PENTAIR

HIGH-FREQUENCY LAYOUT

Best Practices for PCBA Design

GERRY CALLAHAN

Agenda

- **Why *every* design needs to consider High Frequency Layout**
- **Why EMI and SI matter**
  - Electro-Magnetic Interference
  - Signal Integrity
- **Circuit Theory and Wave Theory**
- **The difference between Ground and Return**
- **When is a signal “High Frequency”**
- **Recommendations**
  - Good Practices
  - PCB Stackups
- **Questions and discussion**

Considering High Frequency Layout

- There may be parts of a design that include high frequencies in non-obvious ways
- If a layout could radiate, it’s also susceptible to interference
- Requirements change, parts change

EMI and SI

- Everything we sell must obey FCC rules
- Even if a circuit doesn’t have high-frequency sources, it could pick up signals that cause problems
- One part of a circuit could interfere with other parts
- The principles for avoiding EMI problems are very similar to maintaining good SI

Good layout habits will pay off later

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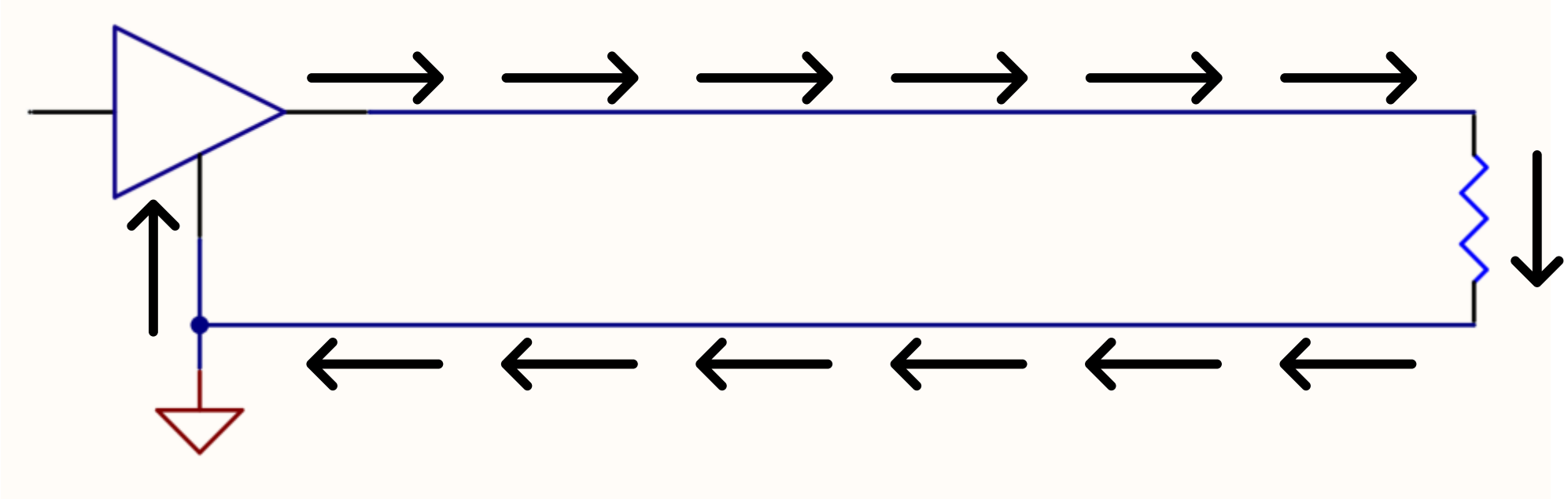
CIRCUIT THEORY AND WAVE THEORY

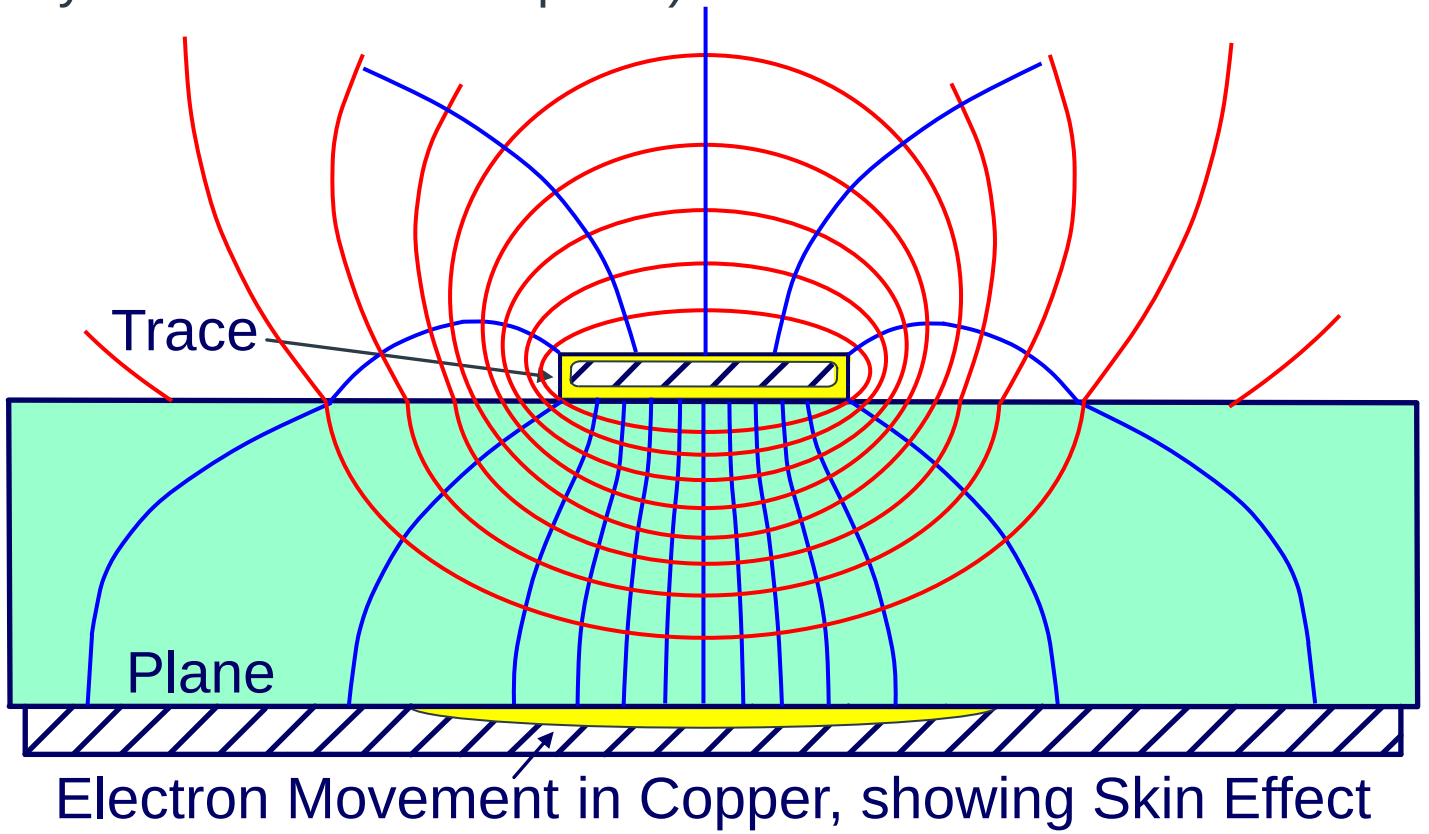
Circuit Theory…



… is WRONG

Voltage and Magnetic Fields

Microstrip (Outer layer trace and return plane)



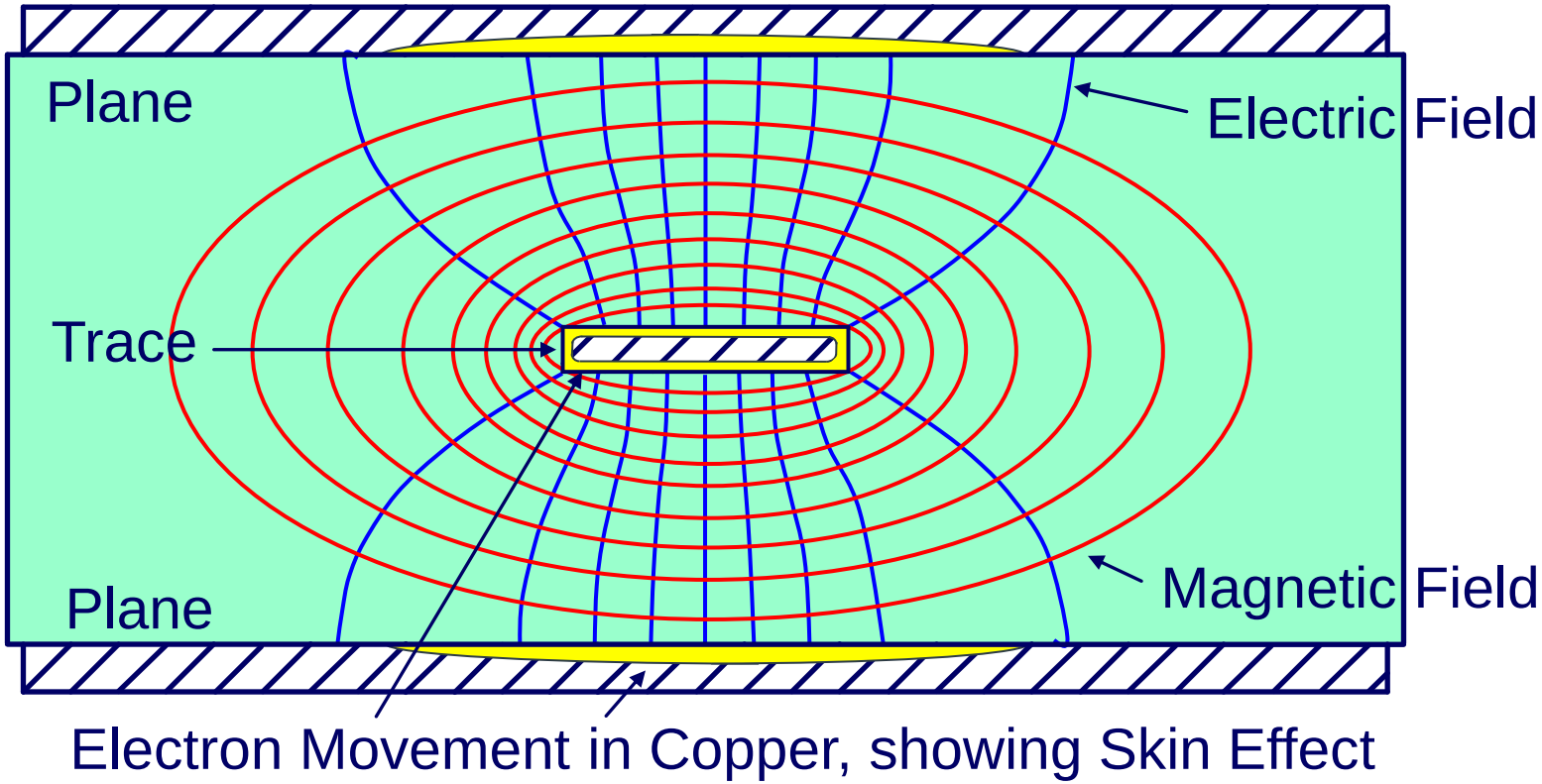
Original source:

RHARTLEY ENTERPRISES
CONTROL OF NOISE, EMI & SI

Moderate Volume Fields (EM Wave), Mostly Contained.

Voltage and Magnetic Fields

Stripline (Inner layer trace and return planes)



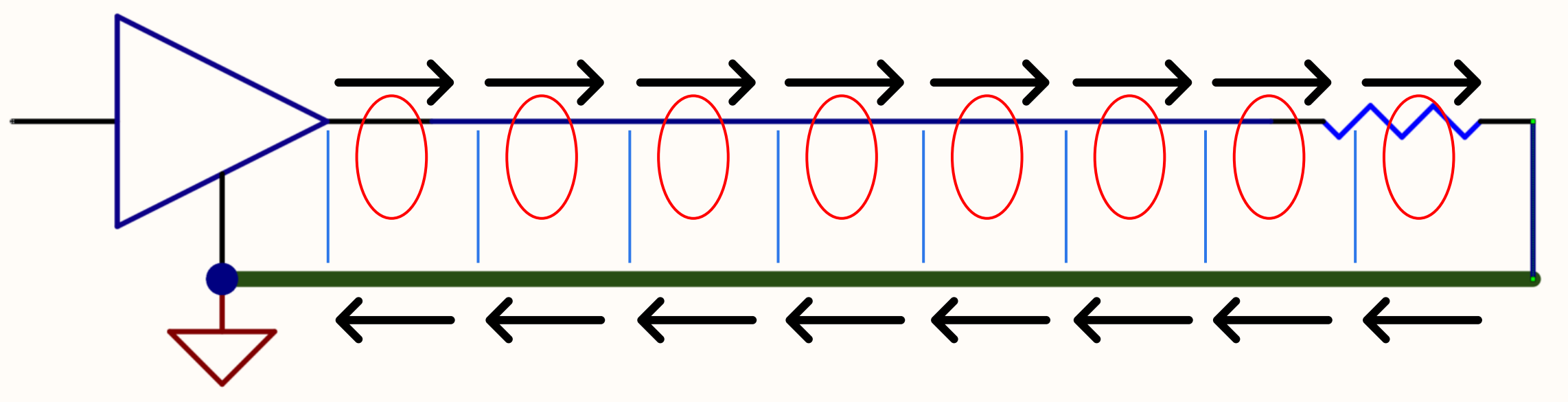
Original source:

RHARTLEY ENTERPRISES
CONTROL OF NOISE, EMI & SI

Low Volume Fields (EM Wave), Completely Contained.

Voltage, Current, and Waves

- How does the signal go from the source to the load?



