Recent Advances in the Development Of a Lightweight, Flexible 16x16 Antenna Array with RF MEMS Phase Shifters at 14 GHz

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ESTO Conference June 2008

Outline

- Introduction
- RF MEMS Switches and Low Loss Phase Shifters on LCP
- 3-D Integrated RF MEMS Phased Array Module (2x2)
- Recent Results on Large Antenna Array
- Conclusions

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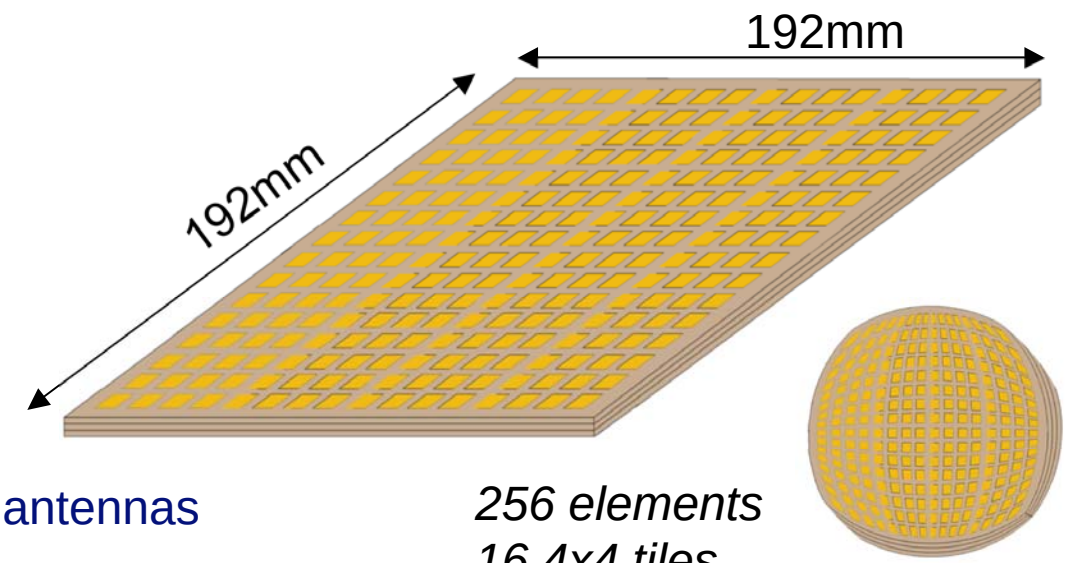
Introduction

- ***Objective***
  - Develop a large lightweight and deployable phased array using RF-MEMS. Integration with other passive and active circuits.

- ***Challenges***
  - Obtain desired beam-steering for earth coverage, with the desired radiation pattern and return loss characteristics
  - Low cross-polarization and back-sidelobe level
  - Low loss
  - Compact Structure
  - High Degree of Integration
  - Expandable Design
  - Flexibility



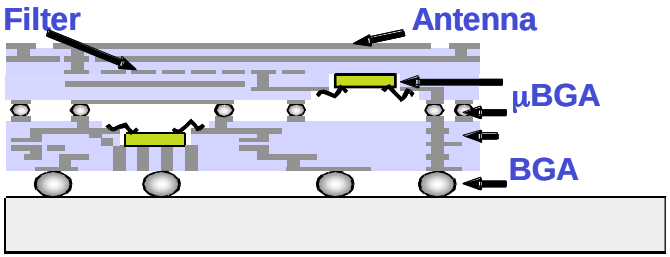
- ***Proposed Solution***
  - Aperture-fed microstrip patch antennas
  - Corporate feed network
  - A 3-D System-on-a-Package Approach

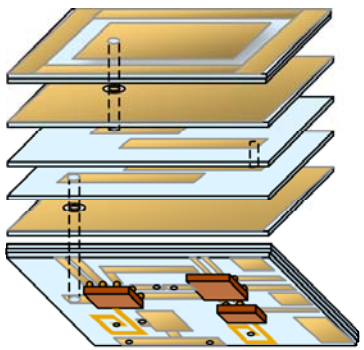
256 elements
16 4x4 tiles
8 4x8 tiles

SOP RF Front End Evolution

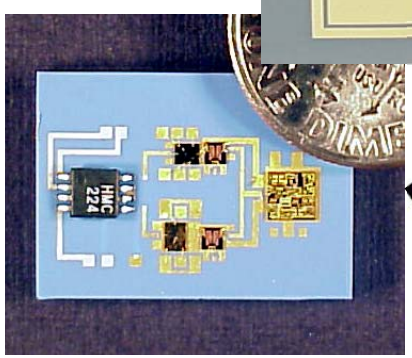
Georgia Institute of Technology

Hybrid Solution

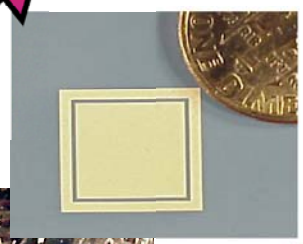




Epoxy PWB

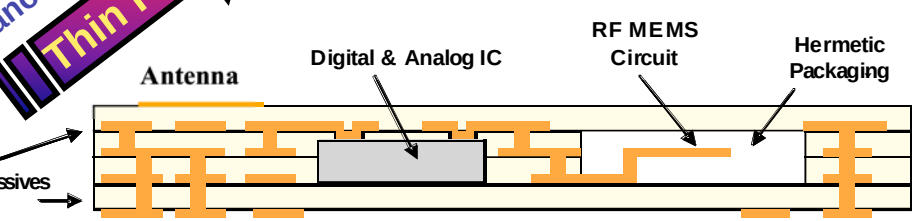


Ceramic LTCC



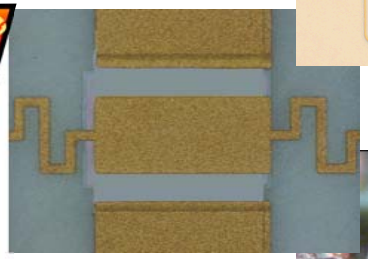
Organic LCP

Nanomaterials Thin Films

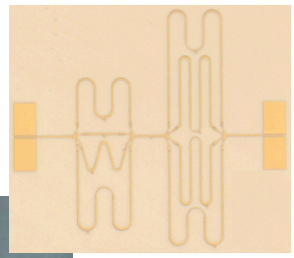


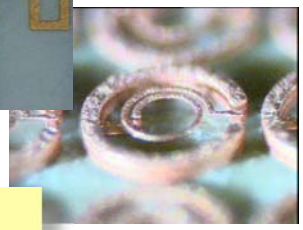
3D

Reconfigurable



RF MEMS

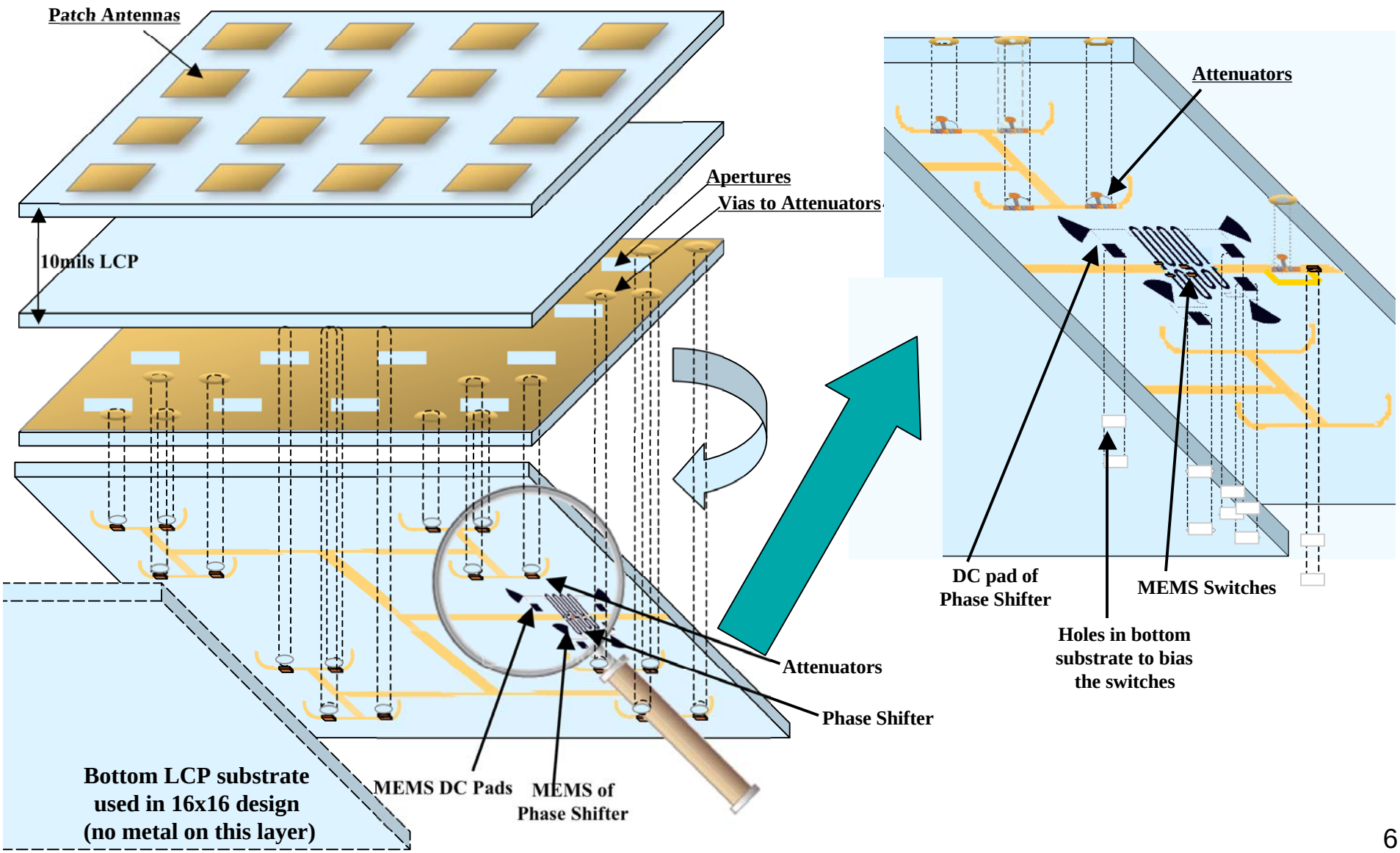




- Lower Cost
- Smaller Size/Weight
- Better Performance
- Multi Functionality

"Best of Breed" Solution

Sub-Array 3-D Integration



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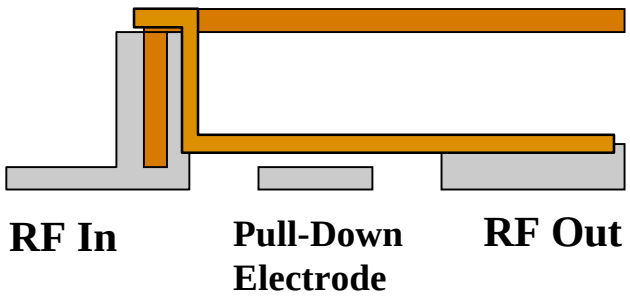
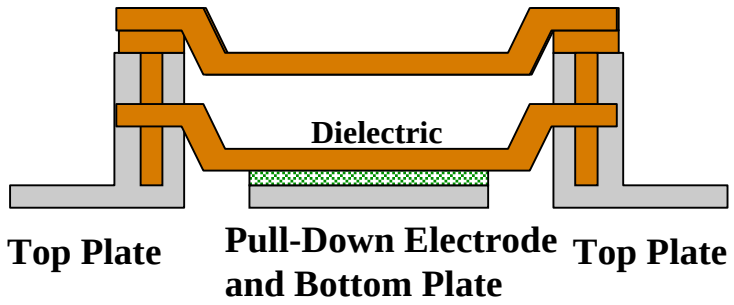
Enabling technologies: RF MEMS and micromachining



