Section 3
Planar Circuits Issues

from

A Collection of Thoughts, Tips and Techniques for Microwave Circuit Design

by

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This set of 26 pages is a section focusing on planar circuits, taken from an extended presentation on microwave design.

If you have a question, feel free to write me at R.L.Eisenhart@ieee.org.

Planar Circuit Issues Outline

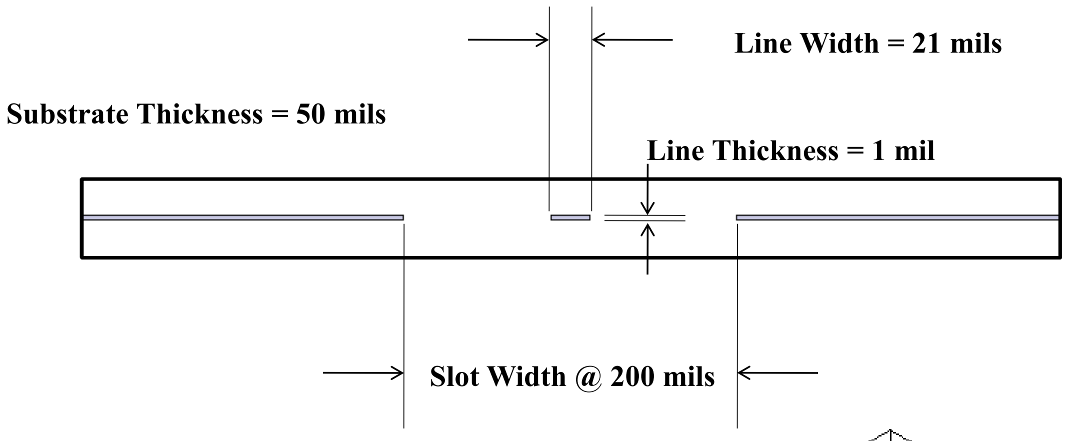
- Stripline parameters
- Right angle coupling to Stripline
- Via Fence Isolation
- Parallel Co-Planar Waveguide (CPW) Isolation
- Multi-plane Circuit Isolation

These pages focus on a variety of planar problem areas.

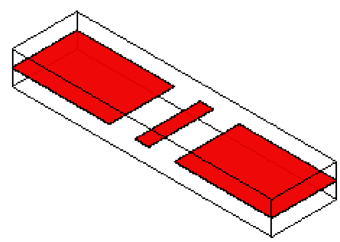
Let’s look at some stripline parameters first.

Strip Transmission Line Nominal Model

Line parameter nominal values - Line Width, Thickness and Slot Width



Substrate Dielectric = FR4 (er = 4.4)



Perspective View

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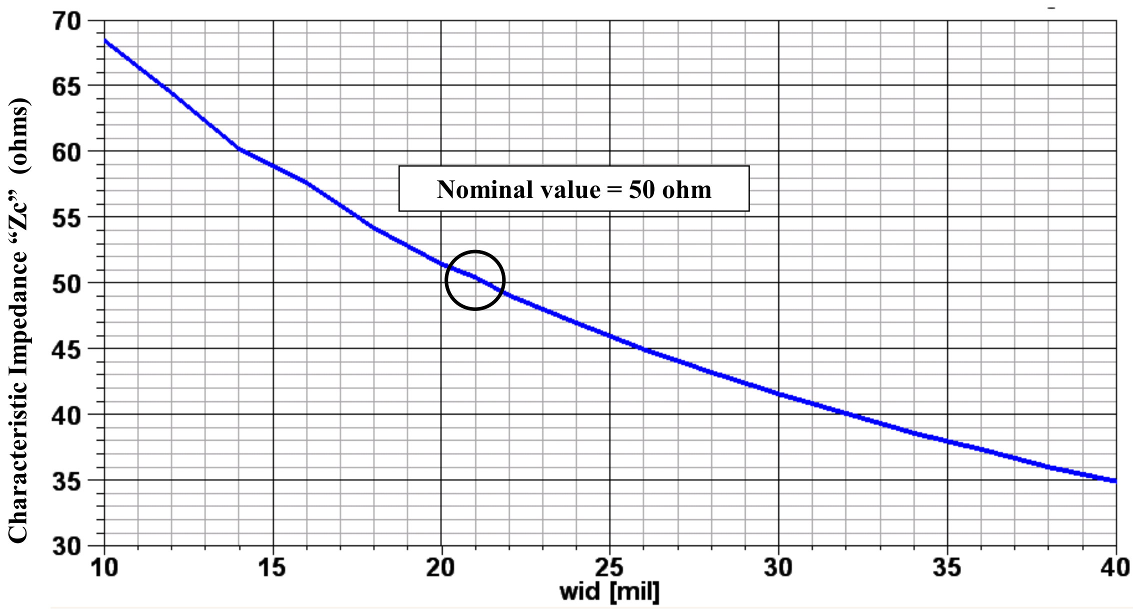
The top and bottom surfaces are ground and tied to the co-planar grounds on the sides.

These side ground planes are not part of the line but the question was to consider if they influenced the Impedance.

NOTE: Avoid a wide dimension between the side walls because a “waveguide mode” can exist separately from the microstrip mode.

Look at the line width effect.

Strip Transmission Zc vs. Line Width



Variation relative to nominal values

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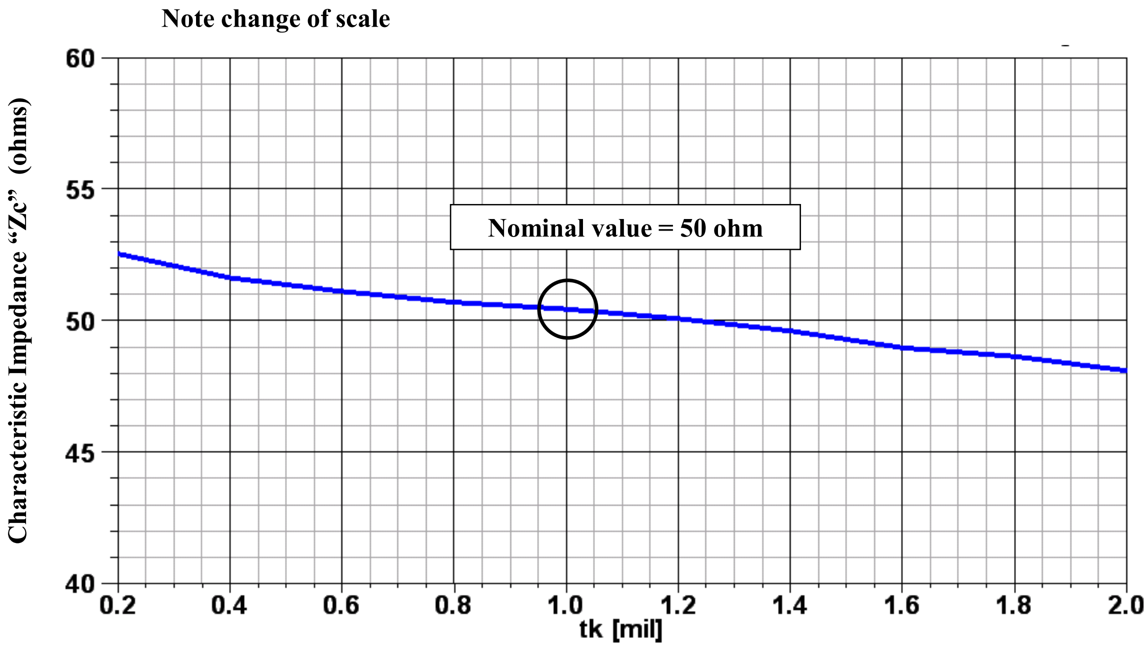
Variation as we would expect, normalized to the substrate size.

