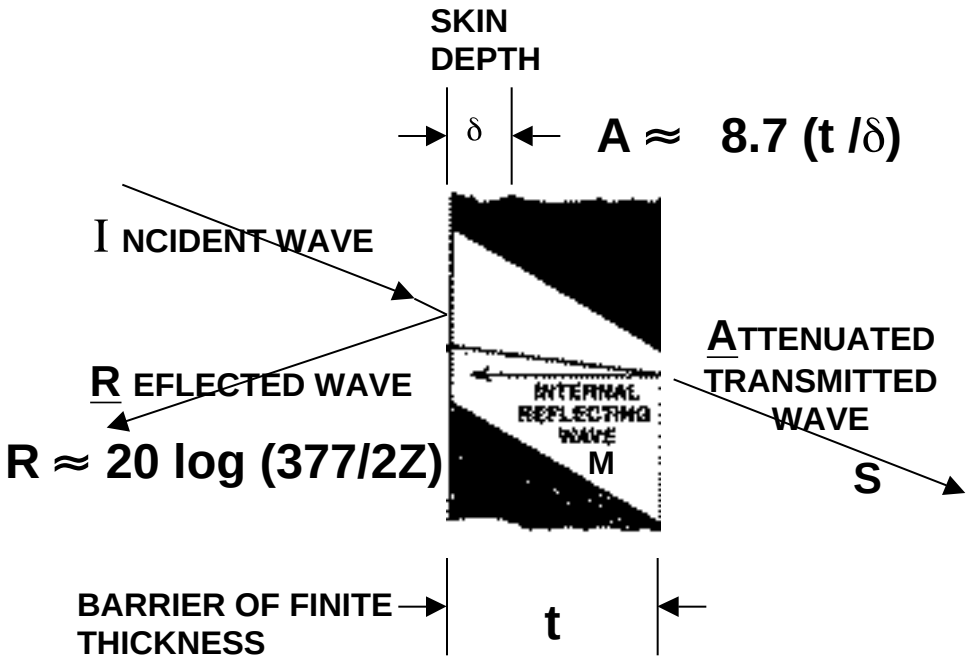


Shielded circuits can be much smaller!



The 5H shield reduces the coupling at 4H spacing below unshielded 20H

Shielding Effectiveness in Plane Electromagnetic Wave



SHIELDING EFFECTIVENESS

$$S=E_2/E_1 = H_2/H_1$$

SHIELDING ATTENUATION

$$A_S = 20\log I/S, \text{ dB}$$

$$A_S = A + R + M, \text{ dB}$$

	Cu	Brass	Al	Steel	Freq, MHz
Z =WAVE IMPEDANCE mΩ, $\propto \sqrt{f}$	3.72	5.58	4.83	104	100
δ =SKIN DEPTH mm, $\propto \sqrt{(1/f)}$	.0067	.0101	.0086	.0019	100