Energy is in the Waves (traveling *between* the layers)

Path of Return Current

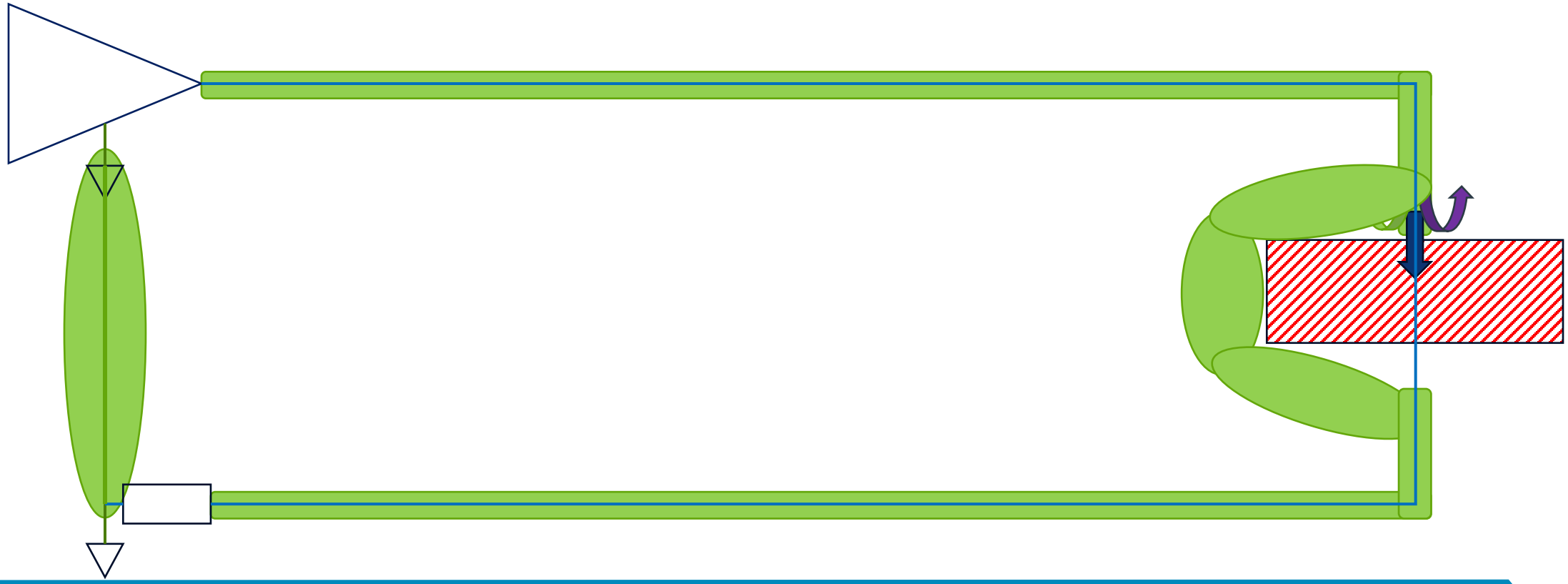
- 2-Layer board, components and signals on top, “ground” plane on bottom

Path of Return Current

- Same layout, except there’s a cutout in the ground plane (between source and load)

Path of Return Current

- Same layout, except there's a cutout in the ground plane (under the trace)



E-M Fields around the ground break are a *mess!*

GROUND AND RETURN

Ground v. Return

- The only true Ground is “Earth Ground”
- Chassis is often called “Ground”
  - May or may not be connected to Earth Ground
- Power Supply negative output (return) is often called “Ground”
  - But it’s usually isolated, definitely not Earth Ground
- Component data sheets often call one of the pins “Ground”
  - But it’s just the power supply return
- The shield of a coax cable is almost never “Ground”
- PCBs usually have a plane for both power and signal return, called the “Ground Plane”

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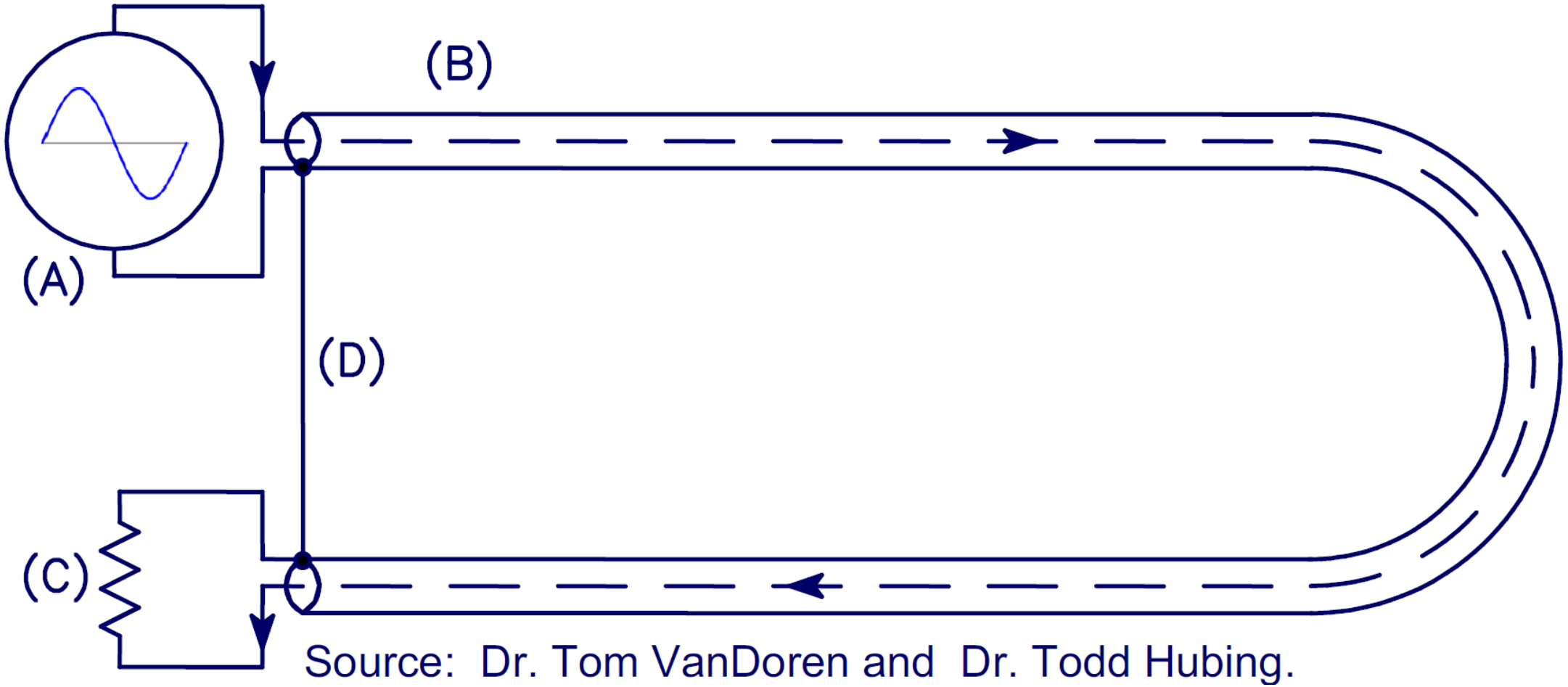
HIGH FREQUENCY

What makes “High Frequency”?

- Frequency ranges where it becomes a problem
- Edge rate v. Repetition rate

Experiment to show that…

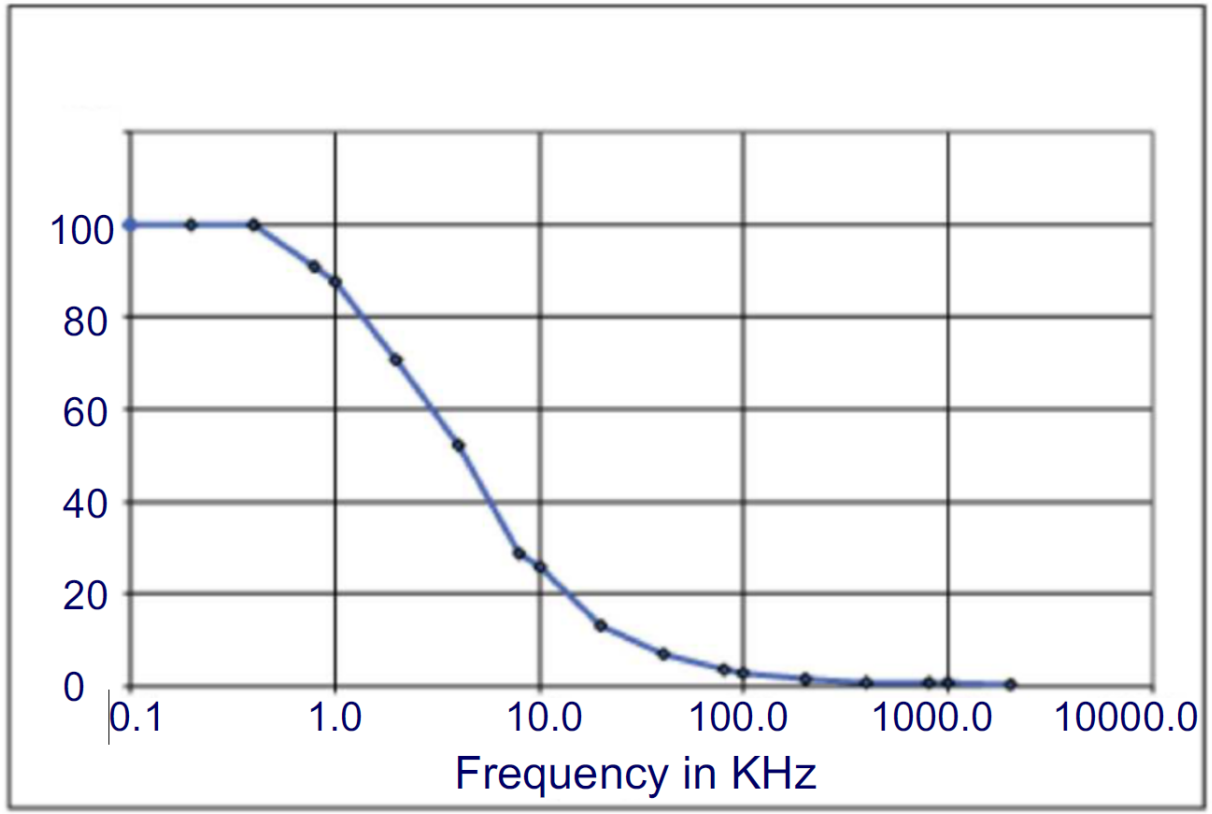


Source: Dr. Tom VanDoren and Dr. Todd Hubing.

…Current takes the path of Least Impedance

Experiment to show that…

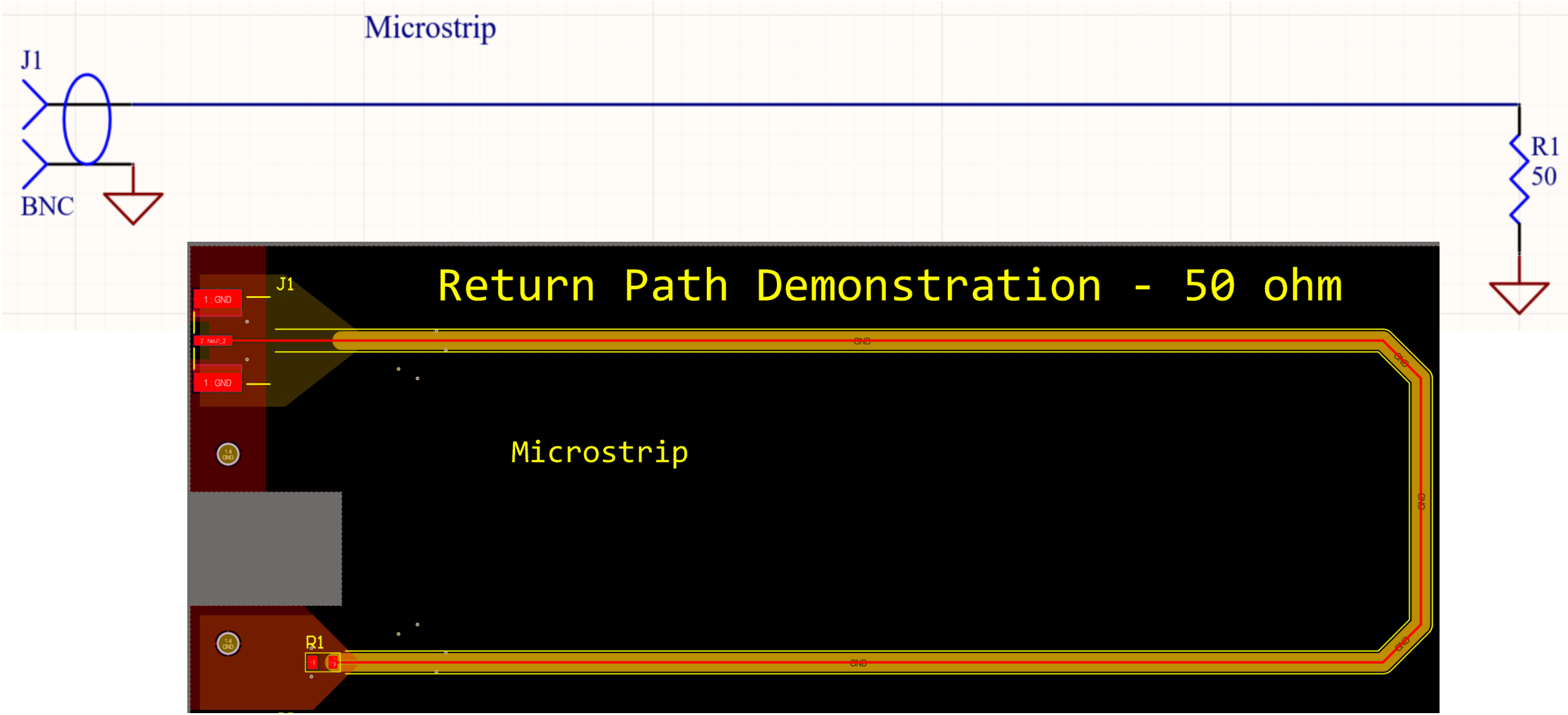
% of Total Current Flowing in the Strap



Source: Dr. Todd Hubing.