Note that narrowing the width by half only increases the Zc by 34%. Zc proportional but a long way from linear. You can see how it would be difficult to realize high values of impedance without going to extremely small line widths.

How about line thickness?

Strip Transmission Zc vs. Line Thickness



Variation relative to nominal values

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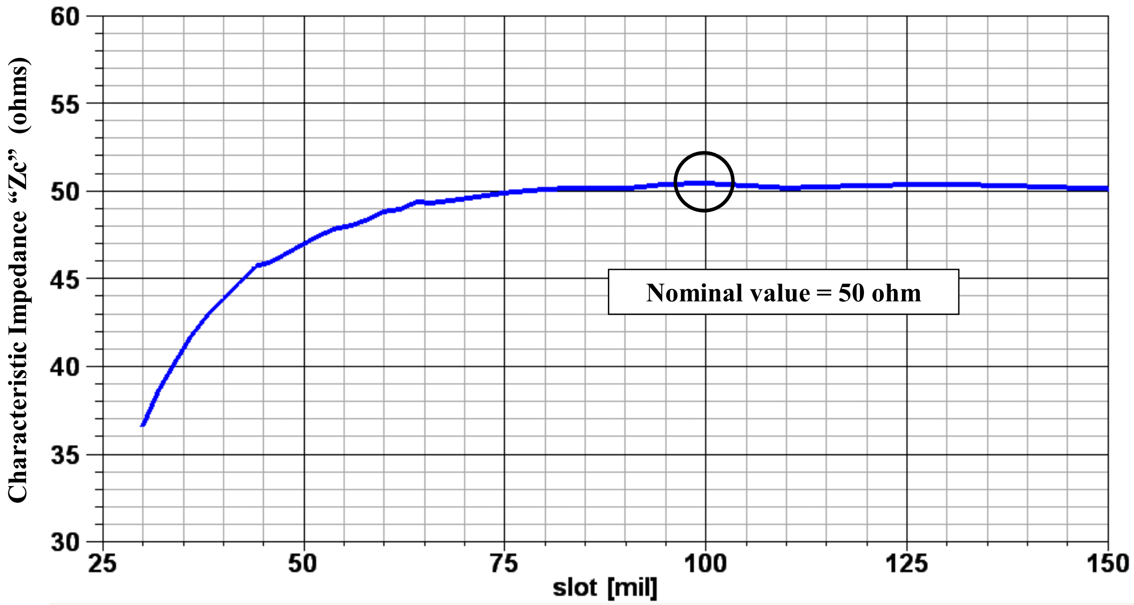
The wider the line the less influence the thickness has on the Zc.

Note here that most of the capacitance establishing the line impedance comes from the line top and bottom surfaces and not the side edges. For zero thickness the impedance is little changed from 50 at 52.5 ohms. The value is not very sensitive to line thickness.

How about the spacing to the side grounds?

Strip Transmission Zc vs. Slot Width



Variation relative to nominal values

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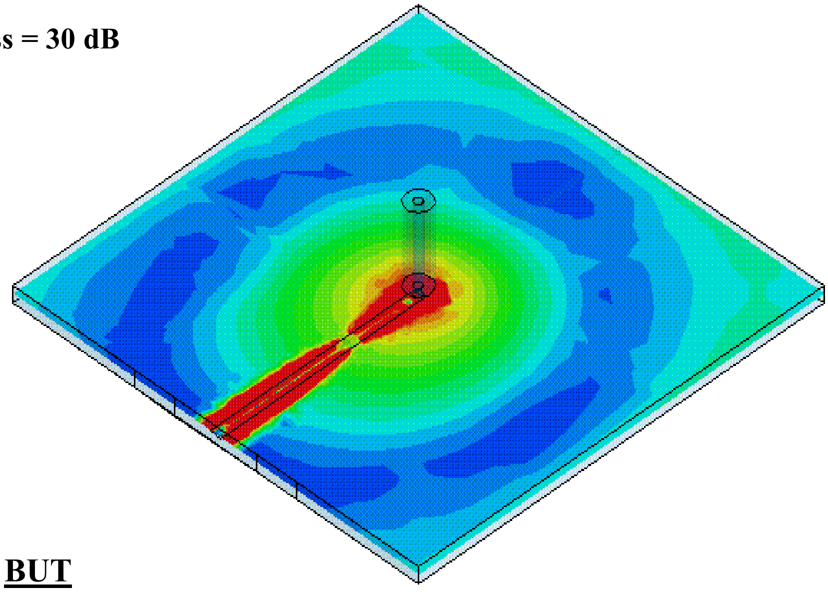
We see that for a slot spacing of greater than 75 mils (gap ≈ 30 mils) the co-planar grounds do not come into play.

Next, consider a simple probe feed to a stripline through one of the ground planes.

Coupling to Stripline through the ground plane

Return Loss = 30 dB



BUT
Major launching of radial line mode in the substrate

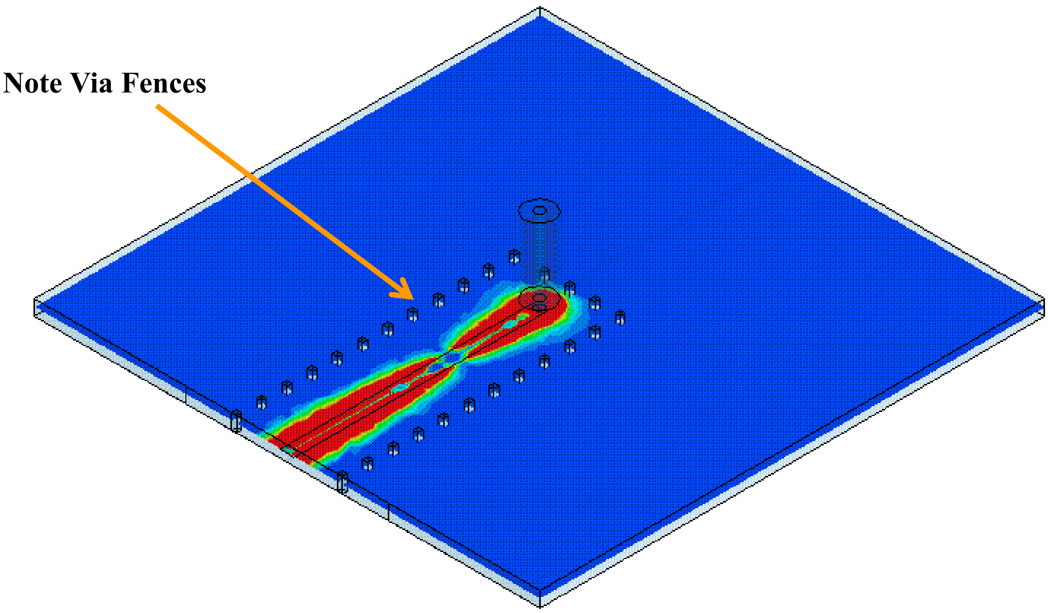
This has a good match (30 dB) at 1 GHz but all the input energy is not going to the port,

and leaking radiation will cause isolation issues with nearby circuits.

This model has absorbing walls to represent a larger board.

What do we do to contain the radiation?

Coupling to Stripline through the ground plane



Need to put the radiation in JAIL !

