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24–71 GHz PCB Array for 5G/ISM

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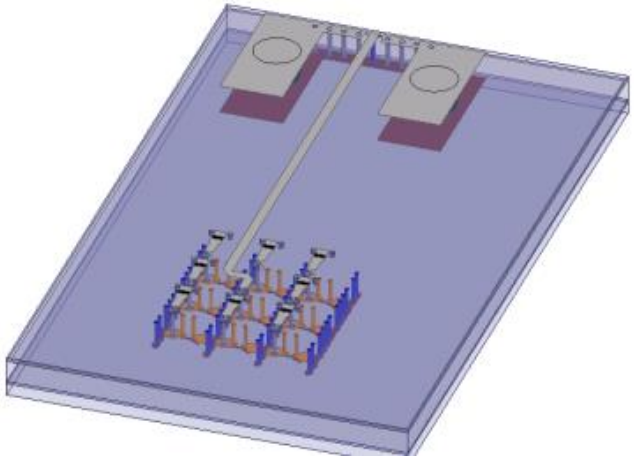

* Novak.187@osu.edu

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Outline

Motivation

Existing UWB mmW Arrays

PCB Limitations

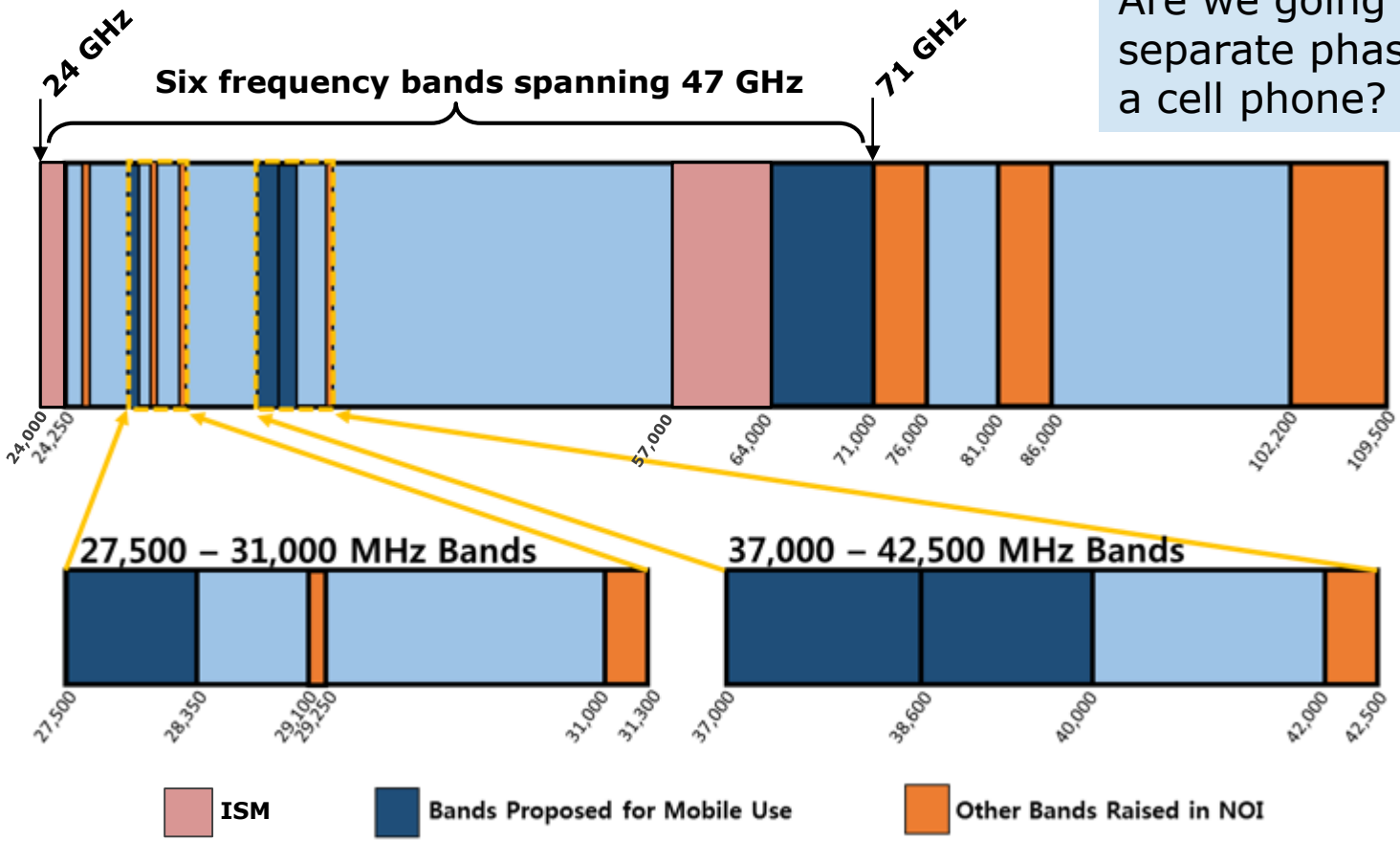
Design for 24–71 GHz

Fabrication & Measurement

A Need for Ultra-Wideband in the Millimeter-Wave Spectrum

FCC proposed 5G bands: 28 GHz, 37 GHz, 39 GHz, and 64-71 GHz [1]
ISM allocations: 24 GHz, 60 GHz

Are we going to integrate 6 separate phased arrays onto a cell phone?

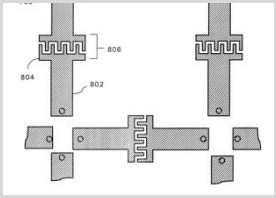


- An Ultra-Wideband antenna allows us to consolidate these bands into one shared aperture
- Low-cost, low-loss PCB fabrication is desirable for mass-market acceptance

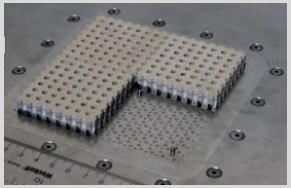
Image modified from: http://www.ni.com/white-paper/53096/en/

Use of Spectrum Bands Above 24 GHz for Mobile Radio Services, GN Docket No. 14-177, Notice of Proposed Rulemaking, 15 FCC Record 138A1 (rel. Oct. 23, 2015)

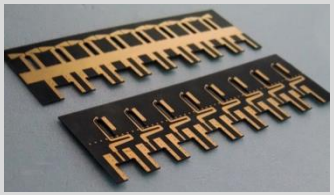
Review of mmW UWB Arrays



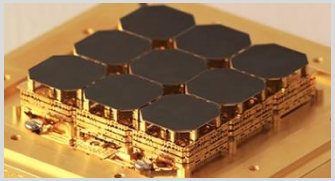
[1] Munk's Current Sheet Array (CSA) introduces inter-digital capacitors to achieve 4:1 BW (up to 18 GHz). Requires bulky external balun



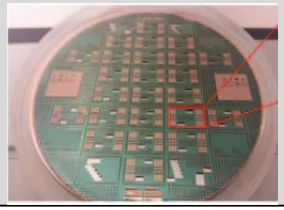
[2] PUMA utilizes direct-fed coupled antennas, scalable up to 45 GHz



[3] Demonstrate TCDAs with 6:1 BW, scalable up to 49 GHz on PCB



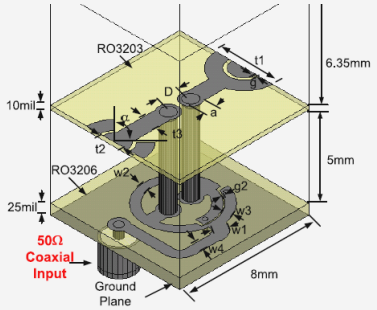
[4] WISM demonstrates 8-40 GHz operation. Utilizes microfabrication



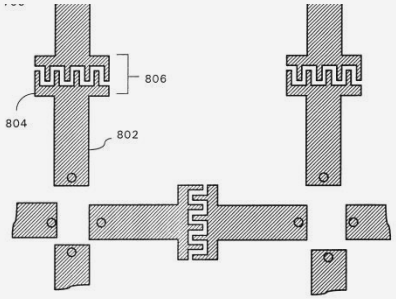
[5] On-wafer array with 35–70 GHz operation, >60% efficiency

[1] Munk, "CSA"; [2] Doane, "TCDA-IB"; [3] Novak, "Ku-TCDA"; [4] NuvoTronics [5] Sahin, "On-Chip UWB Arrays.."

