Reduction Of High-Frequency Signal Loss Through The Control Of Conductor Geometry And Surface Metallization

Don Cullen
MacDermid, Inc.
September 24th, 2002

SMTA International

MacDermid®
Printed Circuit Processing Technologies

Team Members

Gary Brist

PCB Technologist

Intel Corp. Hillsboro, OR

Don Cullen

Director - OEM & Assembly Applications

MacDermid Inc. Waterbury, CT

David Luttrull

Product Director - High Performance Materials

Park Nelco Tempe, AZ

John Martin

Hardware Engineering

Cisco Systems San Jose, CA

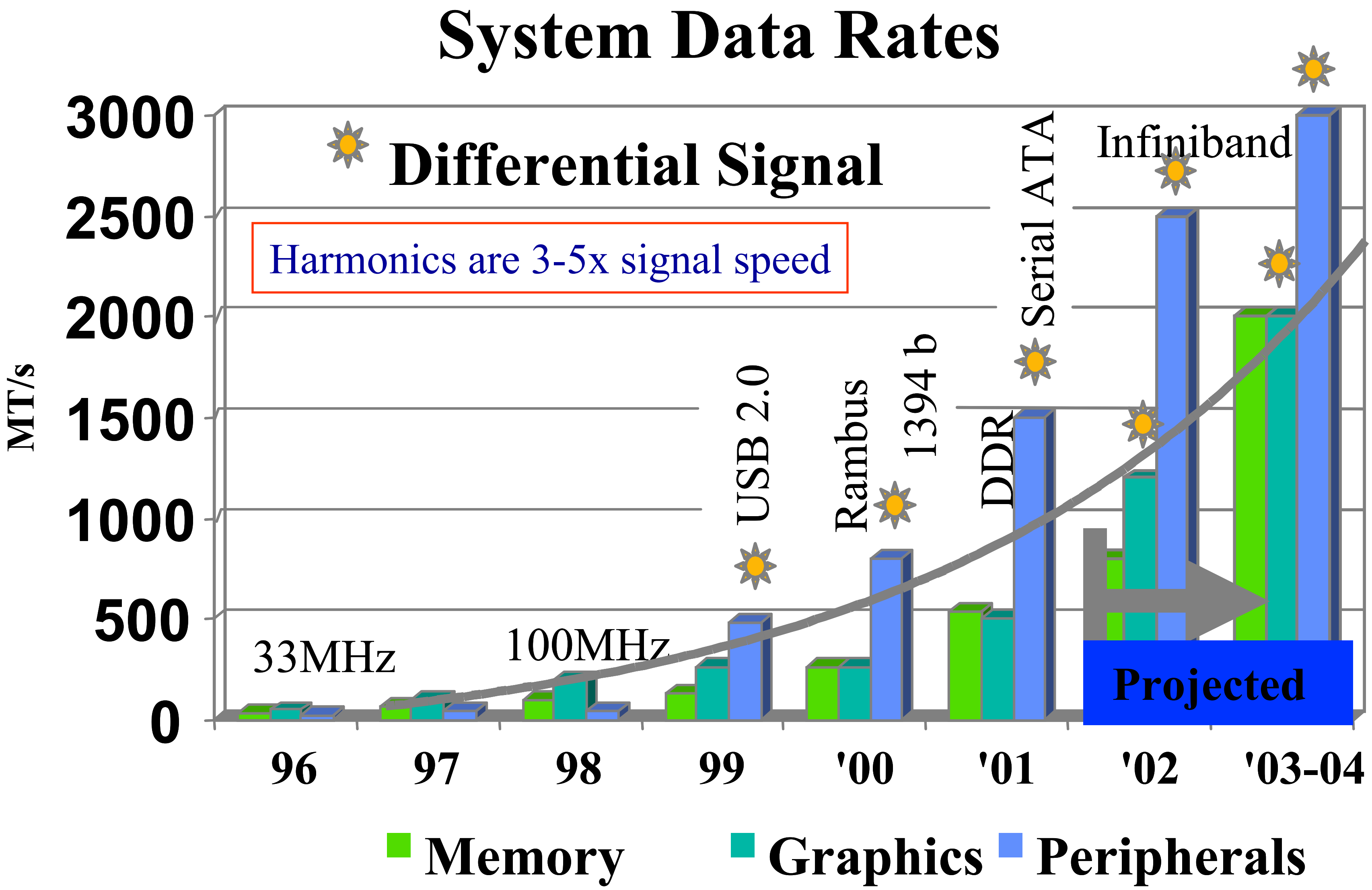
Magic?

..at a Price?

<u>Drivers</u>:

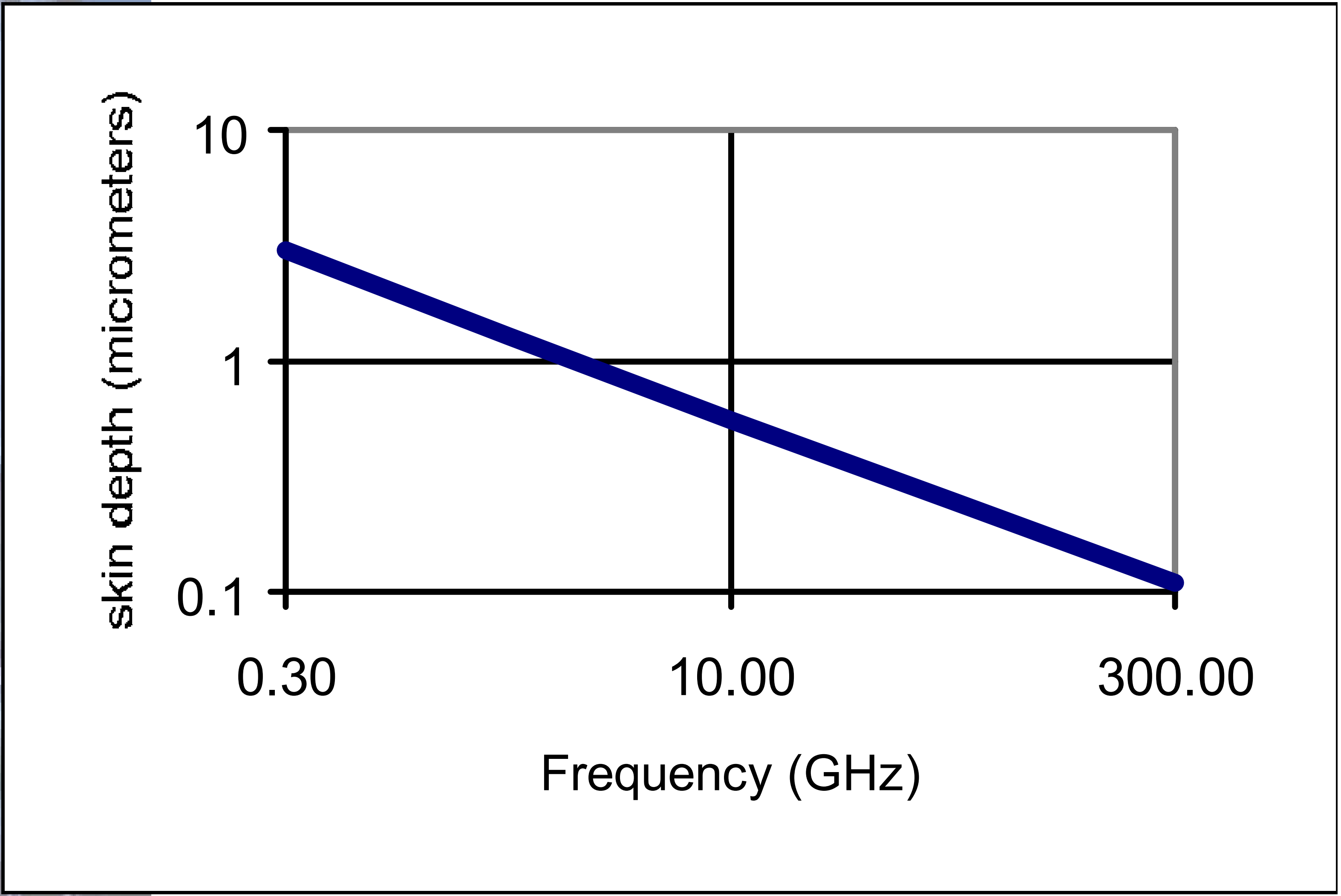
- Density
  - signal loss
- Environment
  - new materials
- Cost
  - old technology

Speed!