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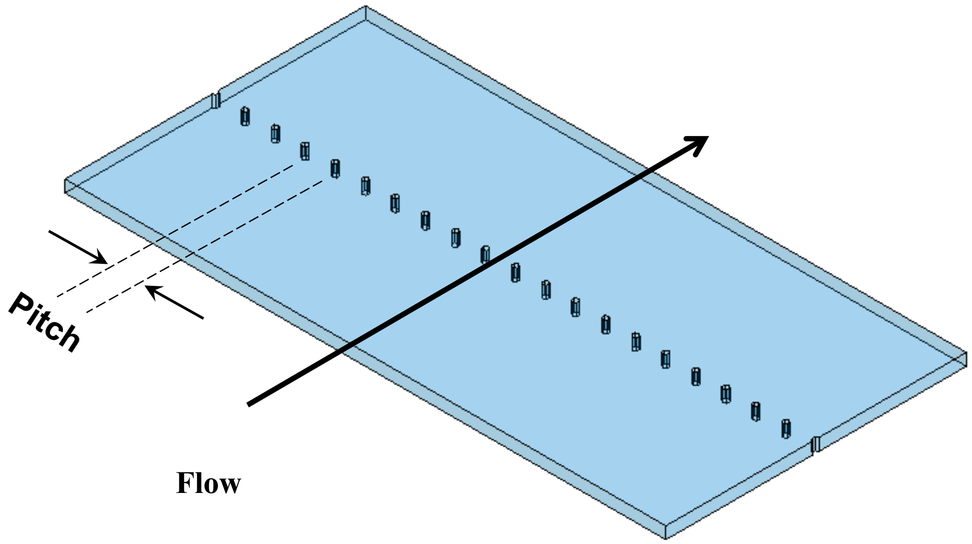
8

Use vias from ground to ground.

Next let's see how effective a via fence can be

Model of a Plane Wave upon a Via Fence

10 mil dia. vias at 25, 50 and 100 mil pitches

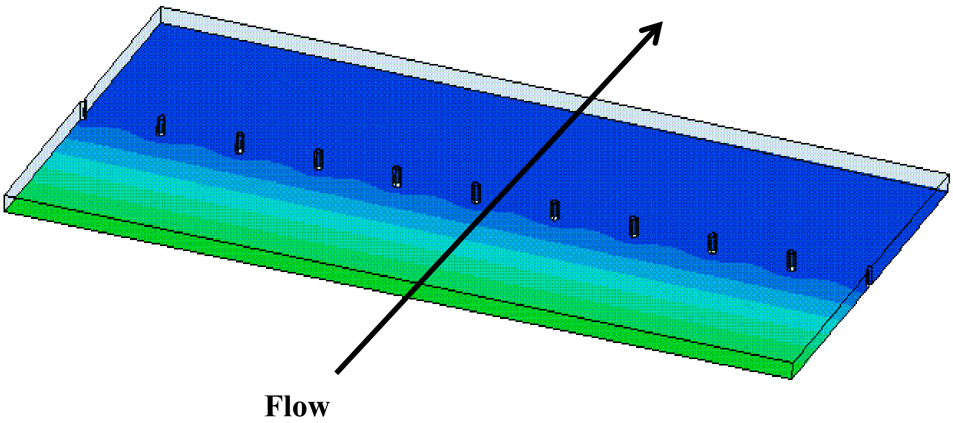


Independent of height. Fatter vias at same pitch = better isolation. Independent of width until you approach lambda/2 in substrate.

Parallel plate mode between two ground planes. Can be modeled on a single cell basis with a parameter of dia/pitch. This propagation is independent of the ground plane spacing and has no lower cutoff frequency.
Let's look at incident radiation.

Fields of a Plane Wave upon a Via Fence,

100 mil pitch at 1 GHz



Vias are like posts along the beach trying to stop a wave.

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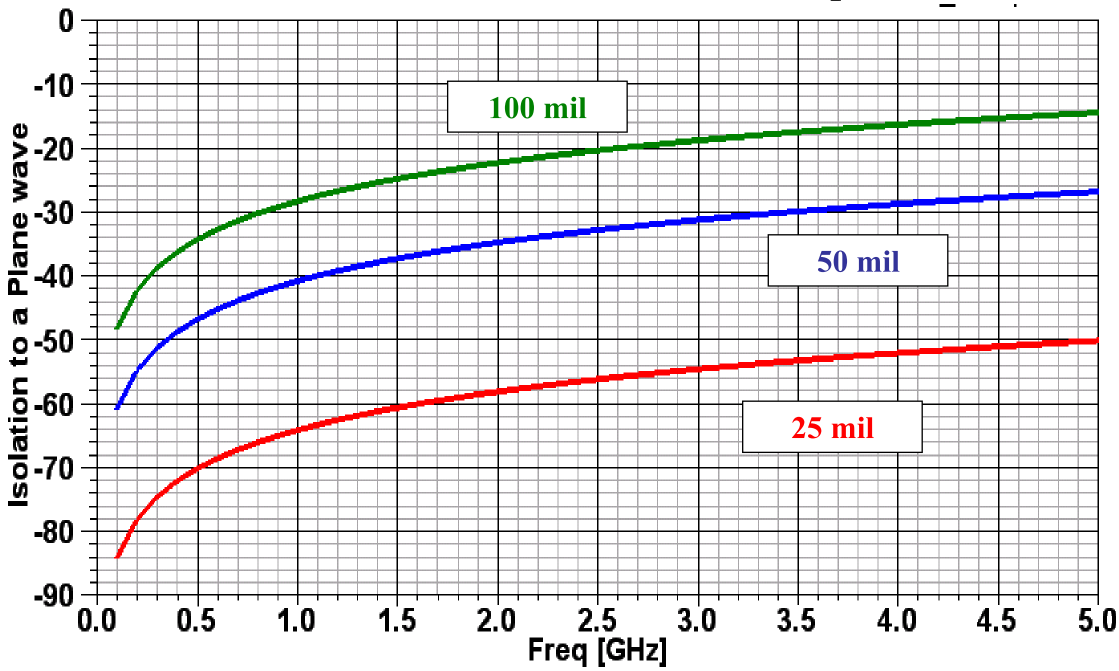
Unfortunately, we can't see the animation with this document where the line of posts reflect the incoming wave.

Can we quantify the effects?

Isolation (dB) for a Plane Wave upon a Via Fence

10 mil dia. vias at 25, 50 and 100 mil pitches



Reduced pitch or increasing via count gains a lot!

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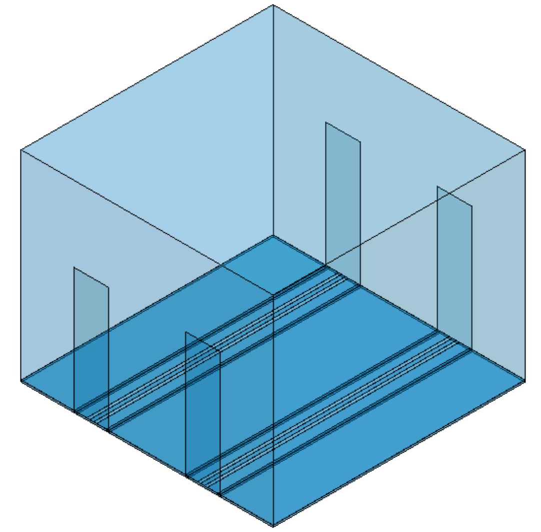
The “shorting effect” of the vias is related to how much of the opening exists, normalized to wavelength.