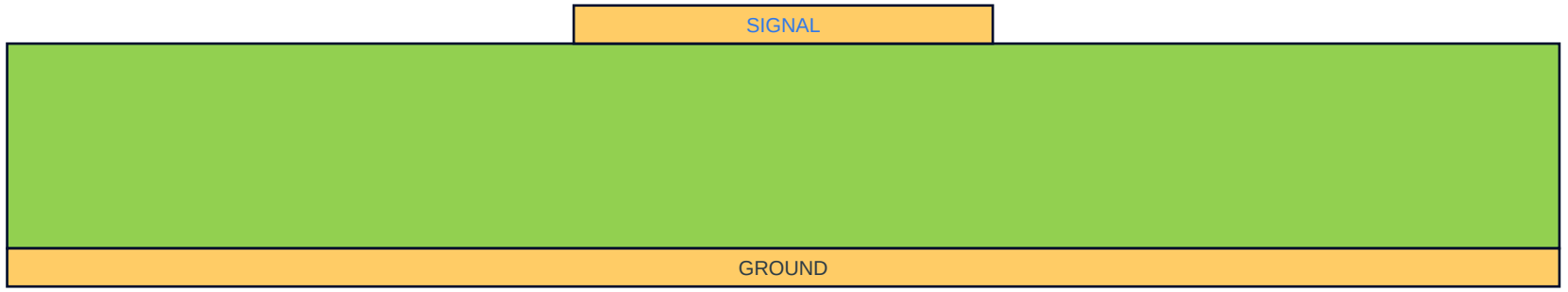
…Current takes the path of Least Impedance