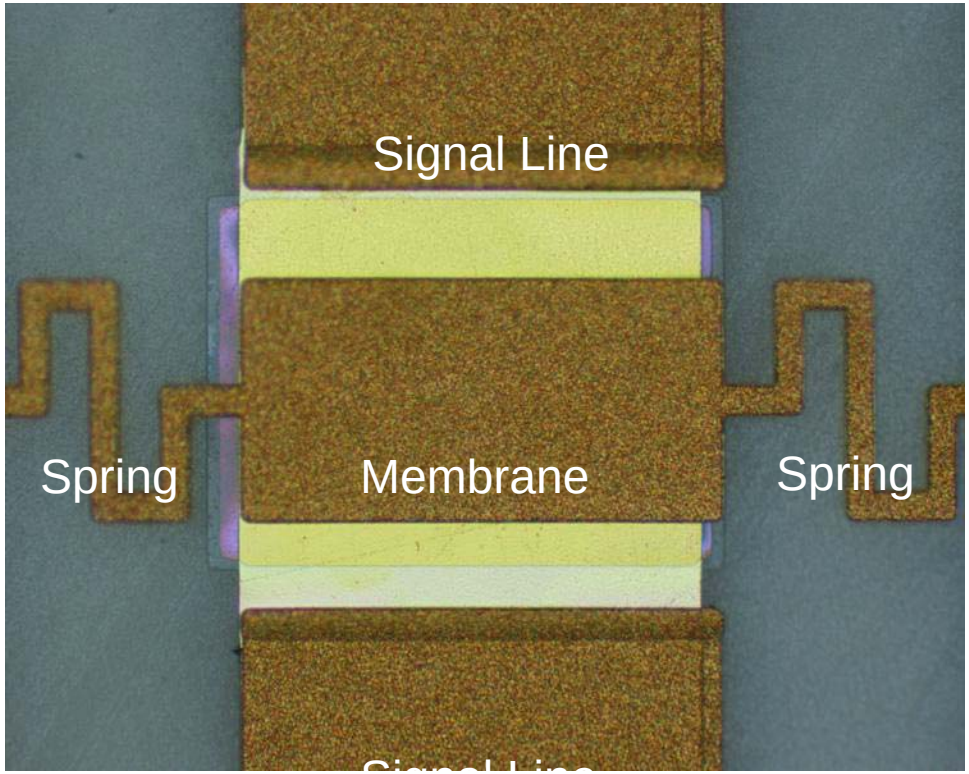
Cantilever beam



Air-bridge

- Electrostatic actuation
- Low loss and low cost
- High linearity – no distortion
- No power consumption
- Switching time 1-50 μs
- Reliability & RF power?
- Packaging?

RF MEMS Switch on LCP

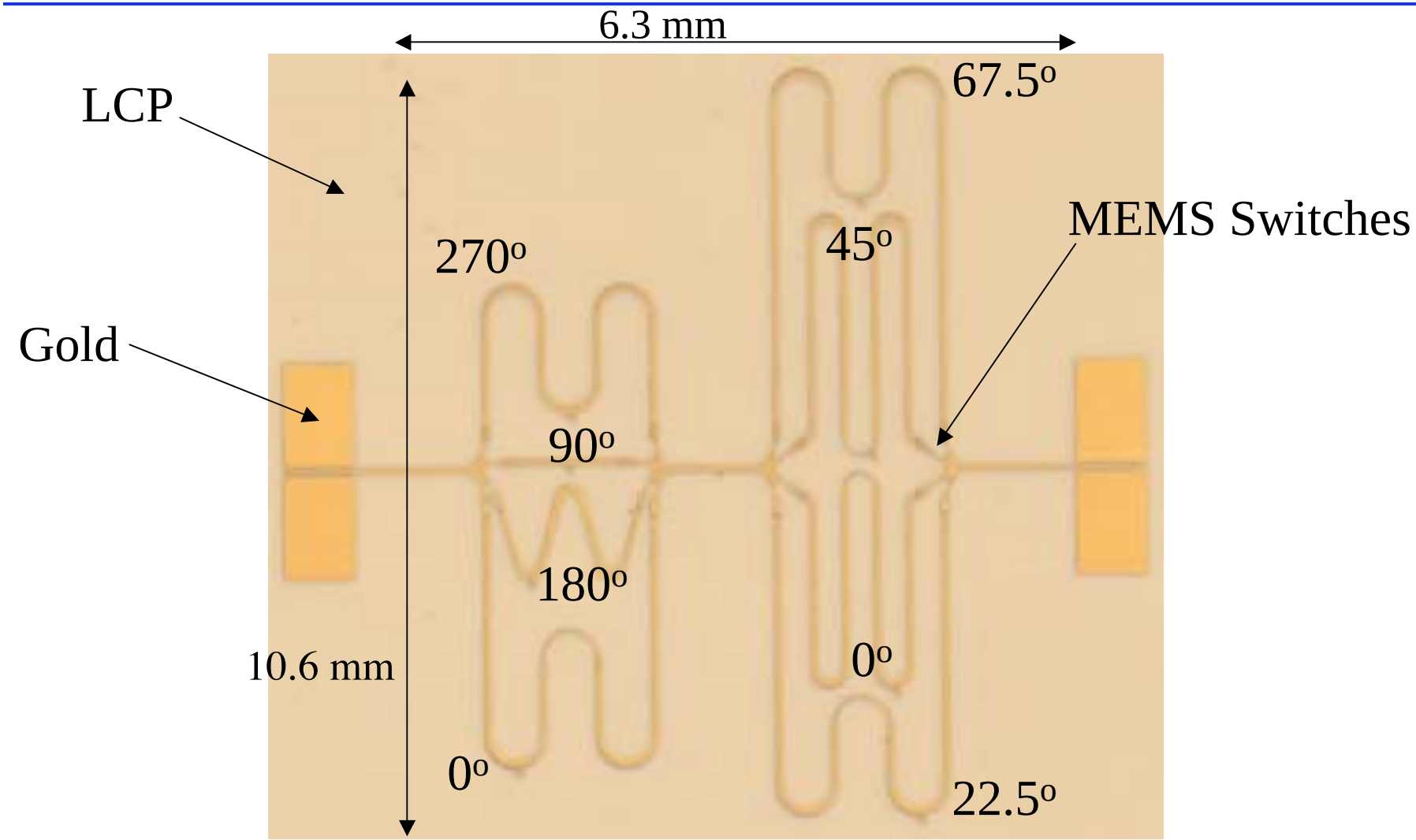


The springs anchor the membrane to the finite ground coplanar waveguide's (FGC's) ground planes [not shown]. A special process was developed to fabricate the MEMS switches on and LCP substrate.

Dark brown – electroplated gold
Yellow – evaporated gold

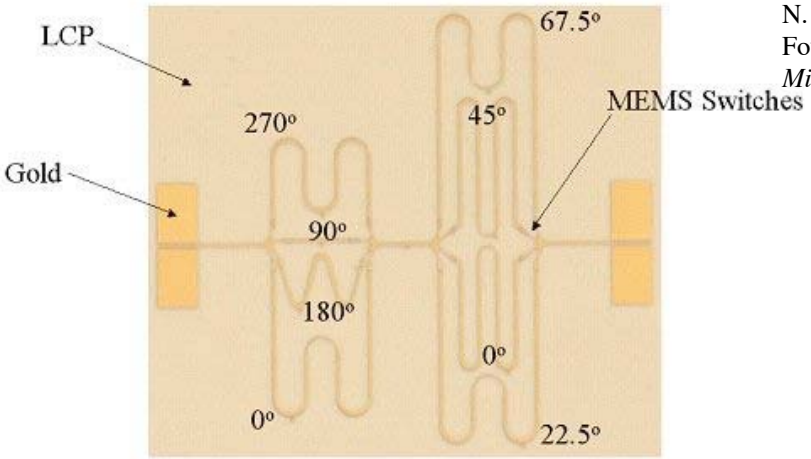
Switching speed ~ 12 usec
Actuation voltage: 20-40 V
More than 0.5B Cycles

Fabricated 4-bit Phase Shifter



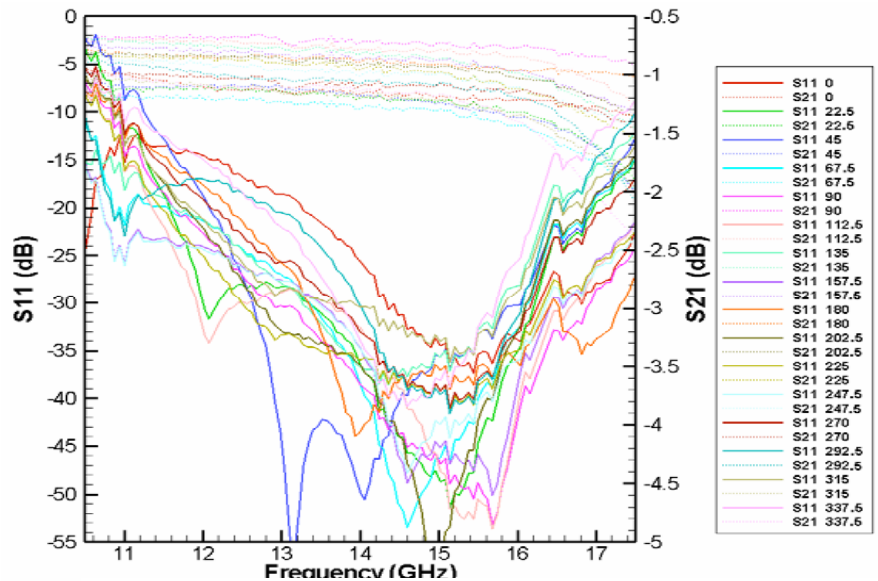
Capable of phase shifts from 0° to 337.5° in 22.5° increments