System Data Rates
Differential Signal
Harmonics are 3-5x signal speed
MT/s
3000
2500
2000
1500
1000
500
0
33MHz
100MHz
USB 2.0
Rambus
1394 b
DDR
Serial ATA
Infiniband
Projected
96
97
98
99
'00
'01
'02
'03-04
Memory
Graphics
Peripherals

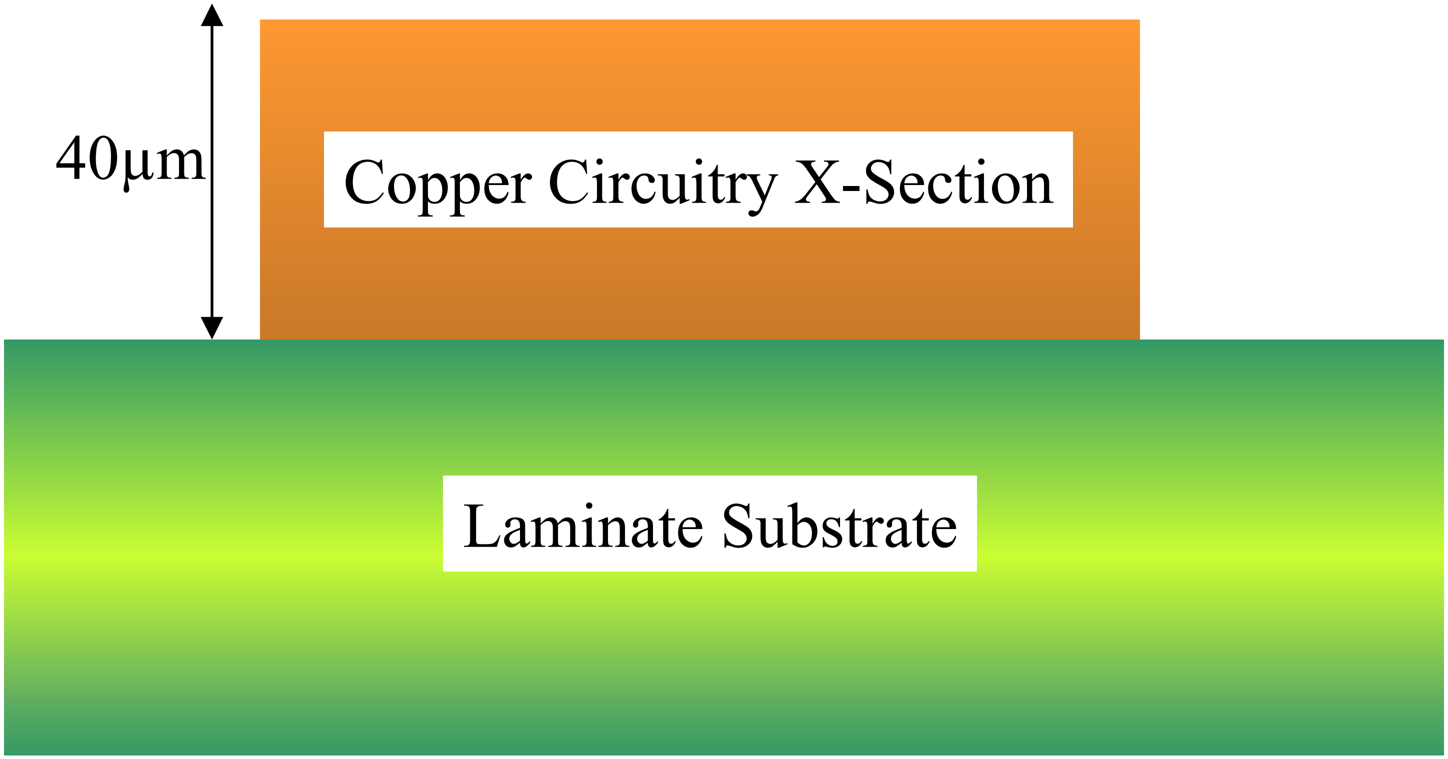
Skin Depth vs. Frequency

A.Scott; Understanding Microwaves



"...distance in the conductor at which the electric field has decreased to 30% of the value at the surface."

Skin Depth Schematic

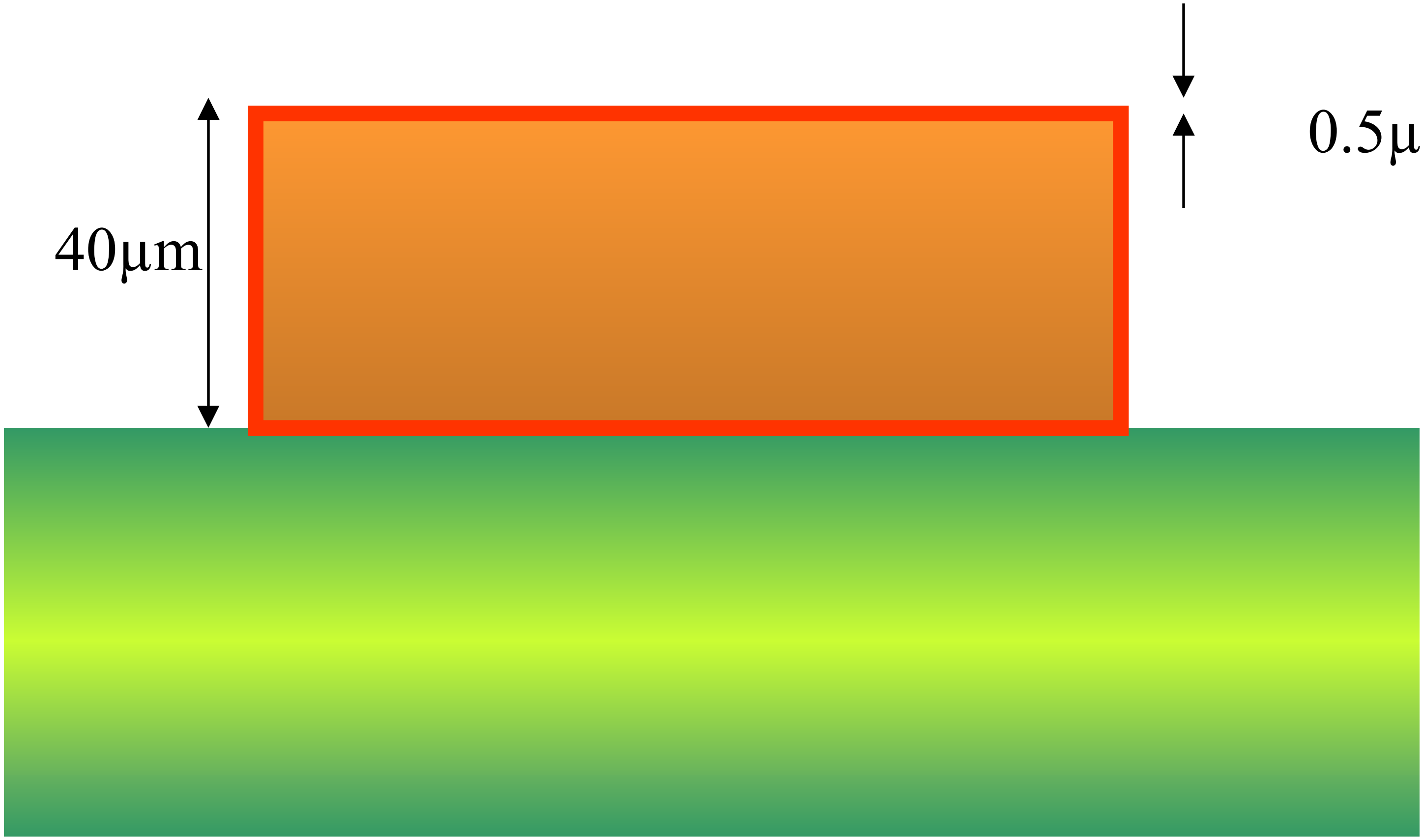


40µm

Copper Circuitry X-Section

Laminate Substrate

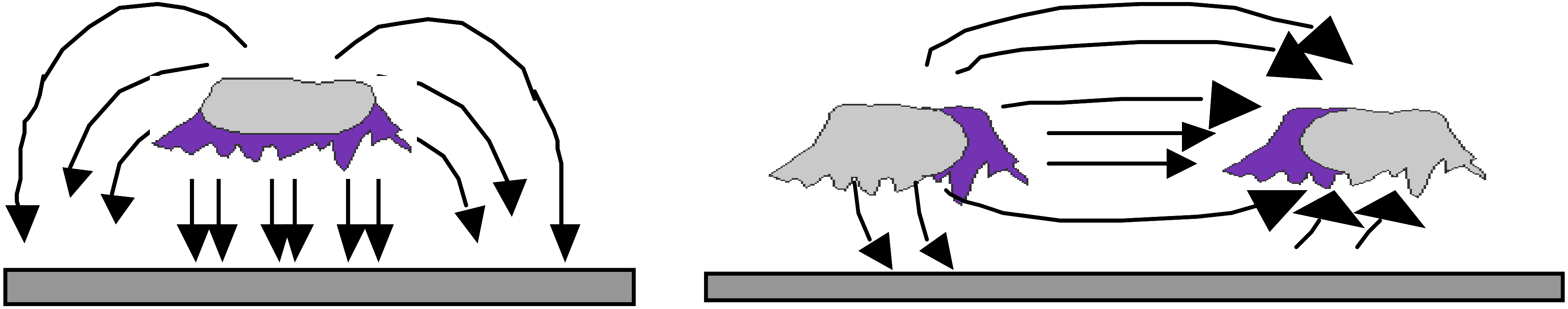
Skin Depth Schematic



Ideal Shape is not Realistic

Skin Depth Schematic

Current Density by Design

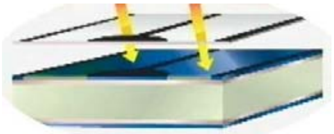


- Single Ended (SE) uStrip vs. Differential uStrip structures
  - Current densities and electric fields more concentrated in trace edges coated with surface finish
  - More sensitive to trace geometries