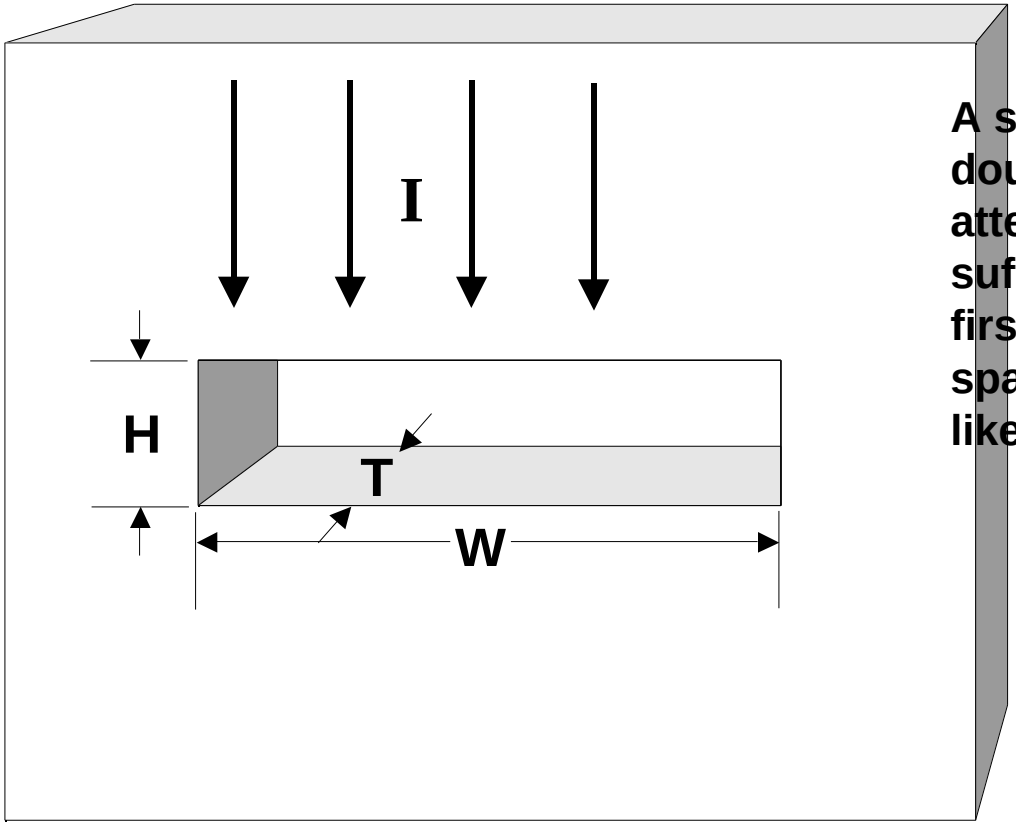
Rectangular Slot in a Shield

$$A \approx -20\log_{10}\left[\frac{\sqrt{WH}}{.24\lambda}\right] + 27.3(T/W),\ dB$$

Slot area

For λ >>2W

Raising T affects only this term.



A second shield can double the entire attenuation, if spaced sufficiently from the first. If very closely spaced, the results are like doubling T.

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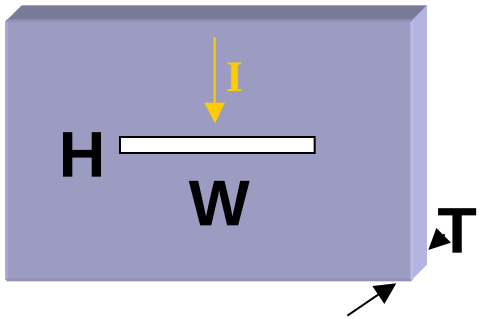
Comments added by A. Podell