Feeding Network is Critical to Wideband Operation

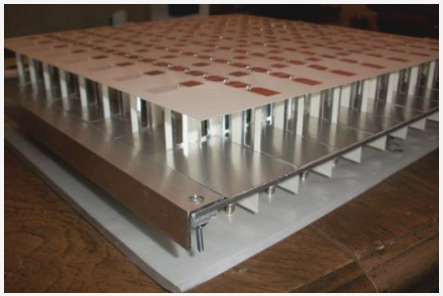


2:1 at 13 GHz



4:1 at 18 GHz


7.6:1 at 5 GHz

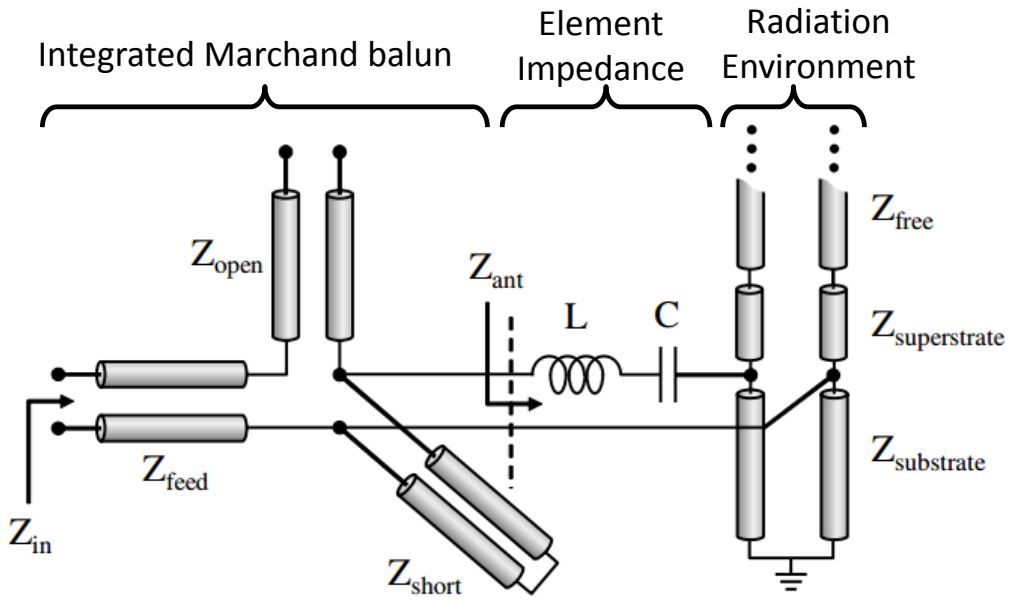

8:1 BW at 4 GHz

- Lower complexity
- Higher Frequency
- Lower bandwidth

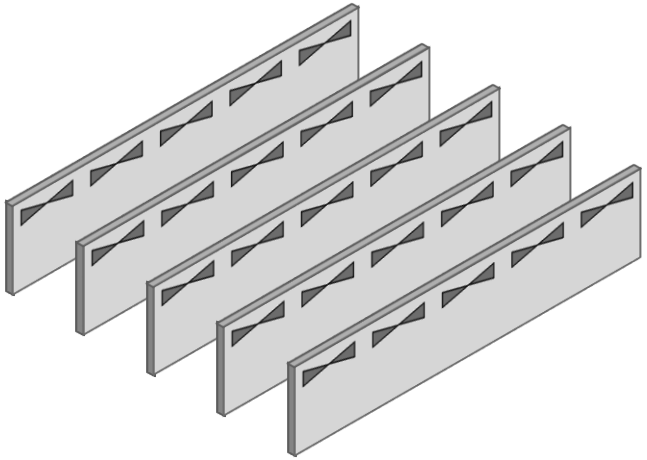
→

- Higher complexity
- Lower Frequency
- Higher bandwidth

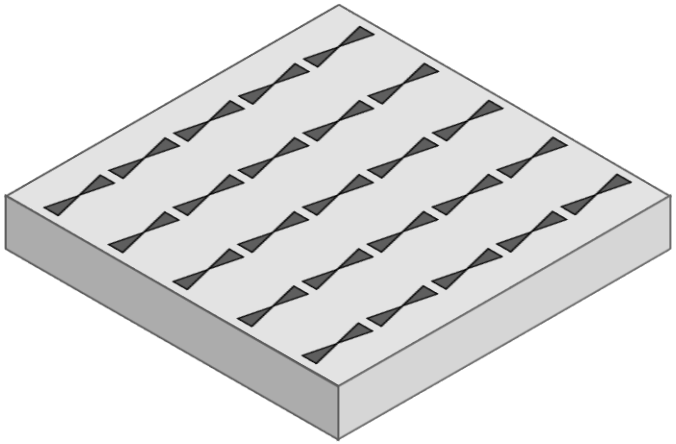
- Improvements in size and performance of TCDAs comes as a result of more complex feed structures
- Wideband integrated balun requires a wide range (>10:1) of impedances
- These feeds do not easily scale, limiting designs to low frequencies



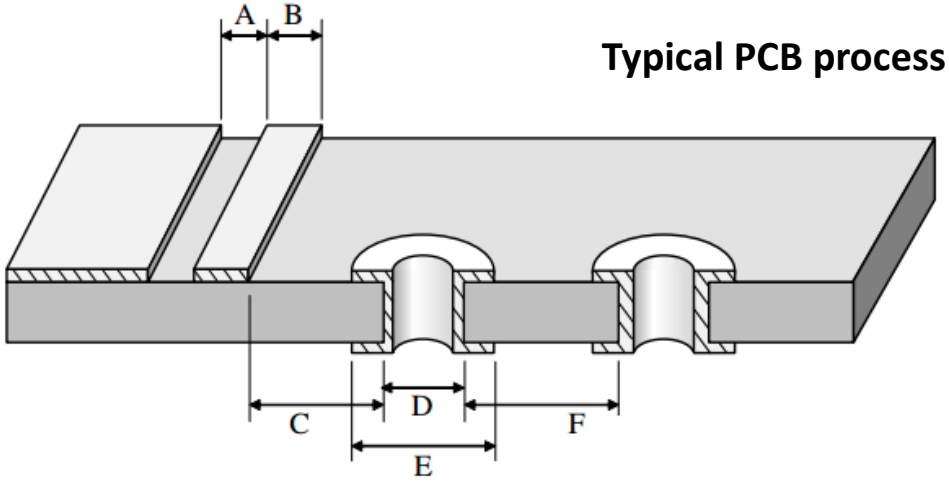
Feed Constraints Due to Planar Fabrication



Eliminating vertical subarrays eliminates Vivaldi and slotline antennas



All mmW fabrication process are inherently planar. Majority of feed must be designed from vias



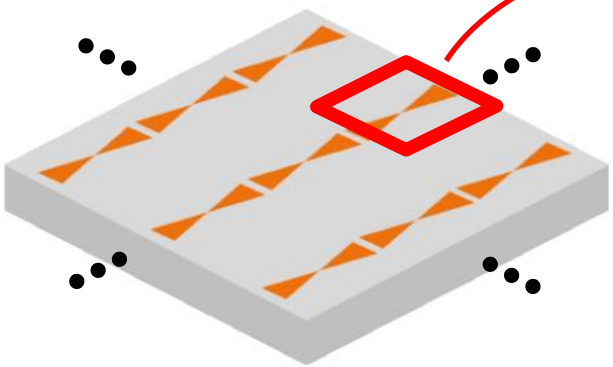
Typical PCB process limits:

Dimension	μm	mil
A	76.2	3
B	76.2	3
C	152.4	6
D	152.4	6
E	304.8	12
F	254	10

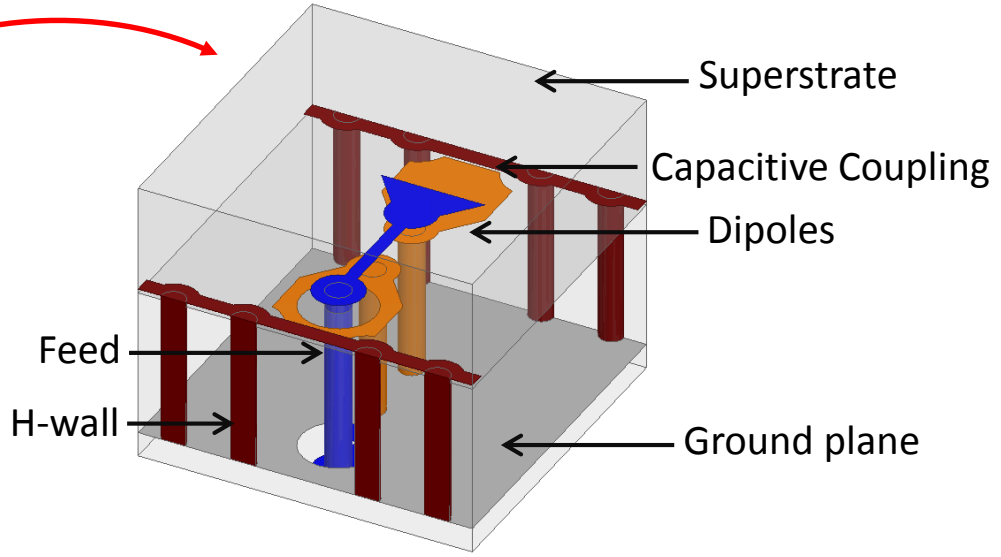
Design should account for PCB fab limitations.
Particularly challenging are via diameter and pitch limits.