Same Experiment in PCBA

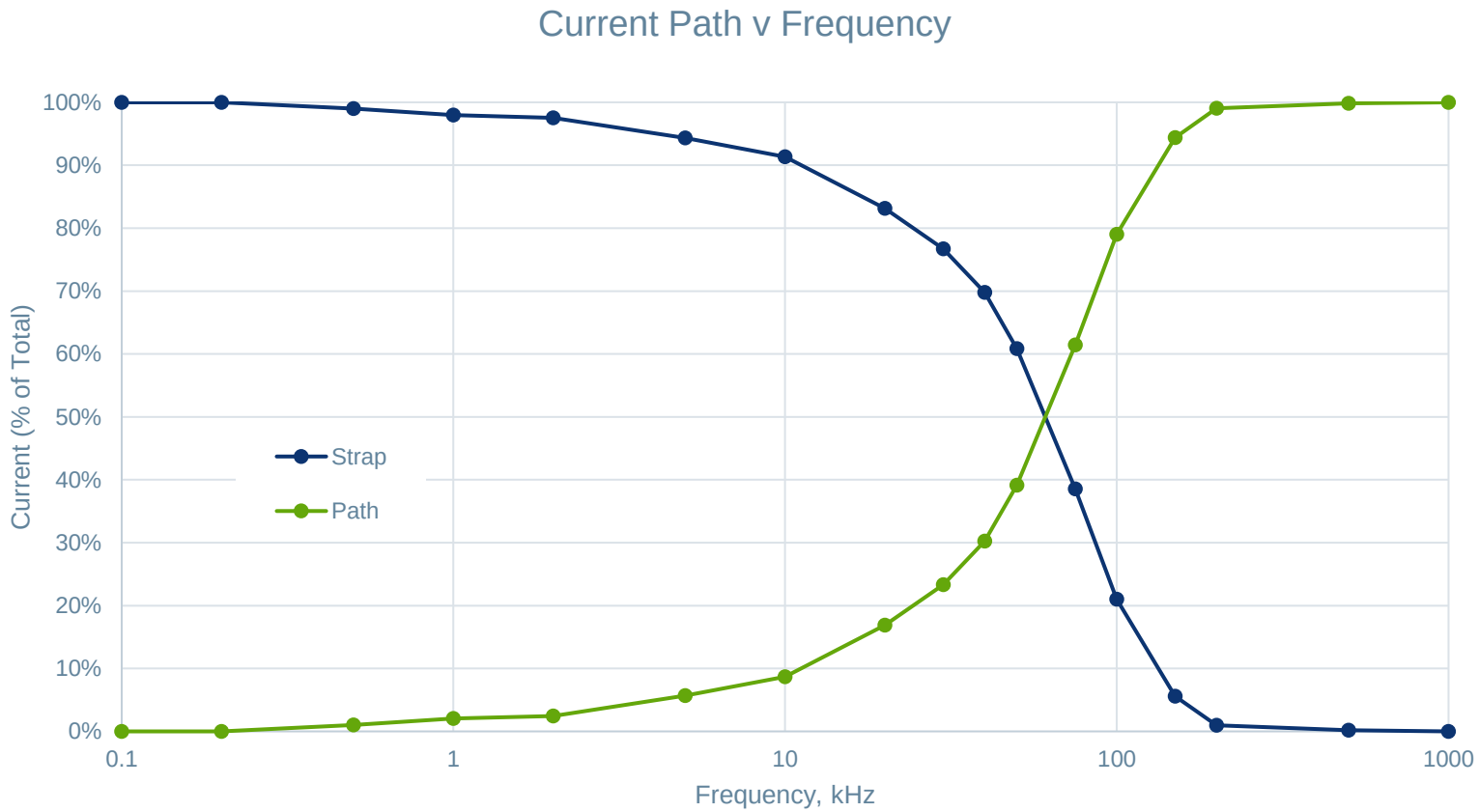


Microstrip Transmission Line

Trace on outer layer, referenced to adjacent layer



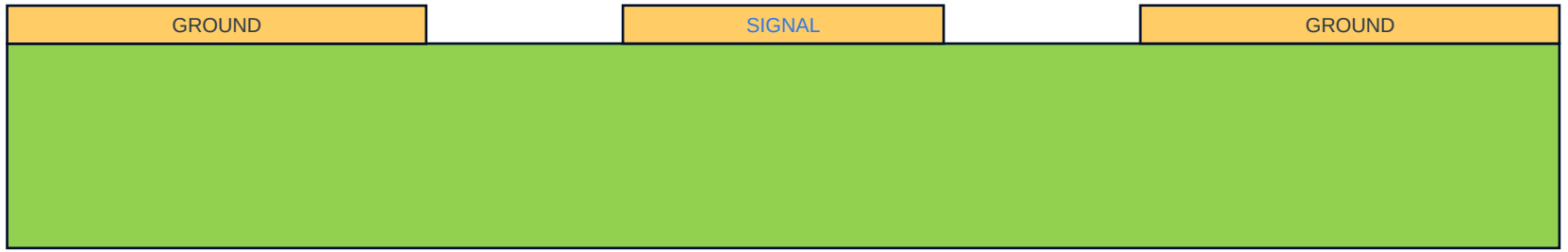
Microstrip Results



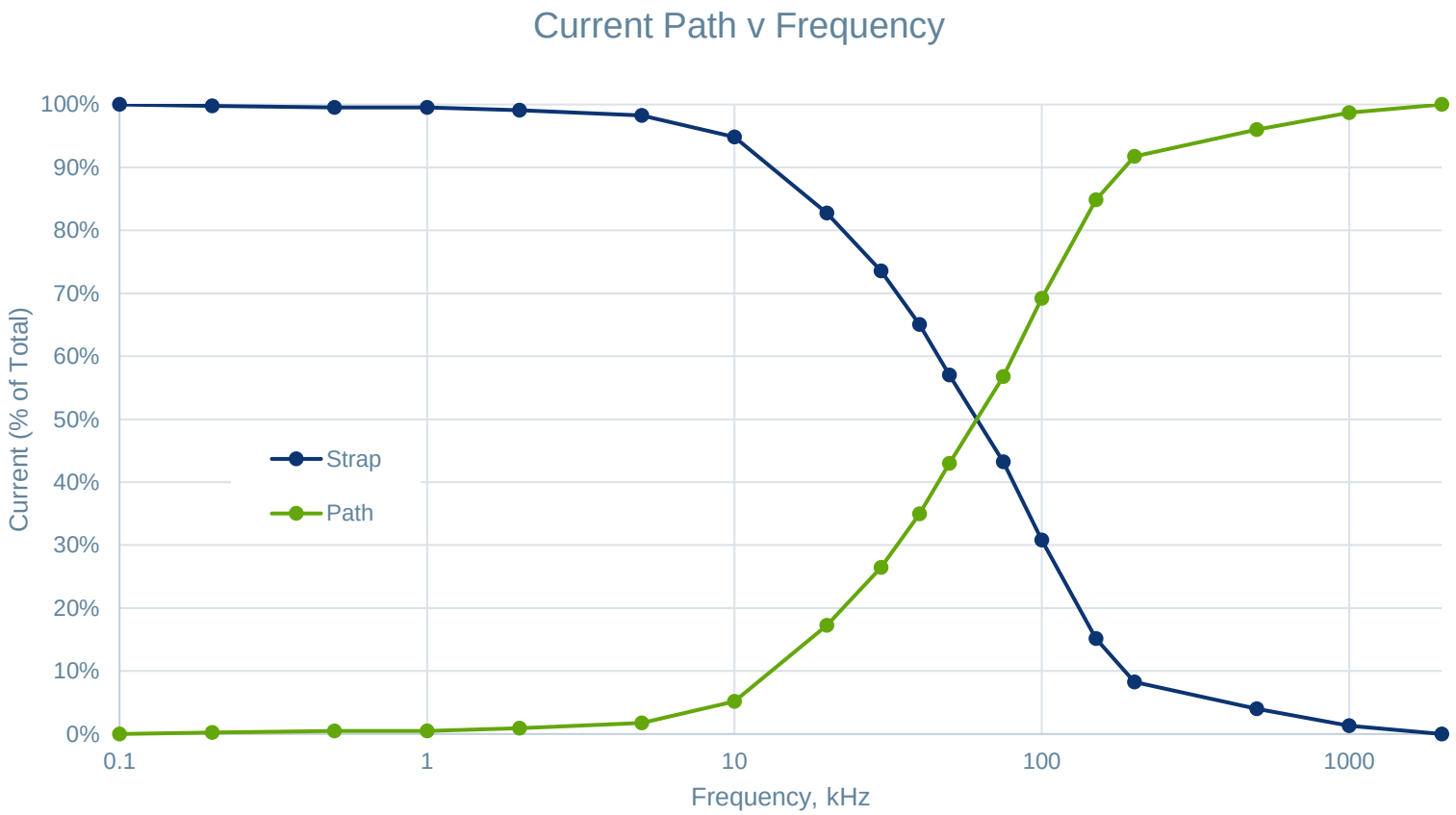
Transition complete at 200 kHz

Coplanar Transmission Line

Trace on any layer, referenced to two traces on same layer



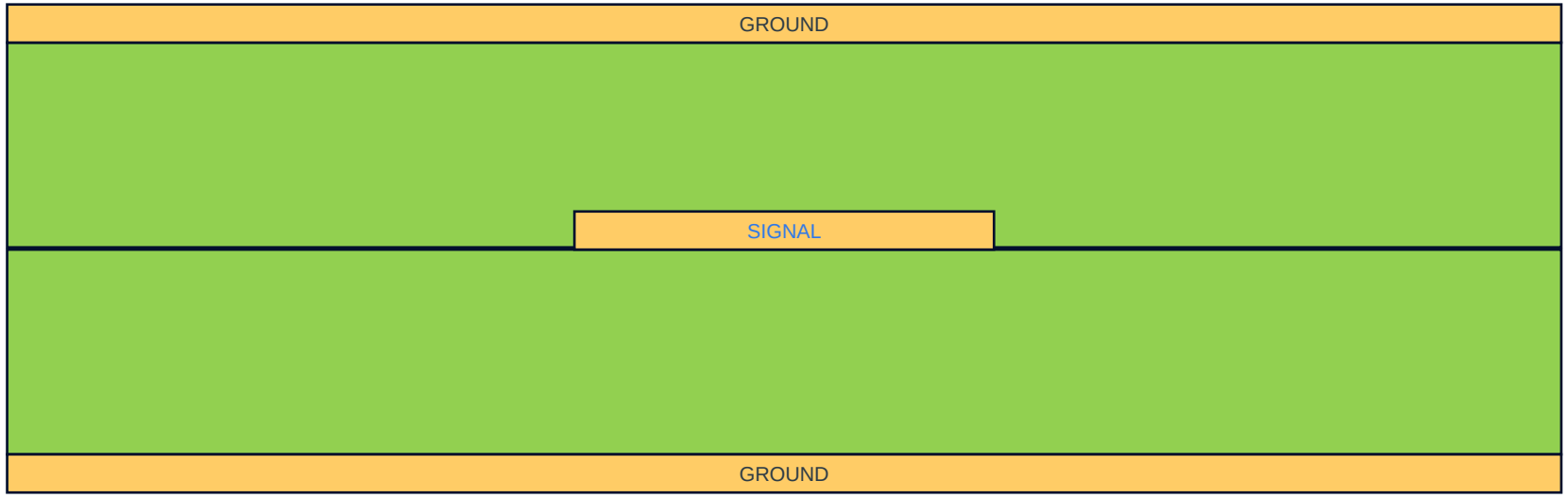
Coplanar Results



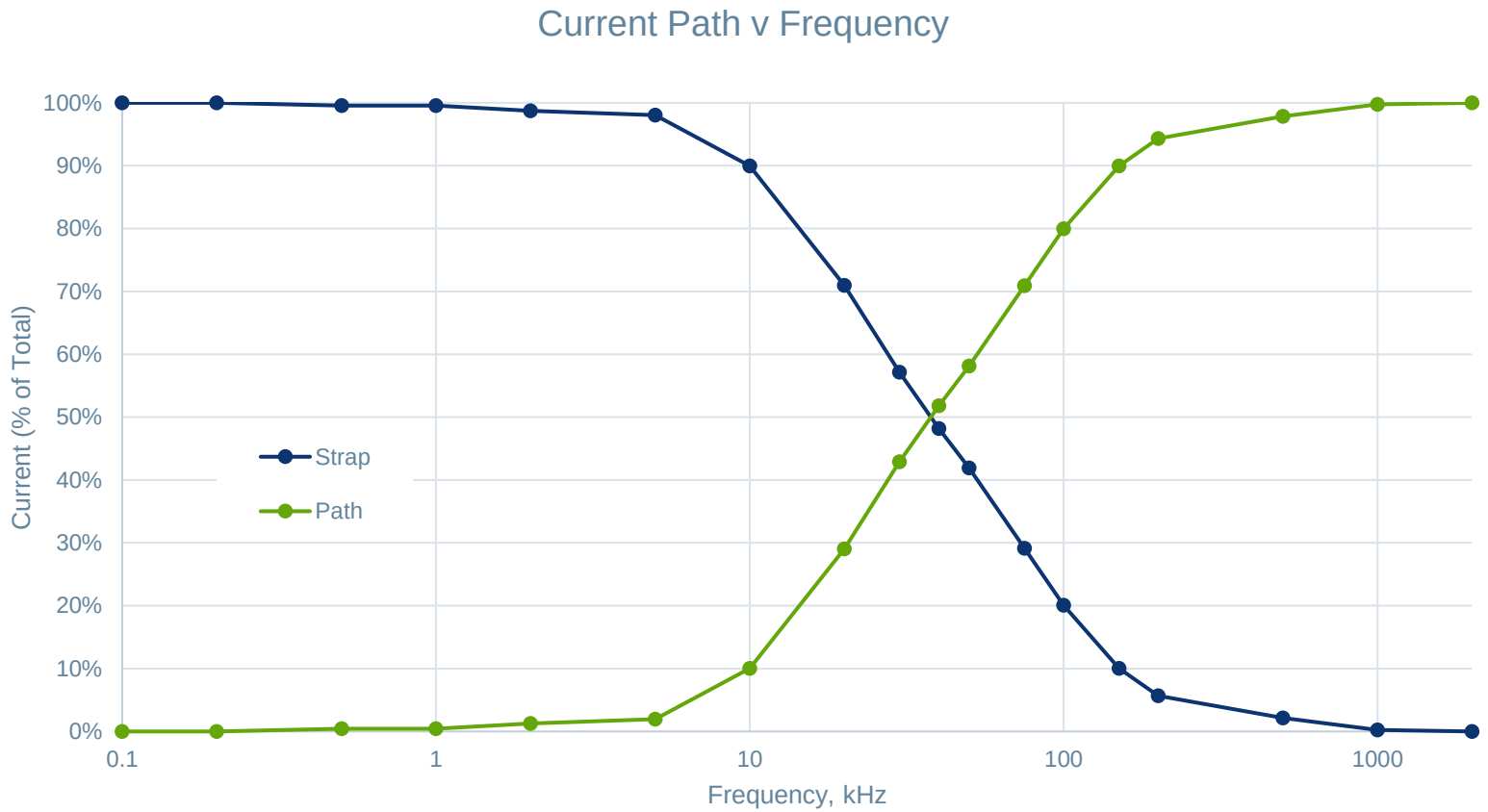
Transition complete at 2 MHz

Stripline Transmission Line

Trace on inner layer, referenced to both adjacent layers



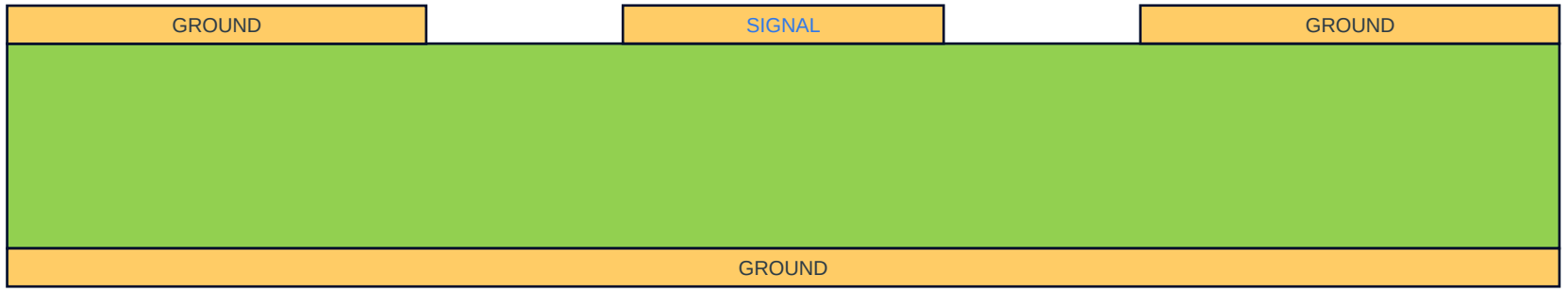
Stripline Results



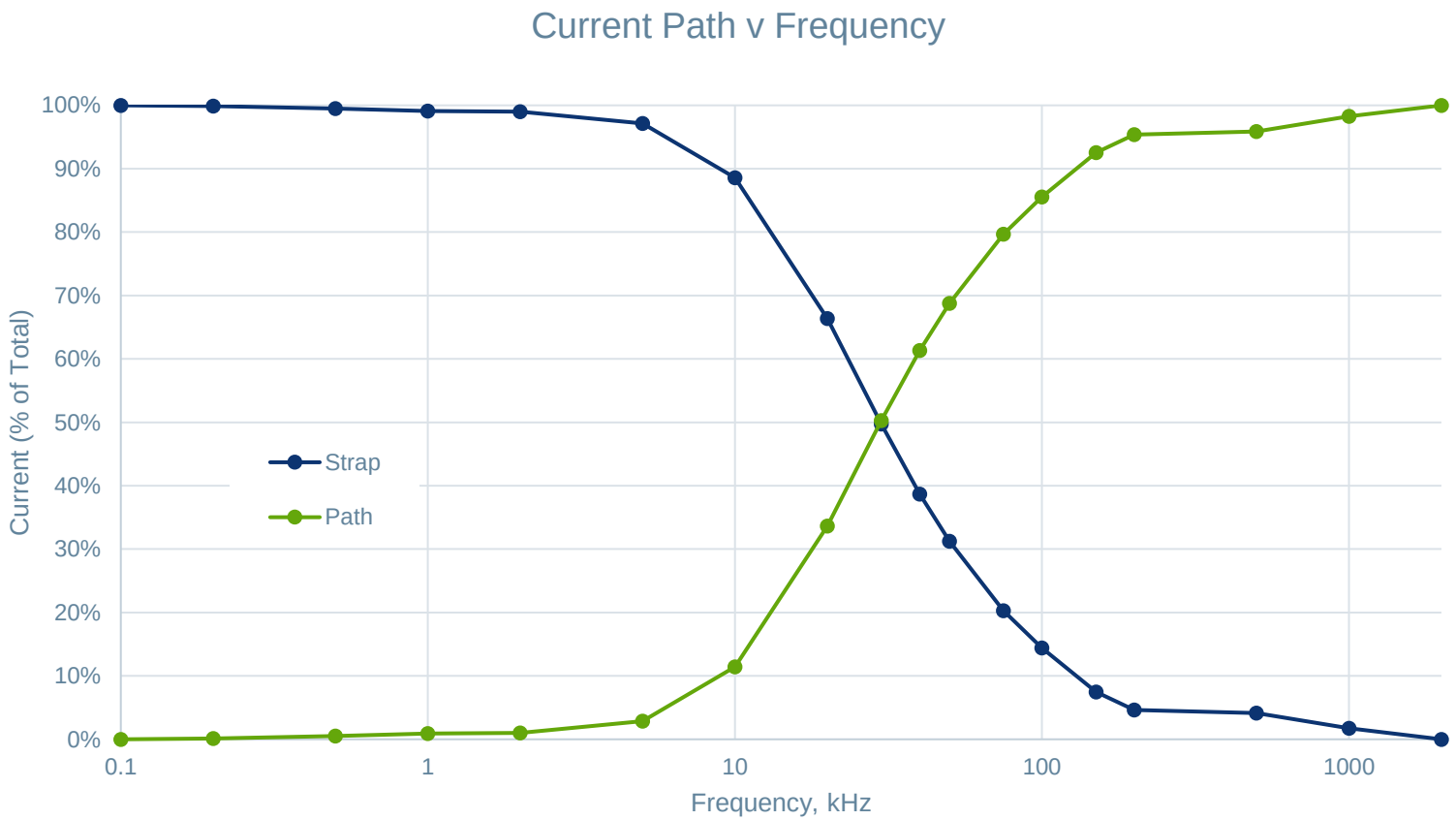
Transition complete at 1 MHz

Coplanar with Ground Transmission Line

Trace on any layer, referenced to two traces on same layer, and adjacent layer



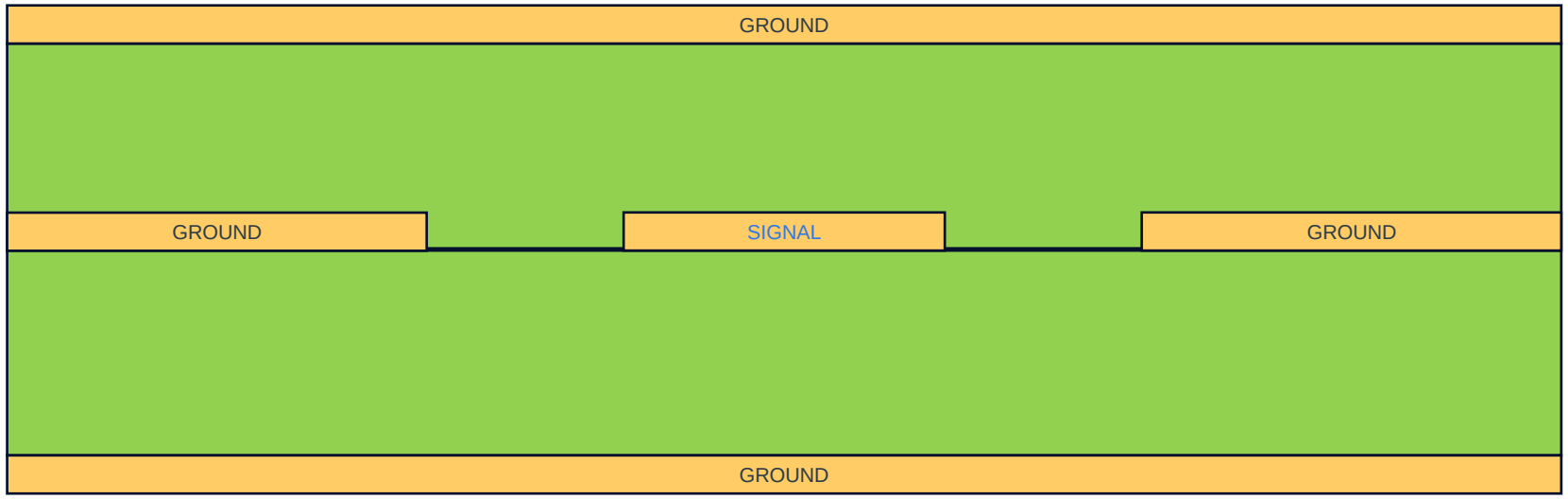
Coplanar with Ground Results



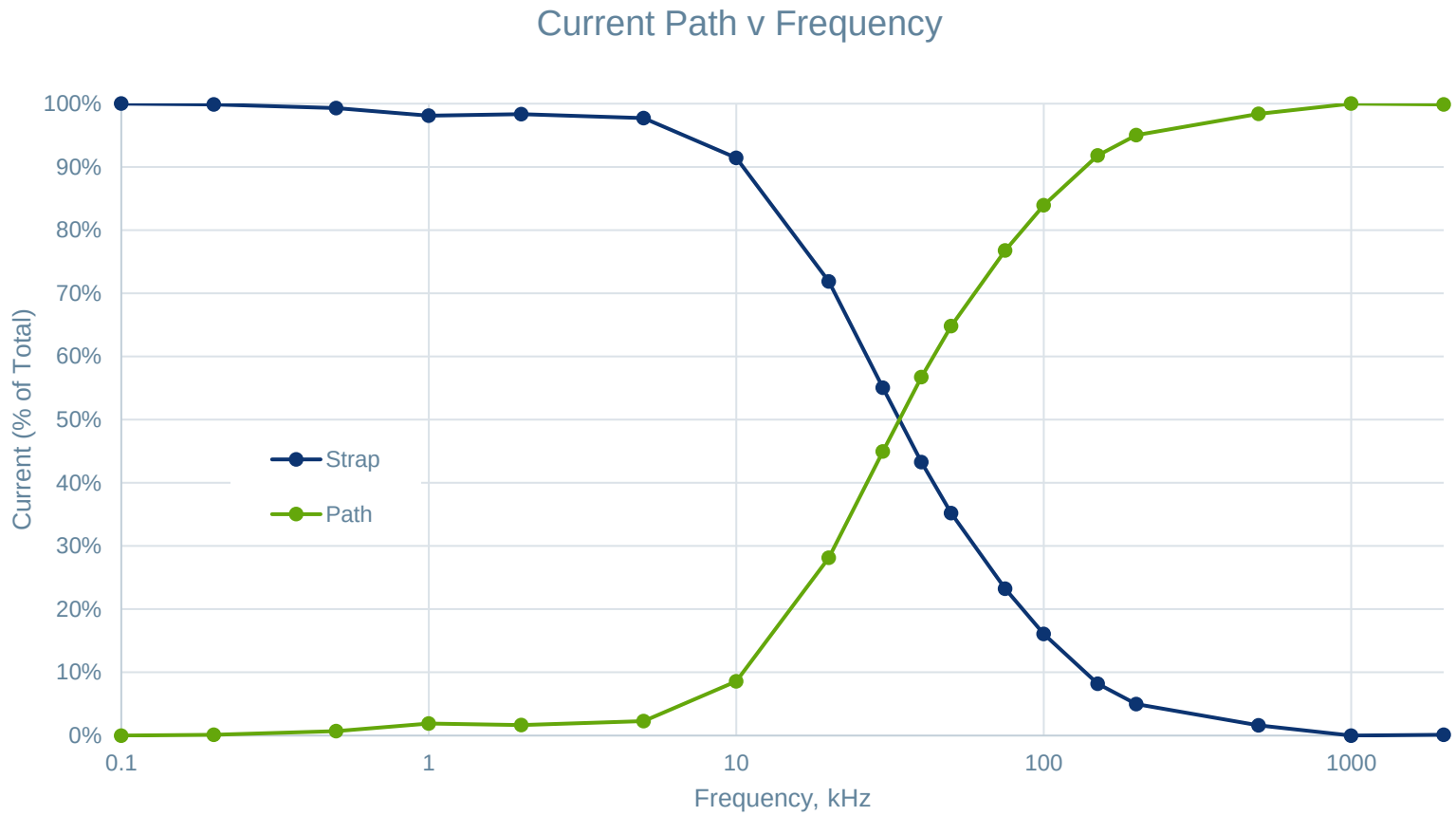
Transition complete at 2 MHz

Coplanar with Double Ground Transmission Line

Trace on any layer, referenced to two traces on same layer, and both adjacent layers