Packaging of 4-bit Phase Shifter

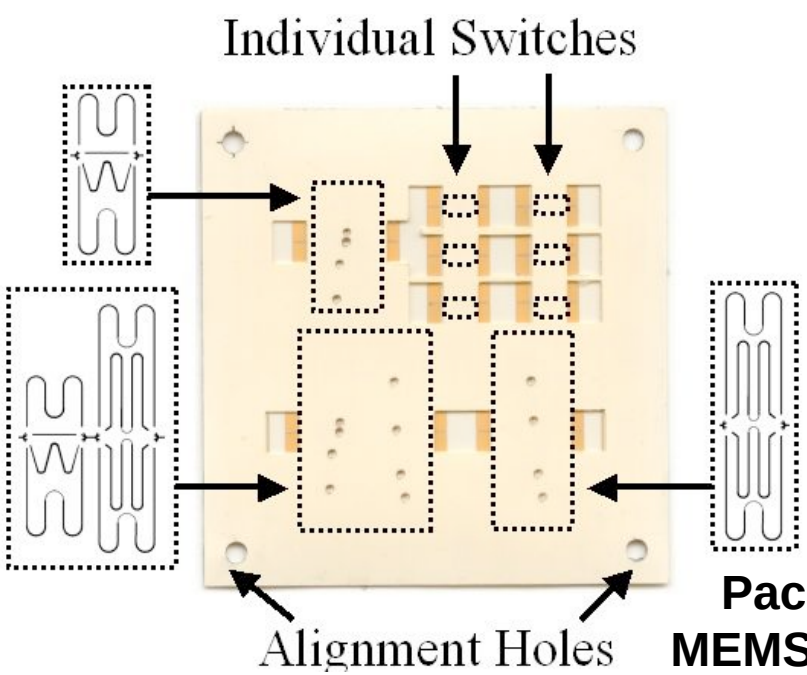


Capable of phase shifts from 0° to 337.5° in 22.5° increments

N. Kingsley and J. Papapolymerou, "Organic Wafer Scale Packaged Miniature Four-Bit RF MEMS Phase Shifter," *IEEE Transactions on Microwave Theory and Techniques,* Vol. 54, No. 3, pp. 1229-1236, March 2006



Isolation and Insertion Loss Measurements



Packaged MEMS on LCP

	Worst Case	Average	Best Case
S11 (dB)	-25.63	-35.74	-49.83
S21 (dB)	-1.29	-1.02	-0.72
Phase Error (deg)	8.25	3.96	0.34

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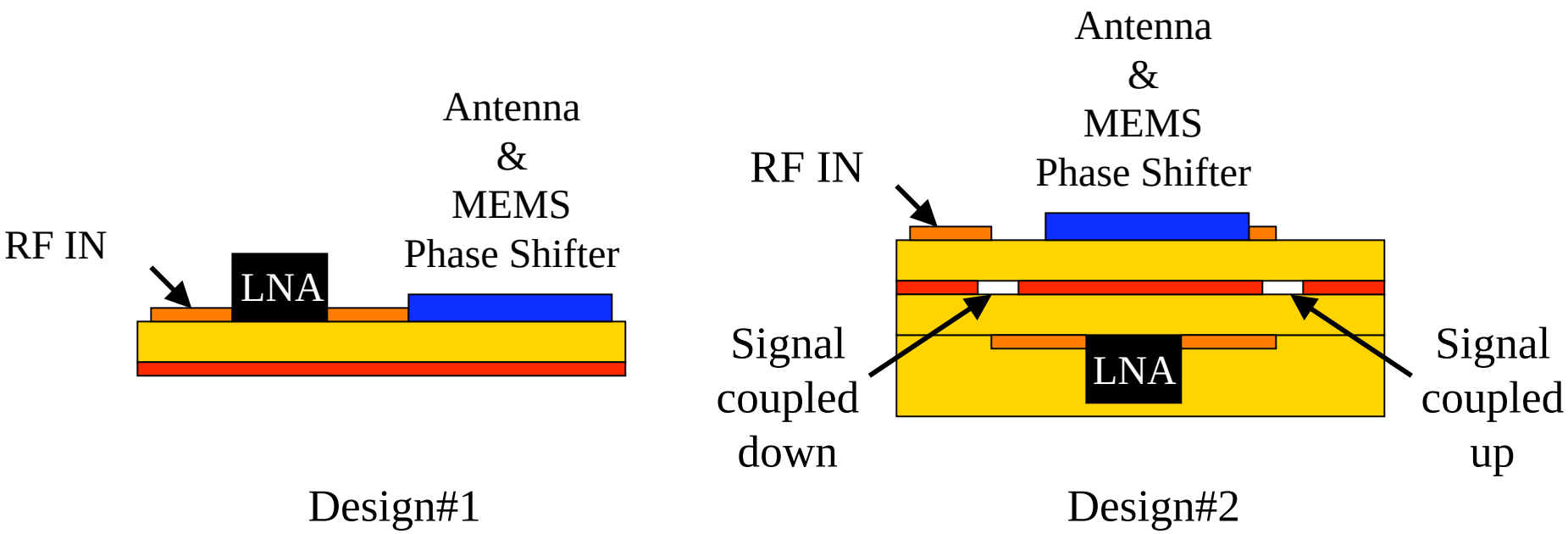
Integrated RF Module on Multilayer Organics



- 2x2 patch antenna design with two 1-bit MEMS phase shifters
- LNA on same layer and different layer
- Multilayer LCP design

N. Kingsley, G. Ponchak and J. Papapolymerou, "Reconfigurable RF MEMS Communication Module on LCP Substrate," *IEEE Transactions on Antennas and Propagation, January 2008*

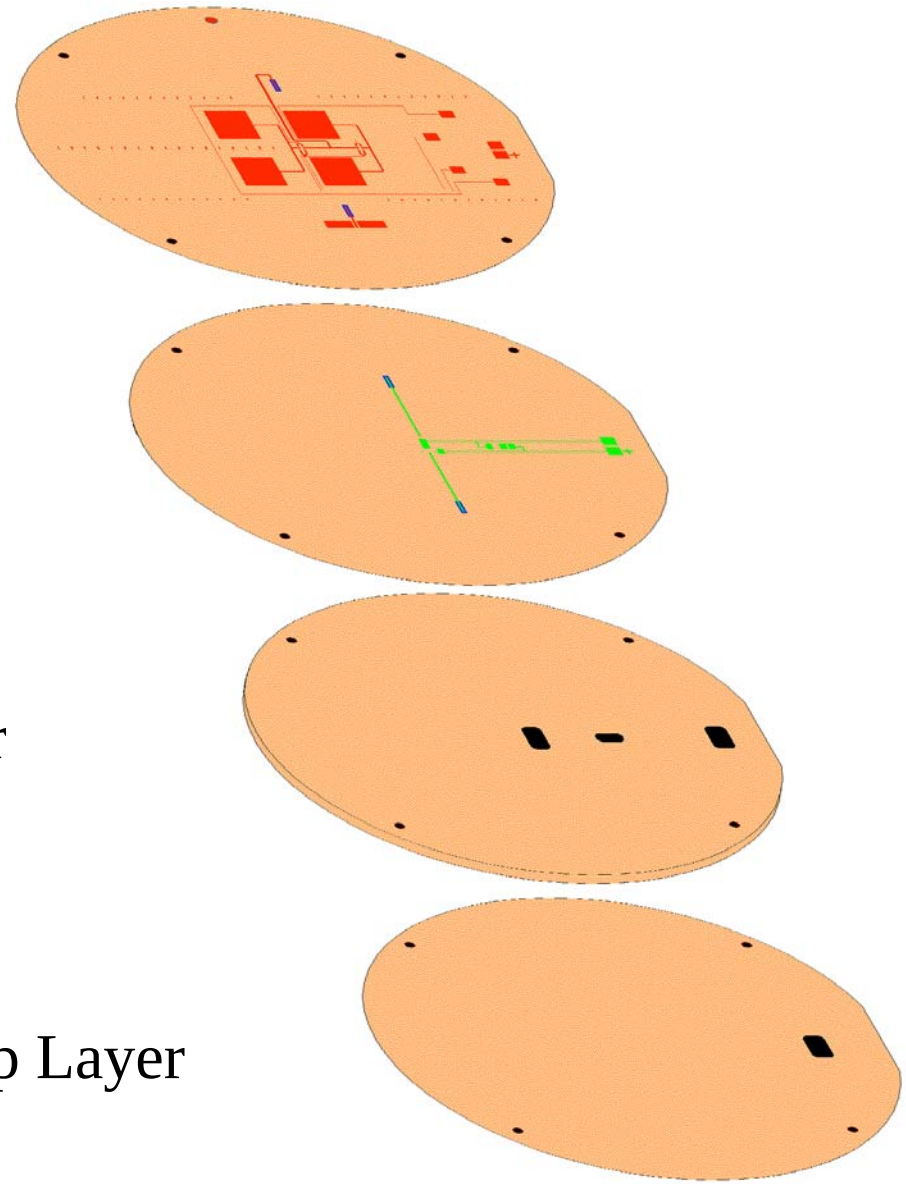
Second Design Stack-Up

Top Layer

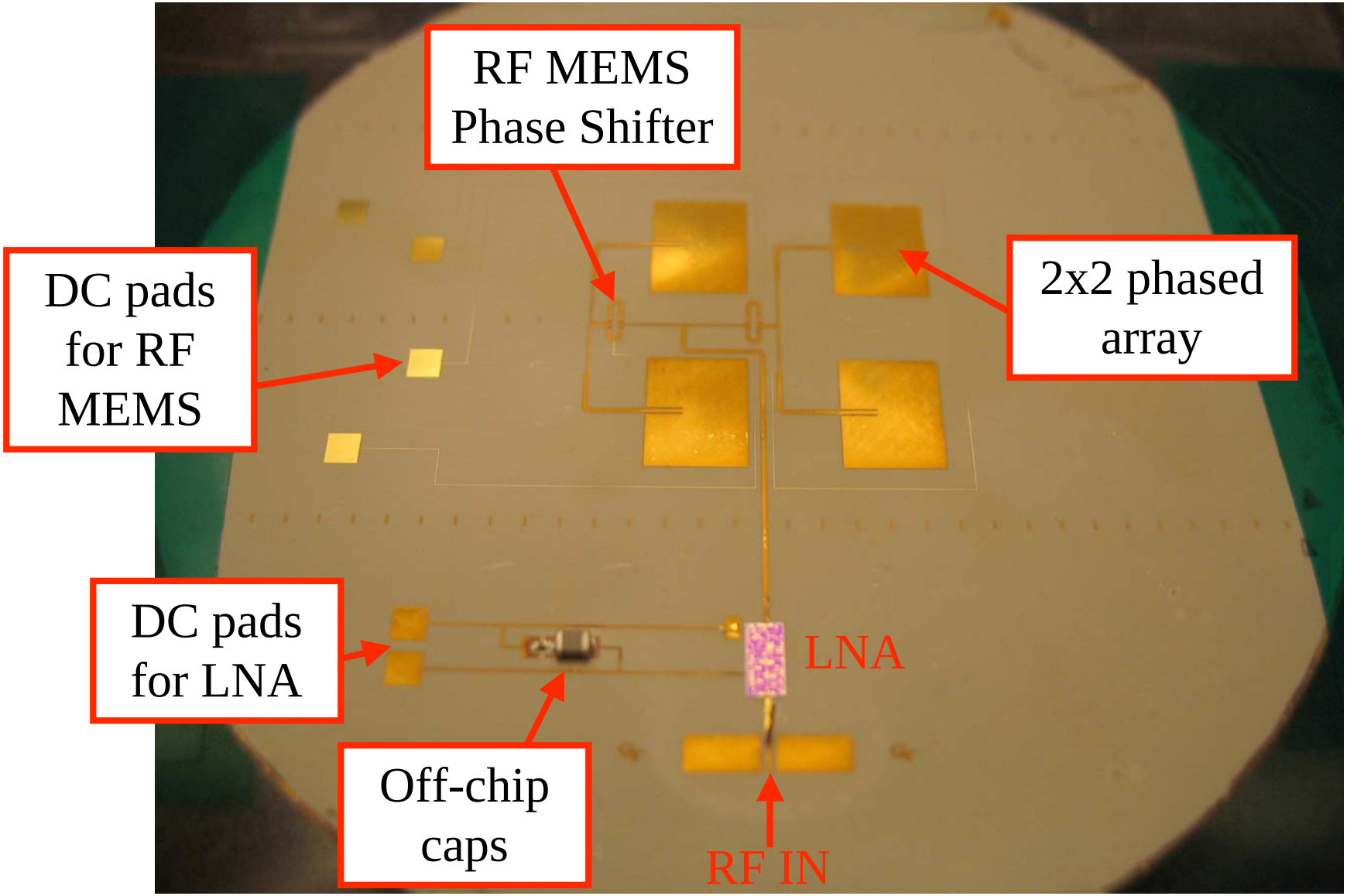
Bottom Layer
(Features on backside)