Slot or Holes in a Shield

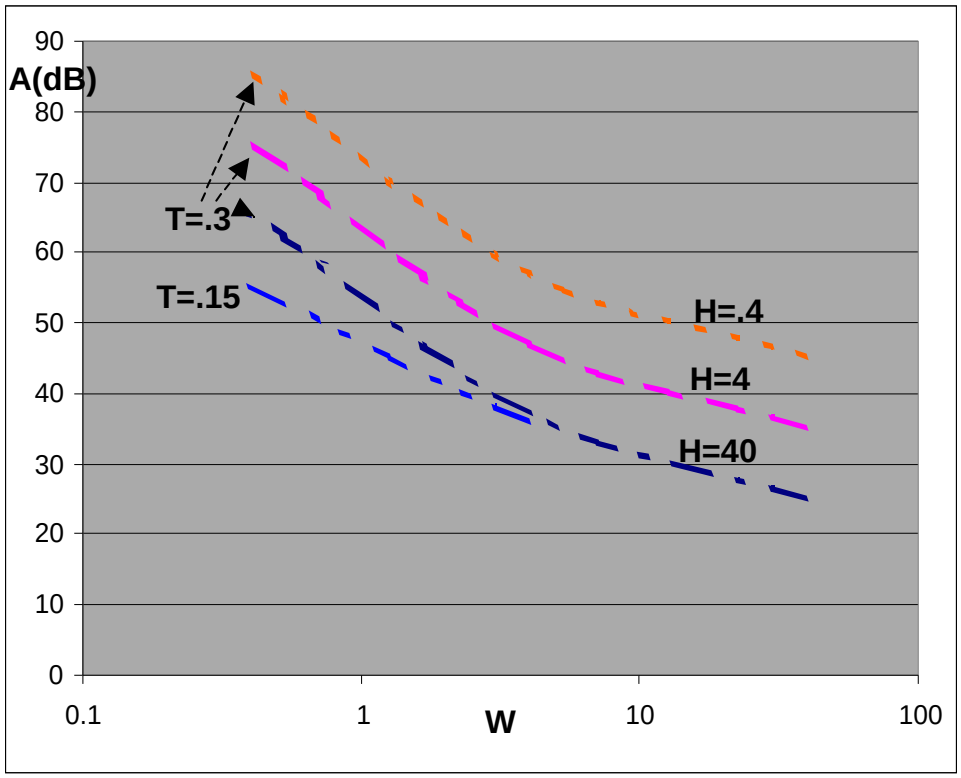


T (mm)	H (mm)	W (mm)	A(dB)
0.3	40	40	25.3
0.3	40	4	37.2
0.3	40	0.4	65.6
0.3	4	40	35.3
0.3	4	4	47.2
0.3	4	0.4	75.6
0.3	0.4	40	45.3
0.3	0.4	4	57.2
0.3	0.4	0.4	85.6
0.15	0.4	0.4	75.4
0.15	0.2	0.2	91.6 85.6 *

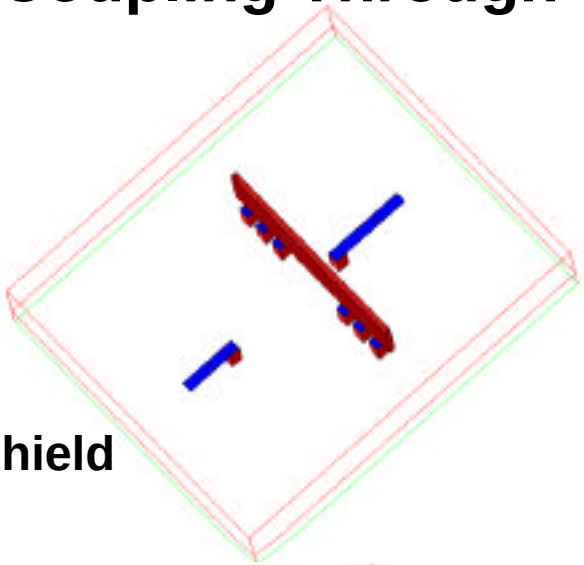
For the same attenuation, the larger the hole, the thicker the shield.

0.15	20	0.2	71.6
0.15	20	2	43.2
0.15	20	20	31.3
0.15	40	40	25.2
0.15	40	4	36.2
0.15	40	0.4	55.3