Coplanar with Double Ground Results



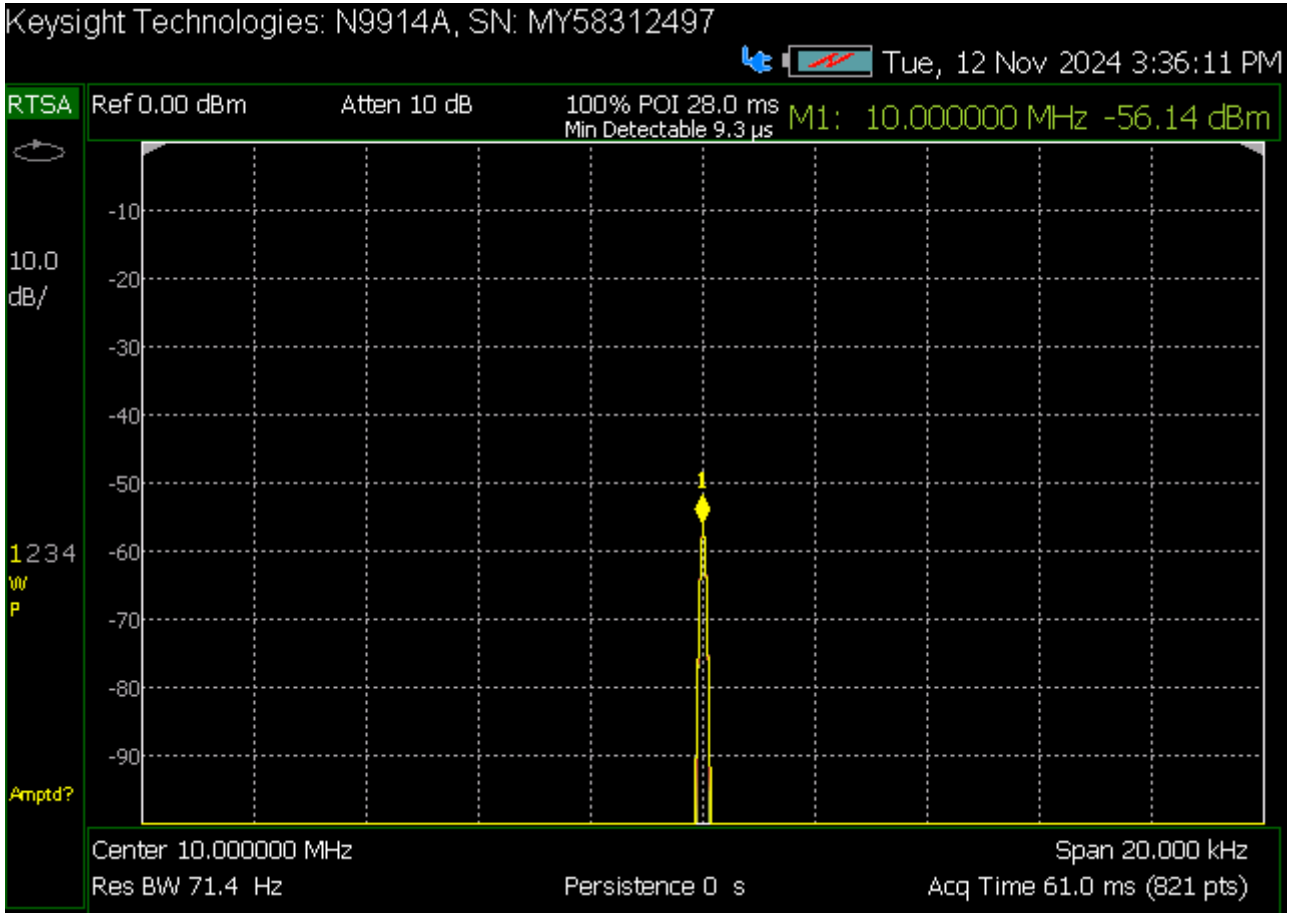
Transition complete at 1 MHz

Comparison of Transmission Lines

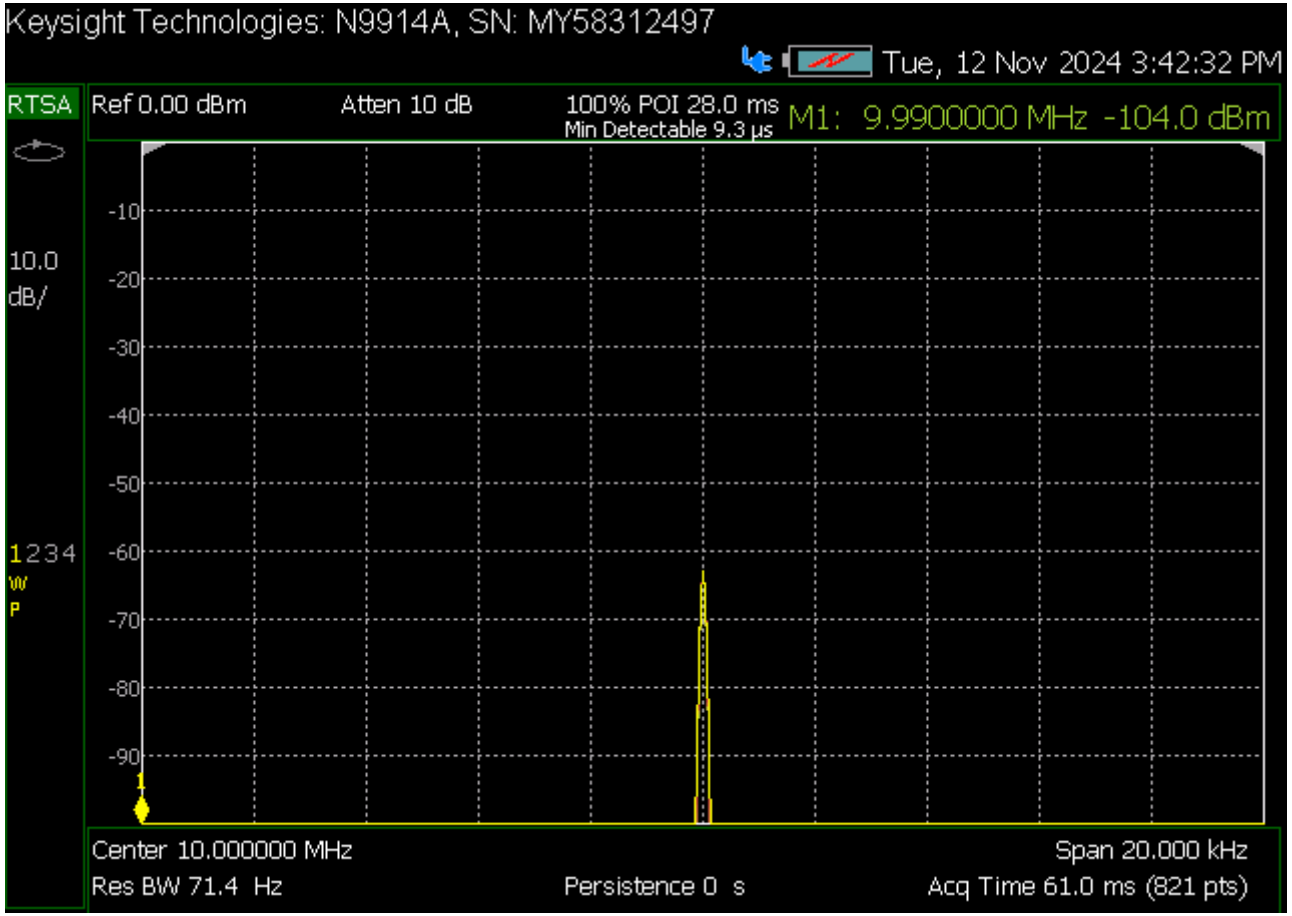
Type	Transition Frequency (kHz)
Microstrip	55.4
Coplanar	64.5
Stripline	39.7
Coplanar with Ground	31.1
Coplanar with Double Ground	34.7