LNA Package Layer

LNA Cap Layer

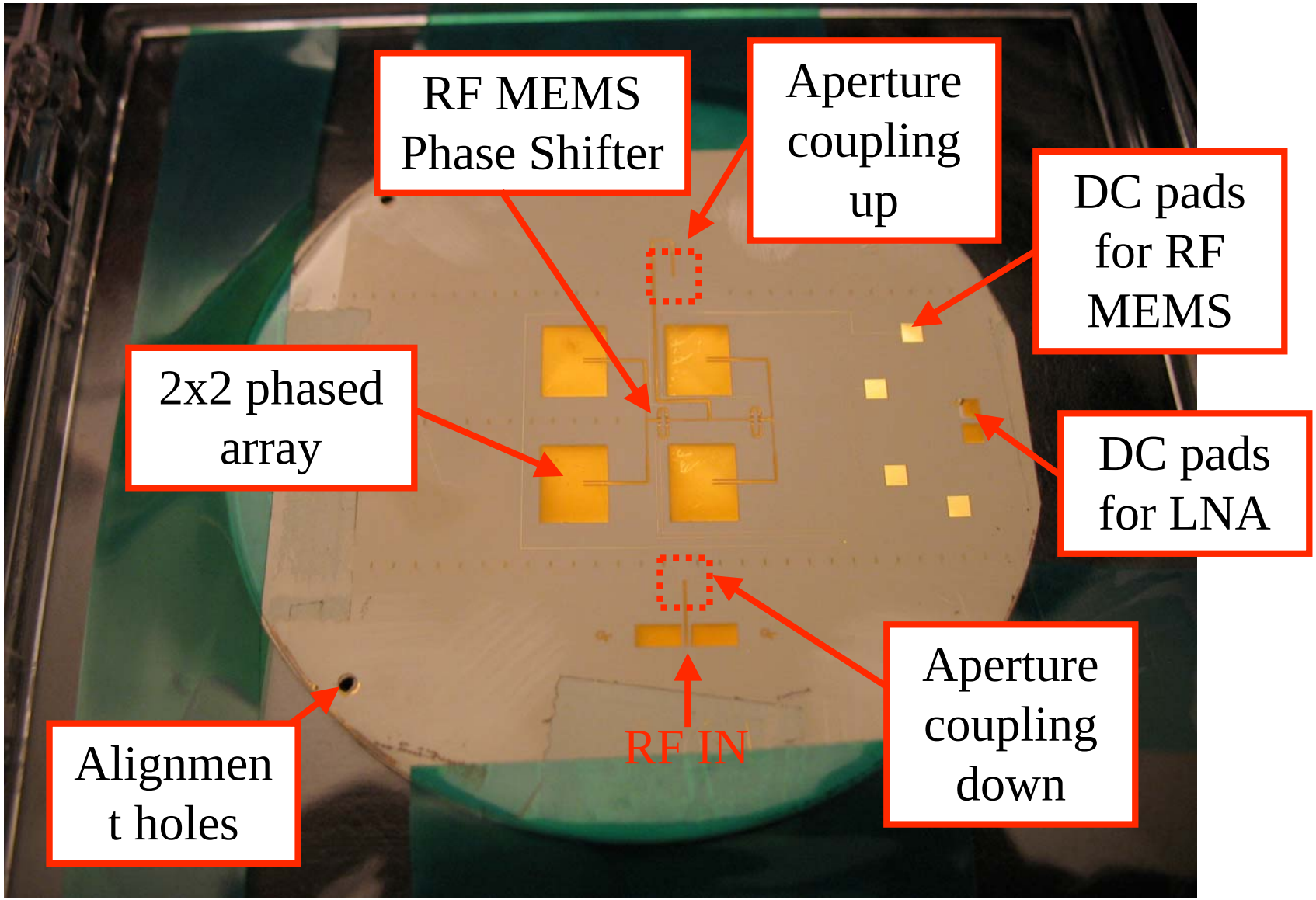


Fist Design Photo



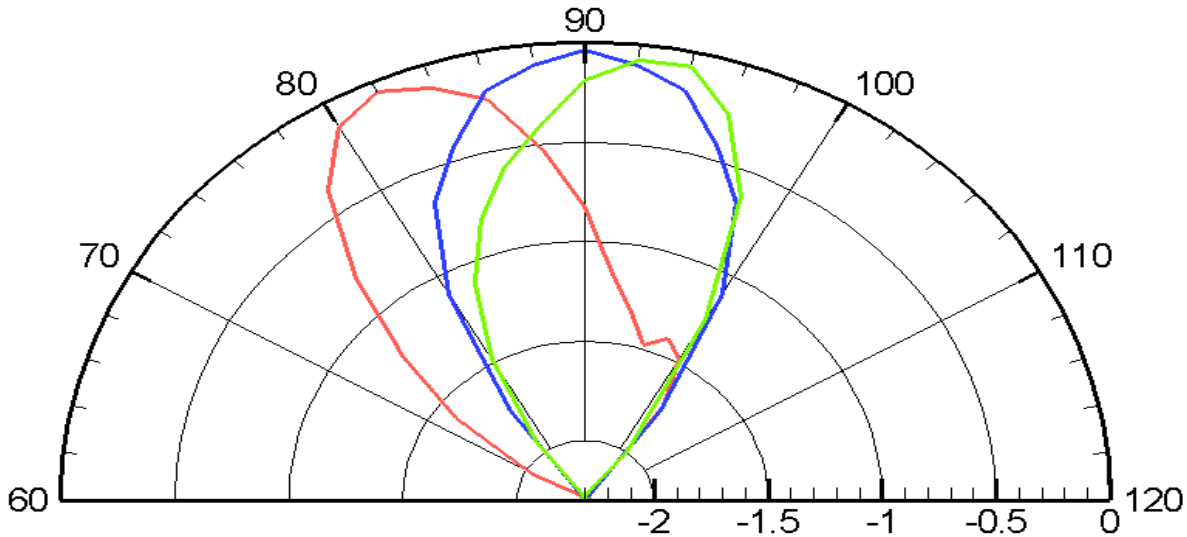
N. Kingsley, G. Ponchak and J. Papapolymerou, "Reconfigurable RF MEMS Communication Module on LCP Substrate," *IEEE Transactions on Antennas and Propagation, January 2008*

Second Design Photo



The LNA and off-chip capacitors are located on an embedded layer. They are fed via aperture coupling.

Radiation Patterns (Design#1)