PCB Process Sequence


Clean Substrate


Innerlayer Resist


Expose/ Develop


Etch


Resist Strip


Innerlayer Oxide


Lamination


Drill


Desmear


Plate Thru Holes


Plating Resist


Electrolytic Copper


Tin Etch Resist

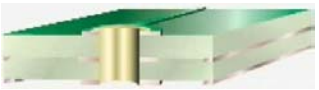

Strip Resist

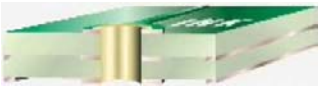

Outerlayer Etch


Tin Strip

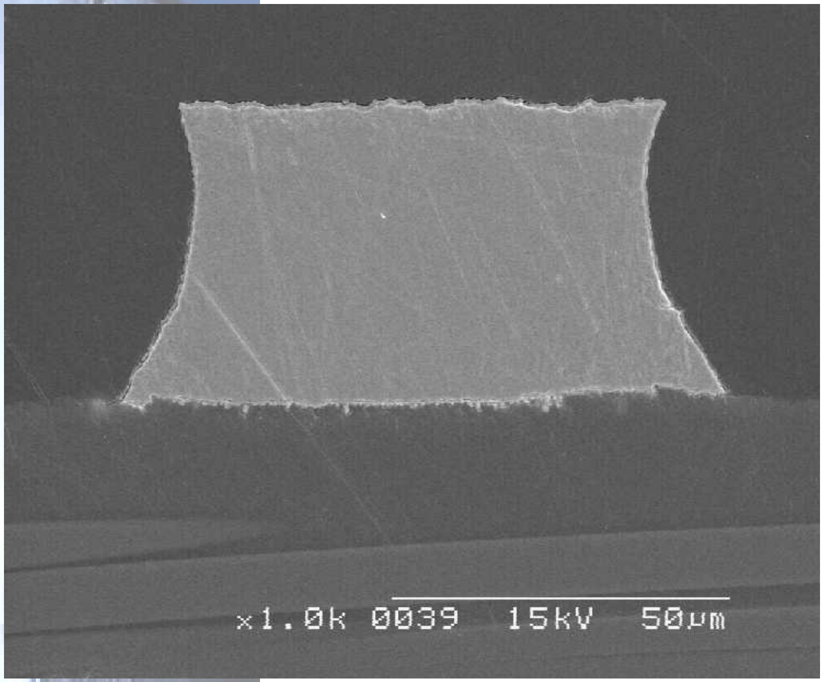

Soldermask

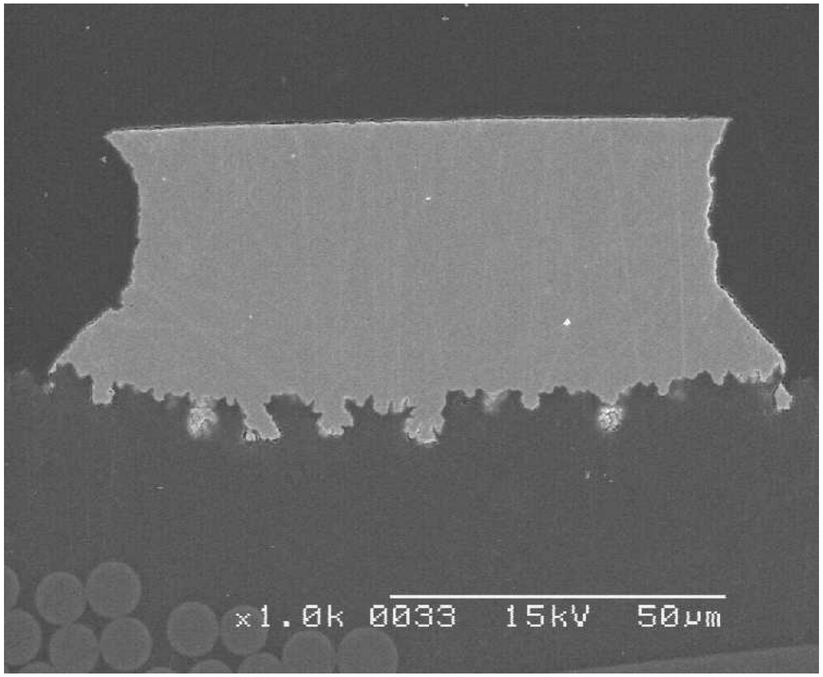

Expose/ Develop/ Bake

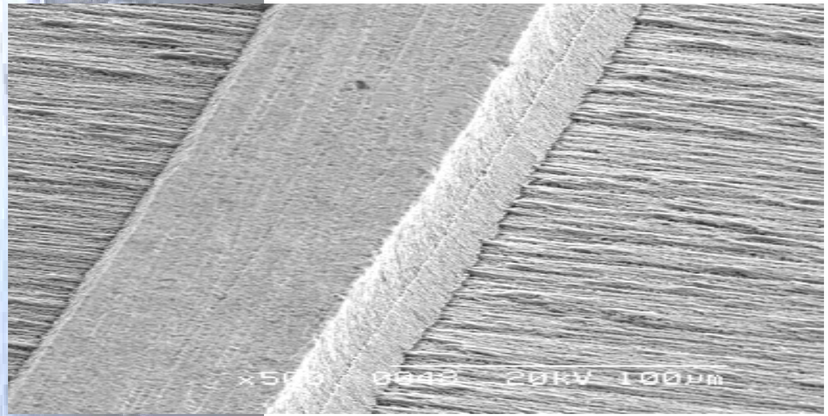

FINAL FINISH

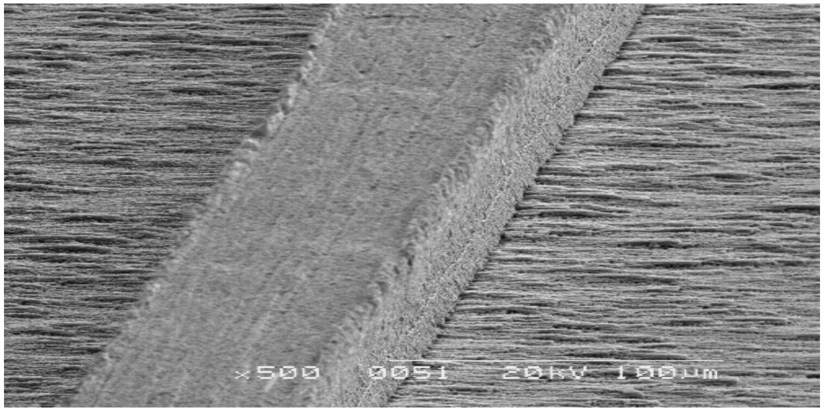

Legend Ink

Conductor Shape



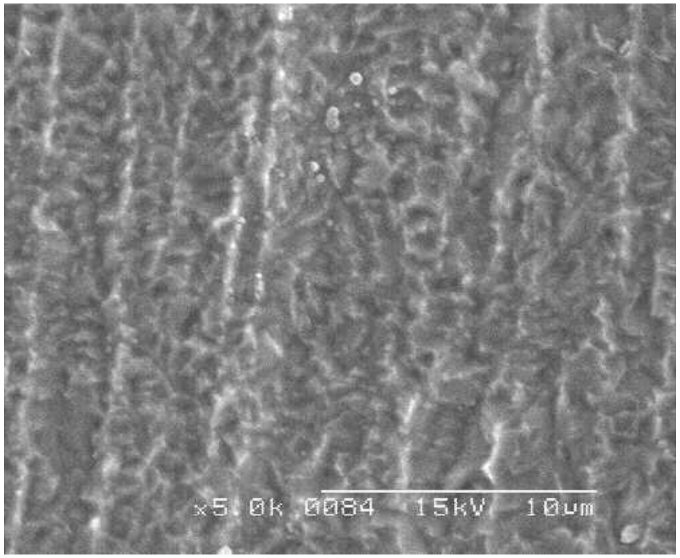




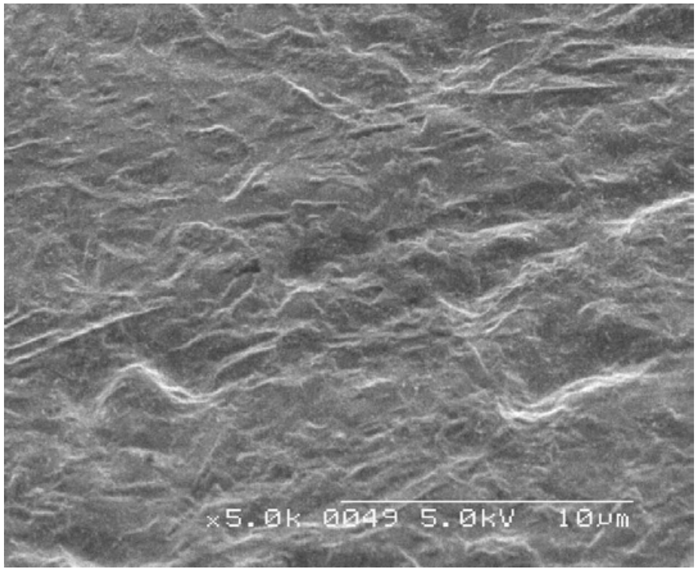


Surface Finish

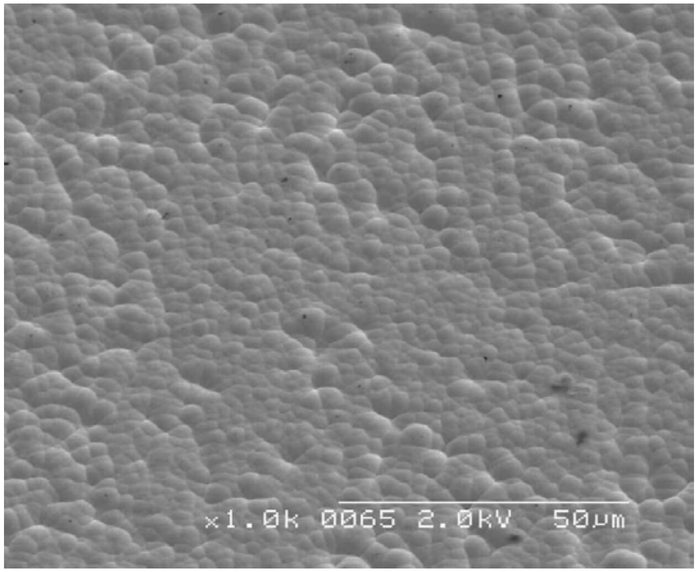
OSP