Ground on Adjacent Planes = Most Effective

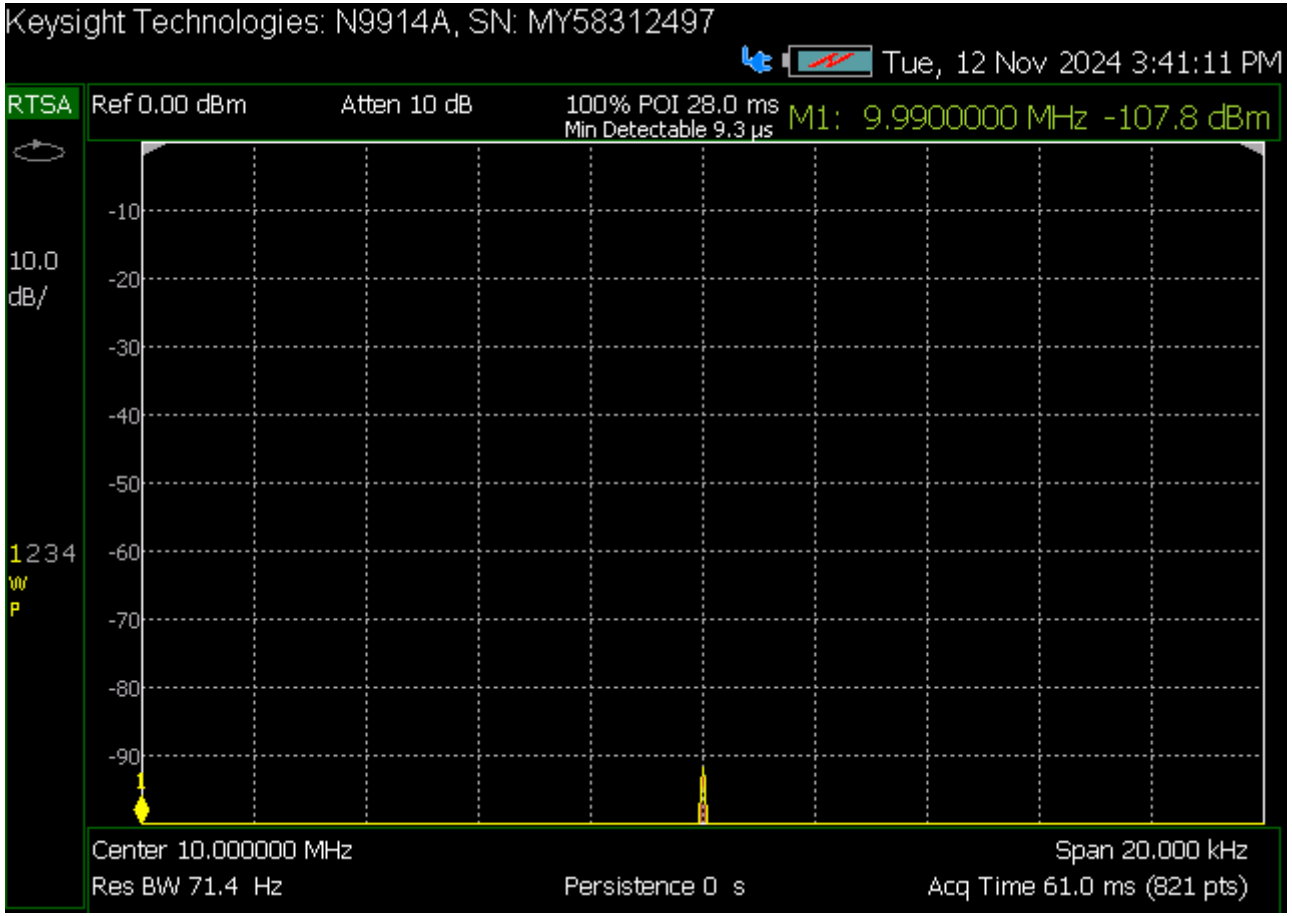
Microstrip - Radiated Emission



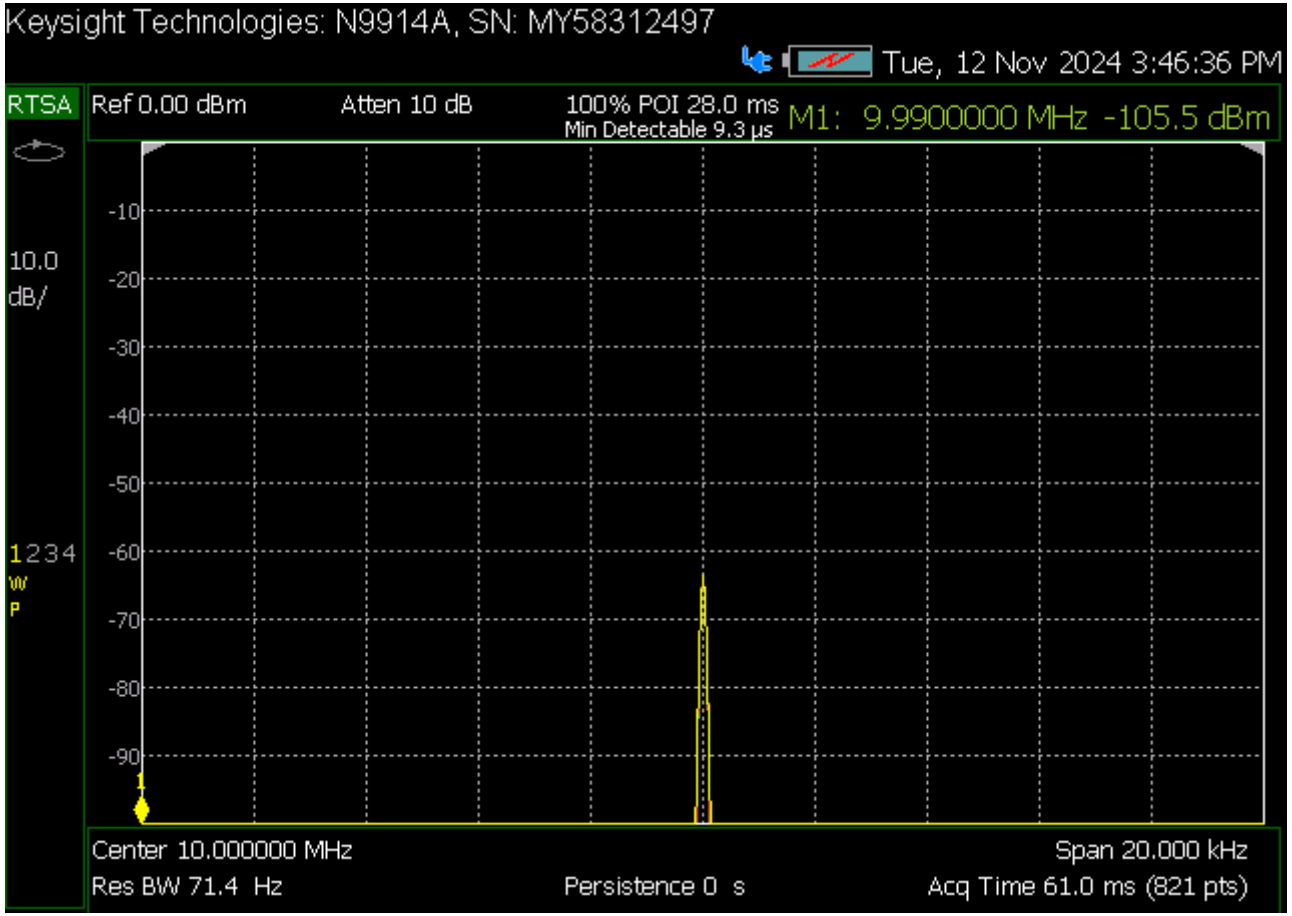
Coplanar - Radiated Emission



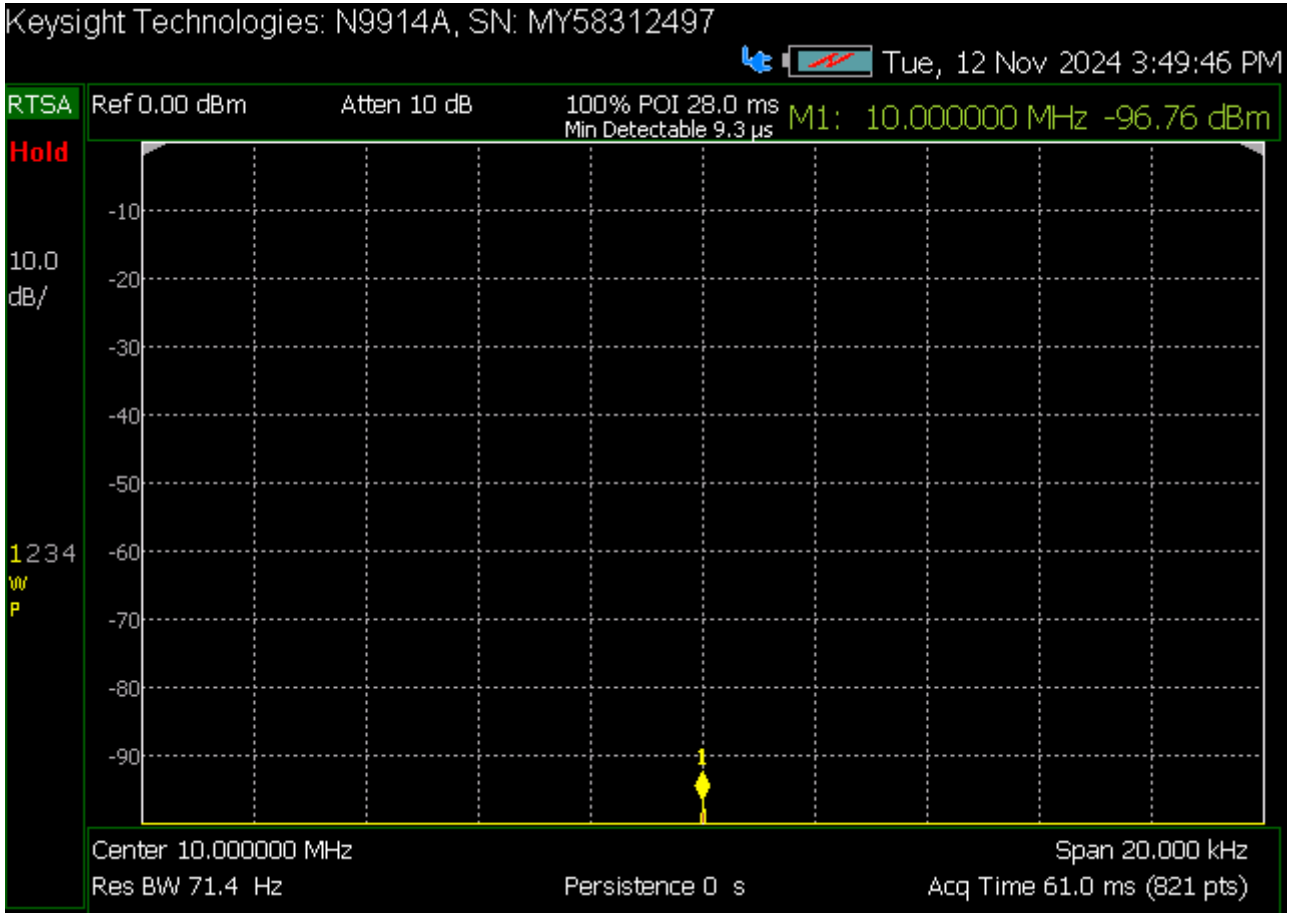
Stripline - Radiated Emission



Coplanar with Ground - Radiated Emission



Coplanar with Double Ground - Radiated Emission

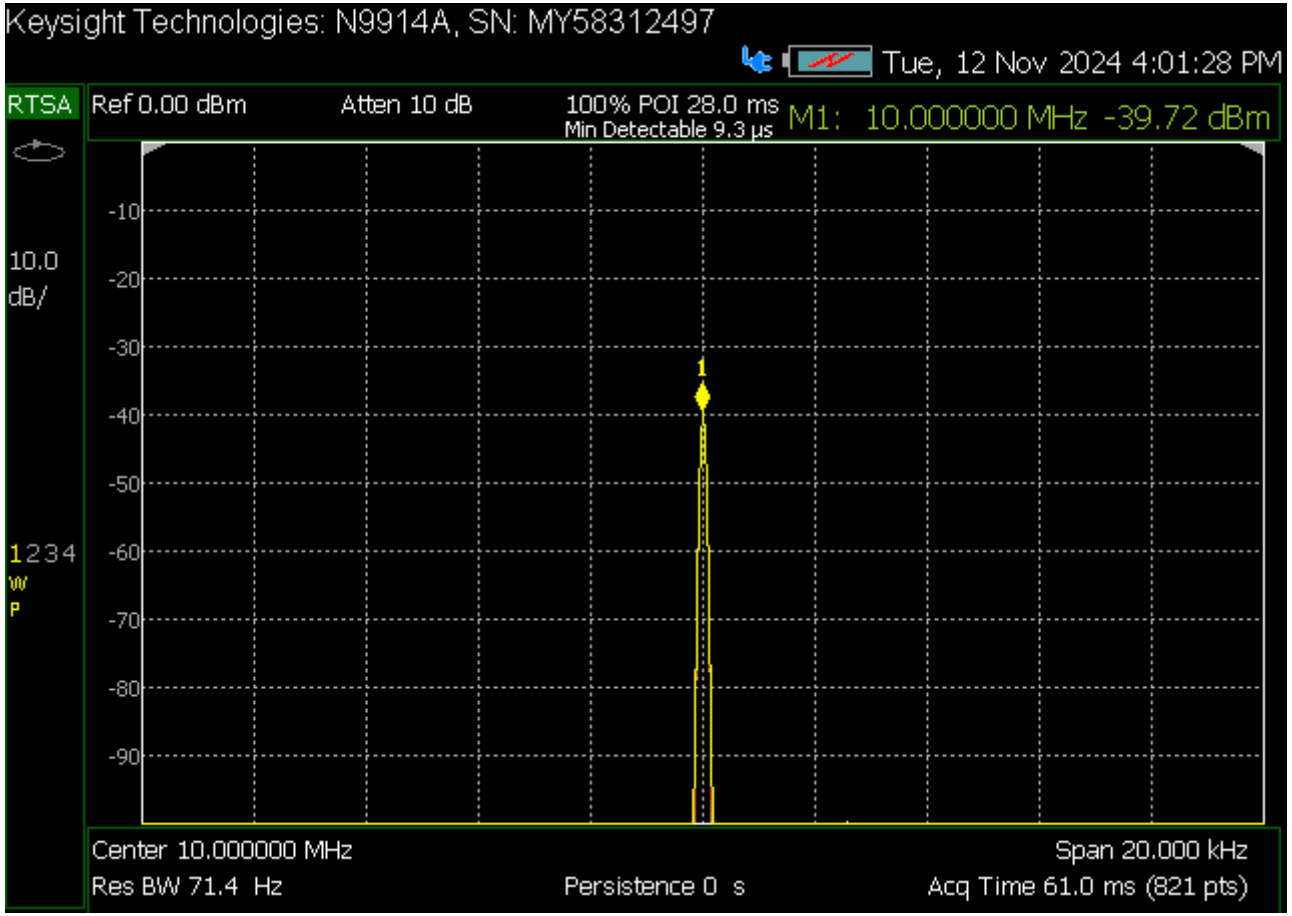


Comparison of Transmission Lines

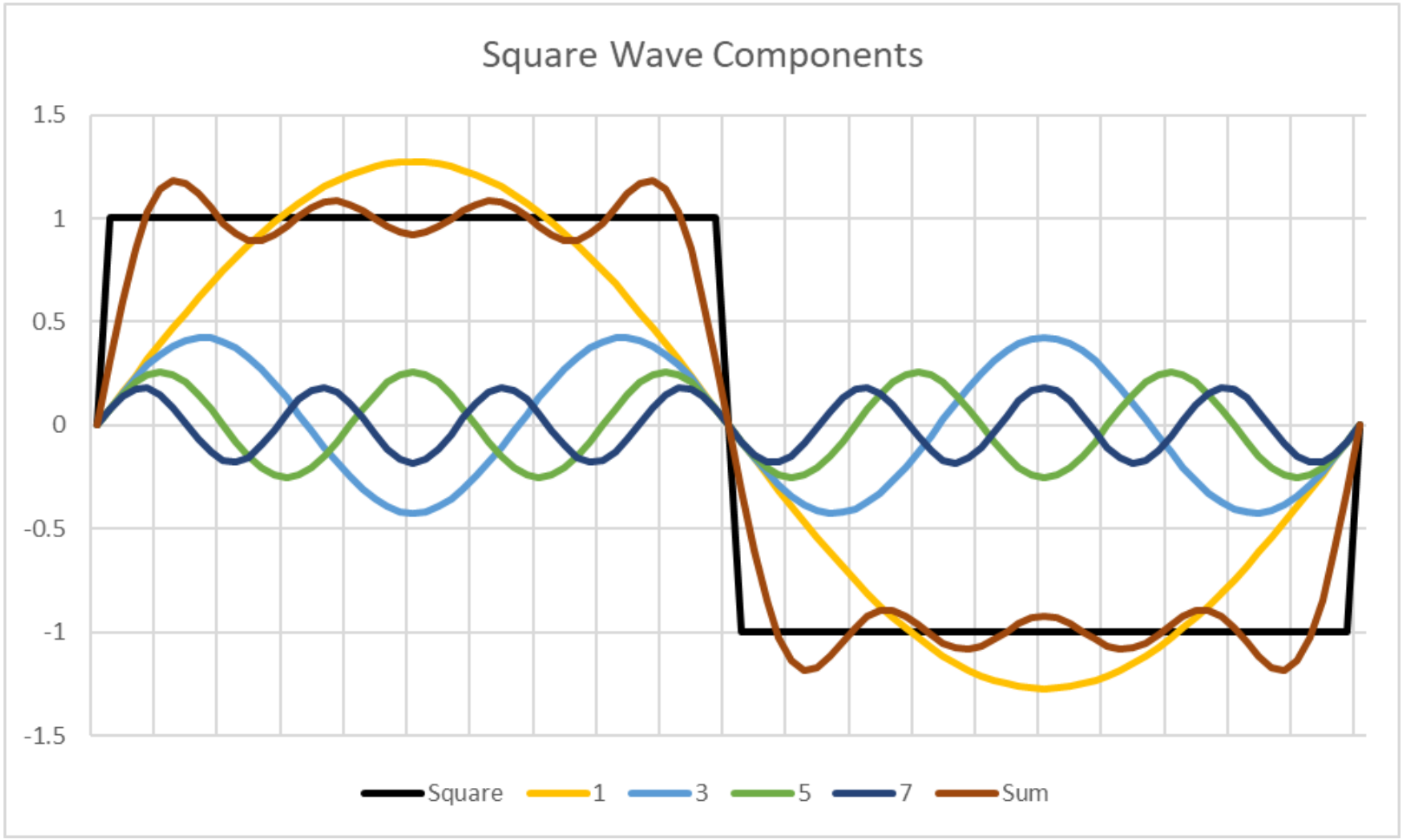
Type	Transition Frequency (kHz)	Field (dBm)
Microstrip	55.4	-56
Coplanar	64.5	-61
Stripline	39.7	-91
Coplanar with Ground	31.1	-65
Coplanar with Double Ground	34.7	-97

Ground on Outer Planes = Most Effective

Microstrip with Broken Return - Radiated Emission



What makes “High Frequency”? (part 2)



A Square Wave contains Sine Waves

What makes “High Frequency”? (part 2)

- The **Rise Time** of a signal has an equivalent frequency:

$$f \approx 0.35 / t_r$$

  - Frequency (repetition rate) tells you how often the problem happens
  - Rise Time tells you how bad the problem is

Edge Rate is the important factor

RECOMMENDATIONS

Good Practices

- Recognize what parts of your circuit contain high frequencies
- Design for the possibility of higher frequencies than originally planned
- Design for Return Path
  - Layout critical signals first
  - The slower signals can go around, and tolerate compromises
- Don’t use high-speed parts unless needed
- Don’t depend on “the way we’ve always done it” to still work in the future