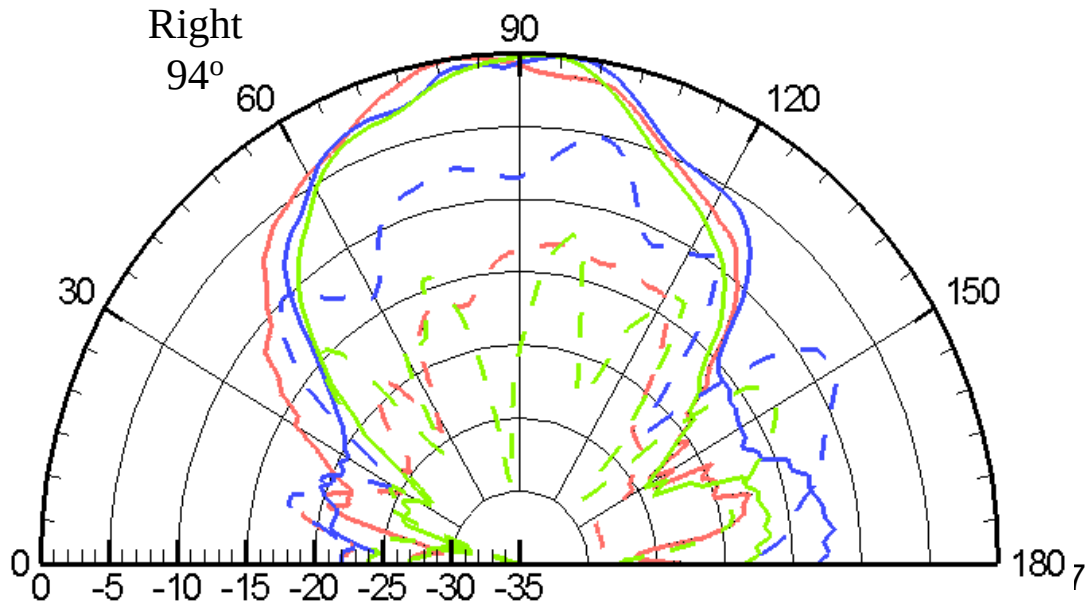
Measured Antenna Efficiency ~ 80%

Left
82°

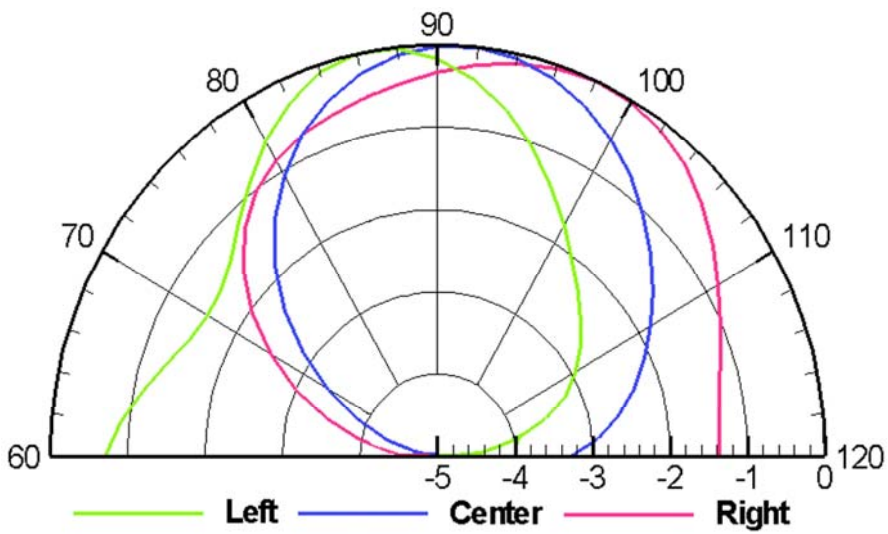
Center
90°

Right
94°

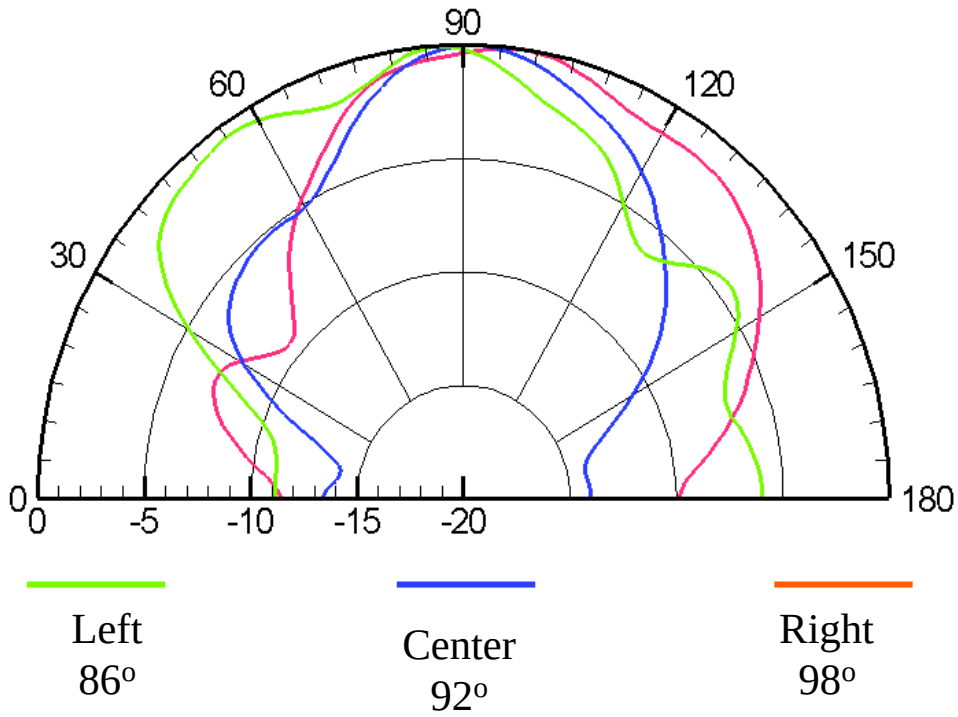
Beam Steering Range: 12 degrees



Radiation Patterns (Design#2)



Beam Steering Range: 12 degrees



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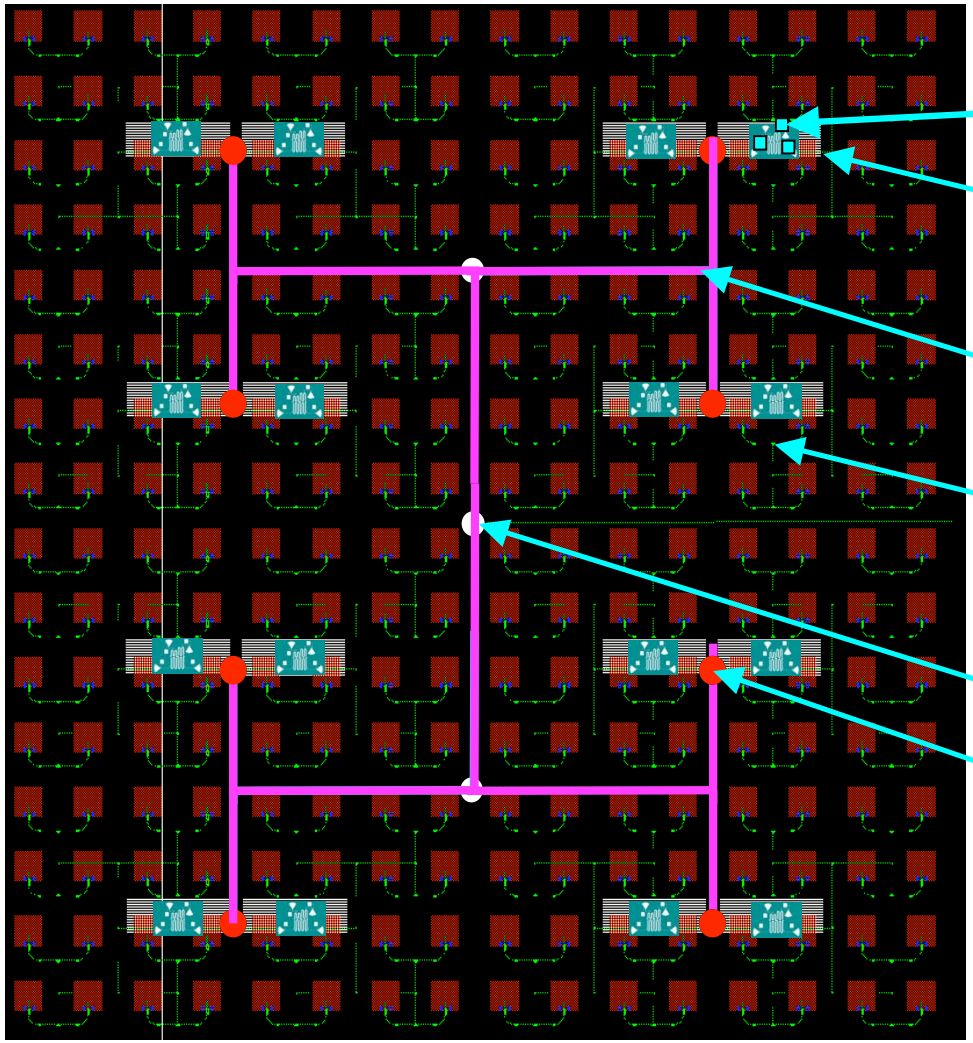
Complete Phased Array Layout



DC bias pads and holes down to the bottom substrate

Space for passives (21 x 5 mm^2)

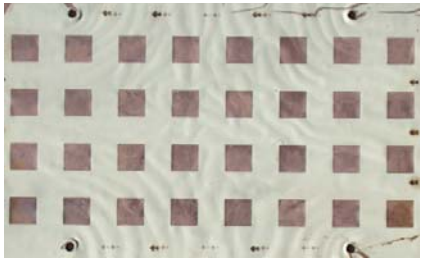
Exposed (bottom) feed lines

Embedded feed lines

Main feed point

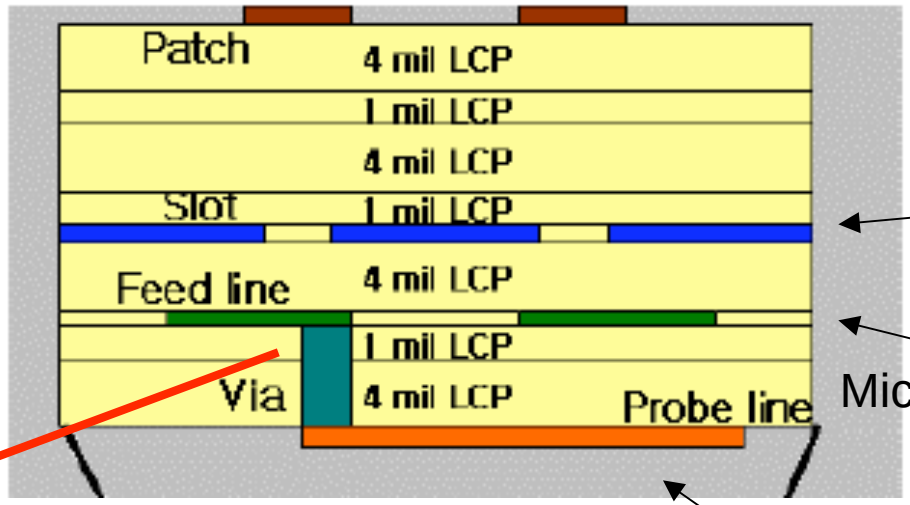
Vias from bottom LCP to embedded substrate