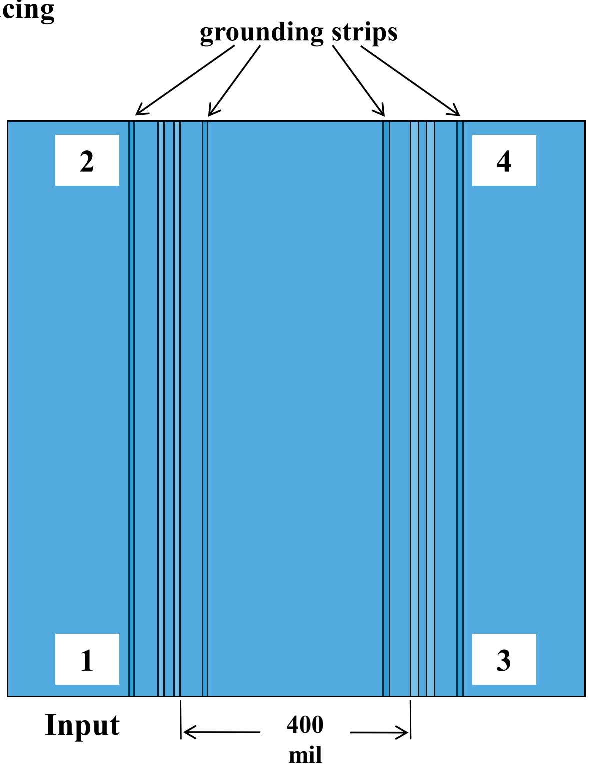
Vias are inductive reactive. Naturally the larger the pitch the less reflection.

Now we’ll consider radiation above the board with parallel co-planar waveguide lines

Simulation Model for CPW lines

Example – 1.0 inch length with 400 mil spacing





Zc = 50 ohm lines
Substrate er = 3.3

Ports

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12

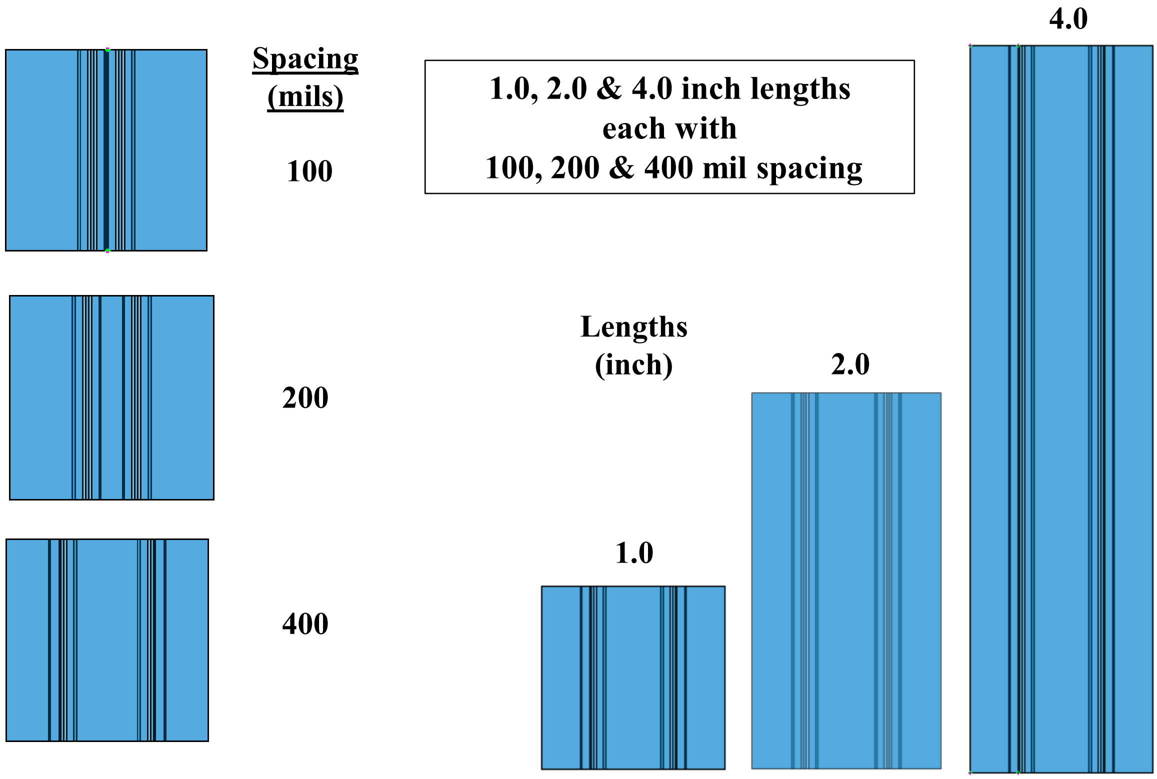
Looking for the isolation (or coupling) between two CPW transmission lines running parallel to one another with varied spacing at different lengths. This shows the general layout for a model using a 400 mil spacing (width of the center ground) between the lines at 1.0 inch in length.

The planar grounds for the CPW are grounded by metal strips through the substrate, as shown in the model. Therefore **ALL** coupling is due to radiation through the **air** above the substrate, no parallel plate contribution.

Take note of the port designations.

What configurations were simulated?

9 Simulation Models for CPW lines



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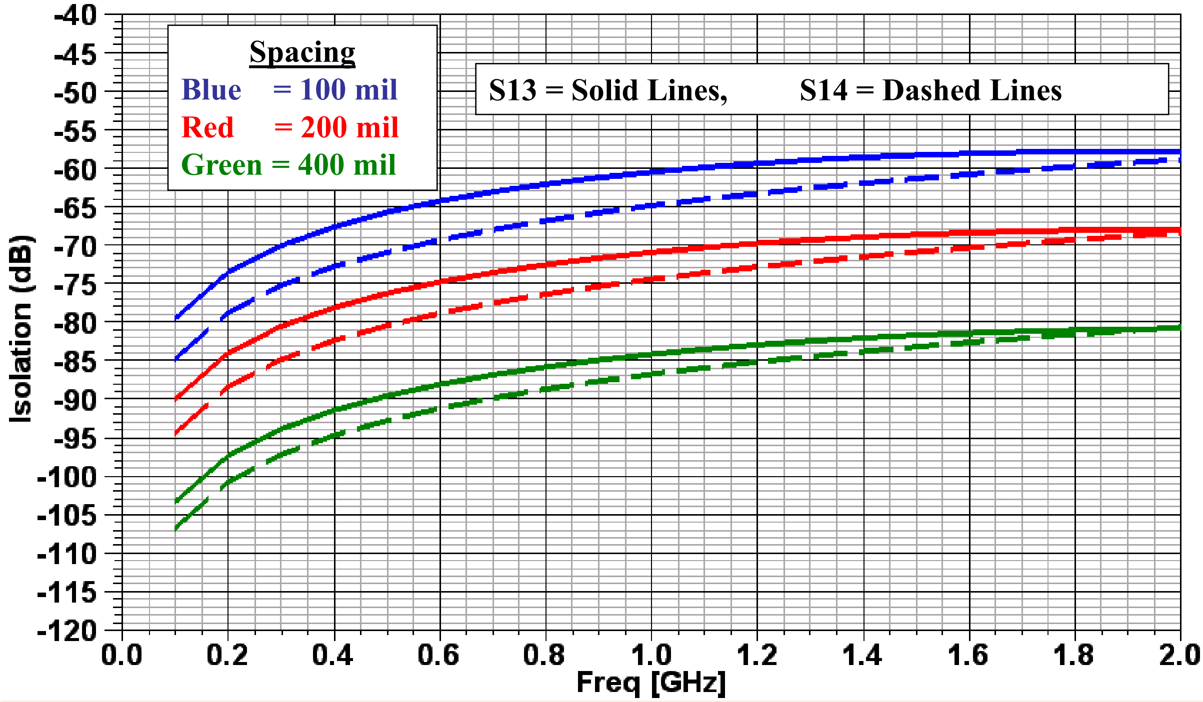
This page shows the 9 combinations of different spacings and lengths considered.

First look at the shortest length.