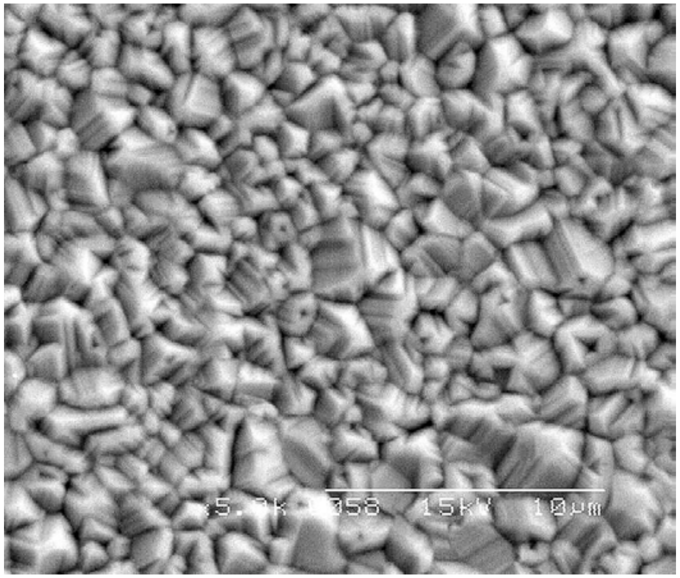
Ag



ENIG

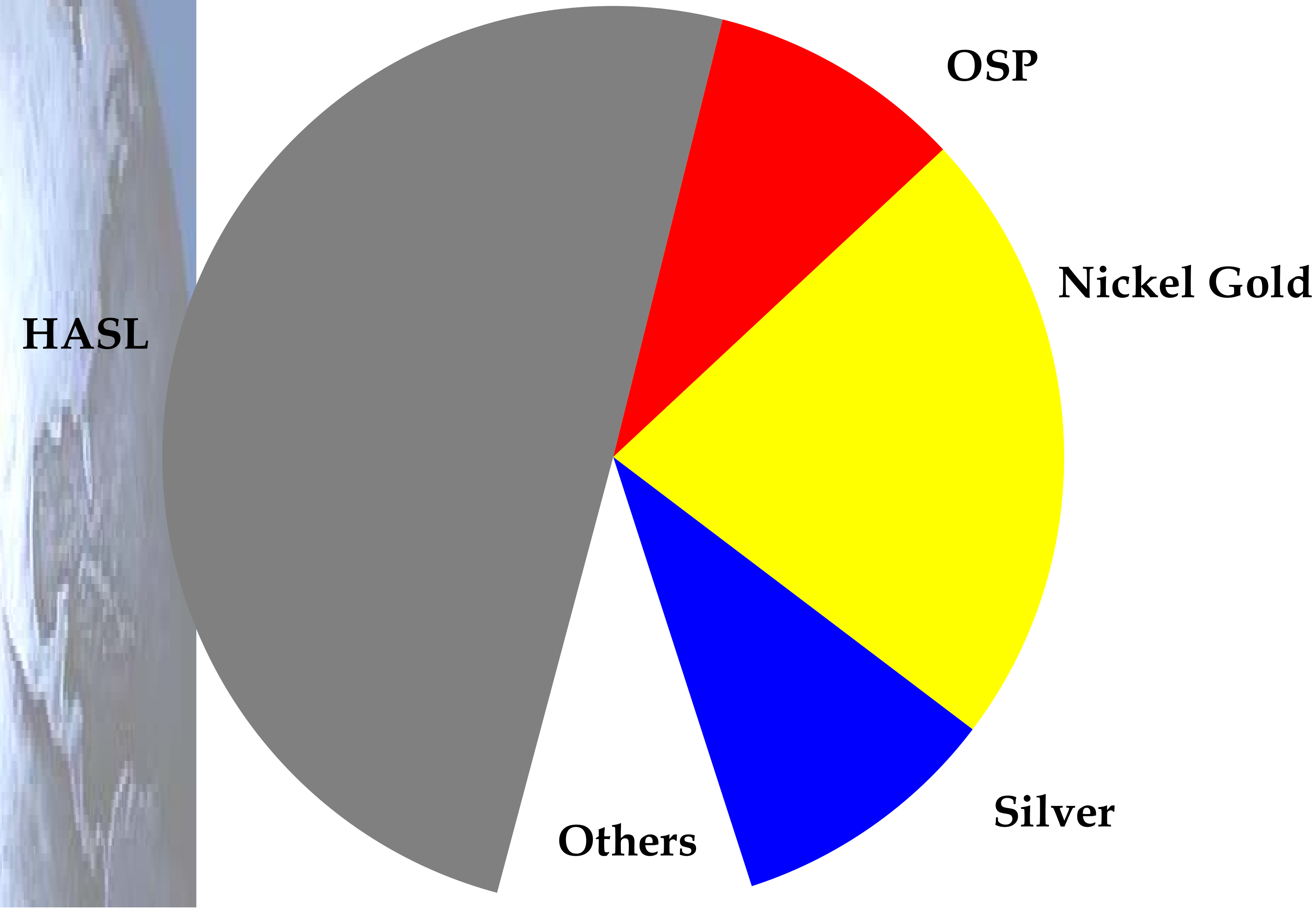


Sn



WW Use of Surface Finish

IPC Technology Marketing Research Council 2002



Metal Conductivity

Silver	1.6 μΩcm
Copper	1.7 μΩcm
Gold	2.4 μΩcm
Nickel	7.4 μΩcm
Tin	10.9 μΩcm
Sn60Pb40 solder	17.0 μΩcm
E-Less Ni P	55-90 μΩcm

Substrate Properties

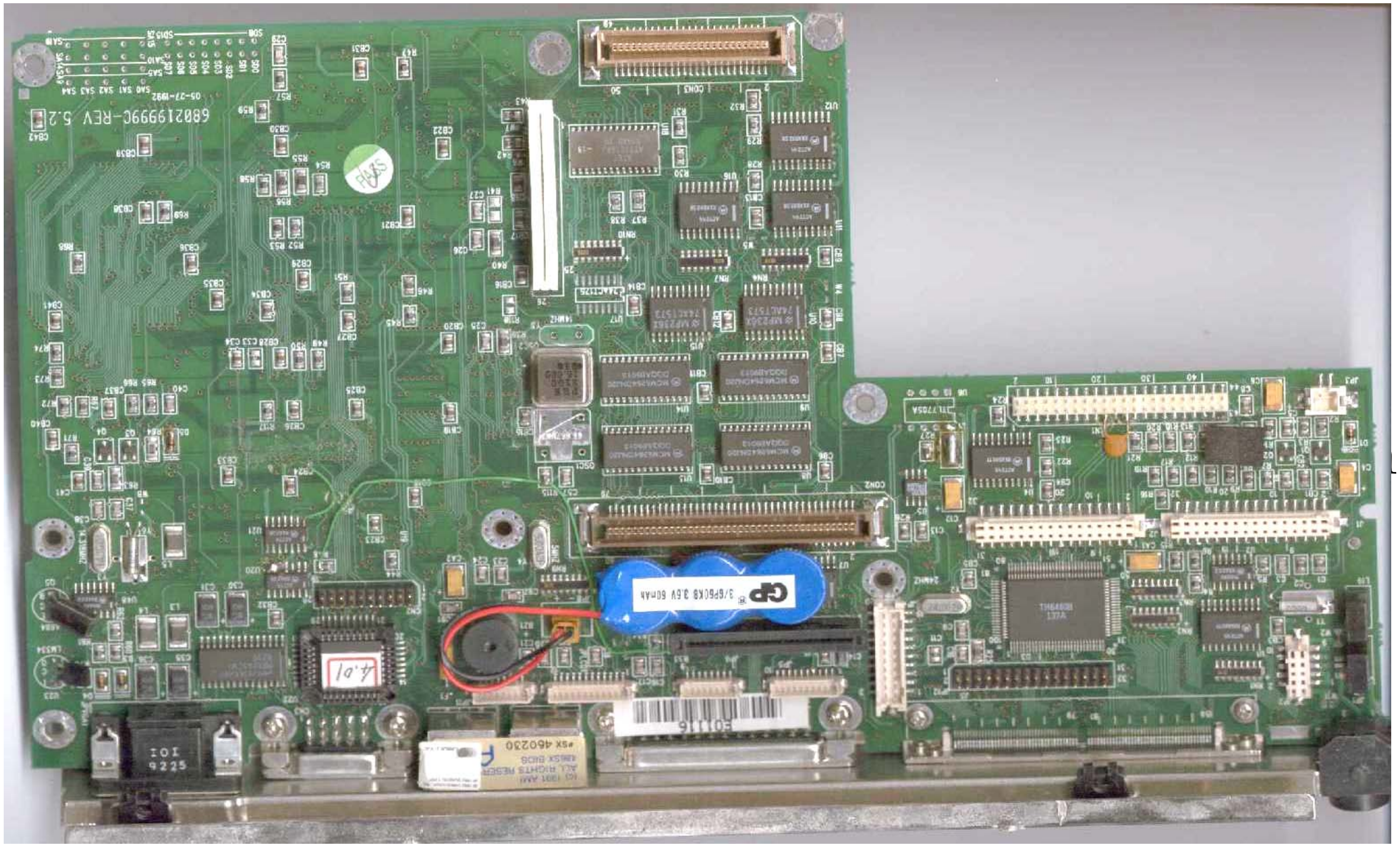
	FR-4	Modified FR-4	APPE
Property	**N-4000-6 FC**	**N-4000-13**	**N-6000-21**
Permittivity *	4.0+/-0.1	3.6+/-0.1	3.5+/- 0.1
Permittivity**	4.3+/-0.1	4.0+/-0.1	3.9+/- 0.1
Dissipation Factor *	0.025	0.013	0.004
Dissipation Factor **	0.0140	0.0088	0.0085
Moisture Absorption	0.20%	0.10%	0.05%
Peel Strength lbs/inch	> 10.0	> 9.0	> 9.0
Flammability	94V-0	94V-0	94V-0