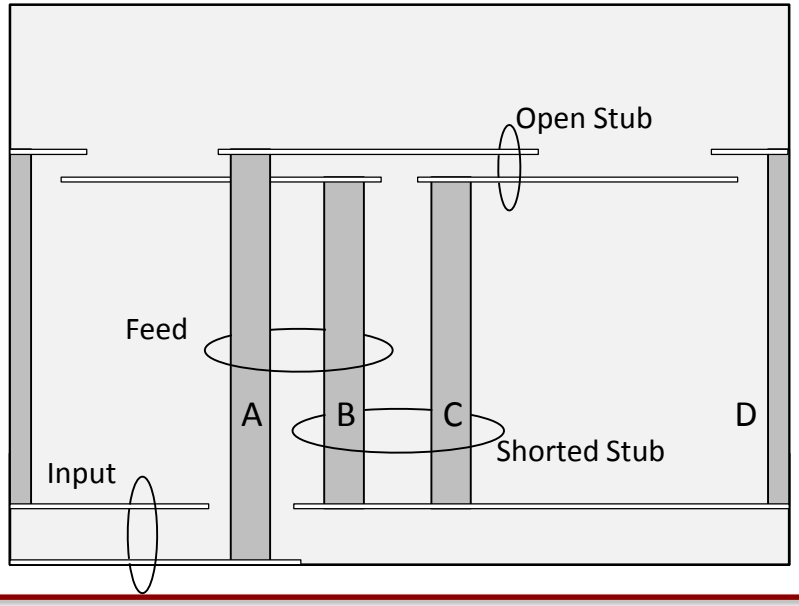
6% of λ at 70GHz

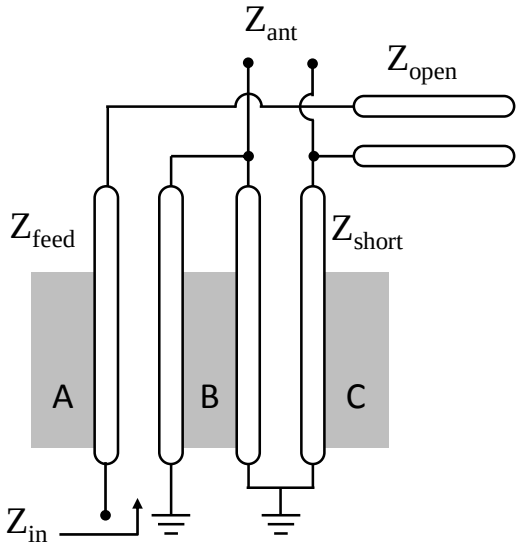
Simplified 3-Pin Marchand Balun



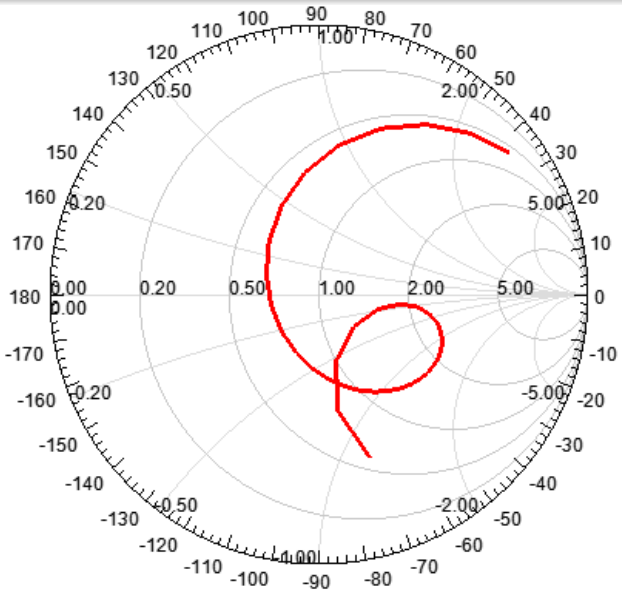
Array of identical elements



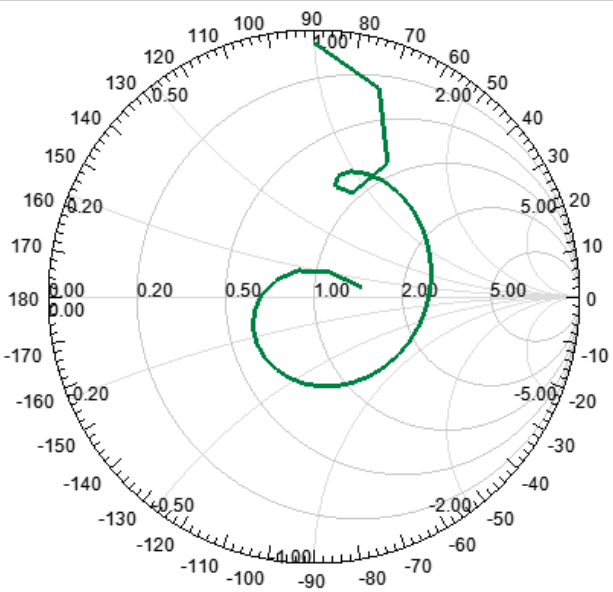




Impedance Analysis

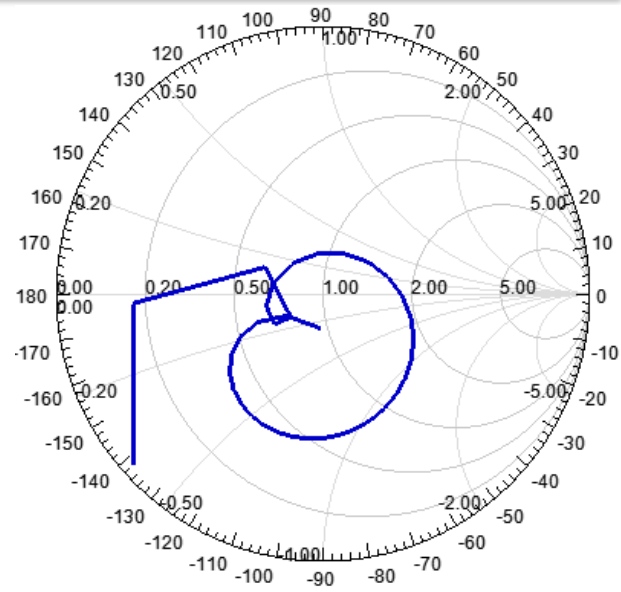


Coupled Dipoles with lumped port



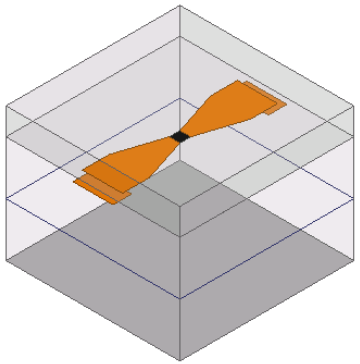
Adding short circuit

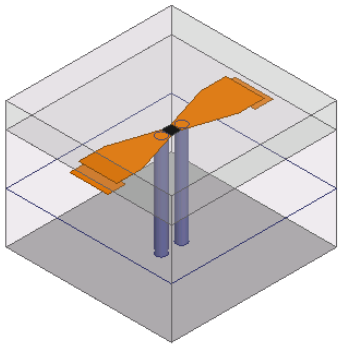
- Almost complete inversion
- Low frequencies at top of chart will be pulled down by added capacitance

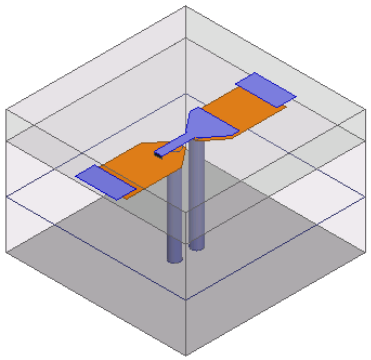


Adding open circuit

- Very well matched at this stage (still lumped port near aperture), requires matched feed from source

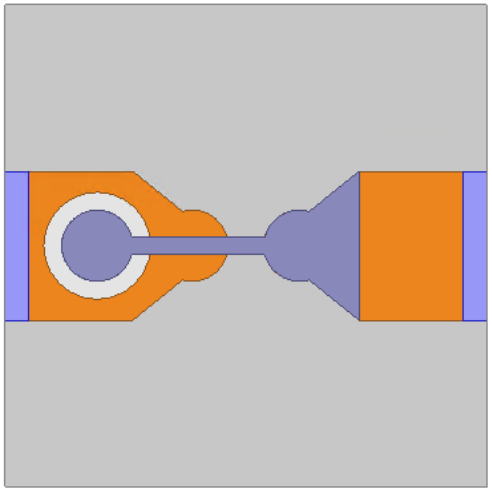




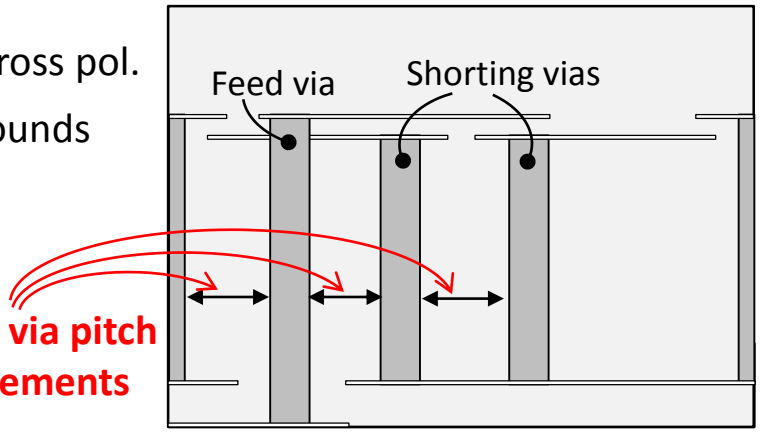


Feed Via Placement

In-Line Feed Via

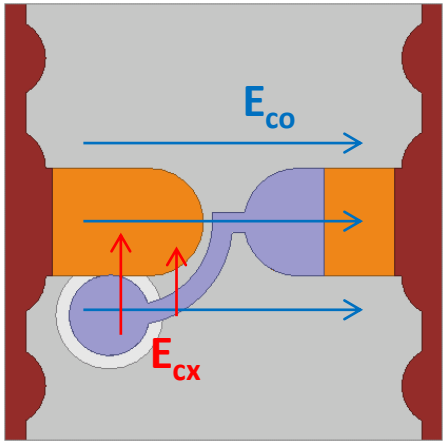


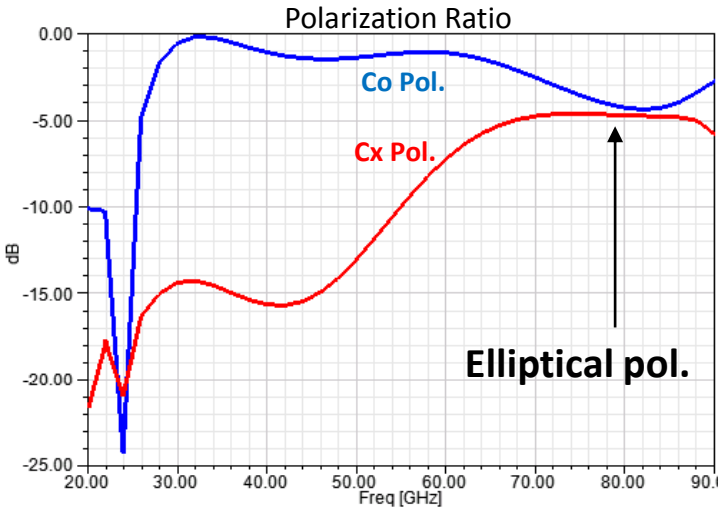
- Symmetrical layout reduces cross pol.
- Achievable via pitch in PCB bounds unit cell size
- Limited to < 75 GHz



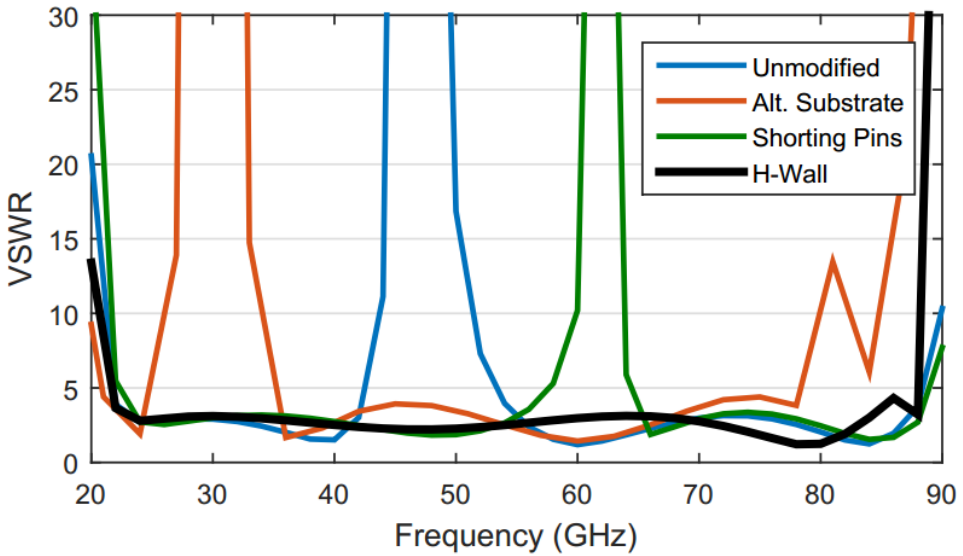
Offset Feed Via

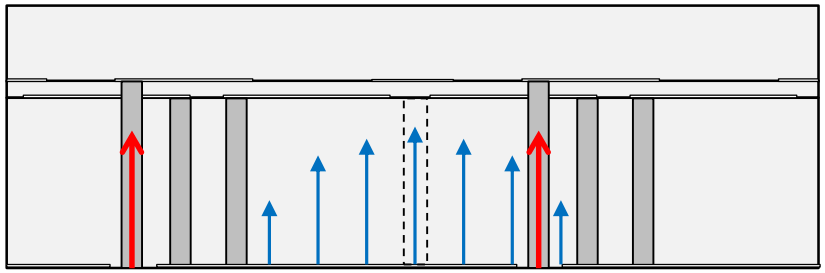
- Offset feed via allows unit cell miniaturization
- Enables operation up to 90 GHz
- Asymmetrical layout introduces high cross-polarized radiation

