SAND2012-2960C

Antenna Array Devised for Amplifier Integration

Planar Antenna Development

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Principal Member of Technical Staff

Sandia National Laboratories

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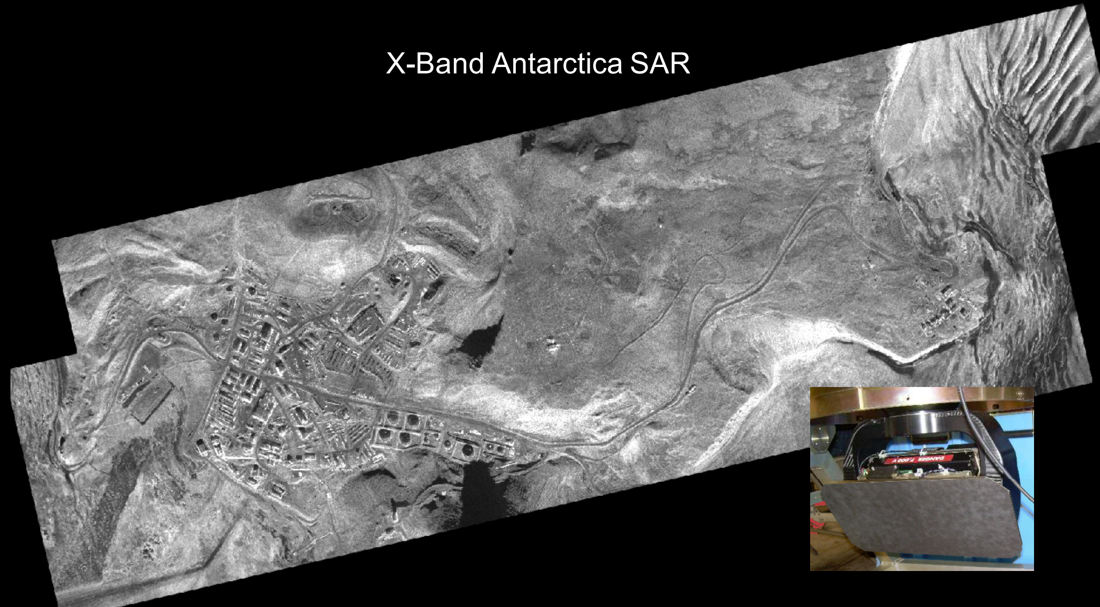
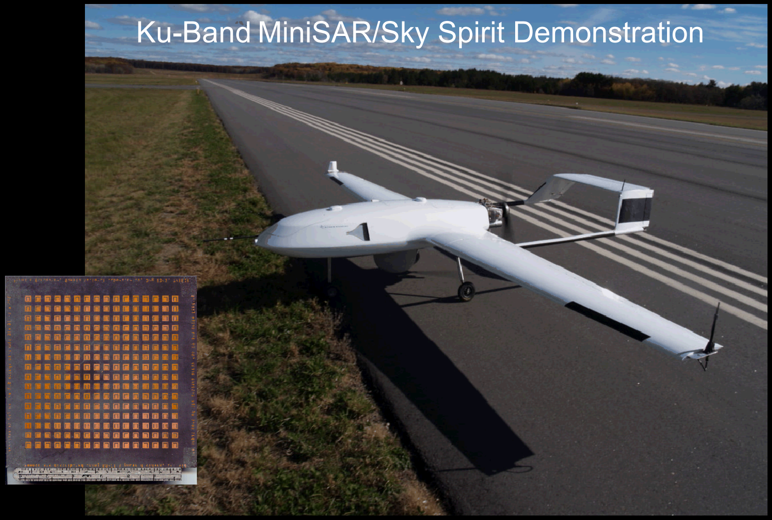
Overview

- ❑Statement of objectives
- ❑Amplifier/array integration for overcoming feed losses
  - ❑ Concept of irregular subarray topology
  - ❑ Attenuator-less tapering on transmit for low sidelobes
- ❑Ongoing integrated amplifier/array design
  - ❑ Design Layout
  - ❑ Calculated and simulated performance