* by Stripline (IPC-TM-650) at 1.5 - 2.0 GHz.
** by Split-Post Cavity Resonator (NIST) at 3.3 GHz.

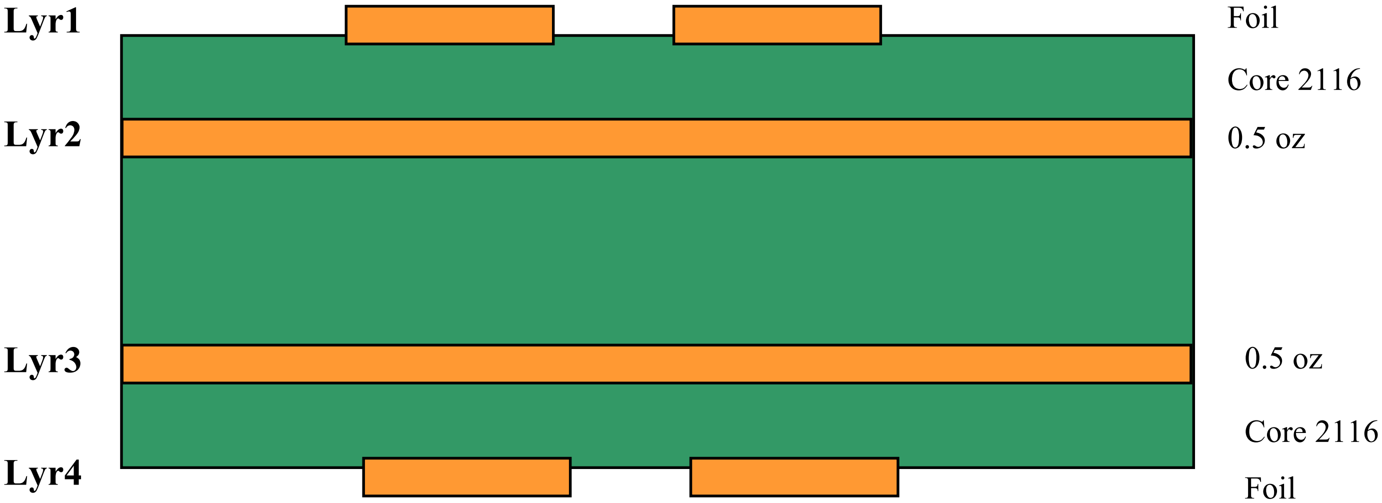
Experiment Matrix

- Substrate Material
    - N4000-6
    - N4000-13
    - N6000-21
- Foil Type
    - standard (ED)
    - reverse treat (RTF)
- Film Thickness and Etching
- Surface Finish
    - Organic Solderability Preservative
    - Electroless Nickel Immersion Gold
    - Immersion Silver
    - Immersion Tin
- Frequency