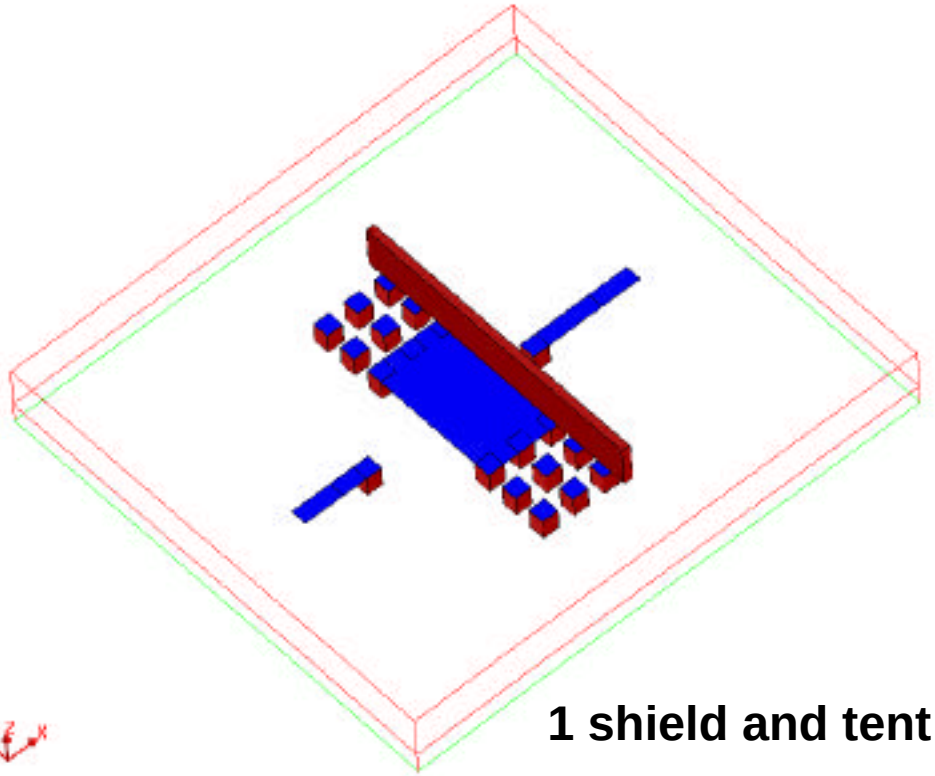
* = includes 6 dB from 2X holes



Coupling Through Slot (skipped via) vs. # Shields

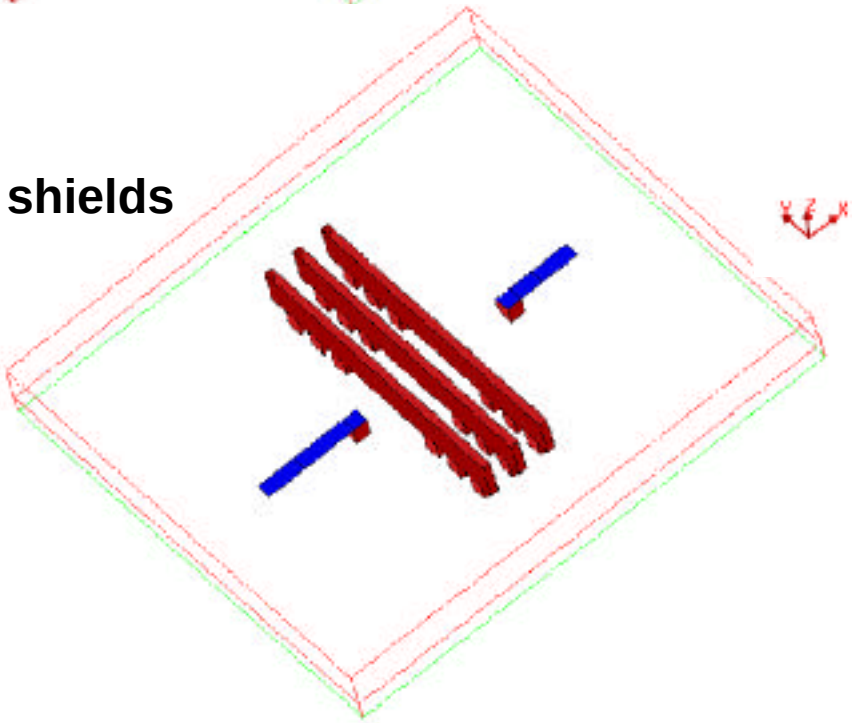