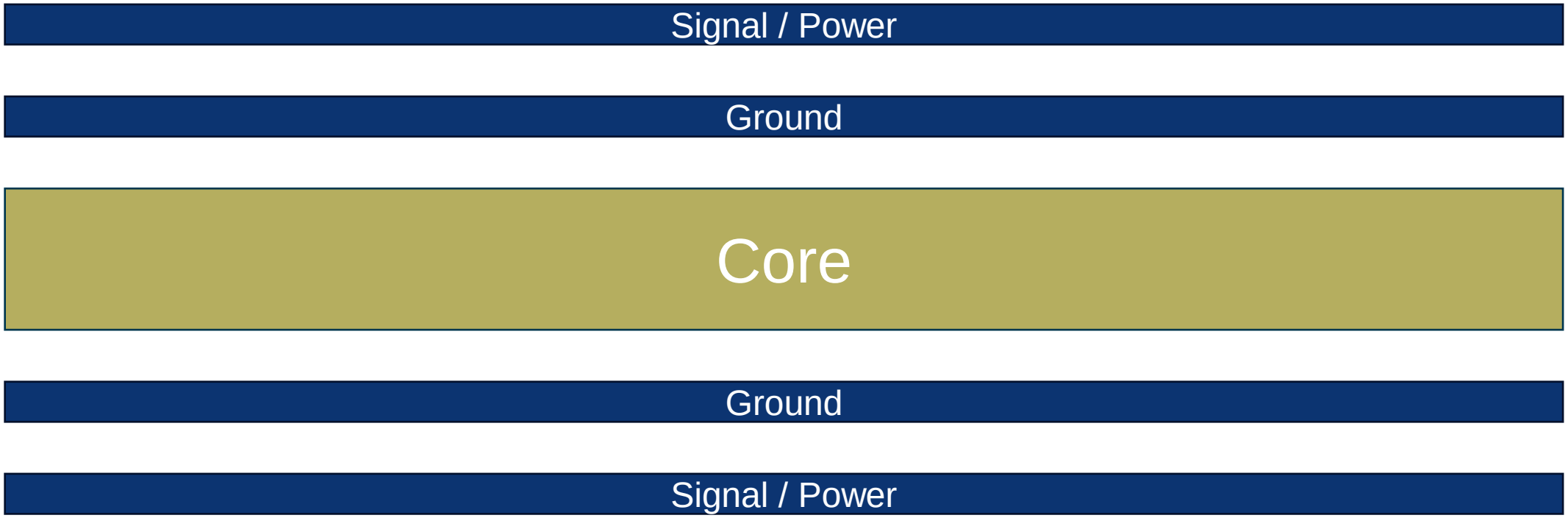
Agency Testing

- For every circuit we make, there will be discussion about FCC testing
- The parts of a circuit that cause a failure will often be a surprise
- Attending a test can be educational (eye-opening!)

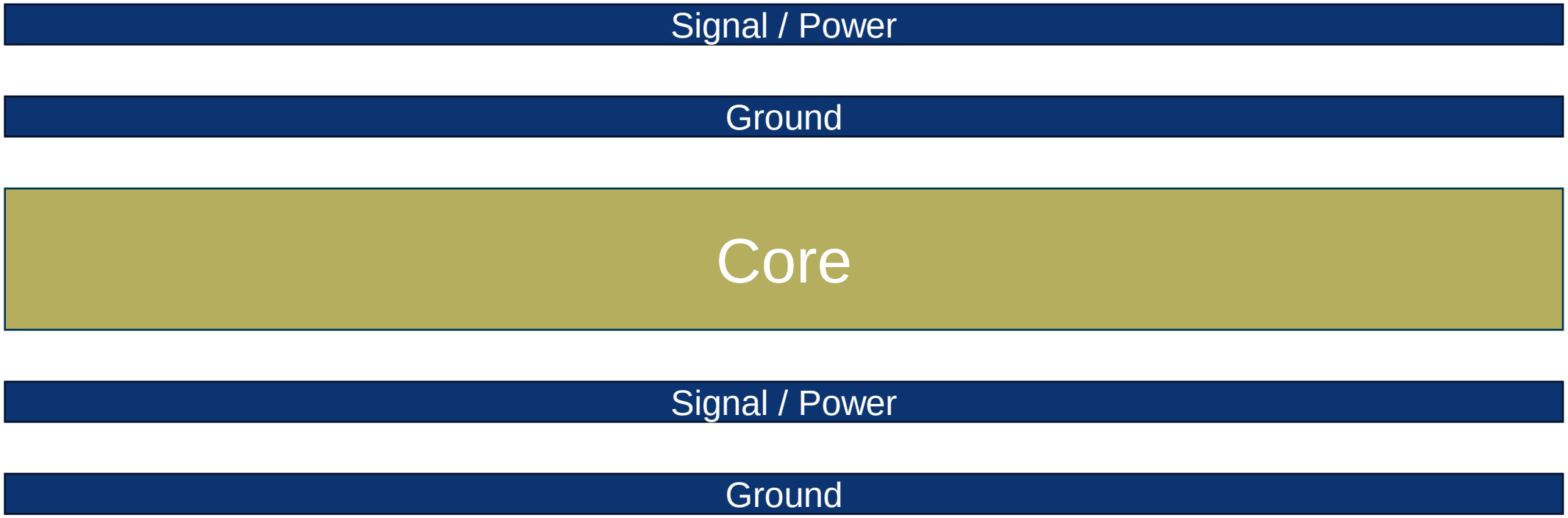
Recommended PCB Stackup – 4 Layers

#	Name	Material	Type	Weight	Thickness	Dk
	Top Overlay		Overlay			
	Top Solder	Solder Resist	Solder Mask		0.4mil	3.5
1	Top		Signal	1oz	1.7mil	
	Dielectric 1	FR-4	Core		14mil	4.8
2	Ground		Signal	1oz	1.4mil	
	Dielectric 3		Prepreg		28mil	4.2
3	Power		Signal	1oz	1.4mil	
	Dielectric 2		Core		14mil	4.2
4	Bottom		Signal	1oz	1.4mil	
	Bottom Solder	Solder Resist	Solder Mask		0.4mil	3.5
	Bottom Overlay		Overlay			

Recommended PCB Stackup – 4 Layers



Recommended PCB Stackup – 4 Layers



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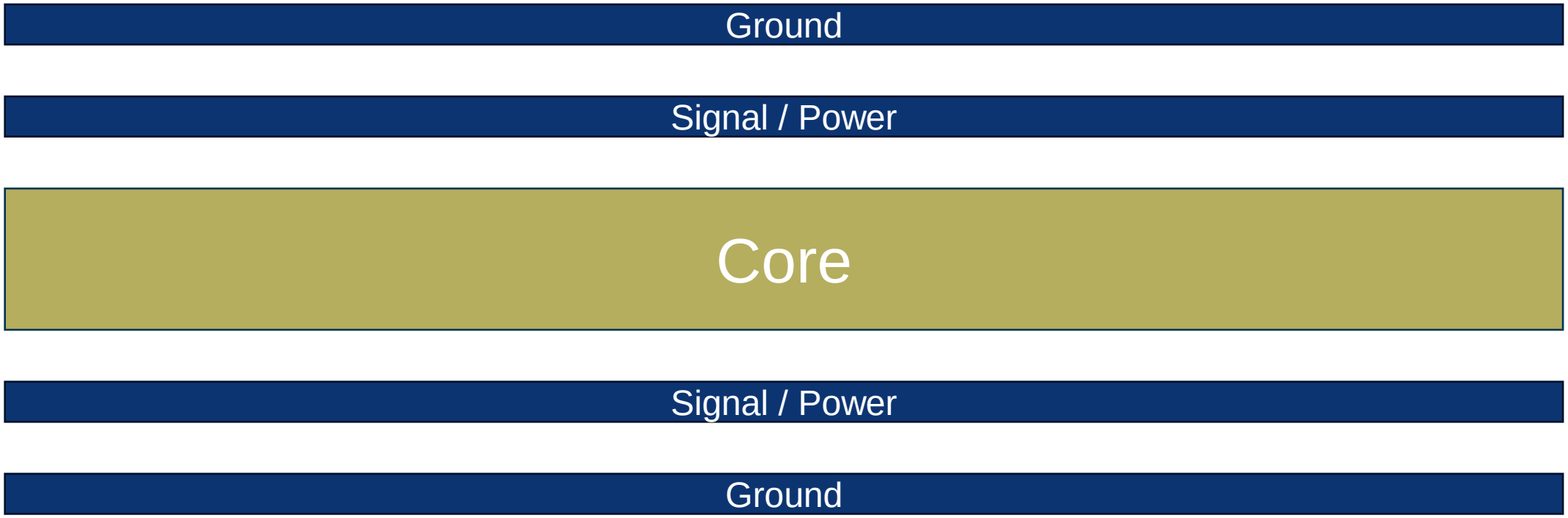
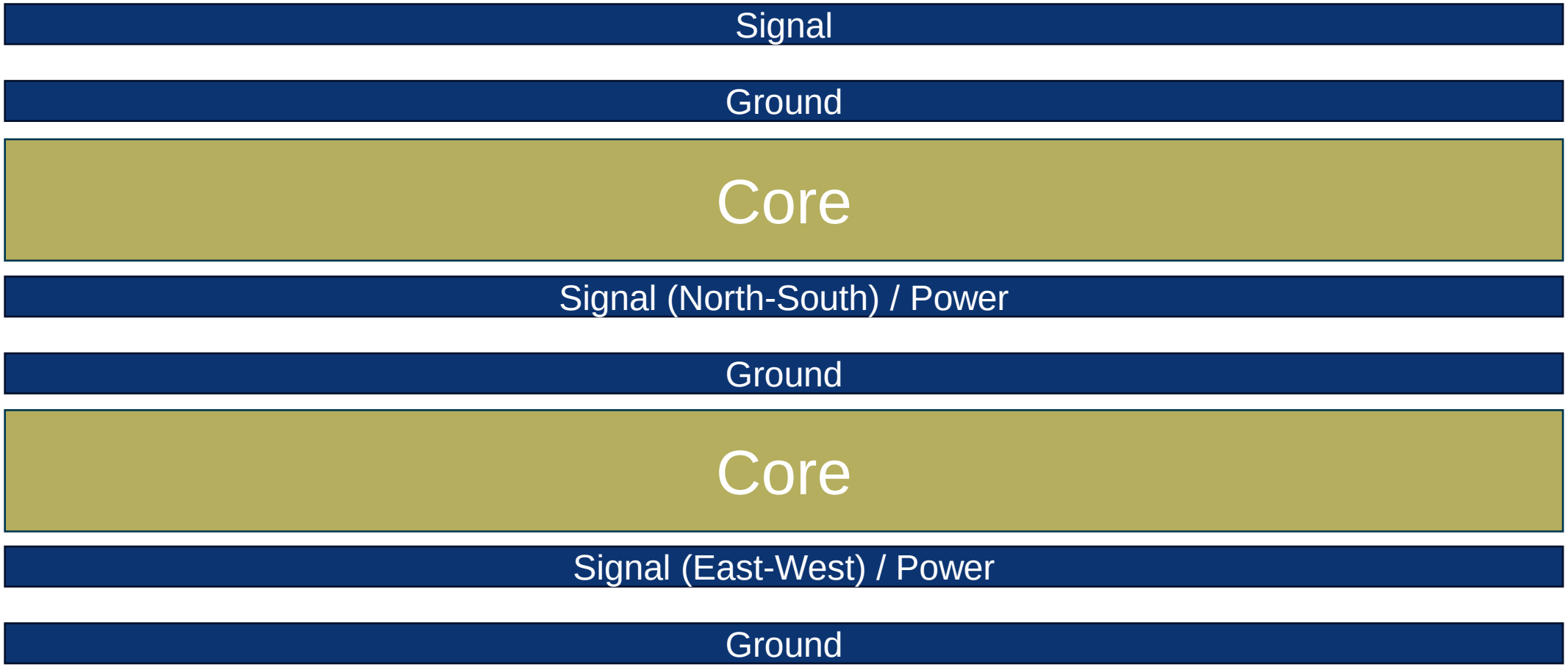