1.0 inch length CPW lines with grounding



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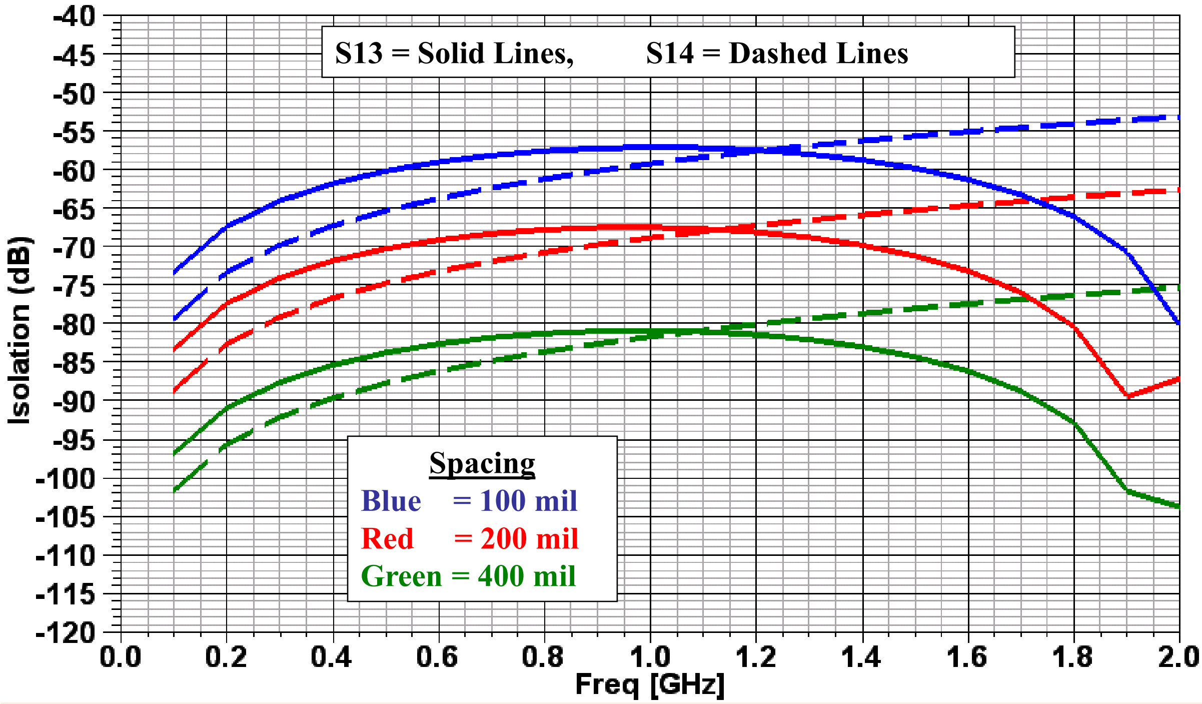
Here we see the coupling at 1 inch length lines. Note that the reverse coupling (S13) is slightly stronger than the forward coupling (S14).

We get a little less isolation (slightly more coupling).

How about doubling the length.

2.0 inch length CPW lines with grounding



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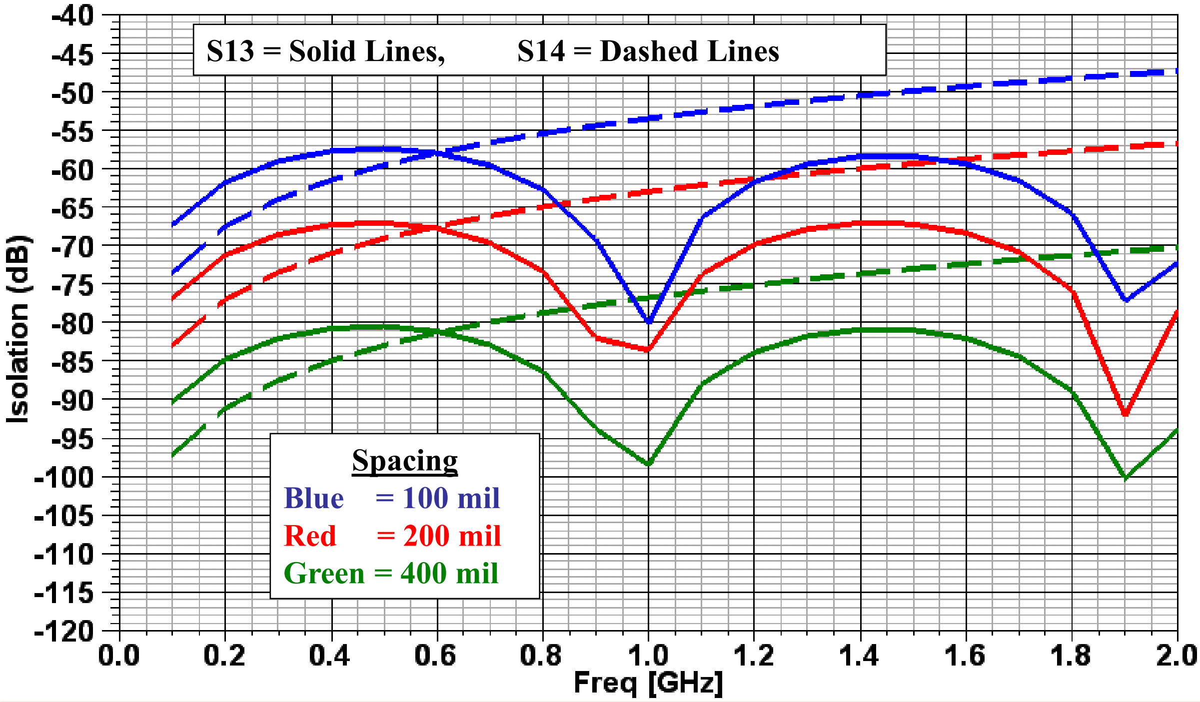
We get a little less isolation (slightly more coupling).

We also see that there is some type of resonance starting to show up with the 2.0 inch case. This is to be expected since 2 inches is greater than lambda/2 for the CPW line at 2 GHz.

How about doubling the length again.

4.0 inch length CPW lines with grounding



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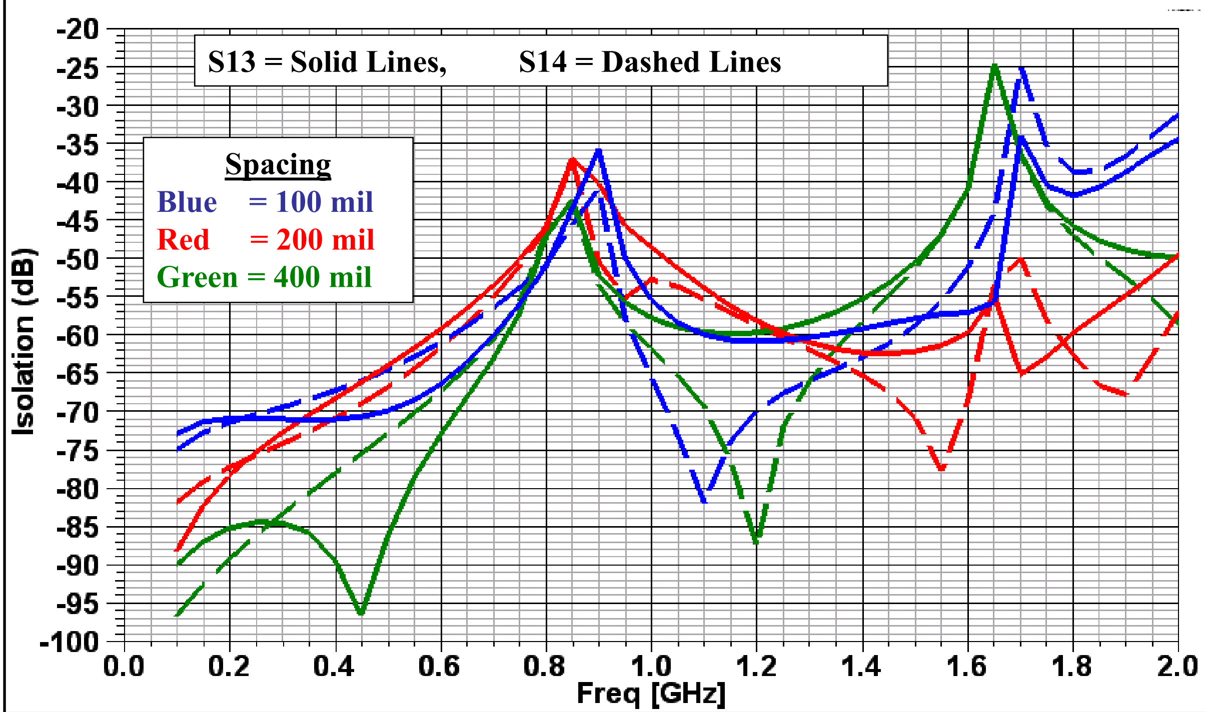
16