Cross-Sectional View of stitched 4x8 structure



Patch Radiator

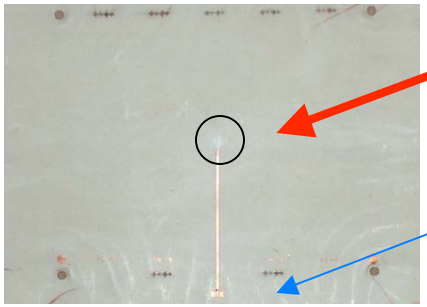
Patch radiator



Ground plane

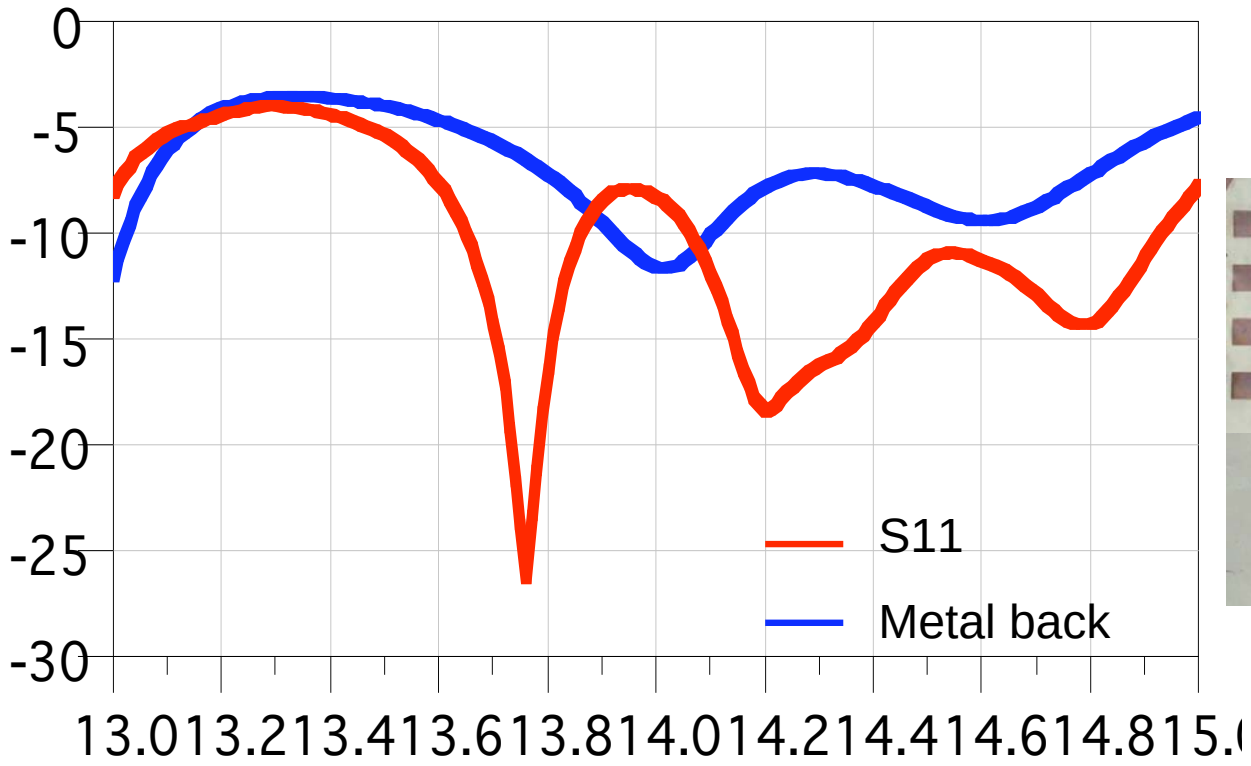
Microstrip line #1

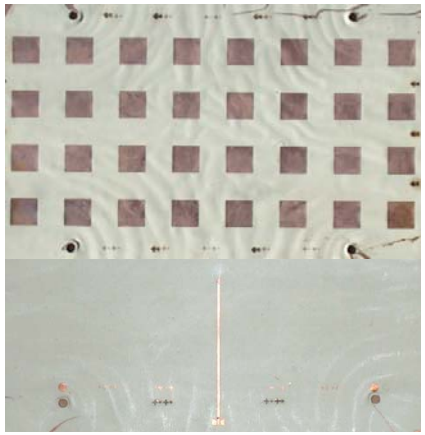
Microstrip line #2



Microstrip to CPW transition
Via is sputtered 5 micron Copper

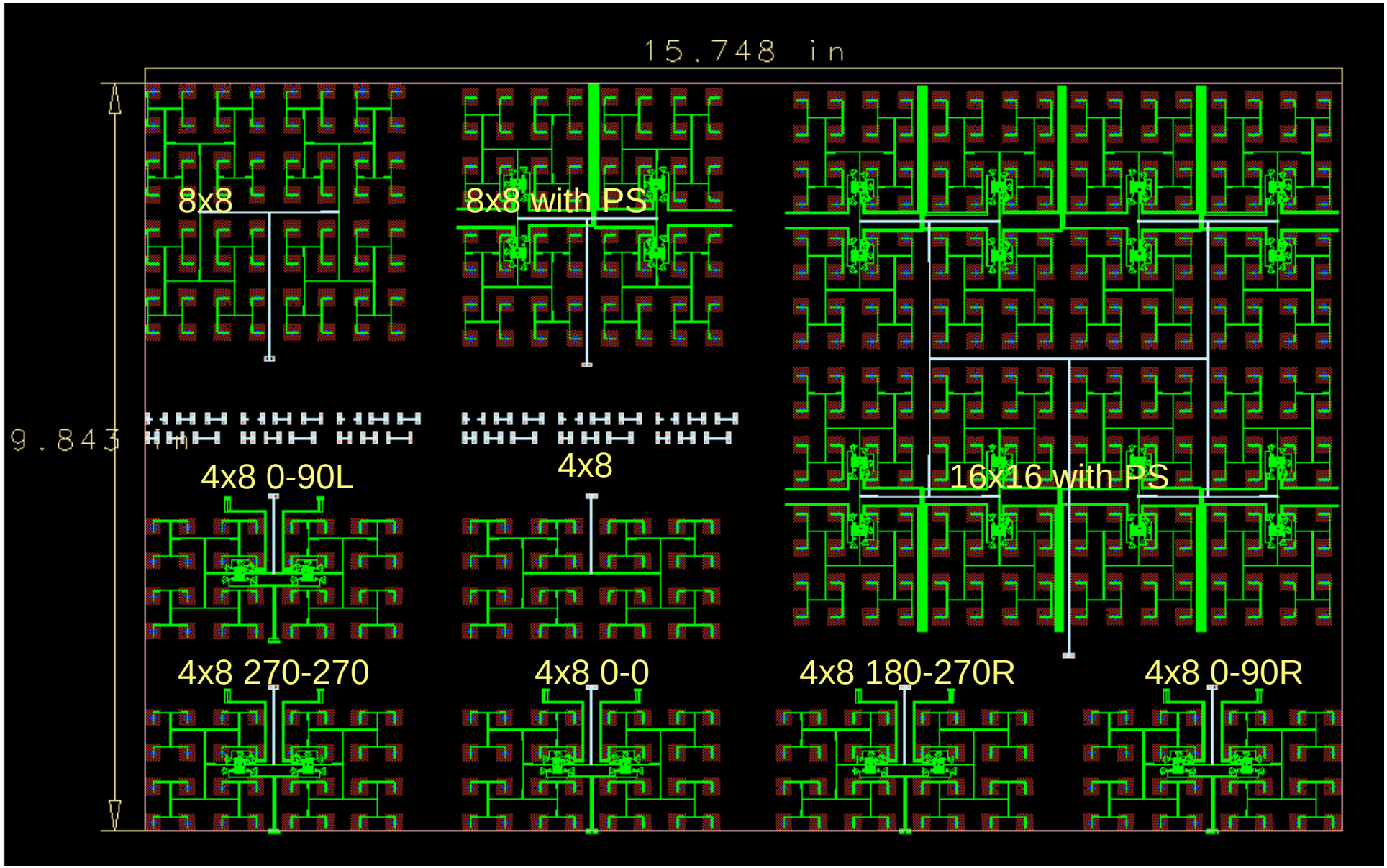
GIT Fabricated Stitched 4X8 Array