Current Sandia SAR Programs Using Passive Patch Arrays

X-Band Antarctica SAR





Ku-Band MiniSAR/Sky Spirit Demonstration

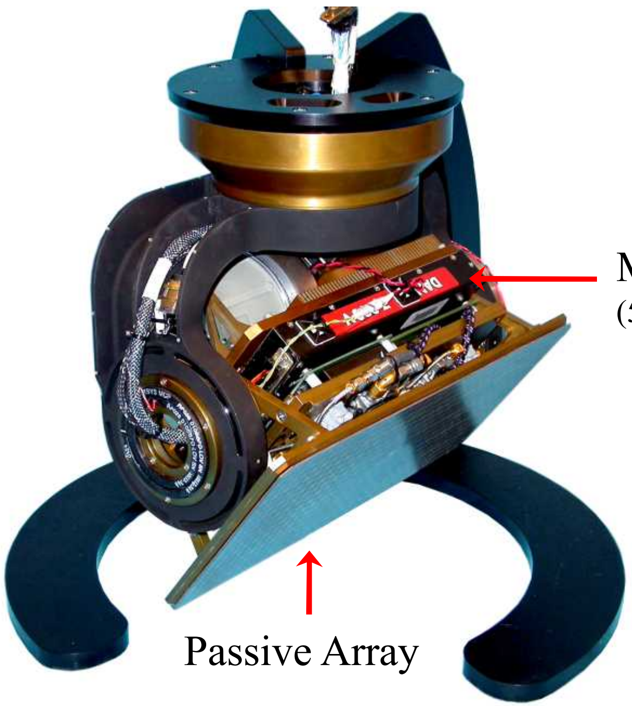
Ku-Band MiniSAR

Non-Steered Amplifier/Array Integration Objectives

Objectives

- Overcome feed network losses by integrating amplifiers within the array's aperture
- Instantaneous bandwidth from 15.2 GHz to 18.2 GHz
- Design array such that all respective amplifiers have the same part numbers
- Operate all power amplifiers in saturation to mitigate any temperature variability
- Use aperture taper in order to achieve ~30 dB sidelobes on both transmit and receive
- Realize aperture taper using an irregular subarray approach that avoids using attenuators
- Improve construction and performance reliability by avoiding via interconnects
- Allow for monopulse capability

Replacing Microwave Power Module (MPM)



Goal:

Replace MPM/Passive array combination with the proposed Amplifier-Array without sacrificing performance. The MPM is large, bulky, and usually the first system component to fail.

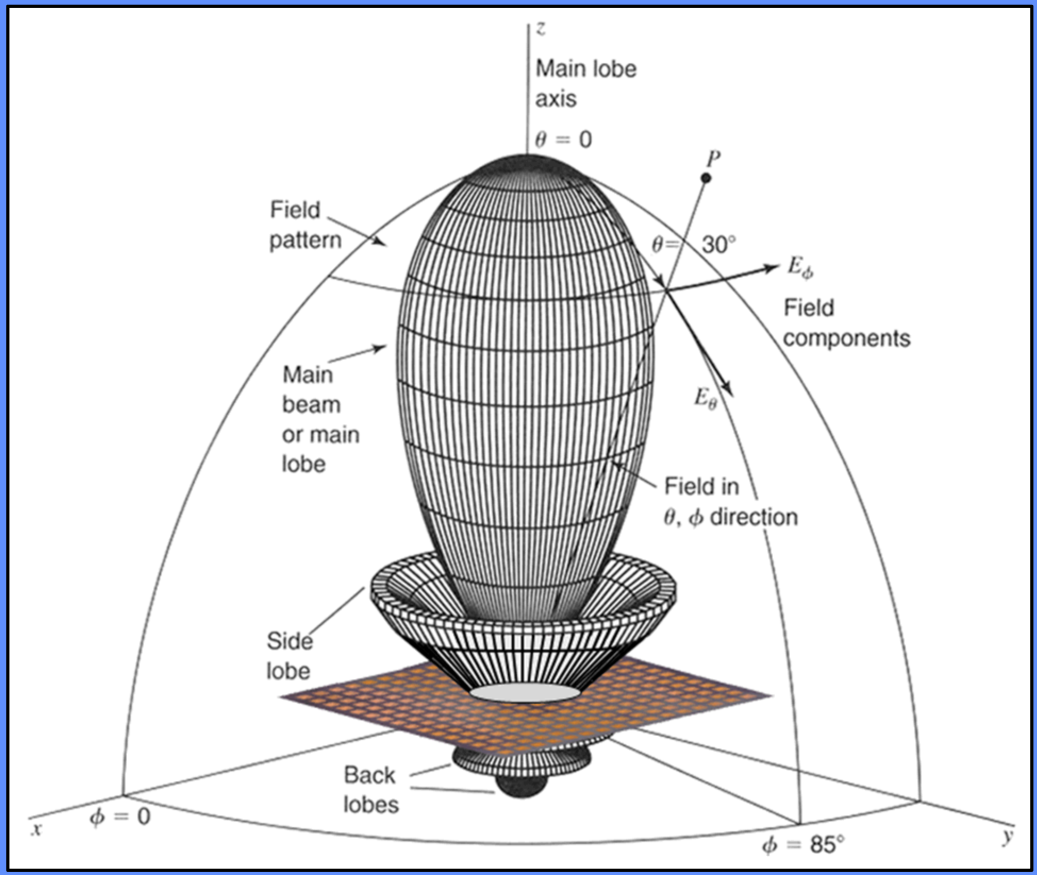
Why Use Irregular Subarrays?

300 W of available DC Power
used to power all
onboard system components

Why?

Small UAVs have limited onboard DC source power. Irregular subarrays realize aperture taper, notably on transmit, without using attenuators. Attenuators would waste lots of RF, erstwhile DC, power.

Pattern Orientations for Subsequent Plots



[1] Kraus, J. D. and Marhefka, R. J., [Antennas], McGraw-Hill, Boston, 14 (2002).