Next - What if we had no grounding at all between the lines?

4.0 inch length CPW lines without grounding on center median



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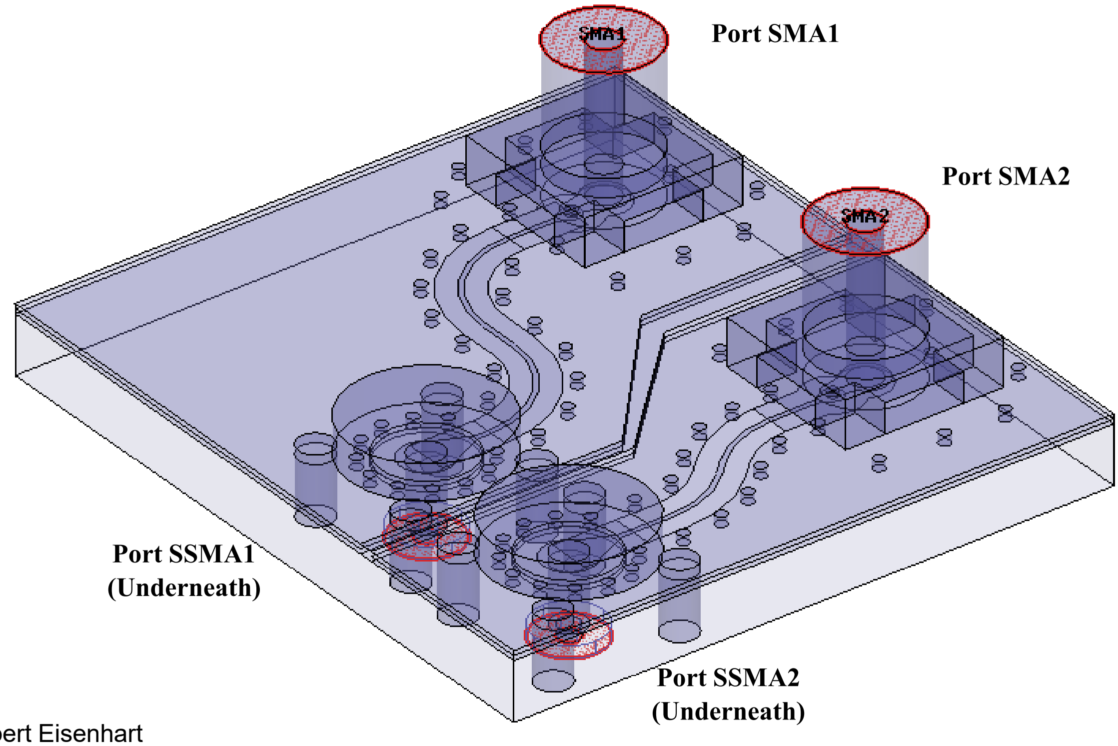
A special case is shown where the grounding strips (representing a perfect wall of vias) have been removed from the “ground” metalization between the lines. The coupling (worst isolation) is much stronger for all spacing's and is actually pretty independent of the spacing. This is no doubt due to the coupling beneath the “ground” strip as a parallel plate mode.

This shows you how important the picket fence vias are to isolate the parallel plate modes.

The next type circuit configuration for consideration is a multi-plane board with connectors on opposite sides.

Multi-plane Model

Looking for isolation between two adjacent circuits on a multilayer printed circuit board. Primary transmission line is stripline.



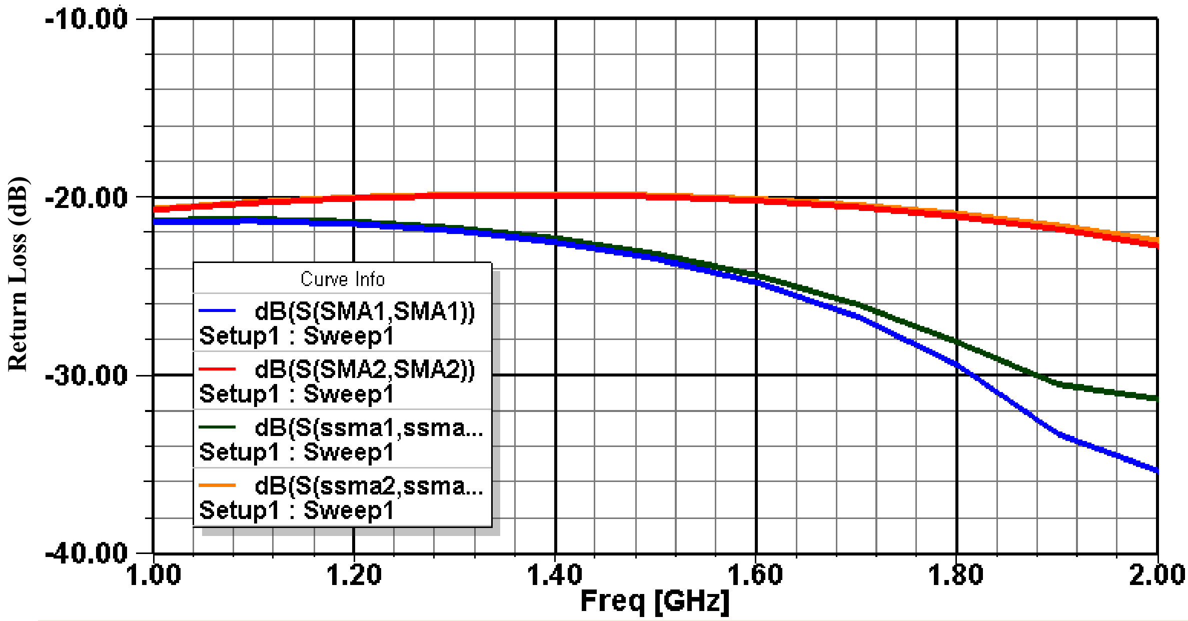
This example circuit will be used to demonstrate the performance of match at the connector ports and the isolation between the ports. Using stripline with side grounds (vias), lots of vias and a physical break in the grounds, we have two paths within one board.

Two SMA connectors to coax and two SSMA connectors thru the board up from the bottom. Initial model is as designed, but the isolation is not good enough.

How is the match at each port?

Multi-plane Port Match

Both connector/board transitions could be improved from a match consideration.