Experiment Goals



Test Vehicle



Lyr1 Foil

Core 2116

Lyr2 0.5 oz

Lyr3 0.5 oz

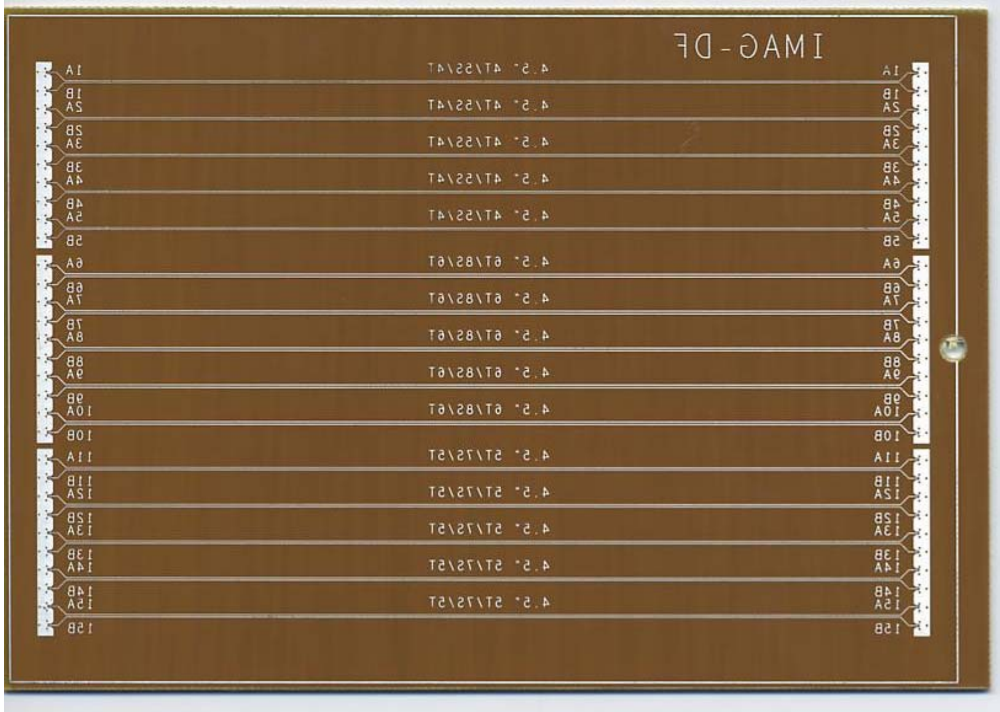
Core 2116

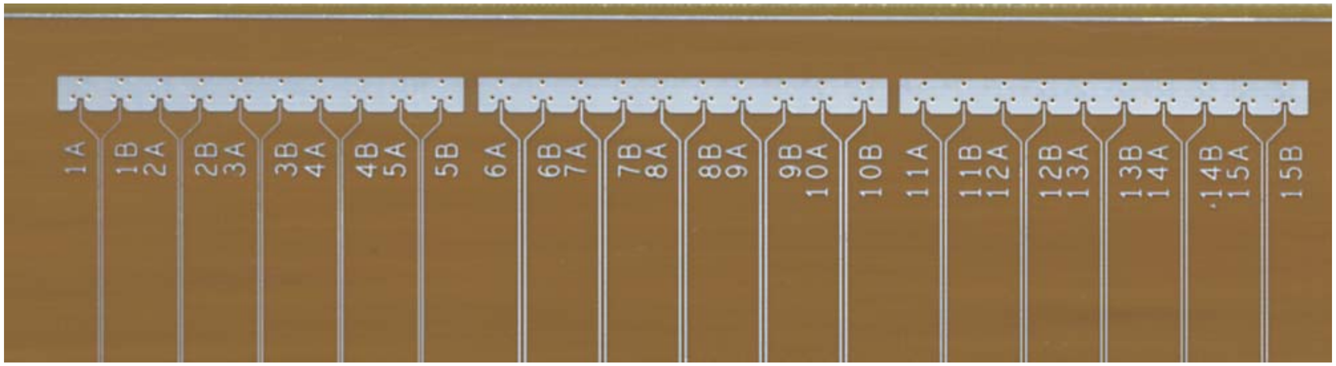
Lyr4 Foil

Total thickness 44-62mils

Conventional Core Lamination: thickness control, resin content control

Transmission Line Design

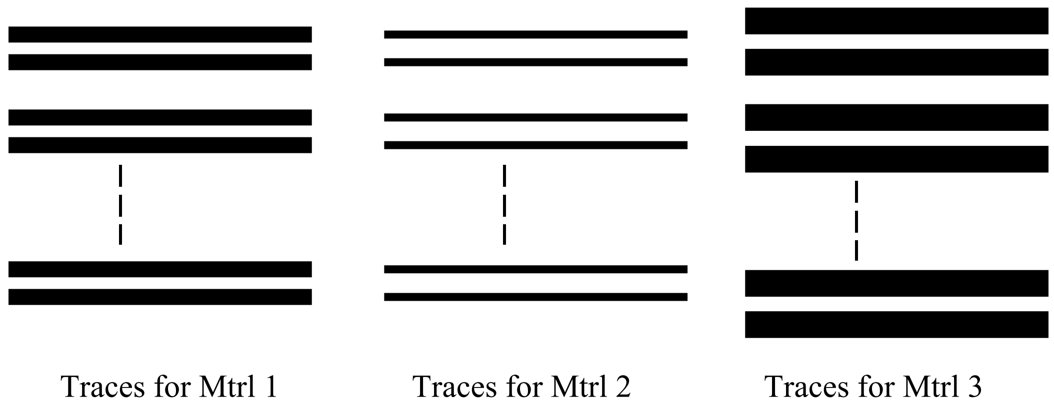




Coupon Design

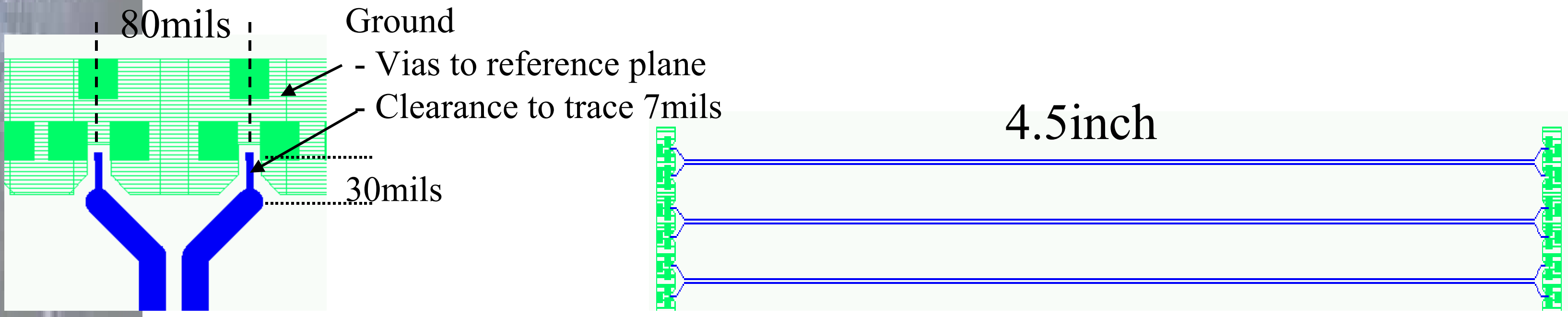
- 3 different line width/space combinations
  - Selected so that 1 line width targets ~100ohm differential on a specific material
  - Allows comparison between similar line width vs similar Zo (characteristic impedance) target

- Repeat 3 width/space combinations 5 times within coupon
  - Correct for measurement variations
  - Encompass spatial variations due to glass weave issues.



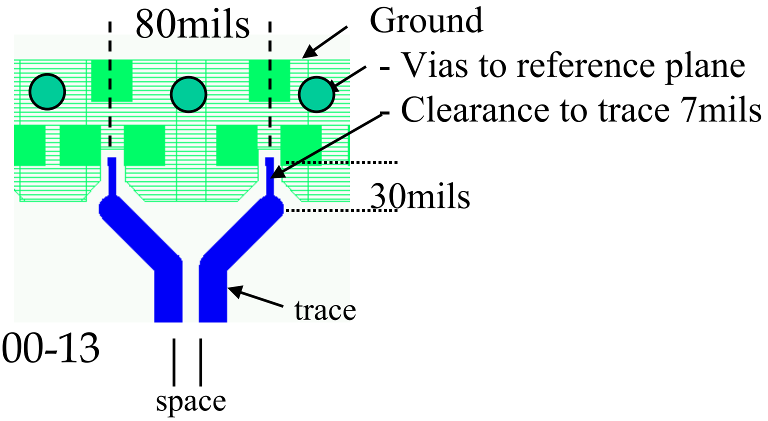
Coupon Design / Measurement

- Desire to not terminate in a connector
  - Utilize Cascade micro probe
    - Good through 18+GHz
    - Better for direct measurement for RLGC extractions
- Measurements to be taken coplanar
  - Sets up E-field as differential
  - Does not require 4port VNA

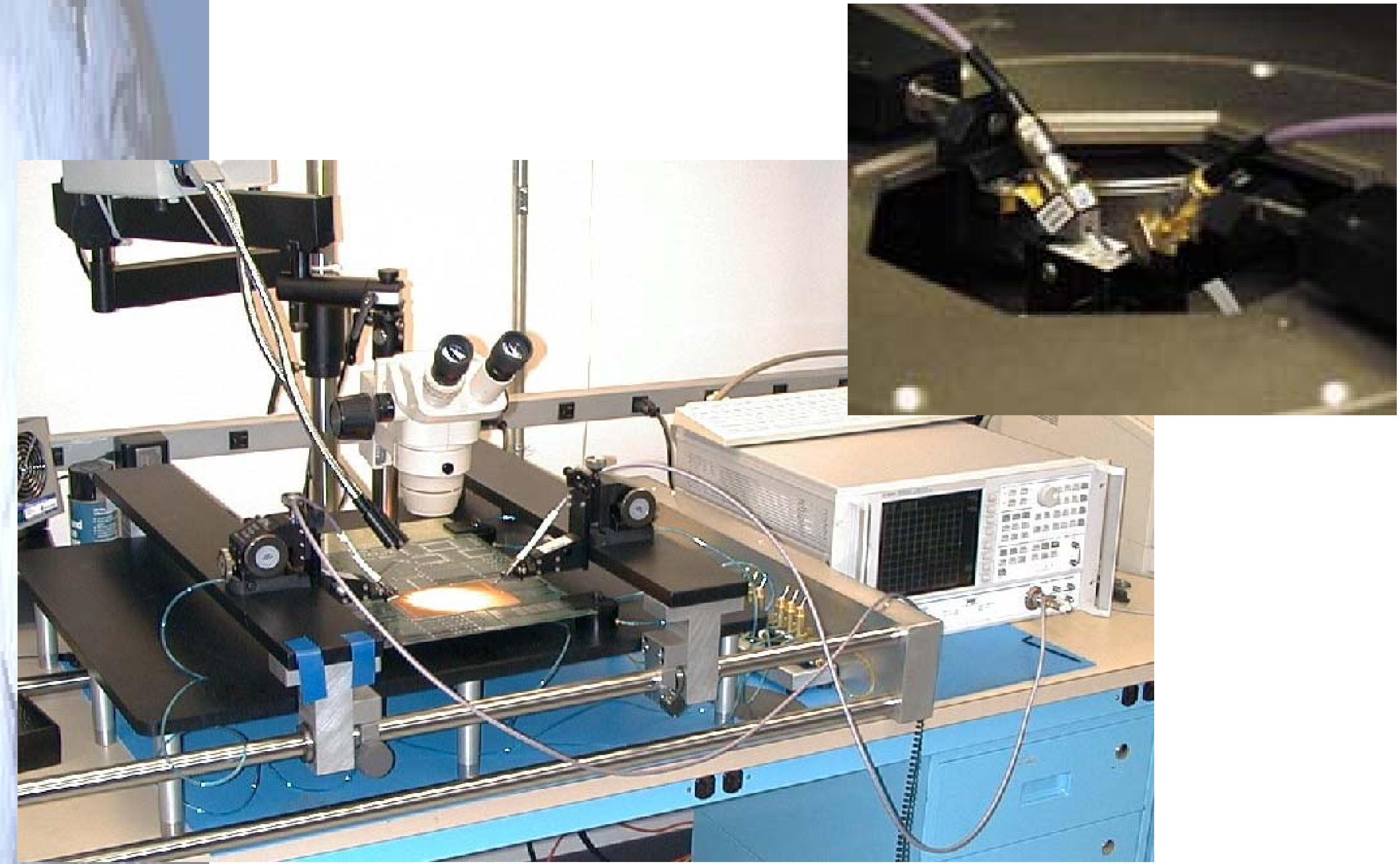


Coupon Design / Measurement

- Coupon Geometries
  - Dielectric Spacing (2116 core) ~4.2mils
  - Trace Pair A
    - Target 100ohm on N4000-6/N4000-13
    - 4mil trace/5mil space
  - Trace Pair B
    - Target 100ohm on N6000-21
    - 6mil trace/8mil space
  - Trace Pair C
    - Target 85ohm on N4000-6/N4000-13
    - 5mil trace/7mil space