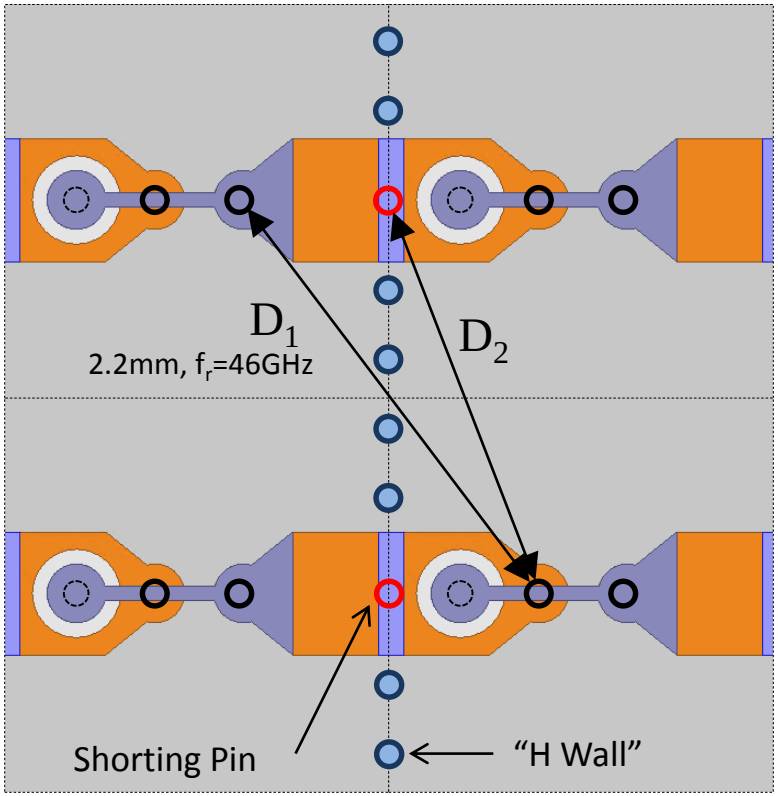




Mitigating Common-Mode Resonance





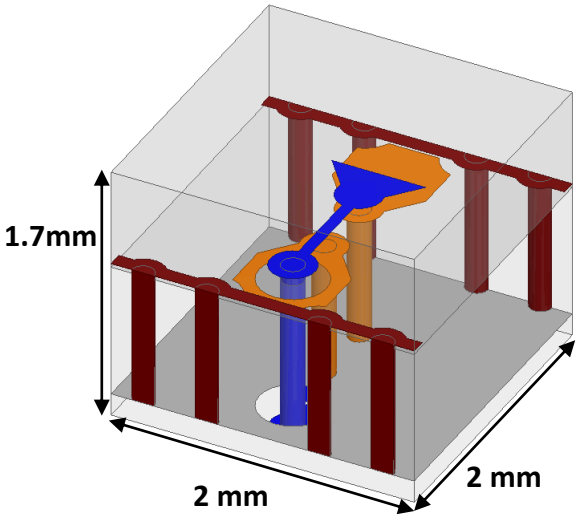


- Resonant length can occur diagonally
- Thus, shorting pin only marginally effective
- High ε_r substrates can lower resonant frequency, but cause surface waves
- Can be resolved with continuous conducting wall along H-plane

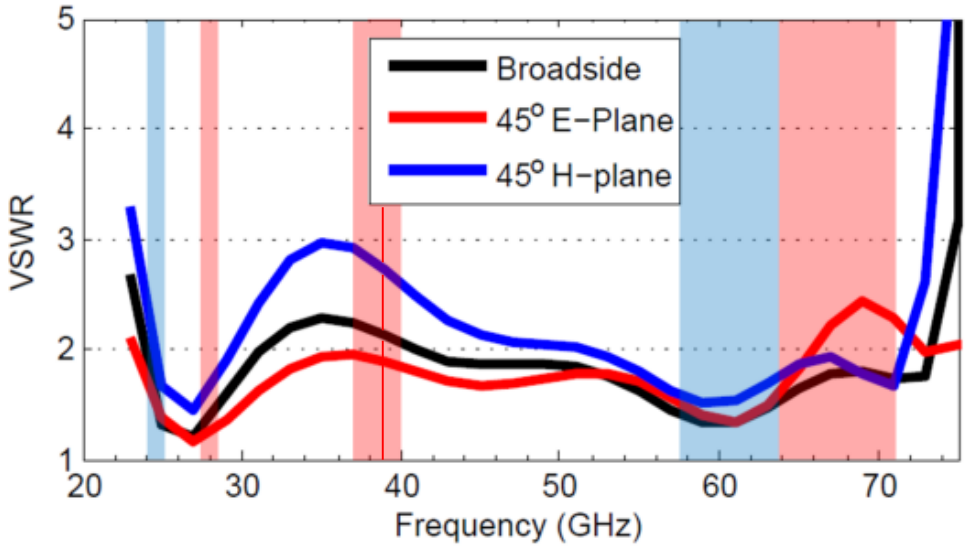
Coverage of the 5G/ISM Bands

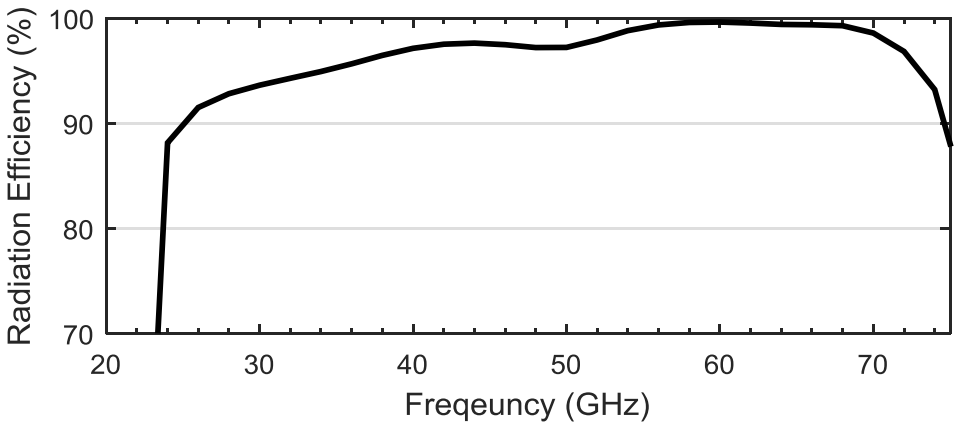
Allocated 5G and ISM bands are highlighted:

Allocation	Frequency (GHz)	Allocation	Frequency (GHz)
ISM	24–25	5G	38.6–40
5G	27.5–28.35	ISM	57–64
5G	37–38.6	5G	64–71