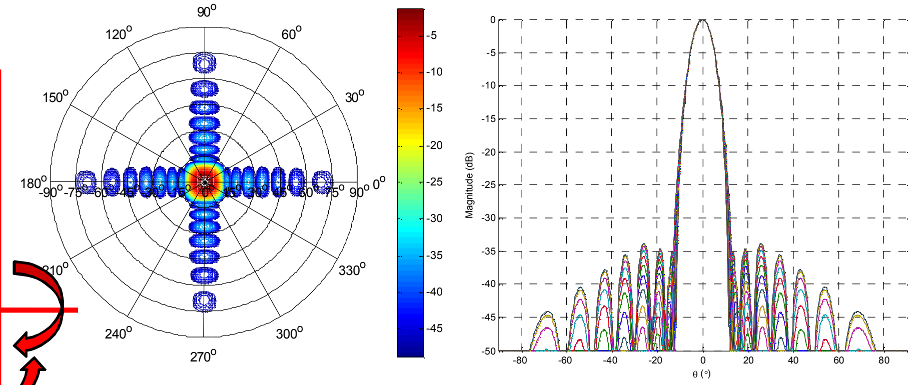
Irregular Subarray Concept

Array Diagrams and Calculated Patterns

Array Patterns with Single Element Rolloff

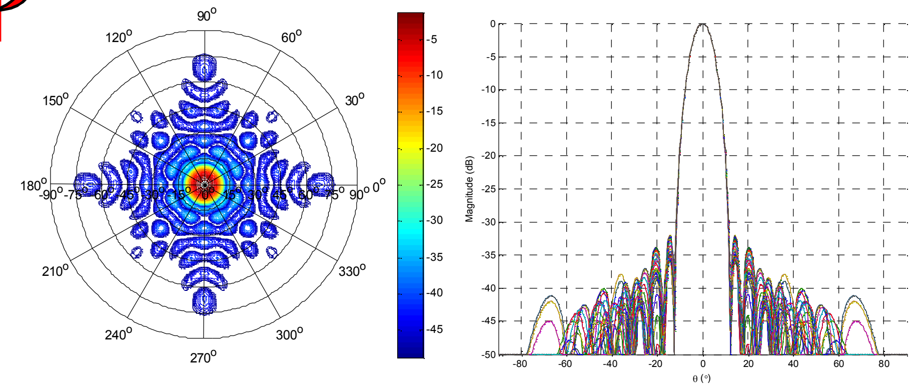
No Corner Truncation (35 dB Taylor)

0.0017	0.0031	0.0066	0.0128	0.0212	0.0301	0.0375	0.0417
0.0031	0.0056	0.0119	0.0230	0.0381	0.0541	0.0675	0.0750
0.0066	0.0119	0.0253	0.0488	0.0807	0.1147	0.1430	0.1590
0.0128	0.0230	0.0488	0.0943	0.1558	0.2216	0.2762	0.3070
0.0212	0.0381	0.0807	0.1558	0.2575	0.3662	0.4566	0.5075
0.0301	0.0541	0.1147	0.2216	0.3662	0.5208	0.6493	0.7217
0.0375	0.0675	0.1430	0.2762	0.4566	0.6493	0.8095	0.8997
0.0417	0.0750	0.1590	0.3070	0.5075	0.7217	0.8997	1.0000



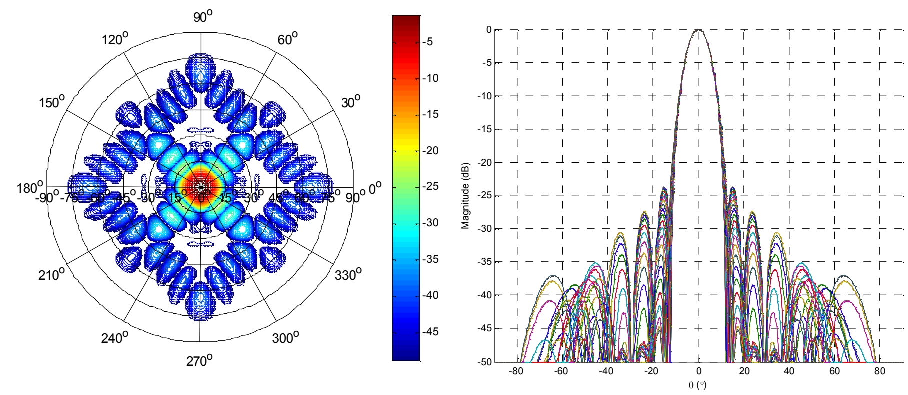
12 x 4 Corner Elements Removed

0	0	0	0	0.0212	0.0301	0.0375	0.0417
0	0	0	0	0.0381	0.0541	0.0675	0.0750
0	0	0.0253	0.0488	0.0807	0.1147	0.1430	0.1590
0	0	0.0488	0.0943	0.1558	0.2216	0.2762	0.3070
0.0212	0.0381	0.0807	0.1558	0.2575	0.3662	0.4566	0.5075
0.0301	0.0541	0.1147	0.2216	0.3662	0.5208	0.6493	0.7217
0.0375	0.0675	0.1430	0.2762	0.4566	0.6493	0.8095	0.8997
0.0417	0.0750	0.1590	0.3070	0.5075	0.7217	0.8997	1.0000