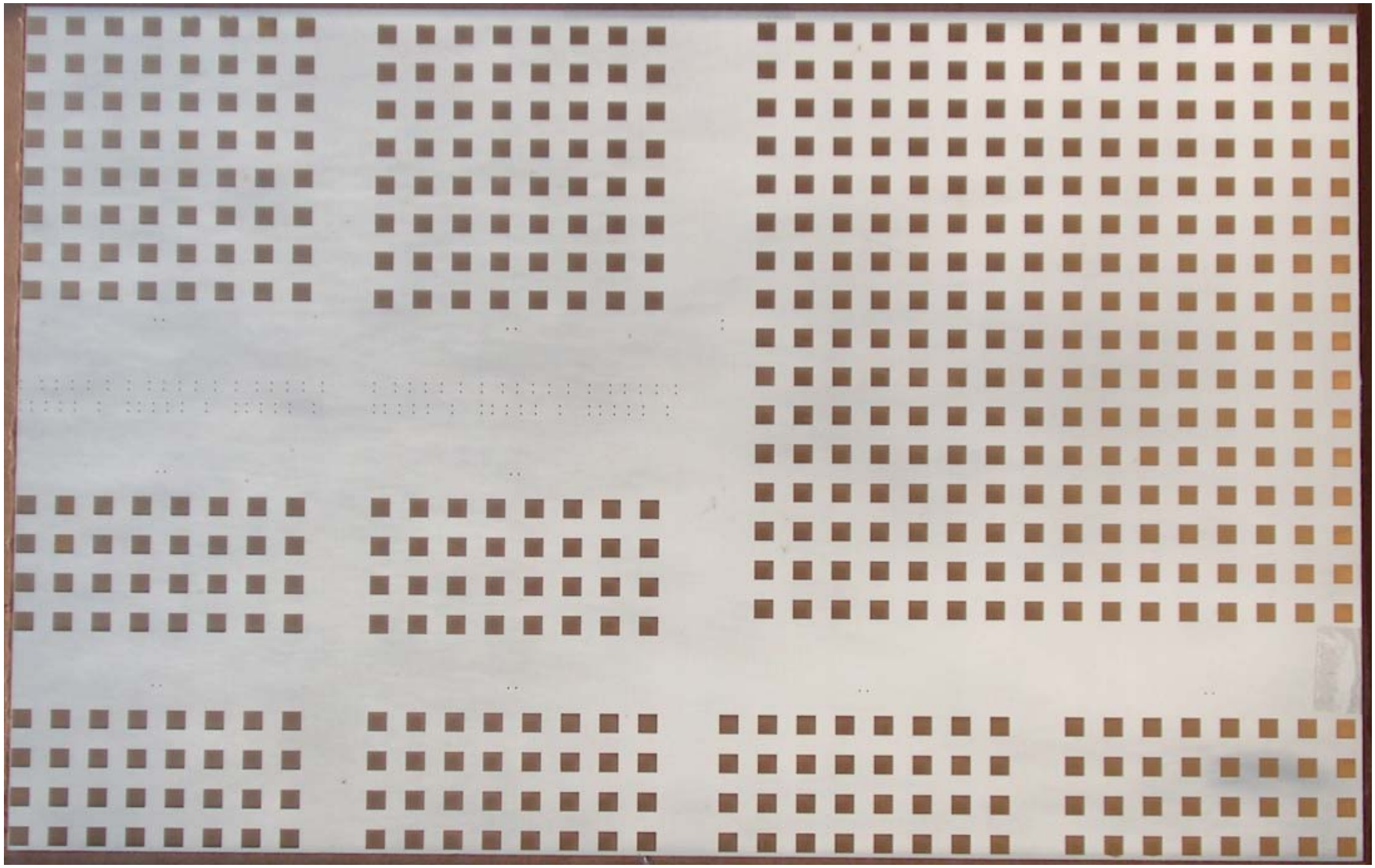


Resonance at 13.75 GHz is suppressed by metal grounding

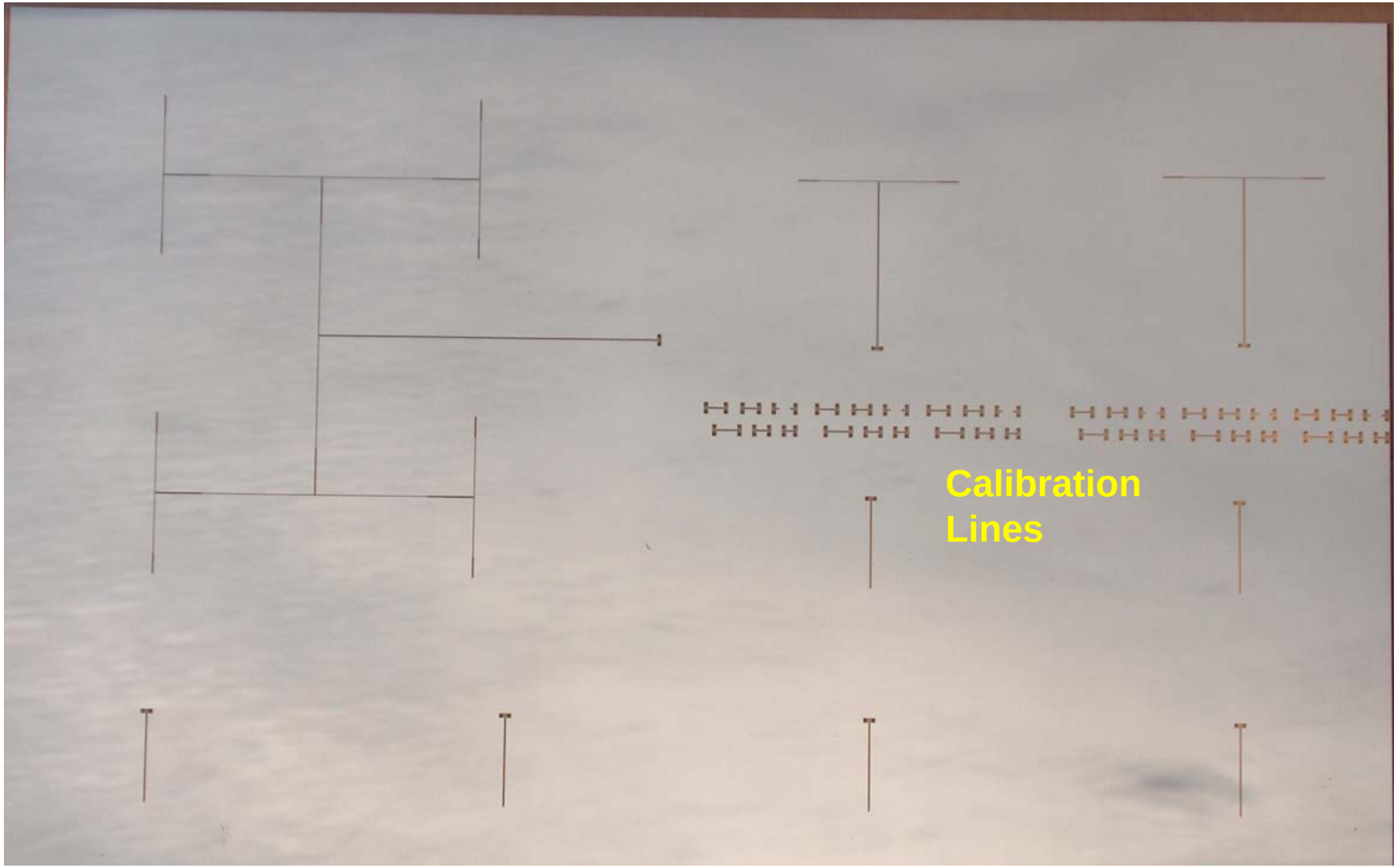
Design and Layout of Large Panel



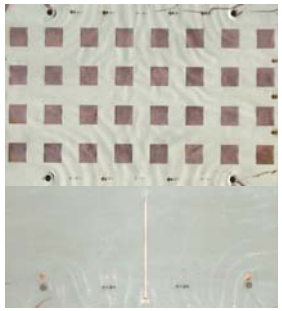
Metro Circuit Fabricated Panel
- Patch Radiator Side



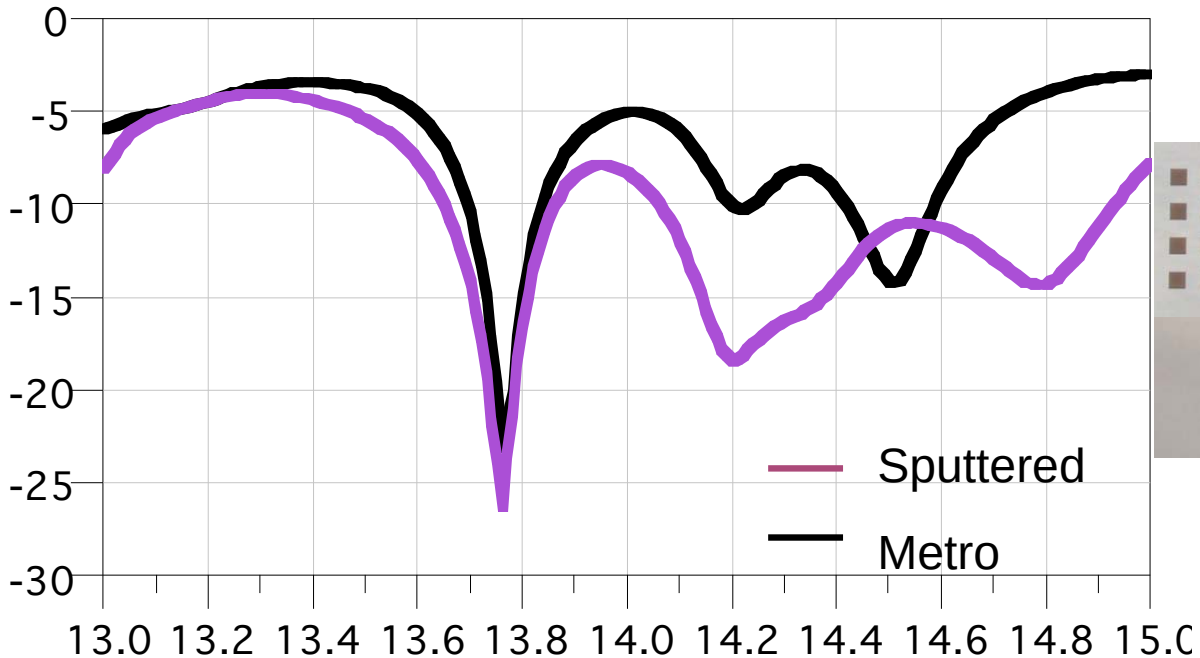
Metro Circuit Fabricated Panel
- CPW transition through plated vias