(95% of grating lobe spacing)

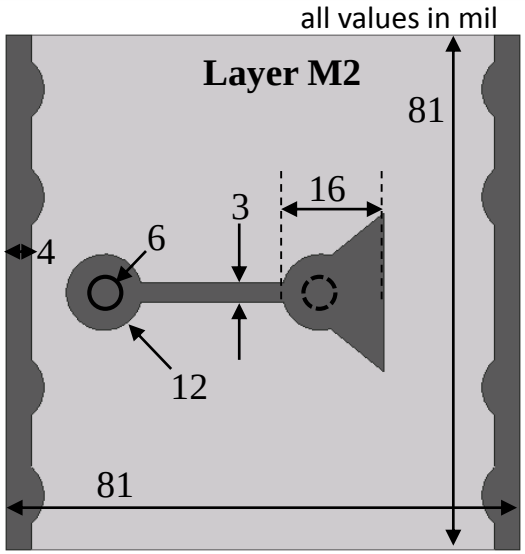


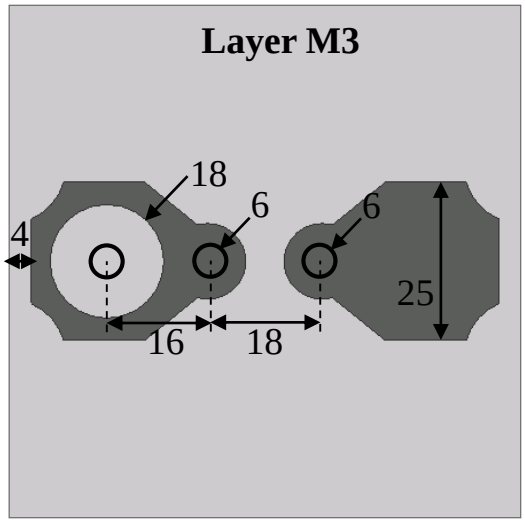


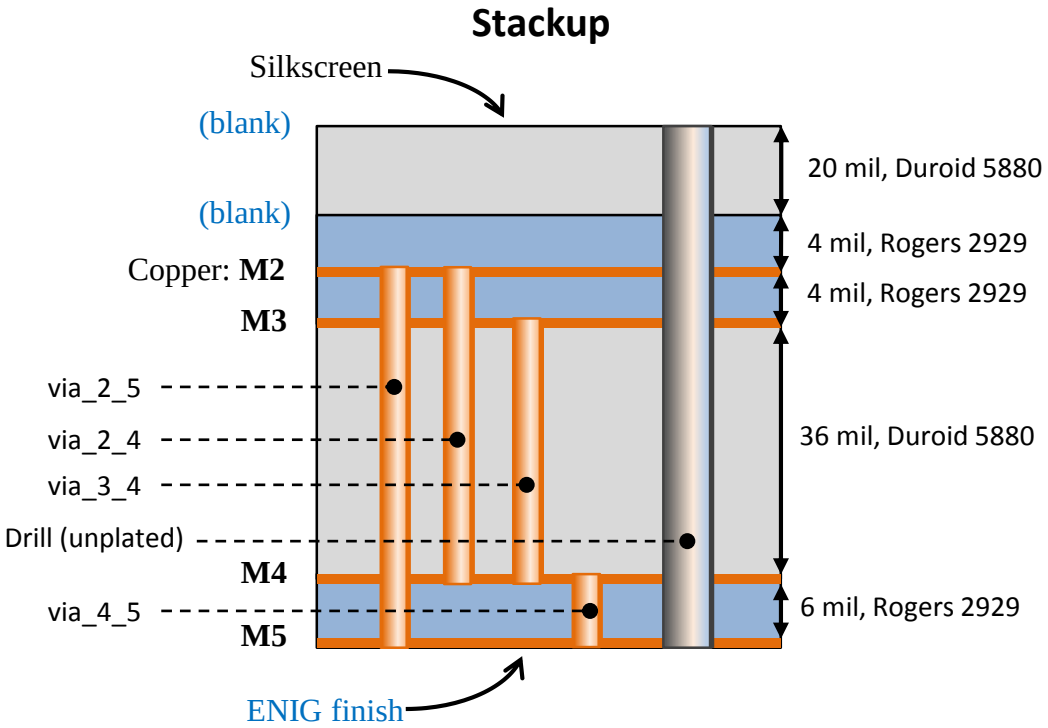
Coverage of all 6 bands (24–71 GHz) with:

- VSWR < 2.2 - Broadside
- VSWR < 2.5 - 45˚ E-Plane
- VSWR < 3 - 45˚ H-Plane
- Radiation efficiency > 90%