24 x 4 Corner Elements Removed

0	0	0	0	0	0	0.0375	0.0417
0	0	0	0	0	0	0.0675	0.0750
0	0	0	0	0.0807	0.1147	0.1430	0.1590
0	0	0	0	0.1558	0.2216	0.2762	0.3070
0	0	0.0807	0.1558	0.2575	0.3662	0.4566	0.5075
0	0	0.1147	0.2216	0.3662	0.5208	0.6493	0.7217
0.0375	0.0675	0.1430	0.2762	0.4566	0.6493	0.8095	0.8997
0.0417	0.0750	0.1590	0.3070	0.5075	0.7217	0.8997	1.0000



Radial symmetry will produce the best SLLs.

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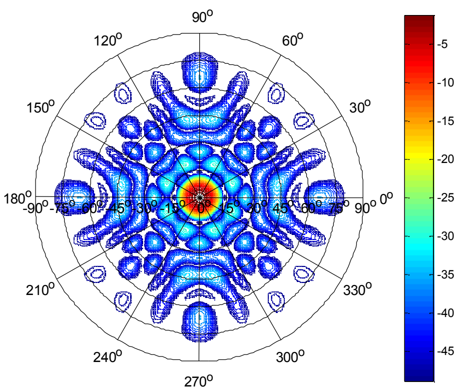
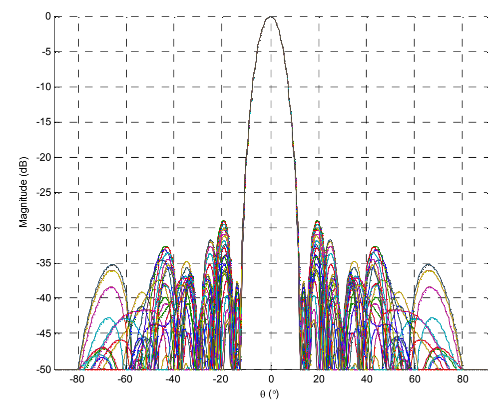
Array Patterns with Single Element Rolloff

Irregular Subarray Approach

$$0.0625\left(2^{n-1}\right),\quad n=1,2,3,4,5$$

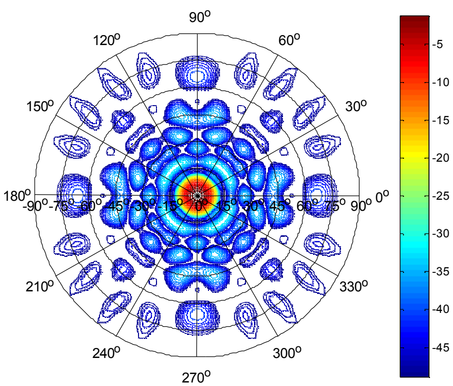
0	0	0	0	0.0625	0.0625	0.0625	0.0625
0	0	0	0	0.0625	0.0625	0.0625	0.0625
0	0	0.0625	0.0625	0.0625	0.1250	0.1250	0.1250
0	0	0.0625	0.0625	0.1250	0.2500	0.2500	0.2500
0.0625	0.0625	0.0625	0.1250	0.2500	0.2500	0.5000	0.5000
0.0625	0.0625	0.1250	0.2500	0.2500	0.5000	0.5000	0.5000
0.0625	0.0625	0.1250	0.2500	0.5000	0.5000	1.0000	1.0000
0.0625	0.0625	0.1250	0.2500	0.5000	0.5000	1.0000	1.0000

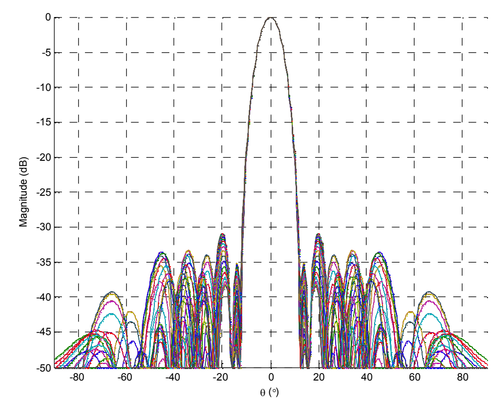




$$0.0625\left(2^{n-1}\right),\quad n=1,2,3,4,5$$

0	0	0	0	0	0.0625	0.0625	0.0625
0	0	0	0	0.0625	0.0625	0.0625	0.0625
0	0	0.0625	0.0625	0.0625	0.1250	0.1250	0.1250
0	0	0.0625	0.0625	0.1250	0.2500	0.2500	0.2500
0	0.0625	0.0625	0.1250	0.2500	0.2500	0.5000	0.5000
0.0625	0.0625	0.1250	0.2500	0.2500	0.5000	0.5000	0.5000
0.0625	0.0625	0.1250	0.2500	0.5000	0.5000	1.0000	1.0000
0.0625	0.0625	0.1250	0.2500	0.5000	0.5000	1.0000	1.0000





All weights are now contained within unity subarrays.
Sidelobe radial symmetry has occurred.