1 shield



1 shield and tent

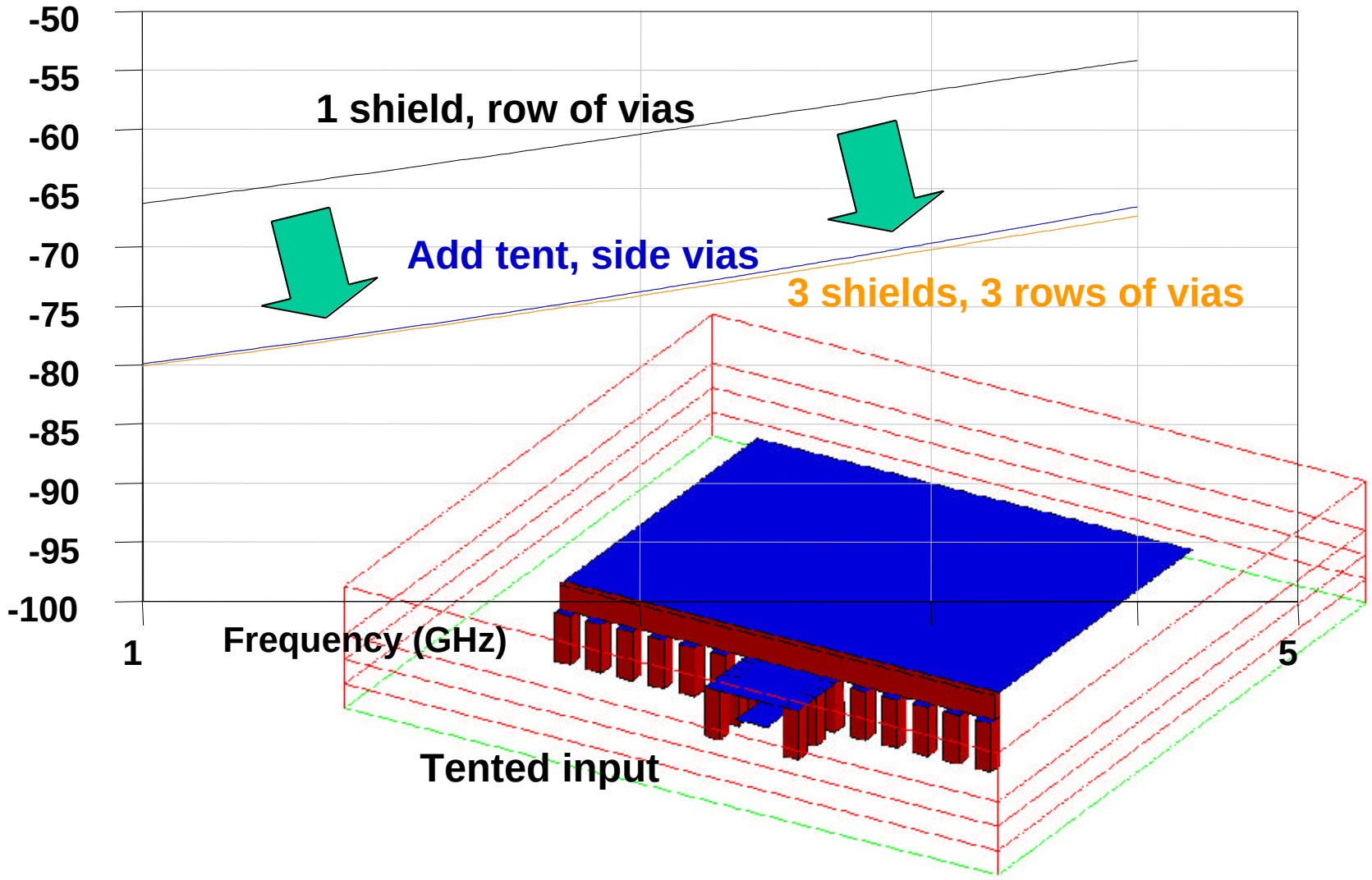
3 shields



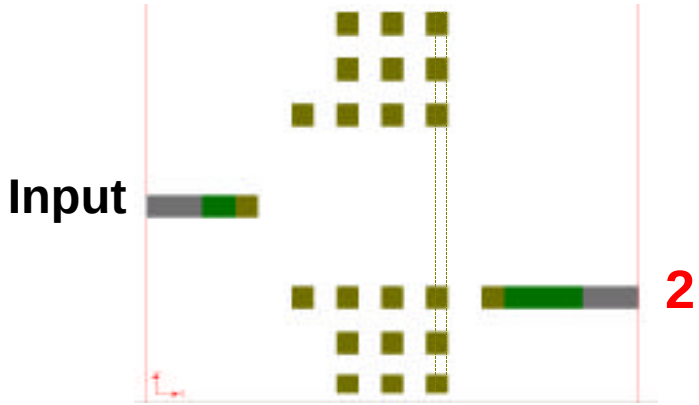
The tent can be a circuit board trace, or a shield lip