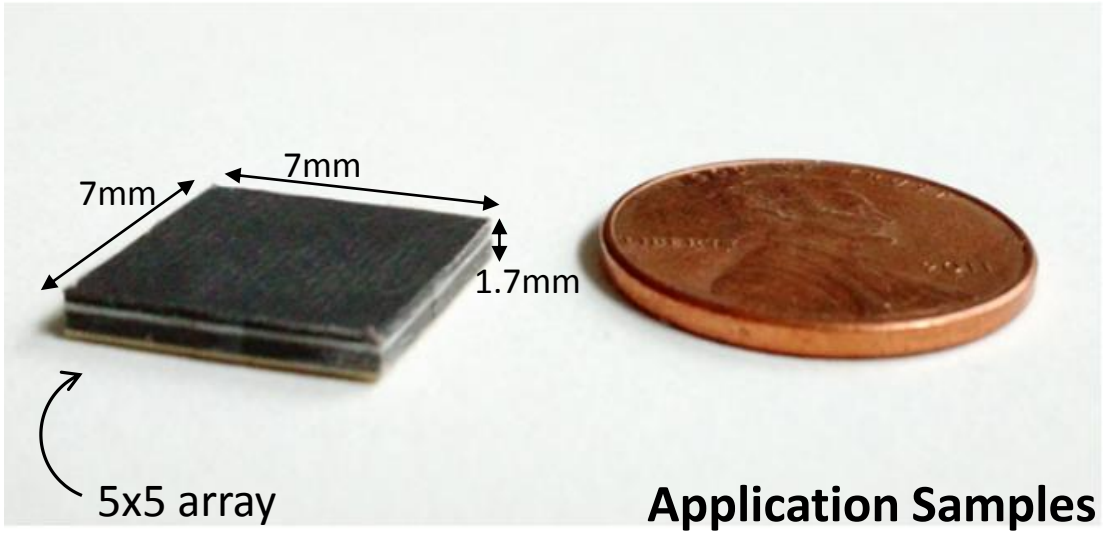
Fabrication Layout



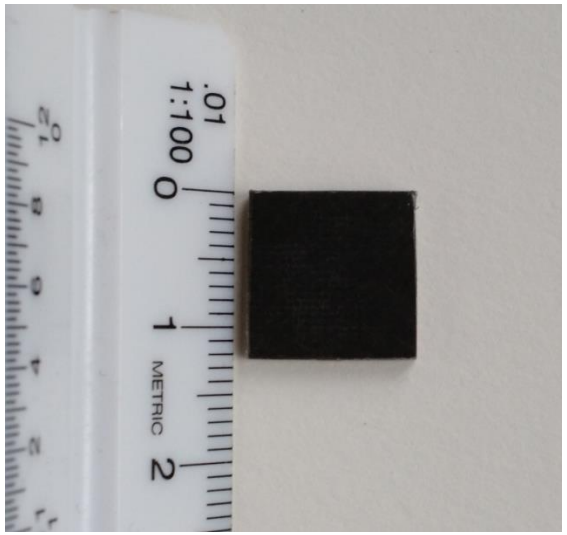




Fabricated Samples



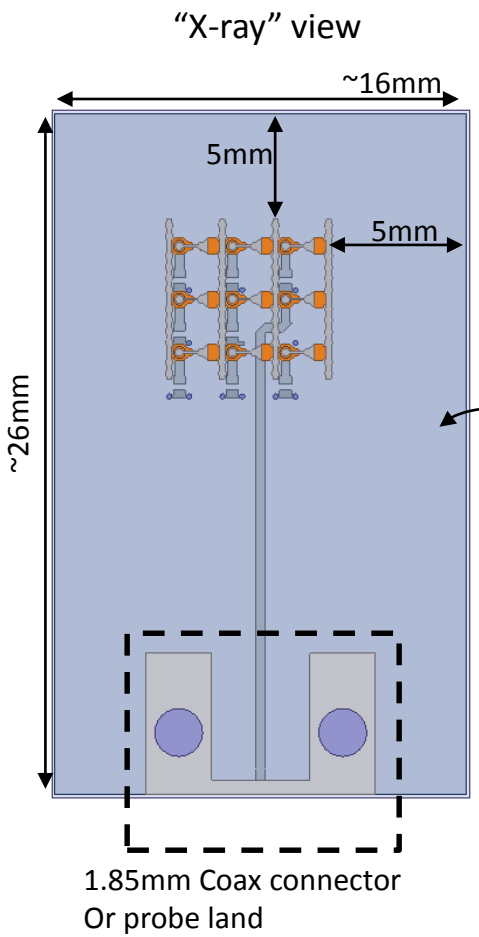
Application Samples

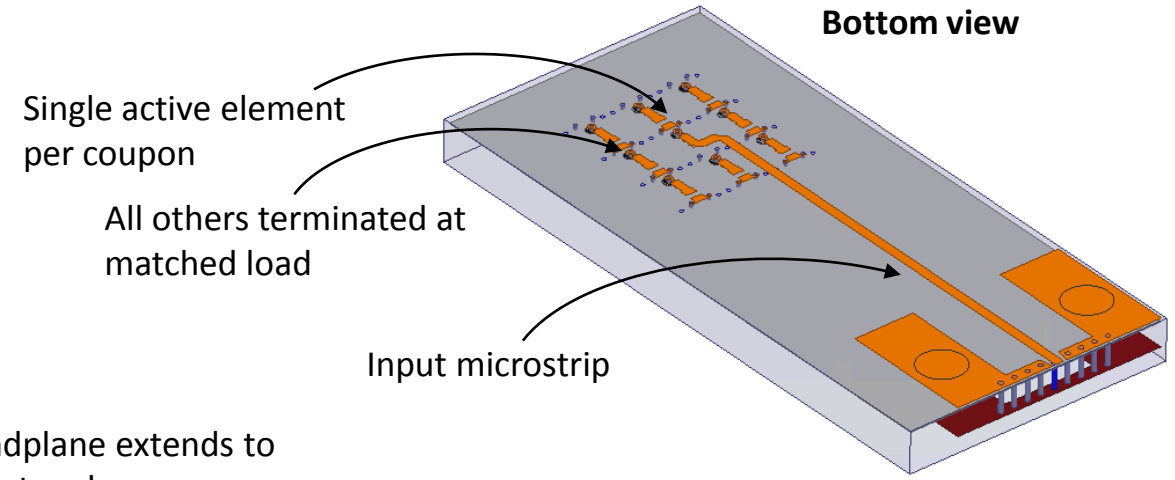


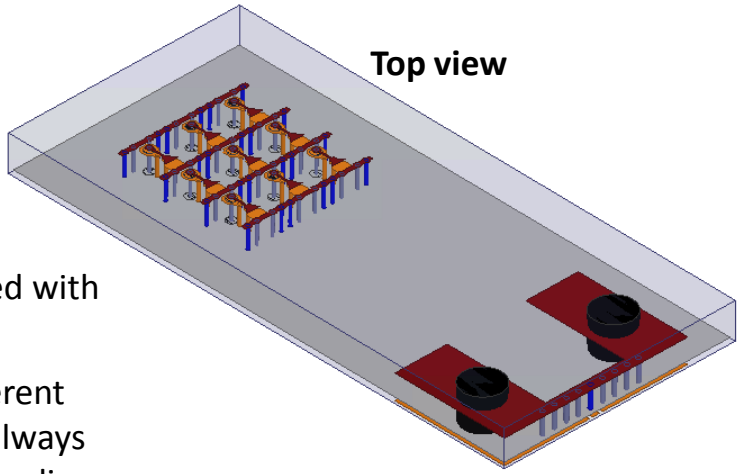
3x3 measurement coupons

Measurement Samples

Example Measurement Coupon

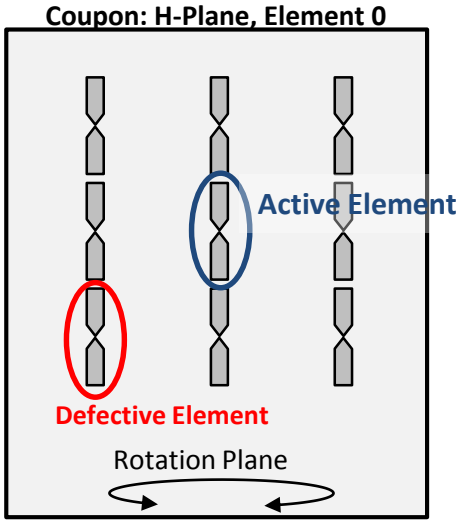


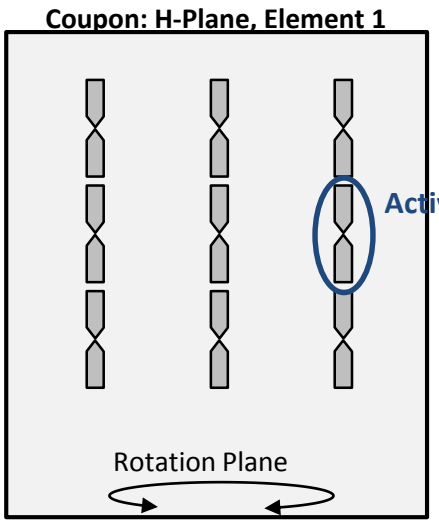




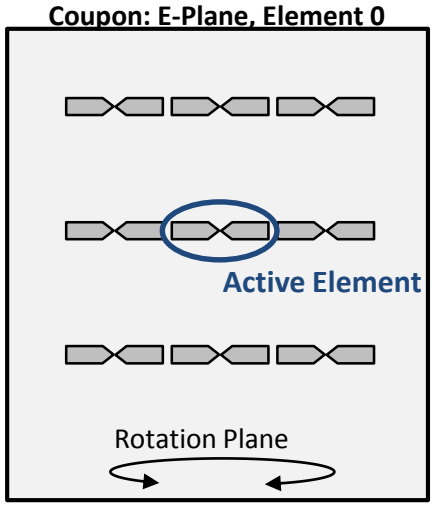
- Active element is not centered with respect to coax port
- Coupon size changes for different elements or array sizes, but always has 5mm groundplane surrounding array