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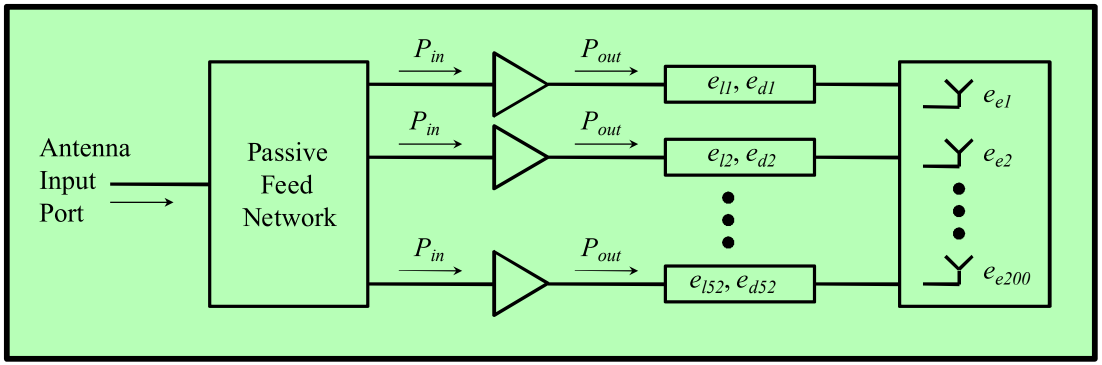
Including Post-Amplifier Subarray Losses



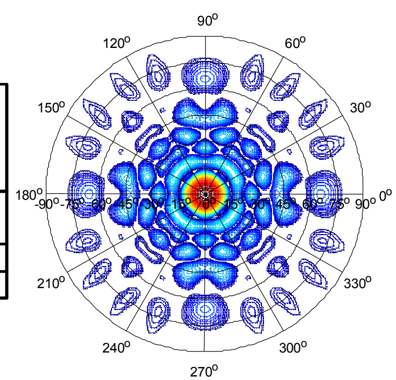
$$e_l = \left(10^{\frac{-|\alpha_l|}{10}}\right)^{\frac{\left[\frac{n_{Sex}-1}{2}\Delta x + \frac{n_{Sey}-1}{2}\Delta y\right]}{\lambda_0}}$$

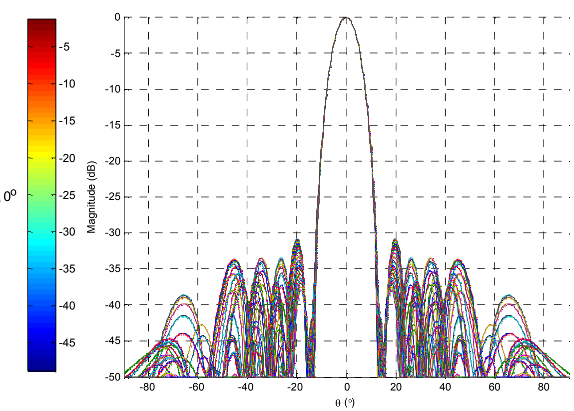
$$e_{Sa} = e_l e_d e_e$$

$$e_d = \left(10^{\frac{n_d L_d}{10}}\right)^{-1}$$

Including Divider and Line Losses

0	0	0	0	0	0.0527	0.0527	0.0527
0	0	0	0	0.0527	0.0527	0.0527	0.0527
0	0	0.0512	0.0512	0.0527	0.1055	0.1055	0.1055
0	0	0.0512	0.0512	0.1055	0.2110	0.2110	0.2110
0	0.0512	0.0512	0.1025	0.2110	0.2295	0.4742	0.4742
0.0512	0.0512	0.1025	0.2049	0.2295	0.4590	0.4742	0.4742
0.0527	0.0527	0.1055	0.2110	0.4742	0.4742	1.0000	1.0000
0.0527	0.0527	0.1055	0.2110	0.4742	0.4742	1.0000	1.0000





Radial symmetry is preserved.