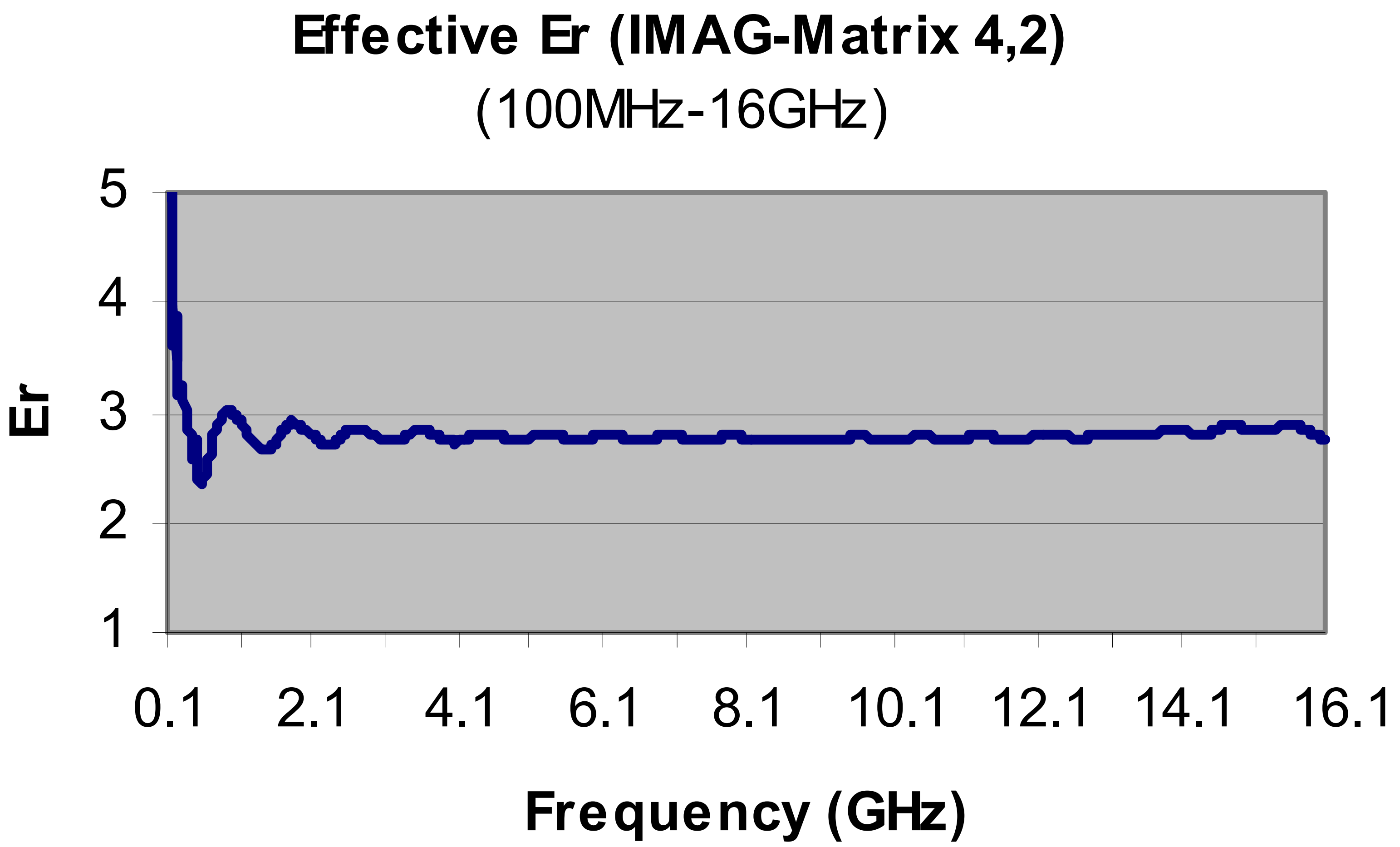
Cascade Probe, Agilent VNA



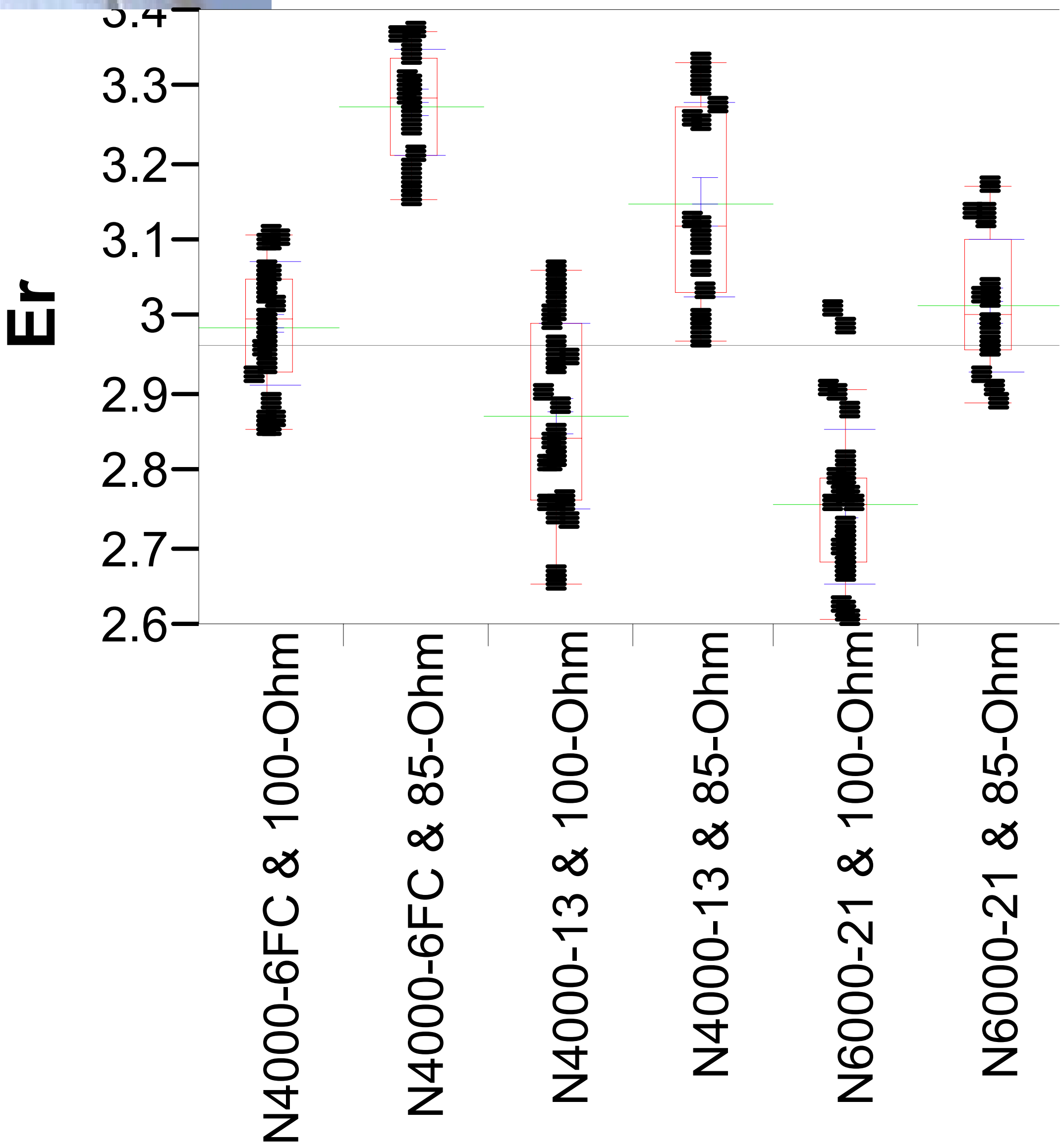
Responses

- Electrical analysis
  - S12 loss
  - Conductor loss (Extracted)
  - Differential Zo
  - Er dK (dielectric constant) from S12
- Mechanical
  - Line width
  - Conductor shape