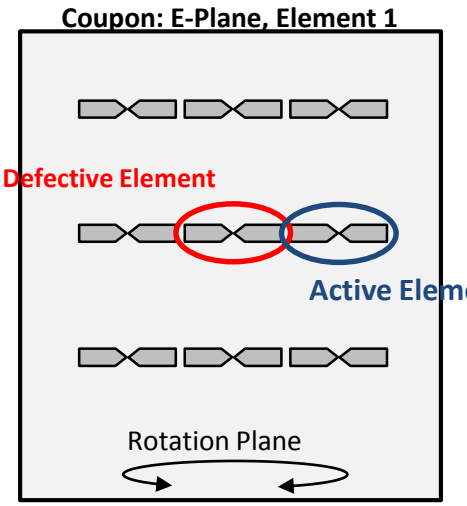
Measurement Coupon Diagrams





- "Defective" elements due to soldering failure, no connection at DC

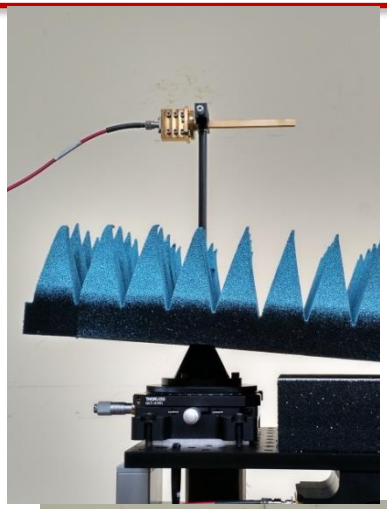




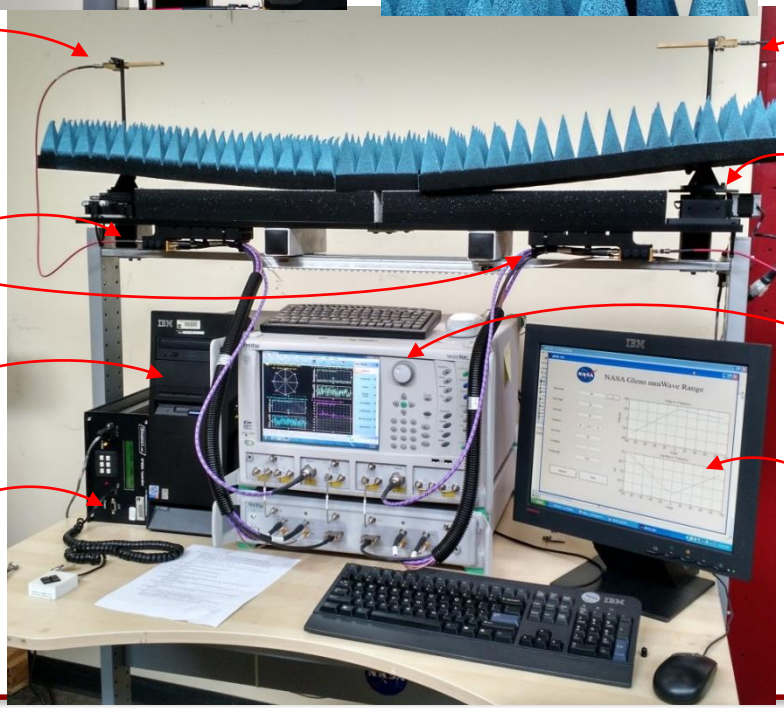
Measurement Setup

Waveguide sources:
20-40 GHz
40-60 GHz

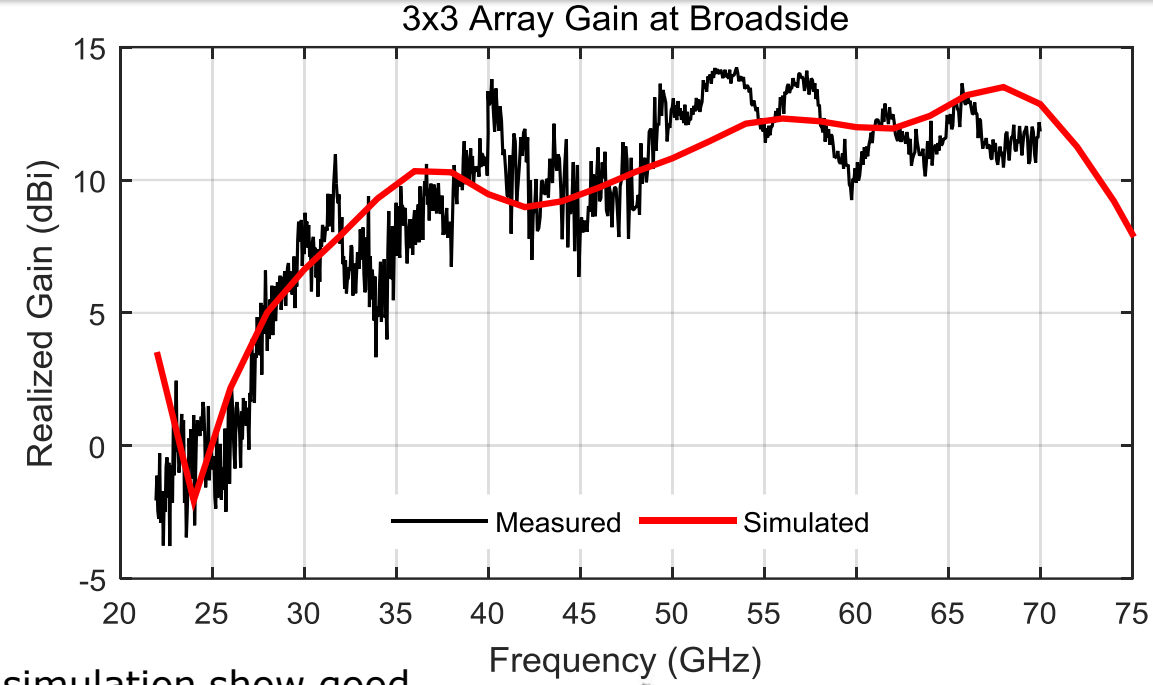
Horn source:
50-75GHz



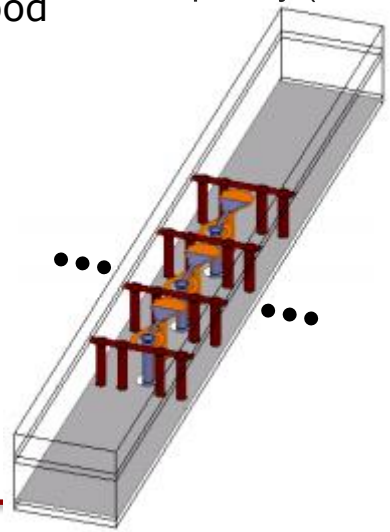
- Coupon mounted on rotating post
- Measurements limited by frequency range of 1.85mm port (<70GHz)
- Horn source required at high band to increase dynamic range



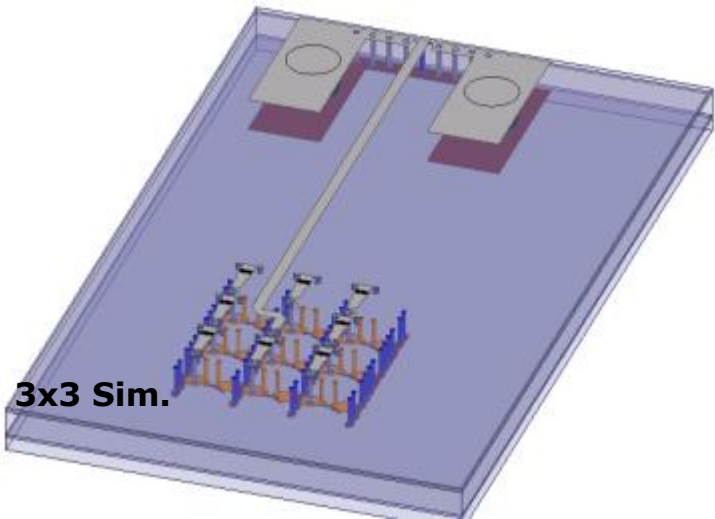
3x3 Measured Results



- Measurements and simulation show good agreement
- 1x3 simulations were used to reduce computational burden, but some compromise in accuracy
- Reduced gain near 35GHz result of excess dielectric and groundplane surrounding the array



1x3 Sim. (periodic boundary)



3x3 Sim.

Conclusions

Motivation

- Multiple mmW communications bands
- Ideally, consolidate into a shared aperture

Design

- Simplified balun design overcomes limitations in PCB fabrication
- Cavity resonance is averted with a conducting wall perpendicular to dipole current

Fabrication

- 3x3 test articles were fabricated and measured
- Close agreement with simulations observed