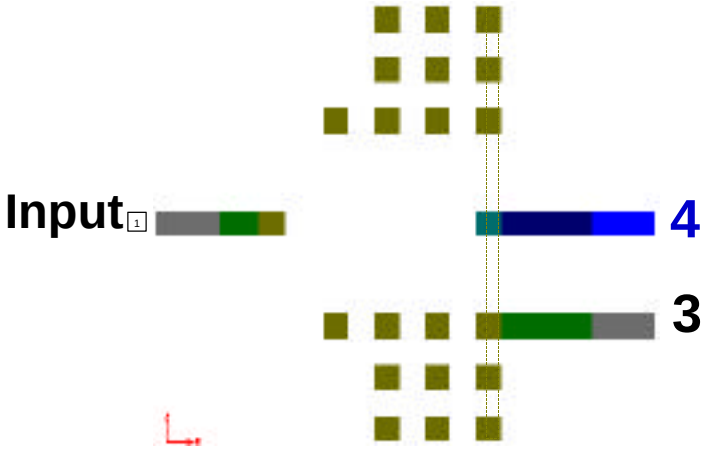
Coupling Through Slot vs. # Shields

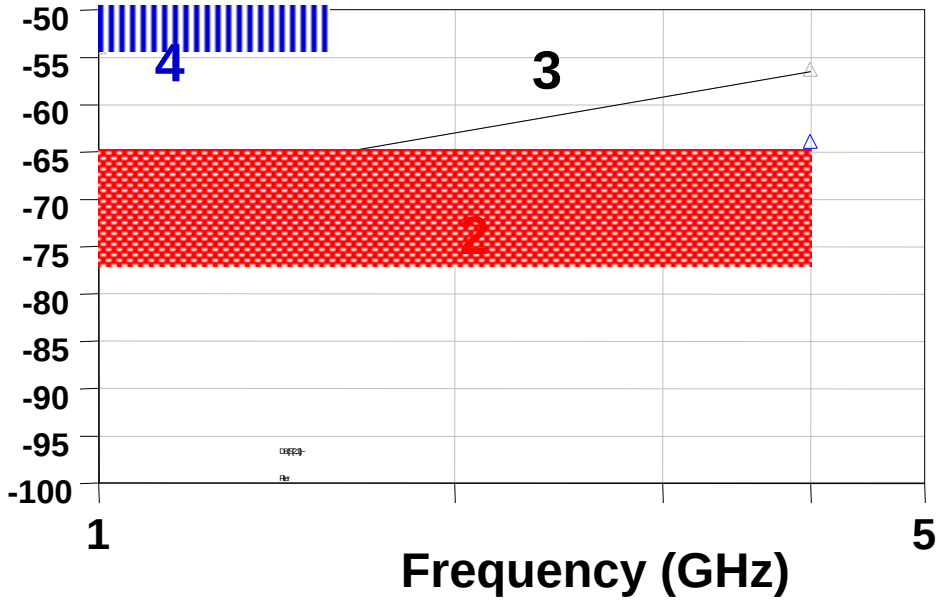
A cutoff waveguide tent is as good as a very thick shield



Grounding to the Shield Ground Vias -BAD Move!