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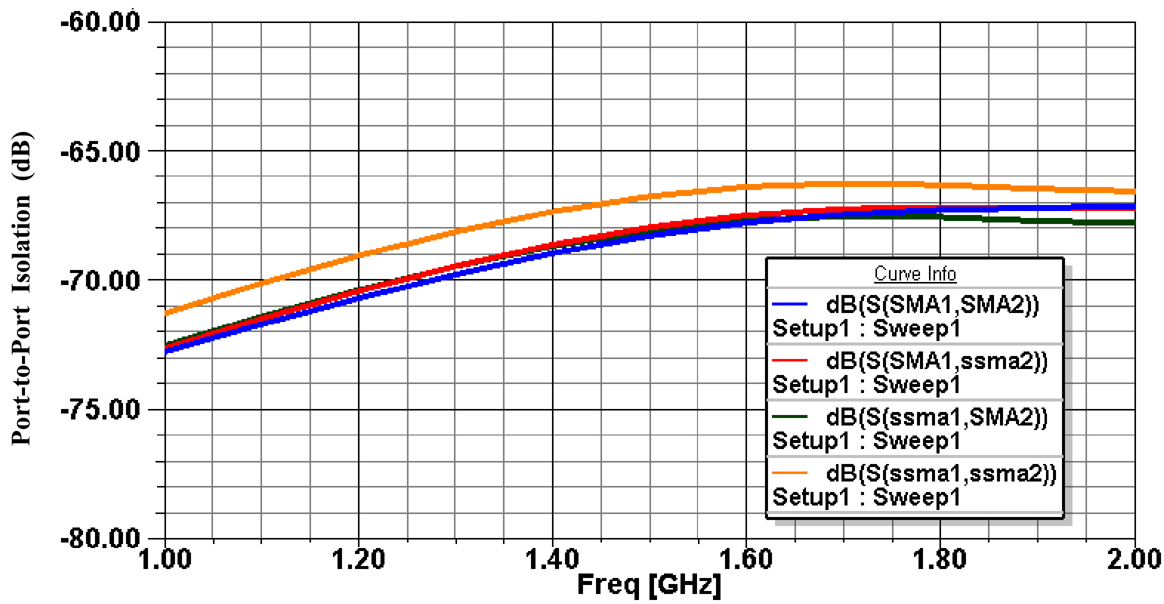
Match at the four ports is decent. Line one a little better probably due to some leakage.

How about isolation?

Multi-plane Circuit Isolation

Nominally there is ~ 68 dB across the circuits.



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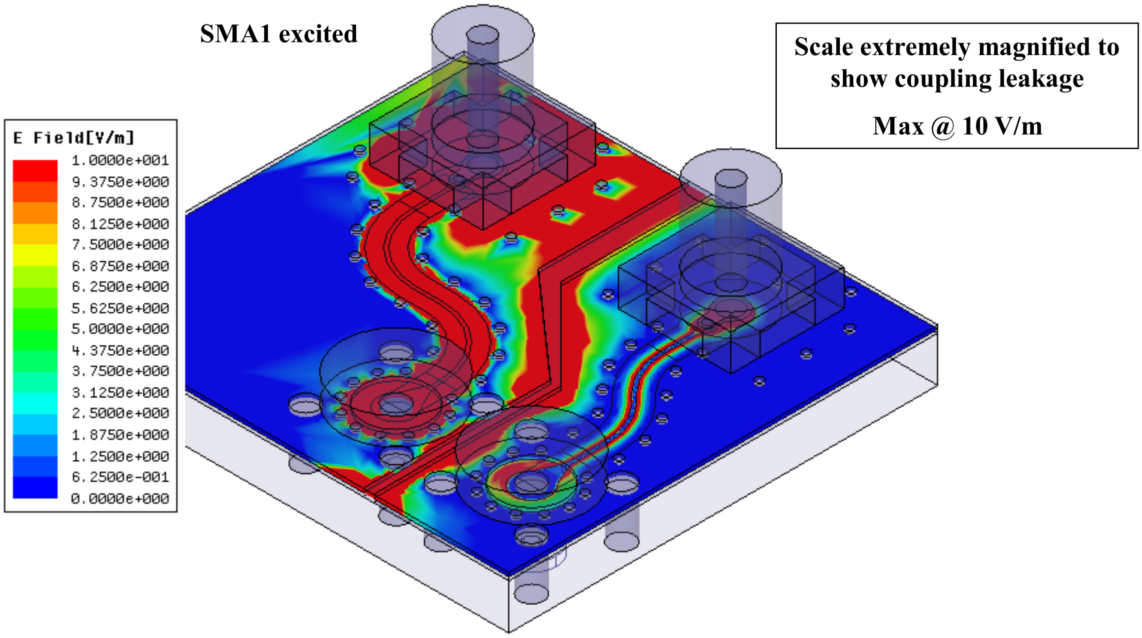
Isolation is fairly consistent, generally getting worse with frequency, as expected, however we desire <-100 dB isolation so we must determine how the energy is getting through.

Use the E-field plots to find the leakage paths.

E-fields on Layer 5 with Port SMA1 Excited (other ports terminated)



Energy leakage on this layer, primarily around the base of the SMA connector where the vias are more widely spaced. This energy is also coupled to the separation slot between the circuits and propagates like in a slot line.

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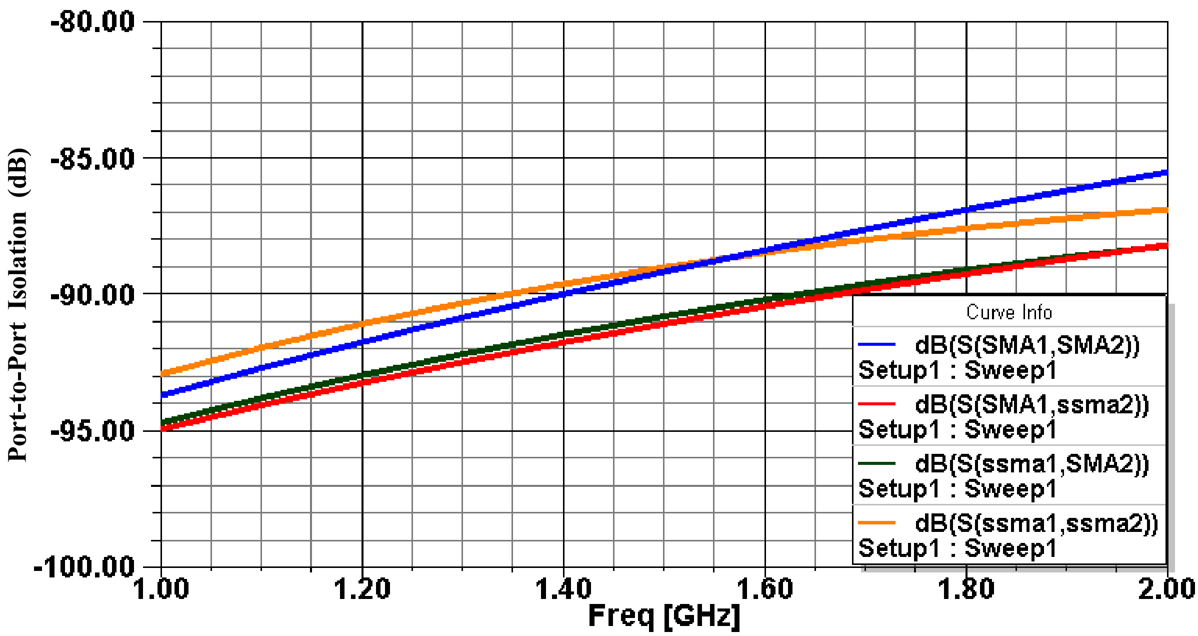
This is in the plane of the stripline center conductor. Leakage from the entry coax launcher, coupling to the break in the ground planes and propagating like a slot transmission line.

Any other leakage?