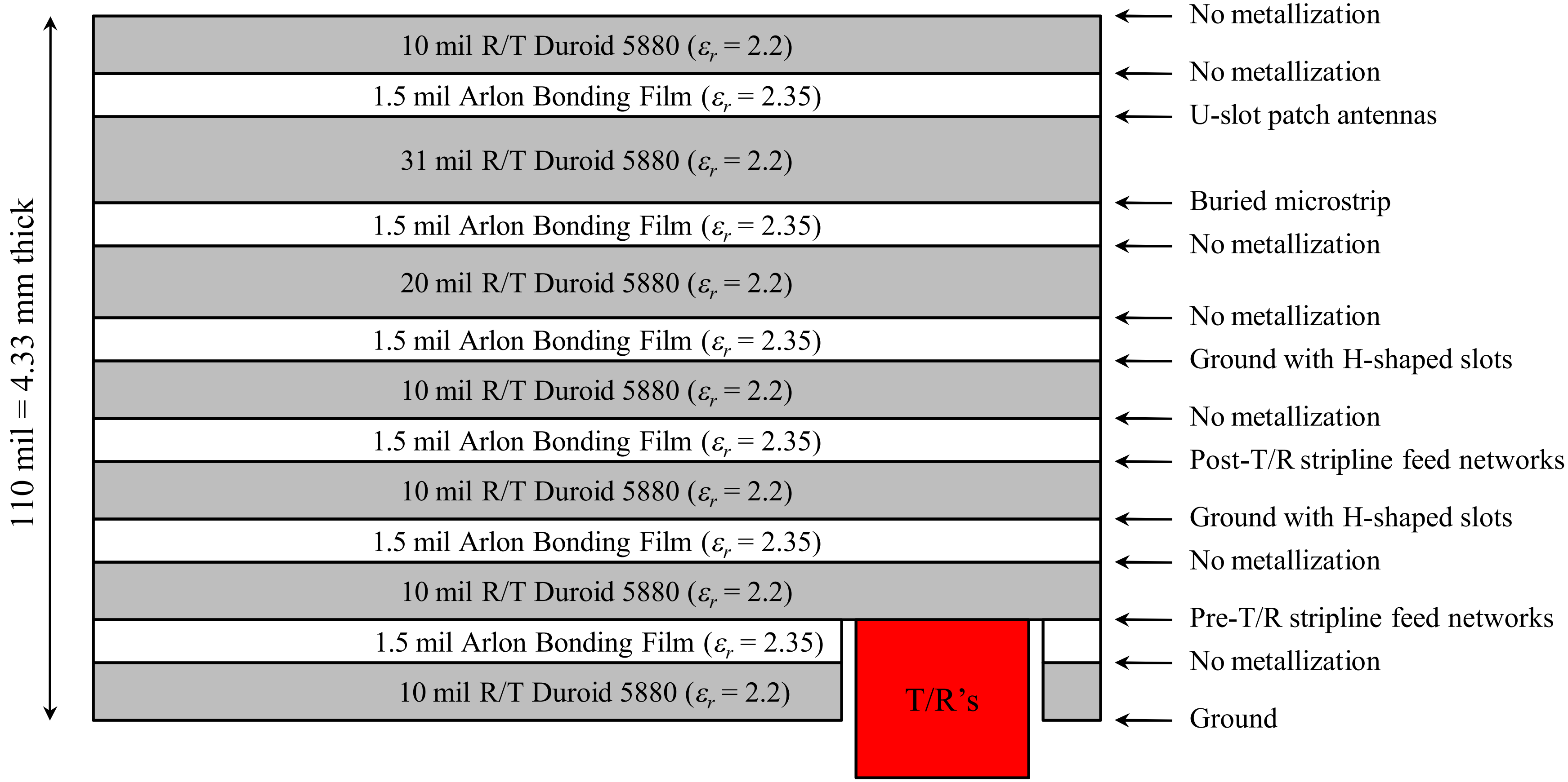
Irregular Subarray Conclusions

The irregular subarray approach allows for all same-part-numbered amplifiers to be operated at saturation under the same input drive levels and bias conditions. This means that temperature variations between the various amplifiers will be minimal, and the insertion phase and magnitude profiles over the 3 GHz of bandwidth will be similar. The amplifiers should all be driven at their 1 dB compression points to minimize any part-to-part fluctuations. Drain pulsing will also minimize DC power consumption.

Proposed Array Architecture

Layout and Simulation

Array Layer Stackup for Proposed Design



The 10 mil R/T Duroid 5880 substrate produces 50 Ω microstrip lines that are easily mated to the standard amplifier QFN packaging. The 10 mil substrates also allow for the stripline to be 50 Ω based.