Dielectric Constant is stable with Frequency



Substrate Results

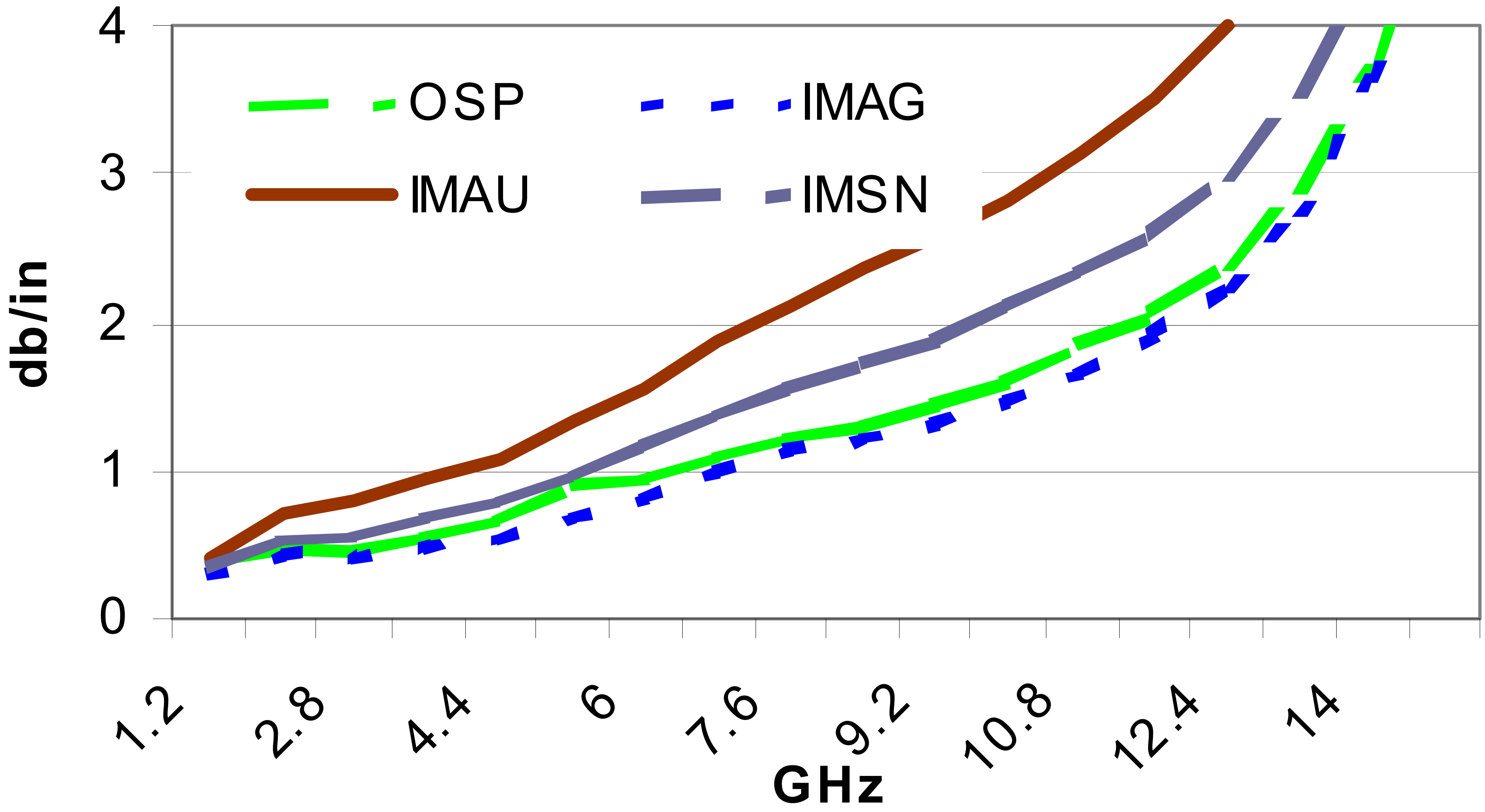


Note:

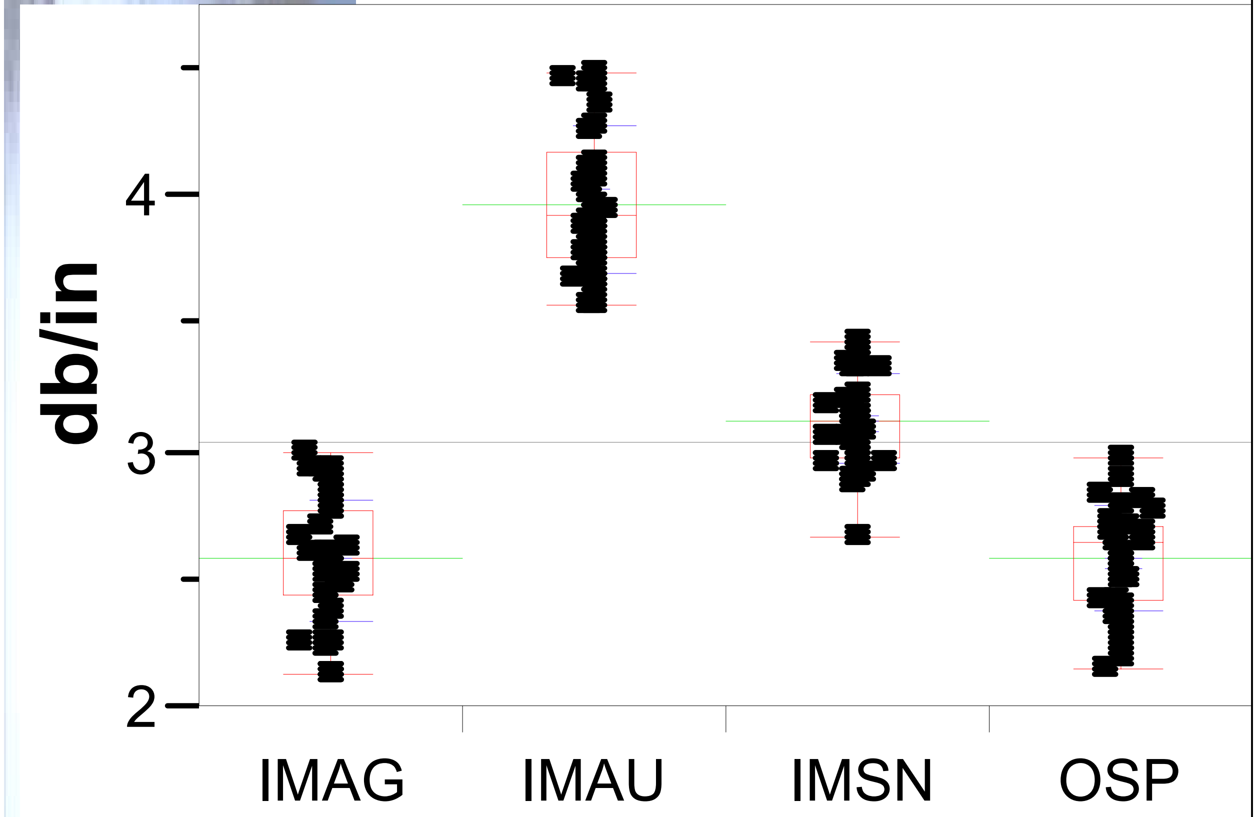
This is the "effective dielectric constant" of the system

- substrate
- air
- no soldermask

Across the Frequency Range



Surface Finish Results

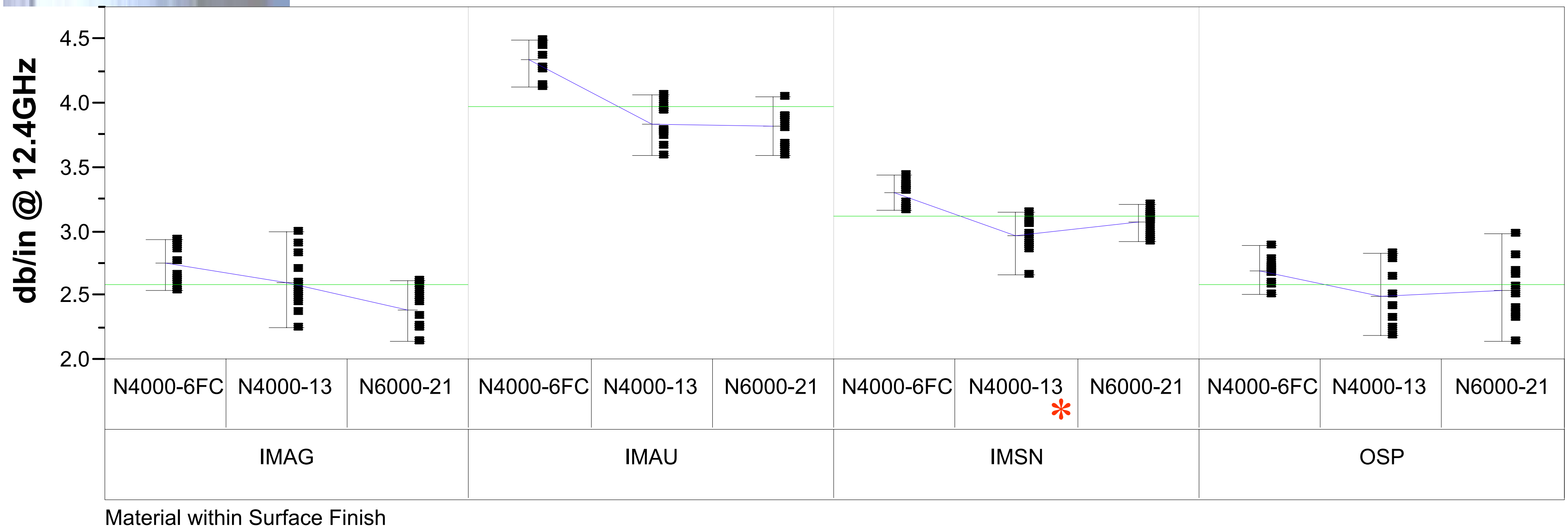


Note:

Expect higher loss from differential pair compared to microstrip designs

- no predominant ground return
- current crowding on traces

Loss by Finish and Material Type



* results chart shape affected by experimental error

Conclusions

- Frequency, as expected, gave the largest contribution to signal loss.
- Maximum loss occurred on the sample made from FR-4, standard tooth foil, poor conductor shape, ENIG.
- Foil tooth had a larger role than expected; study continues.
- Surface finish and foil tooth were more important with differential pair designs than with single-ended designs.
- Higher losses measure on ENIG and Sn followed predicted increases in bulk resistivity.

References

- A.Scott; Understanding Microwaves
- D.Cullen; RF Loss on Teflon Materials
- IPC TMRC, US EPA Surface Finishes
- J.McCall; Loss in Realistic PCB’s
- D.Cullen; On the Surface - Circuitree
- MacDermid CD-Rom

Thank You