Multi-plane Circuit Isolation – Improved



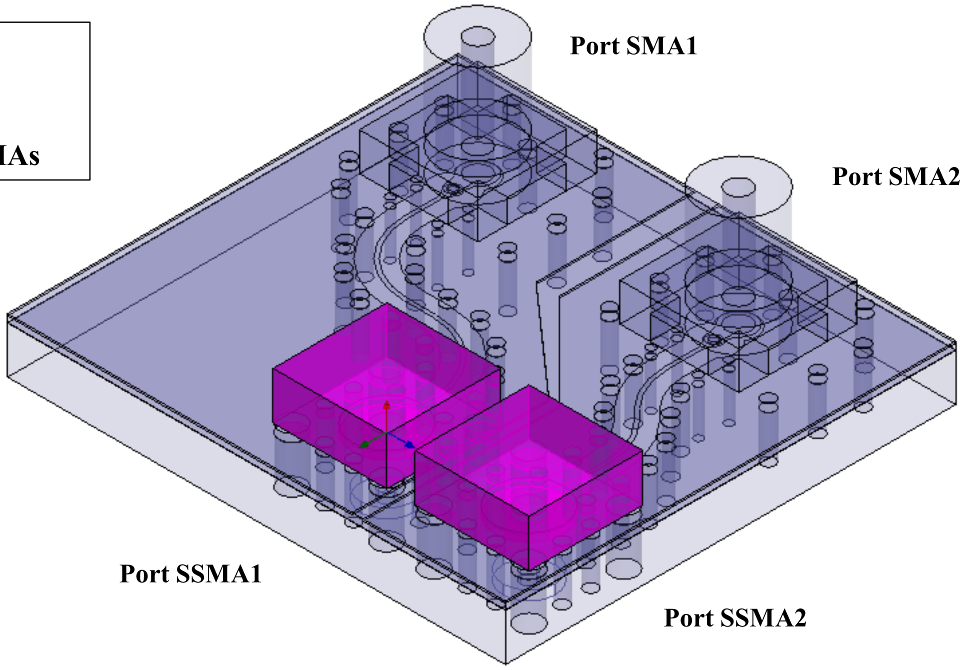
Isolation improved about 22 dB by lengthening all vias, but still expect better.

After better isolation around the SMAs, the isolation has significant improvement of 22 dB. Now to deal with suspected leakage above the board between connectors.

Putting shields over the connector ends results in something like

Multi-plane Model – All Connectors Air Isolated

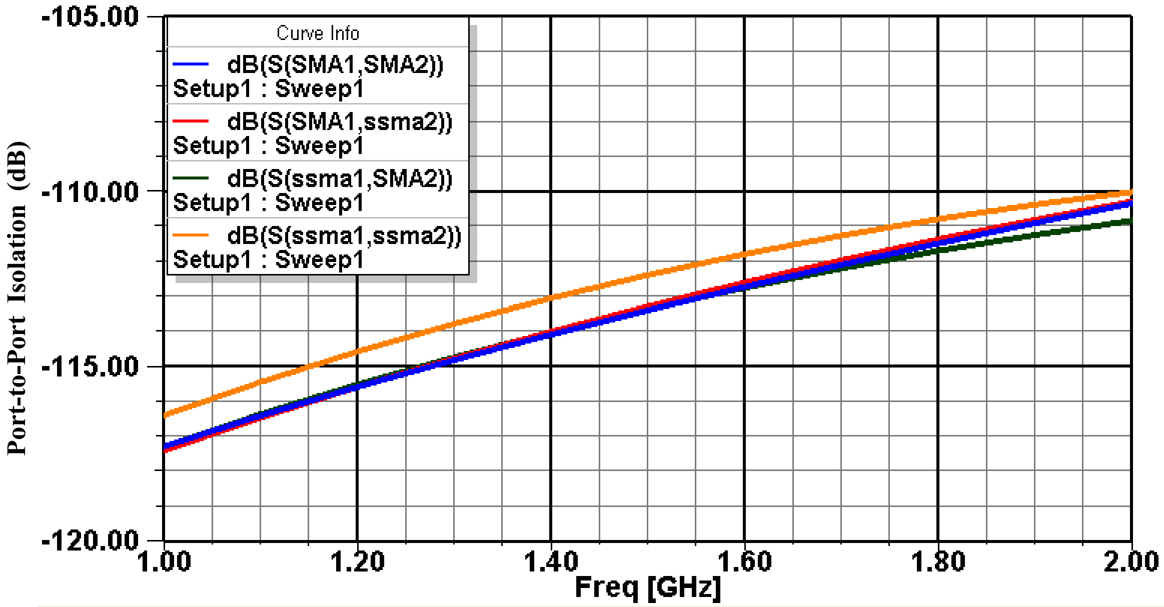
More vias
Larger vias
Longer vias
Caps over SSMAs



Should be great by now.

Final results

Multi-plane Circuit Isolation – Air Isolated



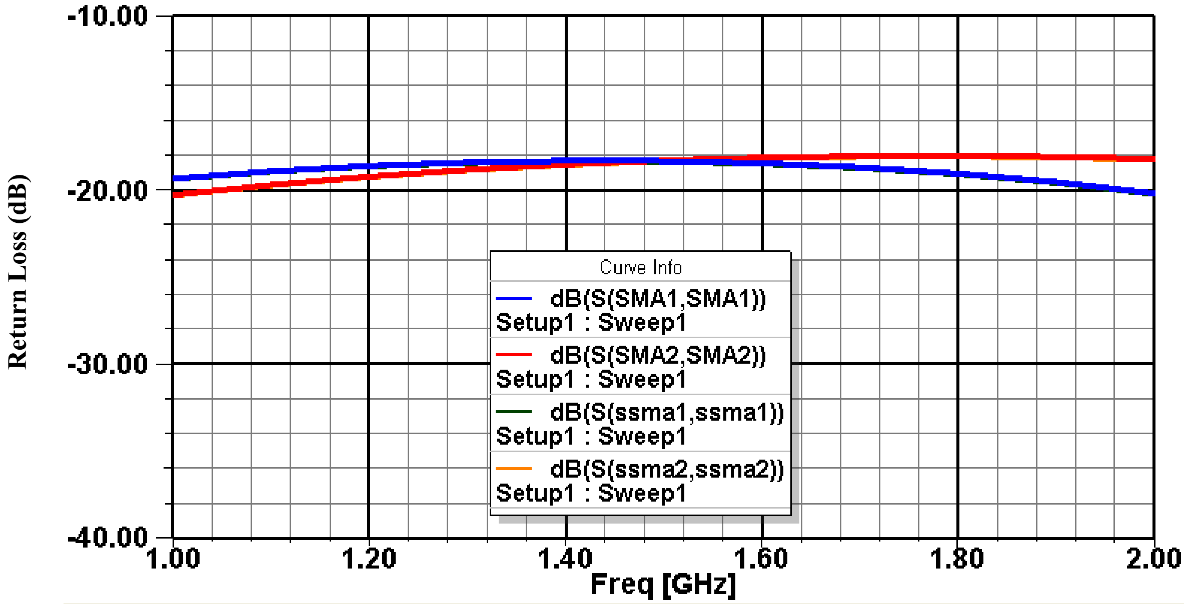
Best Isolation (> 113dB) with full length vias and caps over both sets of connectors

<u>Conclusions:</u> A significant amount of coupling (at these low levels) does happen from the tops of the SSMA connectors and can be removed by shields over the connectors.

Meets the < -100 dB goal for the circuit.

And the match?

Final Multi-plane Circuit Match



Match is more consistent with longer vias and shows that some of the leakage was seen as better match.

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All connector matches look similar with reduced leakage.

In life, you don't get what you deserve, you get what you negotiate

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26

Don't expect others to look out for your best interest.