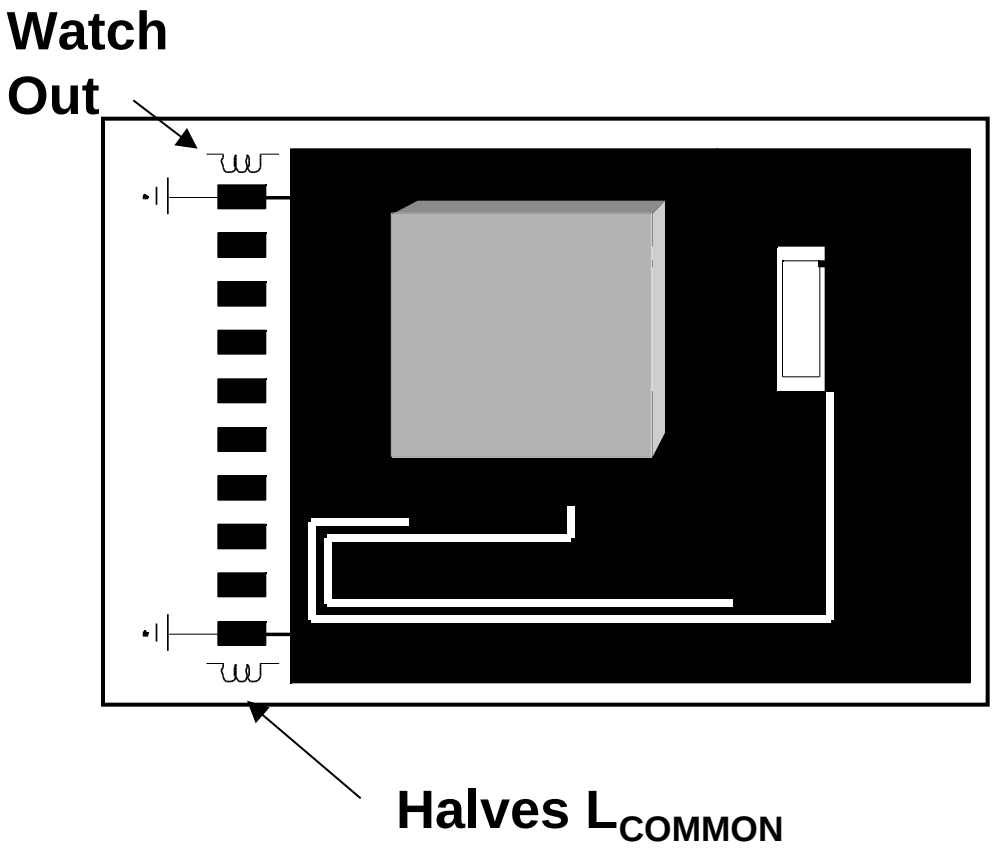
Coupling from input to 3 different output grounds:

2- Separate via

3- Shared ground via

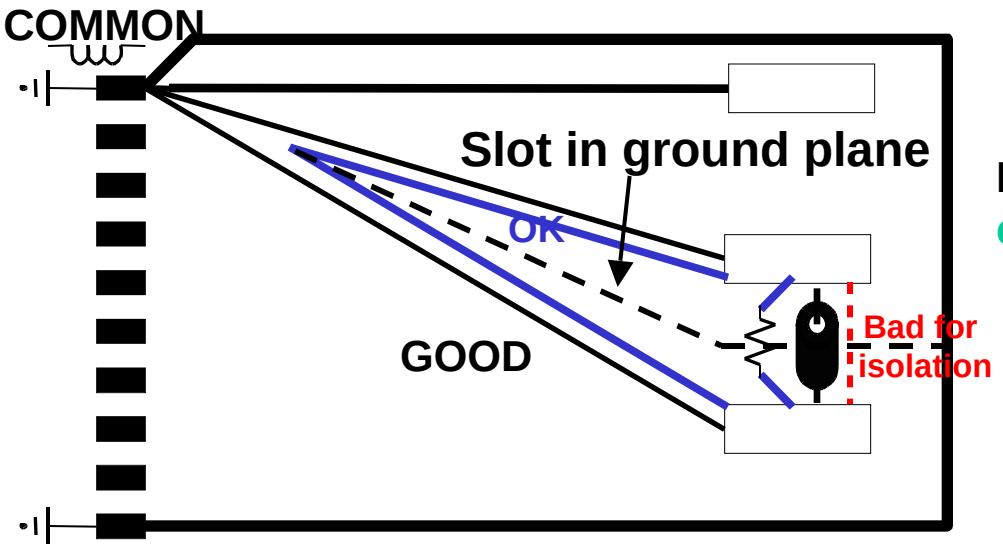
4- Ground to shield, no ground via

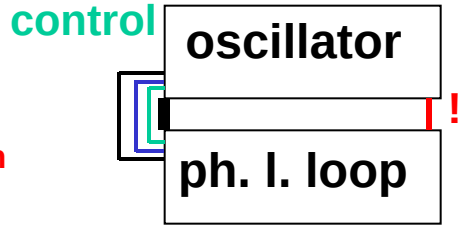
Grounding Techniques
Multi -Point

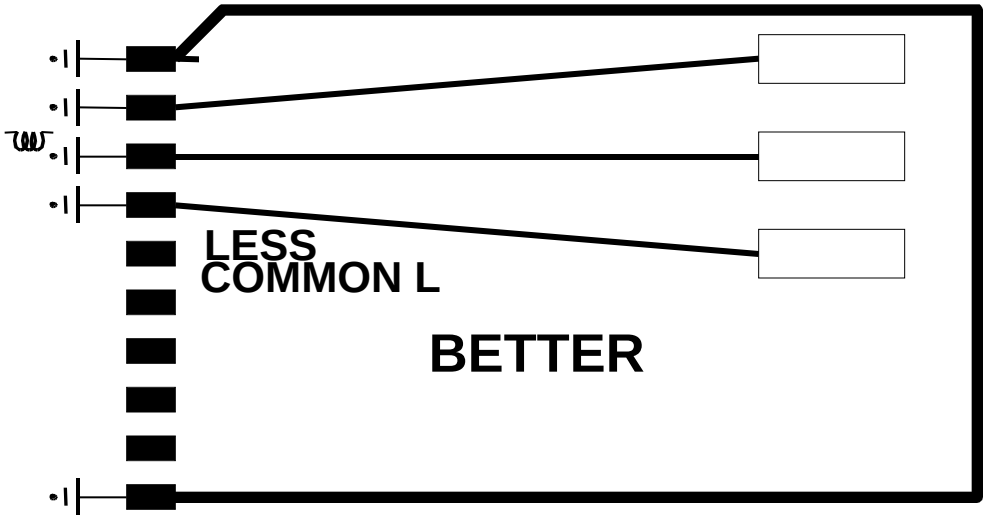


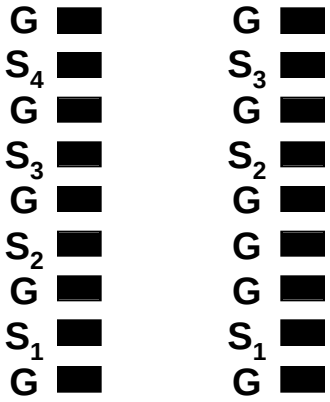
Single Point Parallel Grounds

Some shared grounds don't matter. Just make sure that you isolate the bad grounds. Use a resistor or shielding bead to cross a separate ground.









Electromagnetic Shielding Summary

- Shielding is a 3rd EMC defense line when the EMC design (minimized radiating area) and mitigation (isolating the offending circuitry) fail
- Power and signal connections can destroy the isolation obtained through single point grounding.
- A solid shield perfectly grounded and without penetrations provides adequate shielding for commercial equipment, BUT
- Seams and slots compromise shield performance.
- For the same total area, small holes radiate less than large ones
- The spacing of attachment tabs is critical, closer is better.
- Use small closely spaced grounding vias and small tabs.
- A shield thickness of .8* hole diameter provides 16dB more attenuation than one of .2* hole diameter
- Don't allow ac currents to flow through shield grounds, use separate connections to ground.