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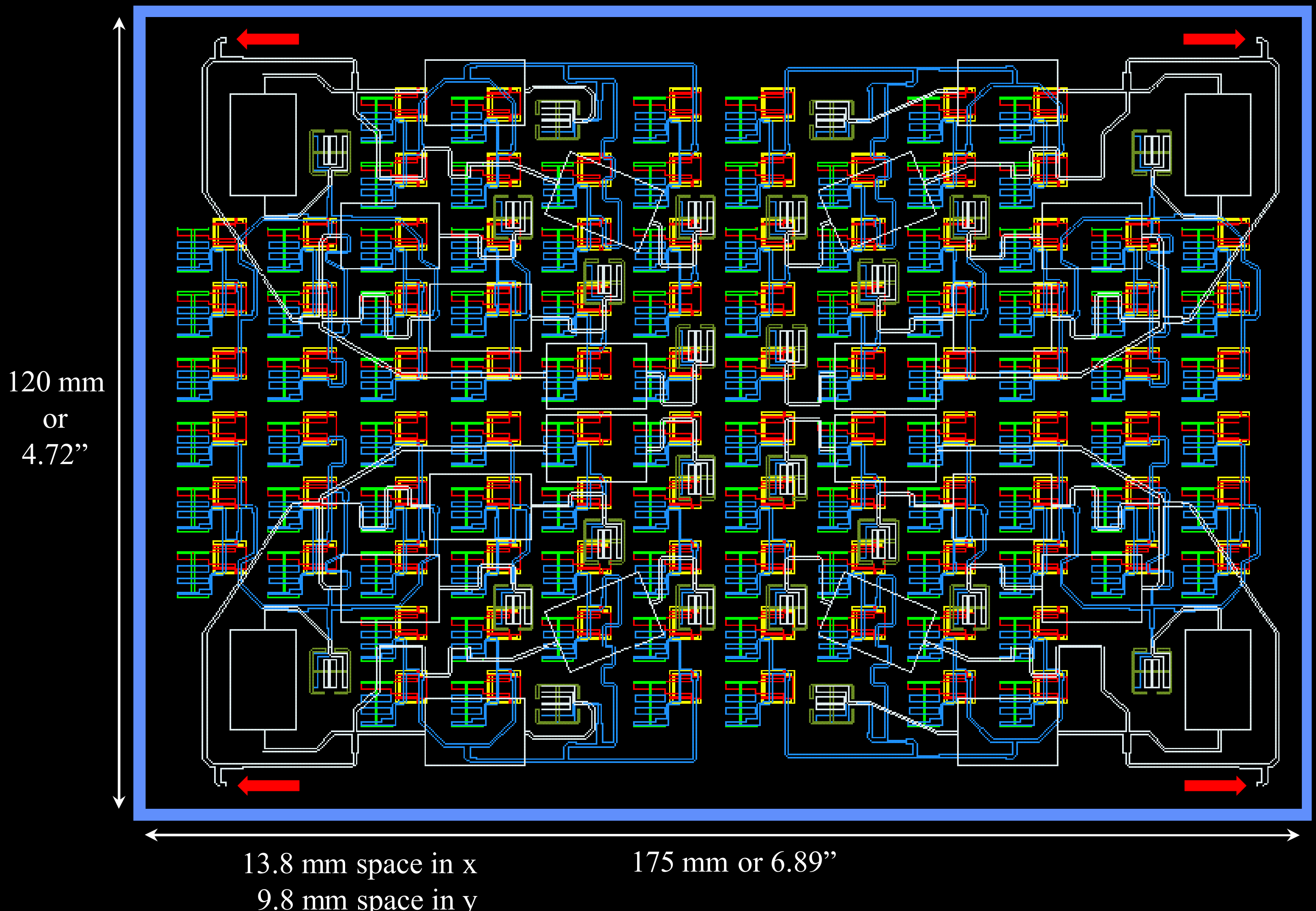
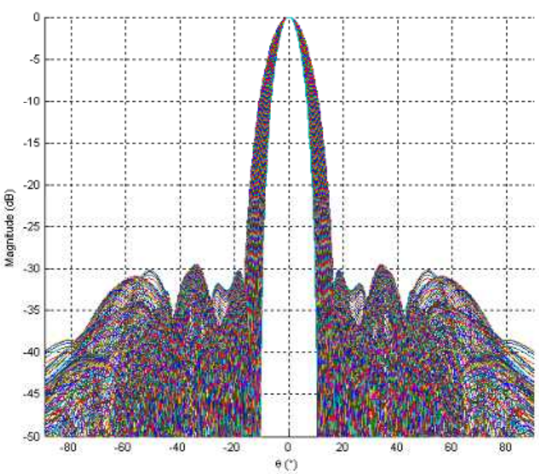
Array Architecture Oriented H-Polarized with Four Input Ports



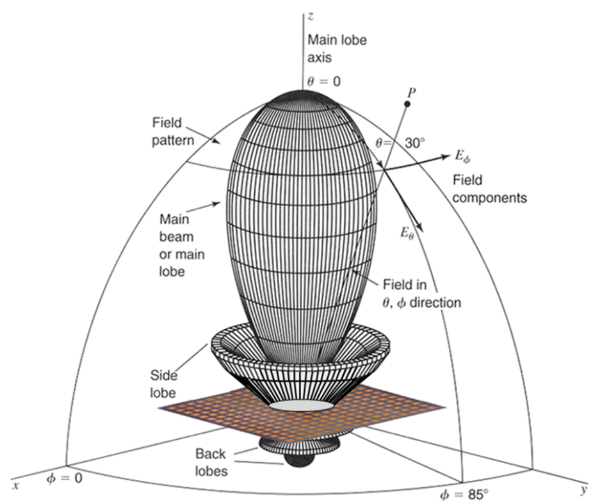
Power Weights and Associated Patterns

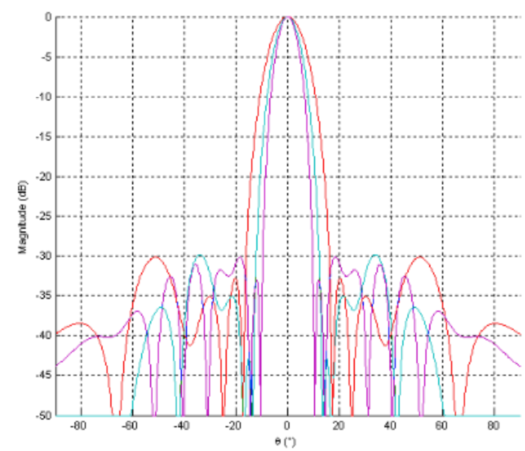
(Array Rotated 90° from Previous Slide)