Recommended PCB Stackup – 6 Layers



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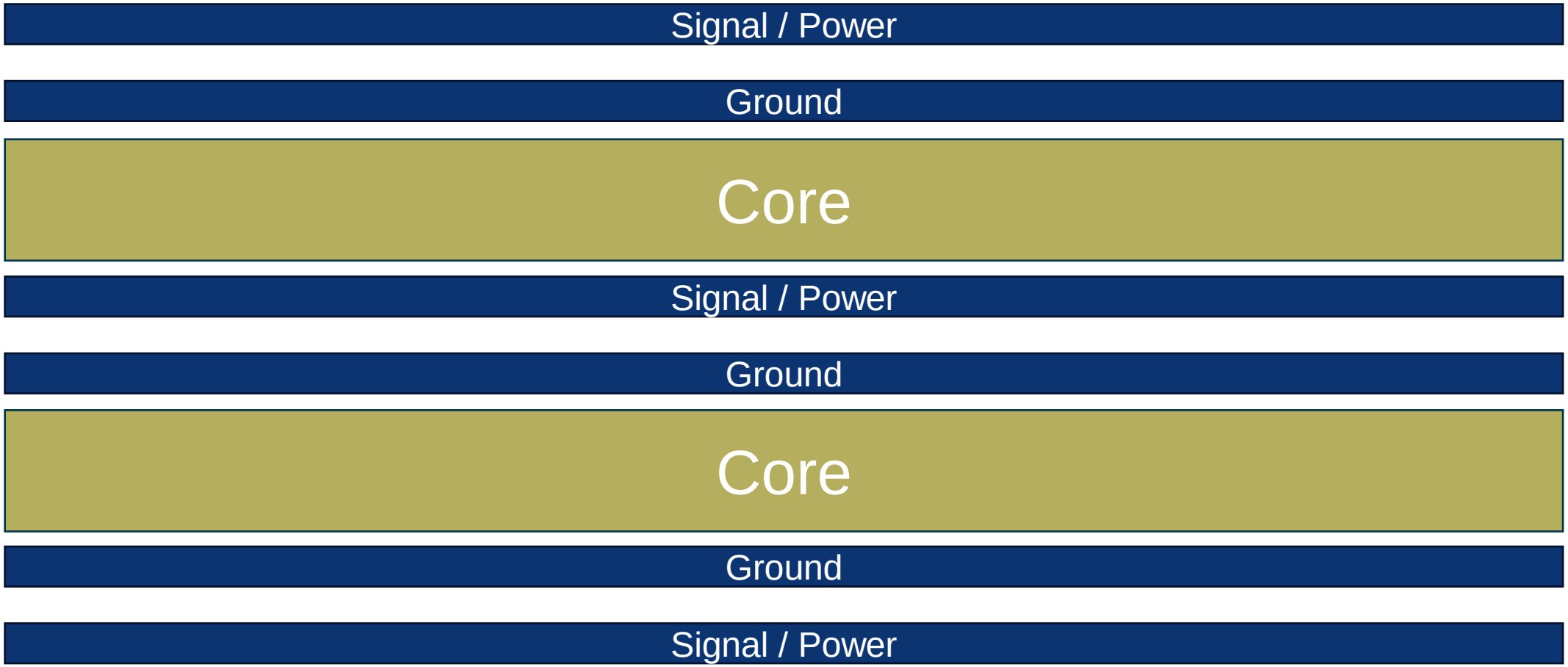
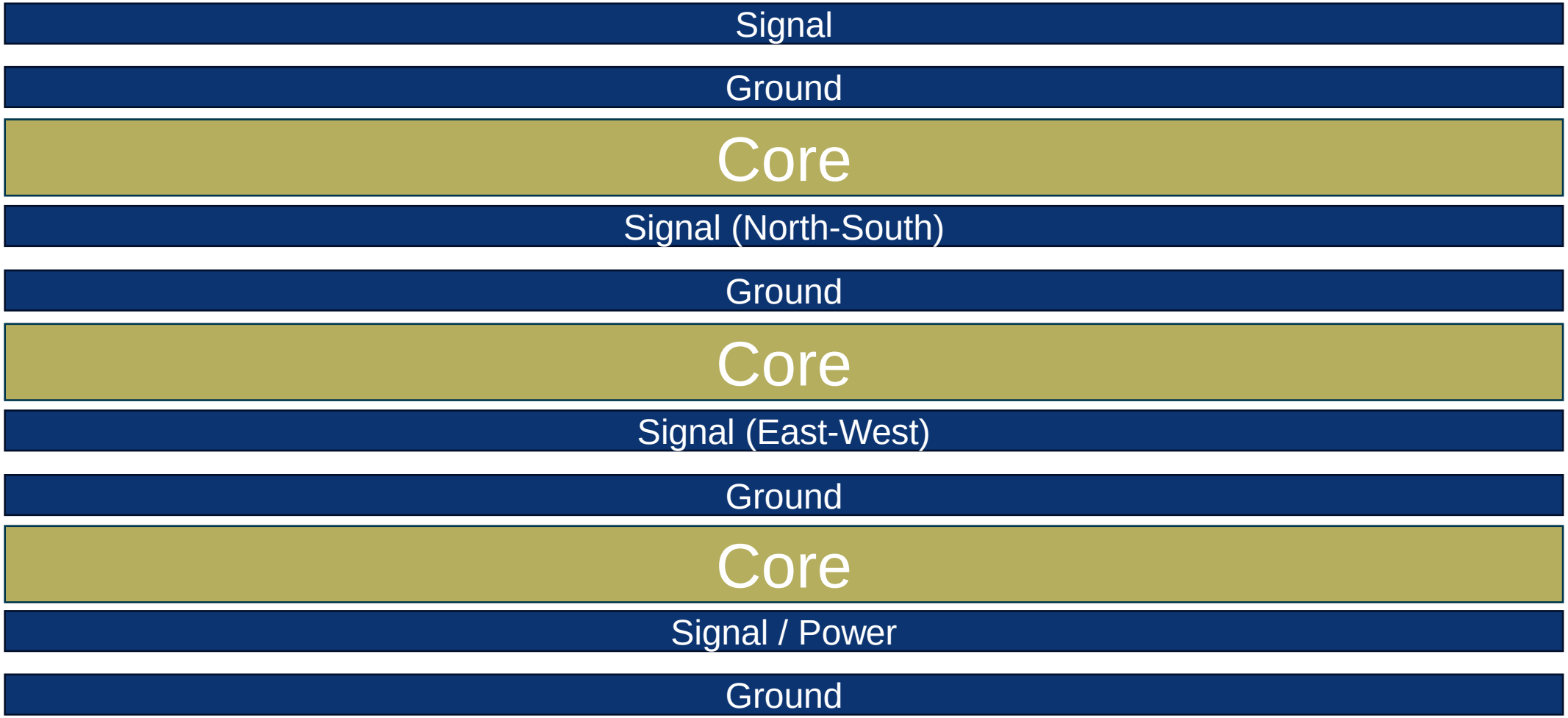


Recommended PCB Stackup – 8 Layers



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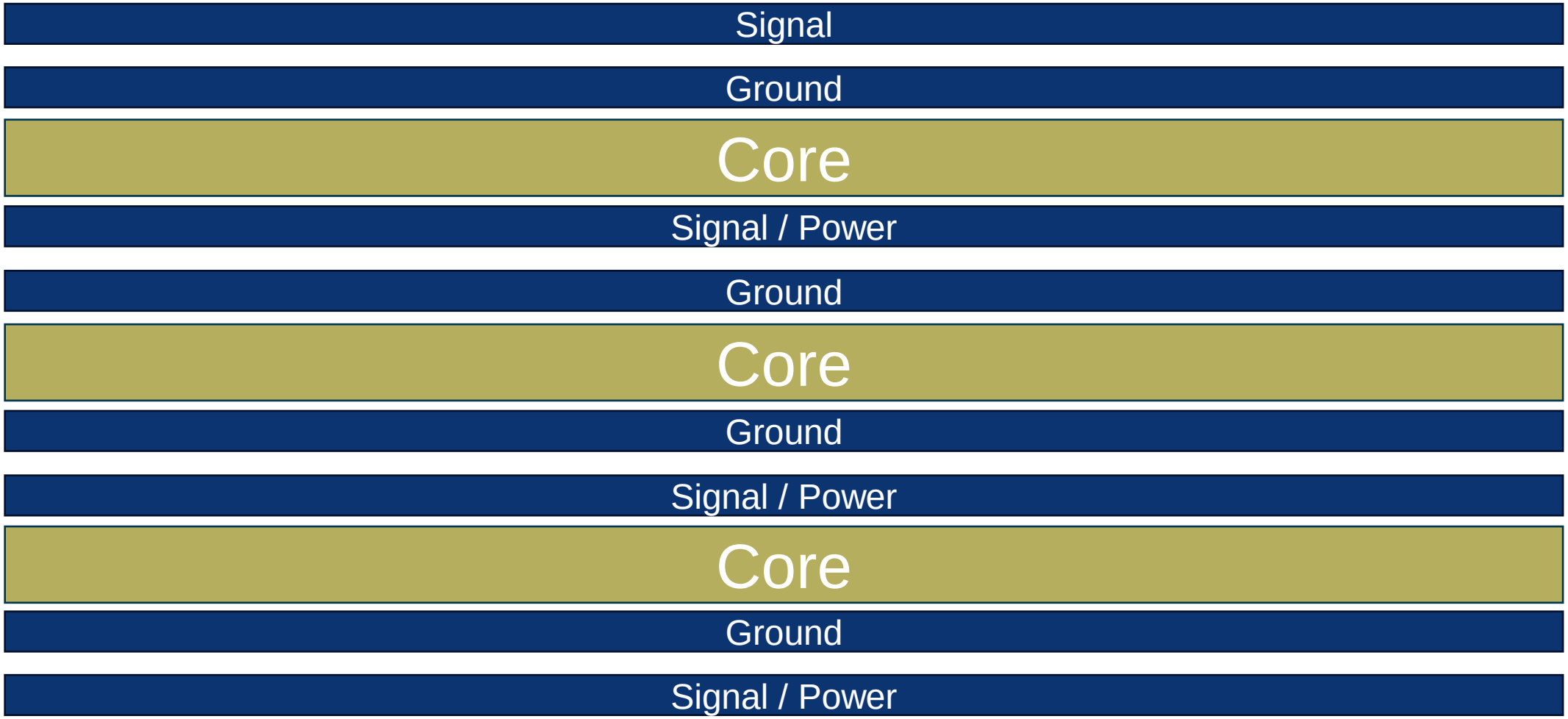
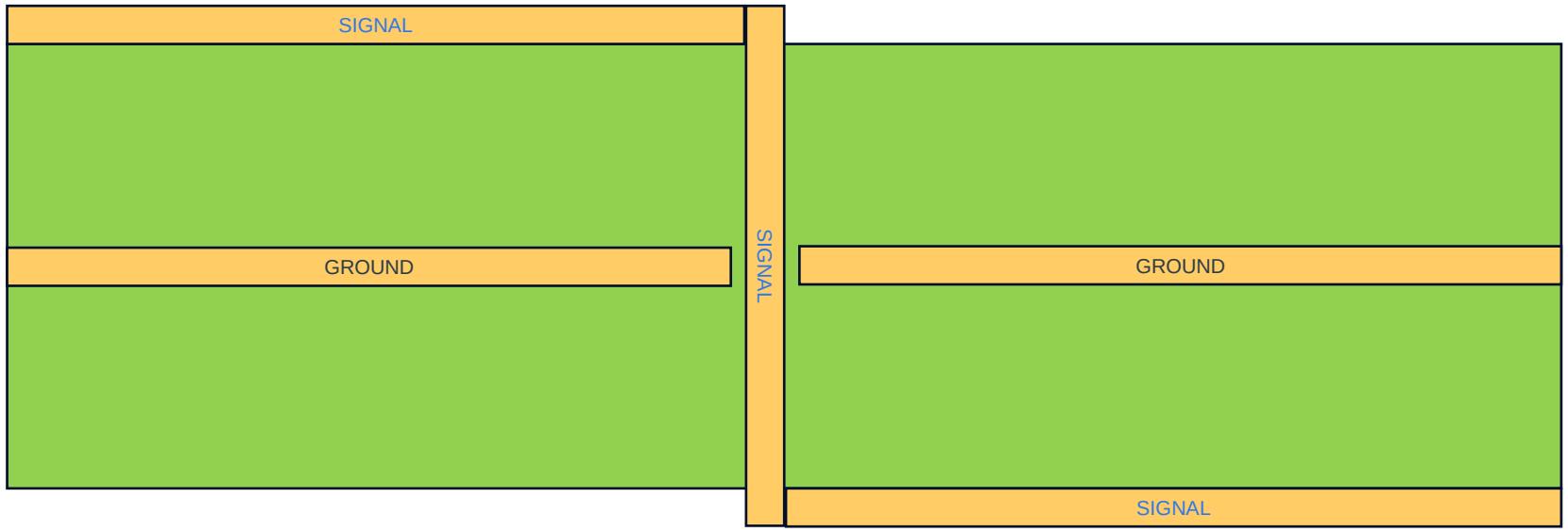


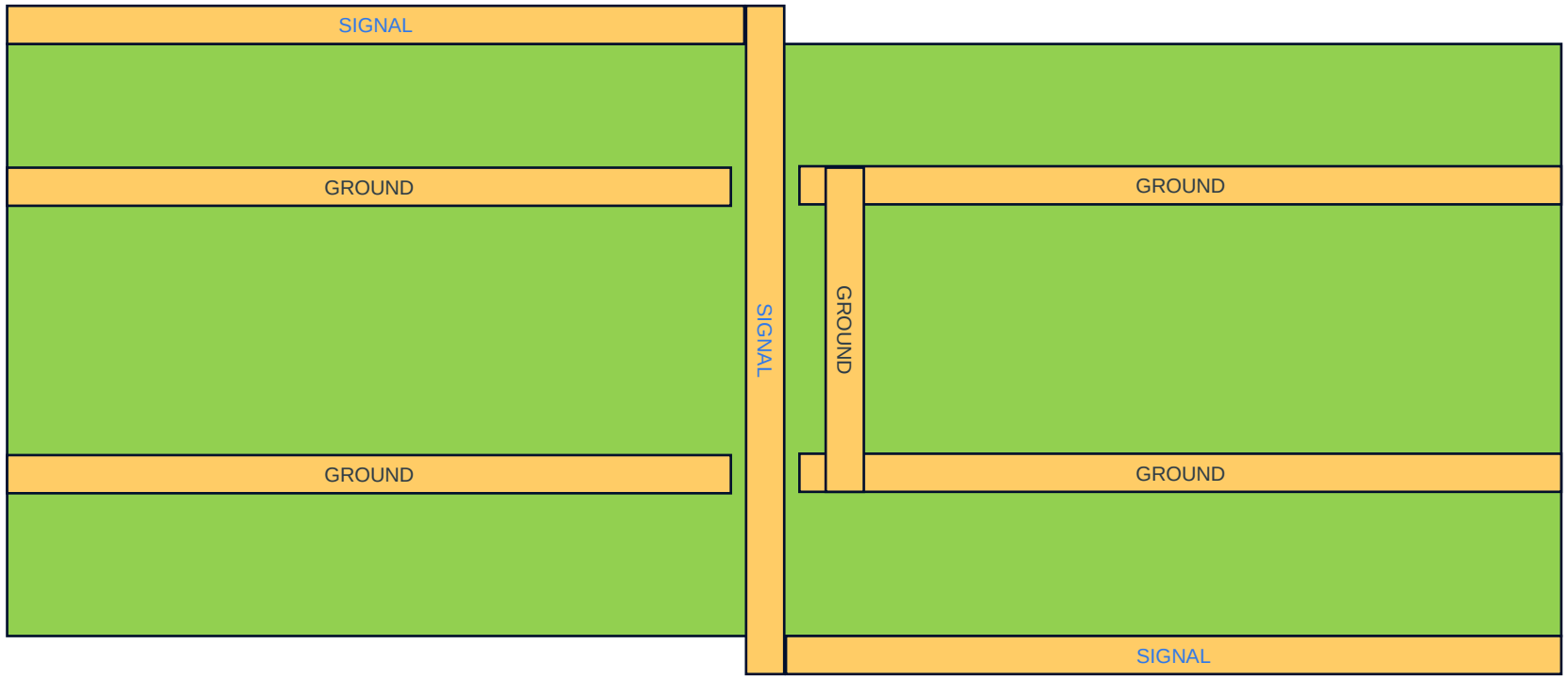
When Signal Trace changes layers

To opposite sides of one reference layer



When Signal Trace changes layers

To separate reference layers



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QUESTIONS AND DISCUSSION

Questions?


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