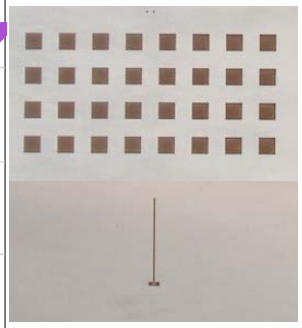


Metro Circuit Fabricated Panel vs GIT Fabricated 4x8 array



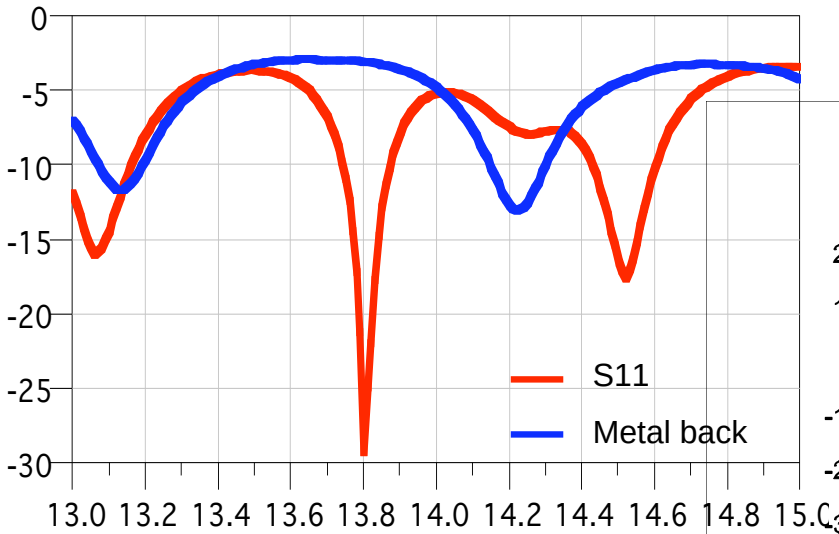
GIT Fab

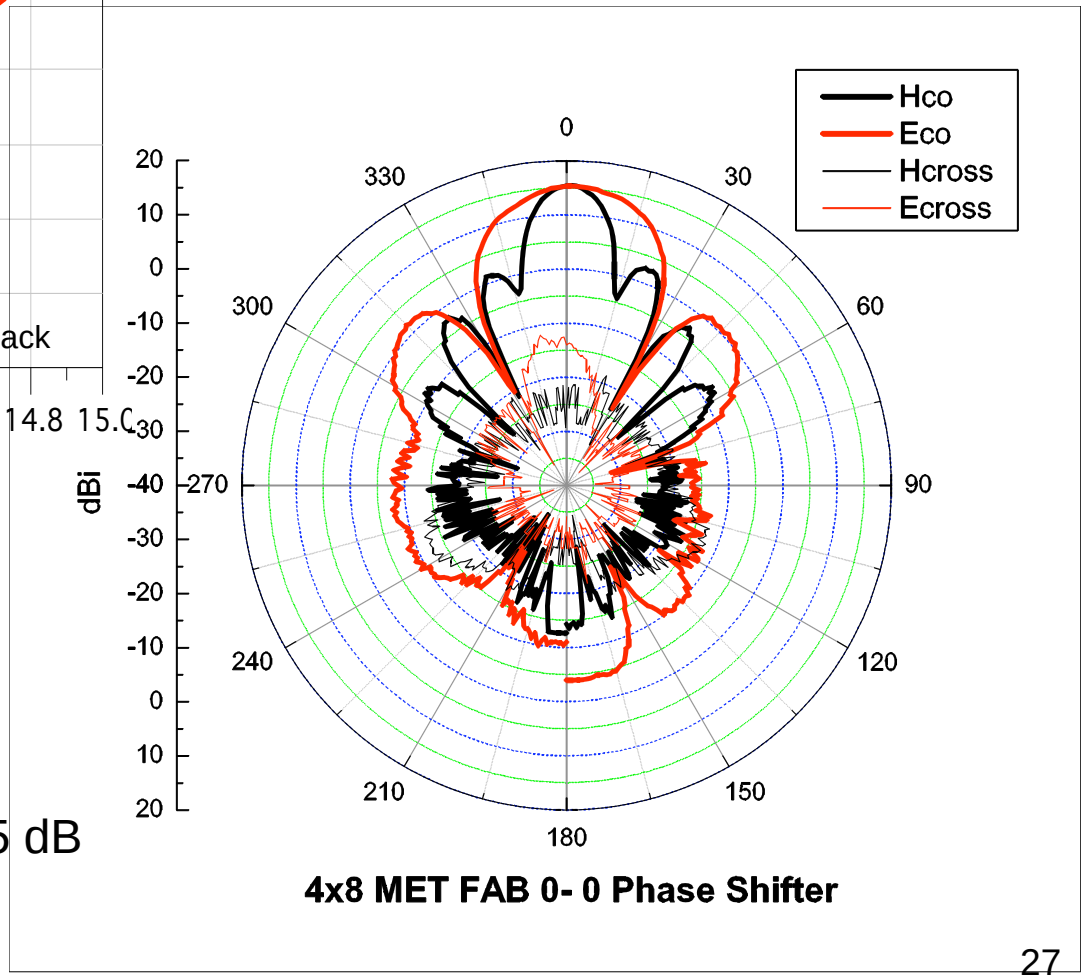




Metro Fab

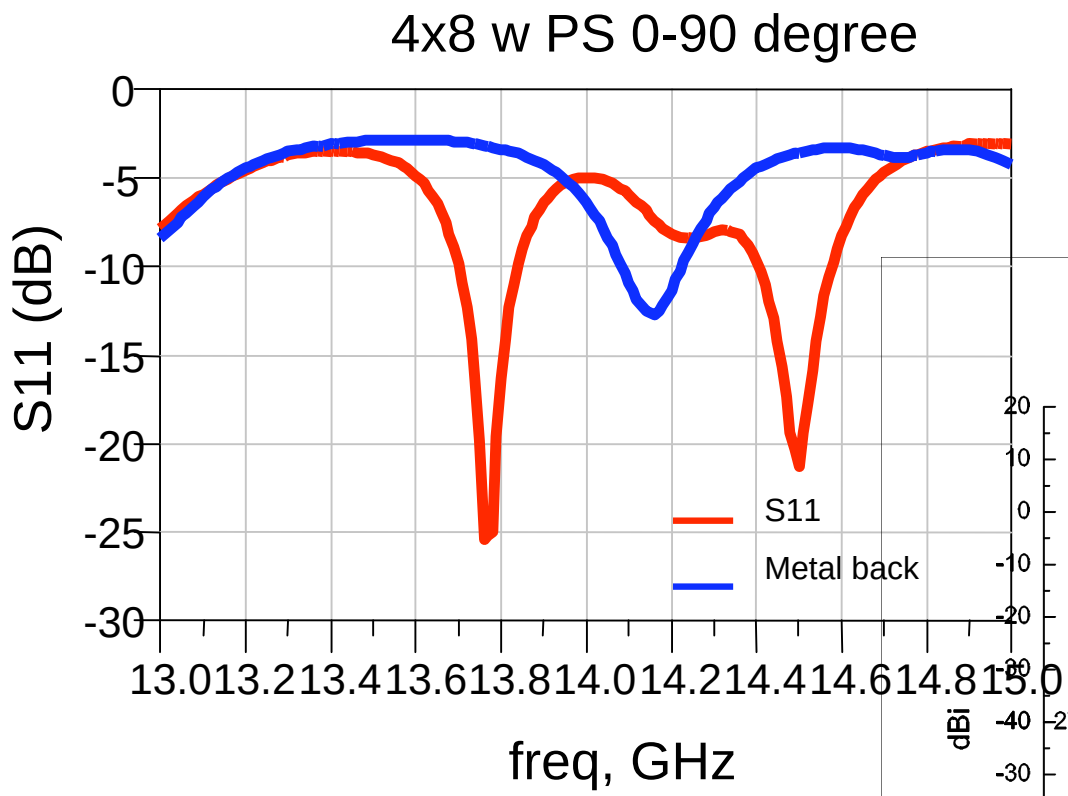
Metro Circuit Fabricated Panel
4x8 with Phase Shifter 0-0 Degree

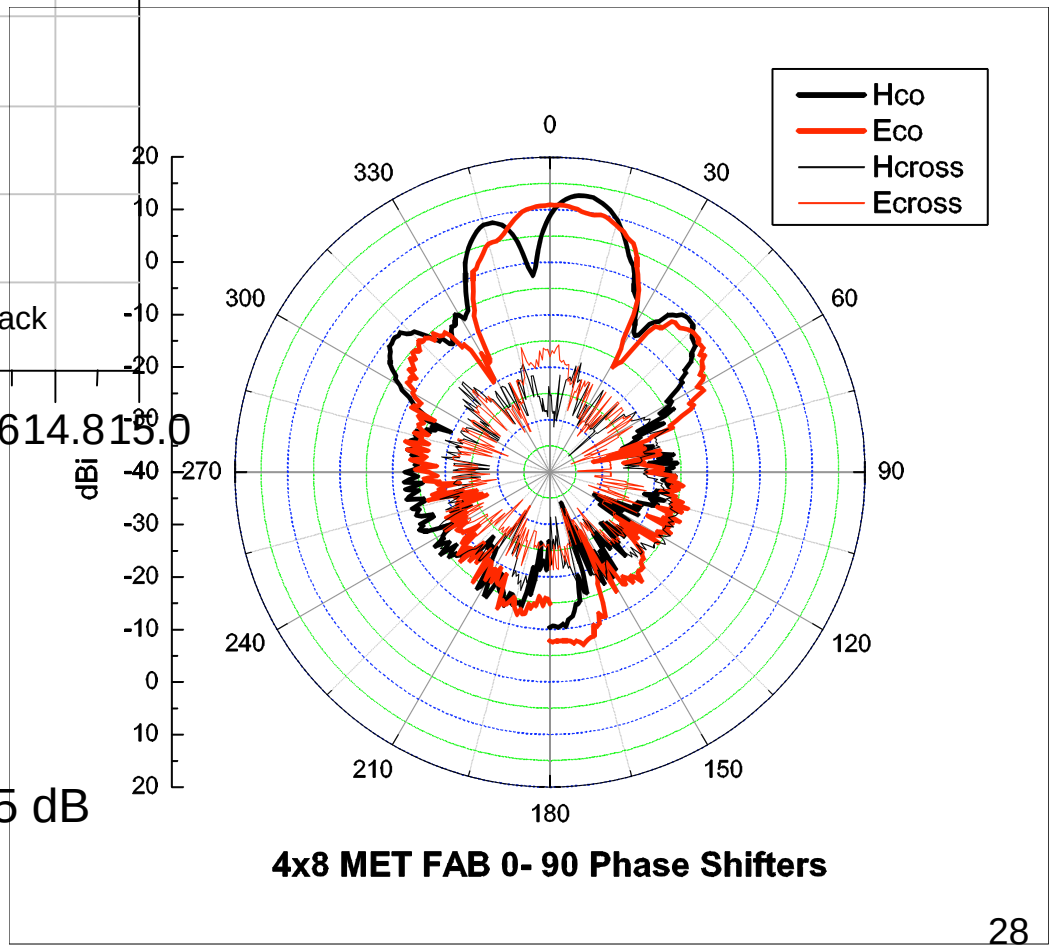




Gain ~ 15 dB

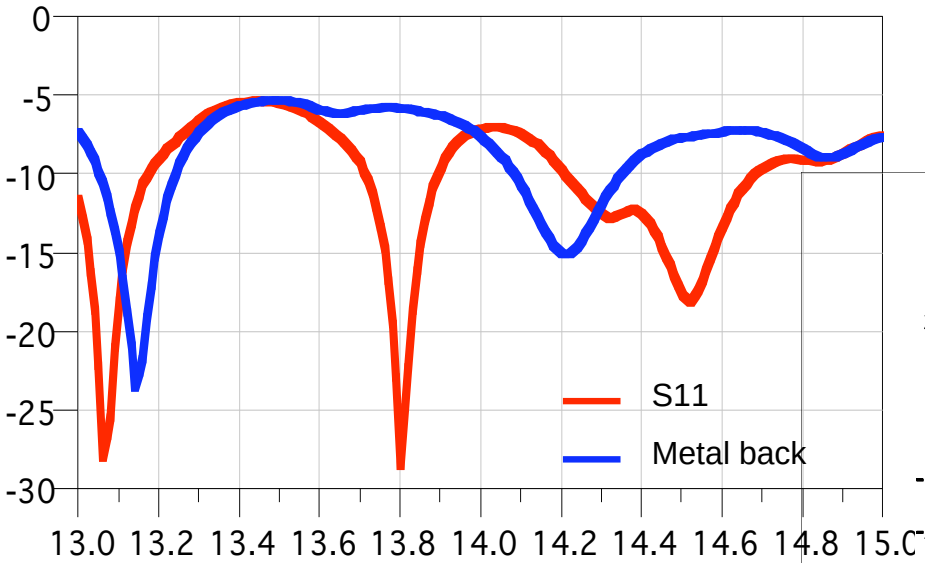
Metro Circuit Fabricated Panel
4x8 with Phase Shifter 0-90 Degree

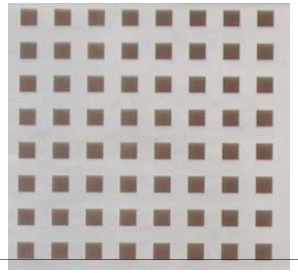


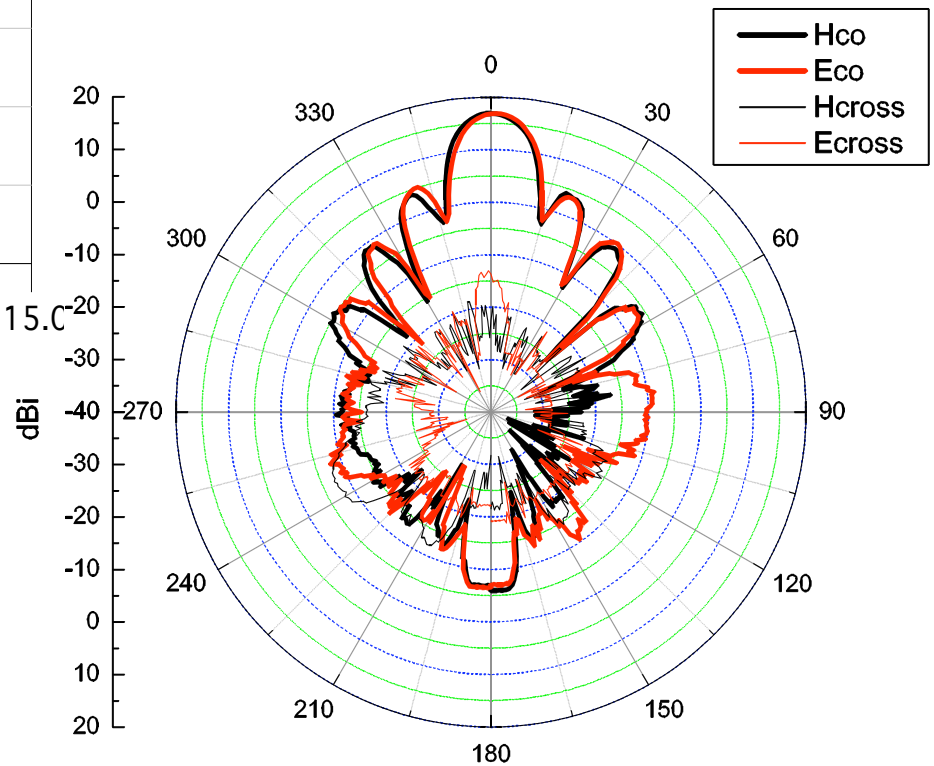


Gain ~ 14.5 dB

Metro Circuit Fabricated Panel 8x8 with Phase Shifter 0-0 Degree







8x8 MET FAB w/ 0degree Phase Shifters

Gain ~ 17 dB

Conclusions

- LCP provides technology platform for low cost multilayer low loss microwave circuits (f>10 GHz)
- Packaged RF MEMS switches and low loss phase shifters (1 dB at 14 GHz) have been developed for the first time
- First demonstration of a low loss 14 GHz phased array LCP RF module with amplifier and RF MEMS phase shifters (12 degrees steering)
- Development of low loss stitching technique for multilayer large arrays above 10 GHz
- Very encouraging results for stitched 4x8 and 8x8 sub-arrays at 14 GHz
- Feeding network design very important for overall loss minimization