0	0	0.0163	0.0163	0.0327	0.0327	0.0163	0.0163	0	0
0	0	0.0490	0.0490	0.0980	0.0980	0.0490	0.0490	0	0
0.0330	0.0330	0.1389	0.1389	0.2777	0.2777	0.1389	0.1389	0.0330	0.0330
0.0330	0.0330	0.1372	0.3201	0.4573	0.4573	0.3201	0.1372	0.0330	0.0330
0	0.2725	0.2725	0.4732	0.4732	0.4732	0.4732	0.2725	0.2725	0
0.0743	0.0743	0.4732	0.4732	1.0000	1.0000	0.4732	0.4732	0.0743	0.0743
0.0743	0.0743	0.4732	0.4732	1.0000	1.0000	0.4732	0.4732	0.0743	0.0743
0	0.2725	0.2725	0.4732	0.4732	0.4732	0.4732	0.2725	0.2725	0
0.0330	0.0330	0.1372	0.3201	0.4573	0.4573	0.3201	0.1372	0.0330	0.0330
0.0330	0.0330	0.1389	0.1389	0.2777	0.2777	0.1389	0.1389	0.0330	0.0330
0	0	0.0490	0.0490	0.0980	0.0980	0.0490	0.0490	0	0
0	0	0.0163	0.0163	0.0327	0.0327	0.0163	0.0163	0	0



Phi's stepped every 0.5 degrees.





E_θ (ϕ = 0°, 45 °, 90 °)

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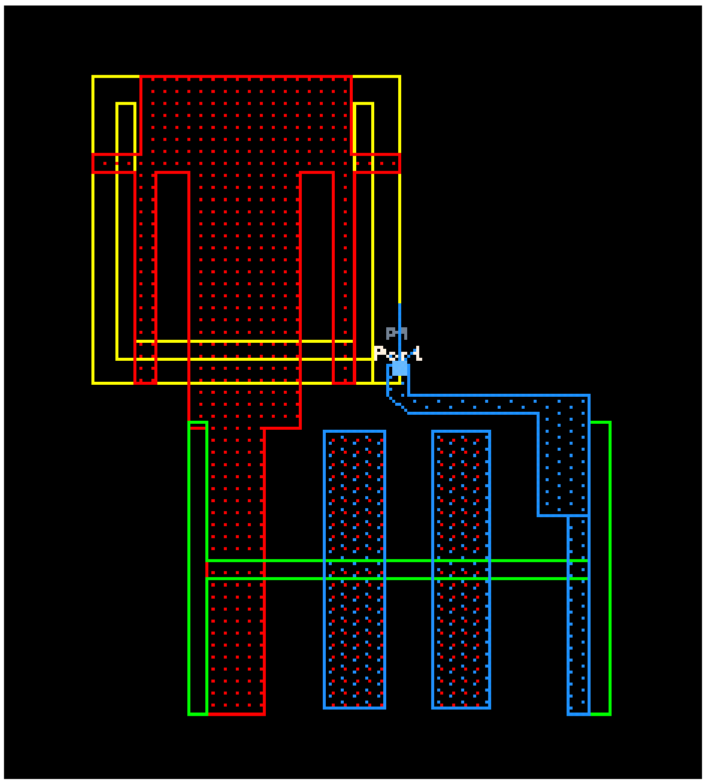
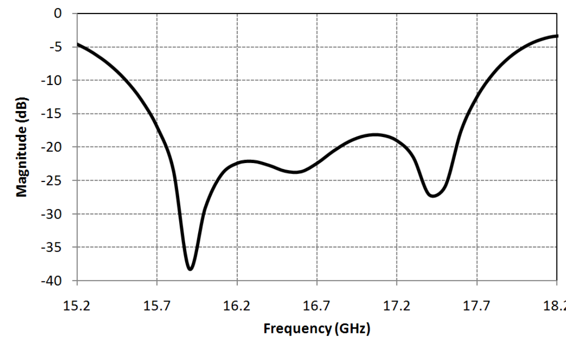
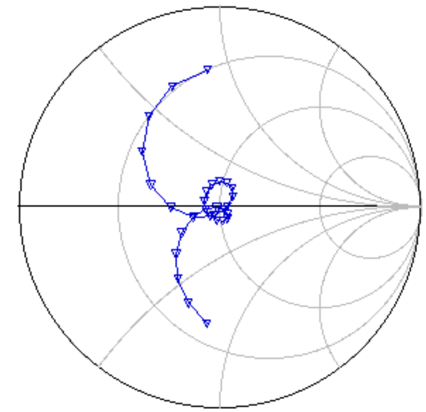
Single Element Unit Cell

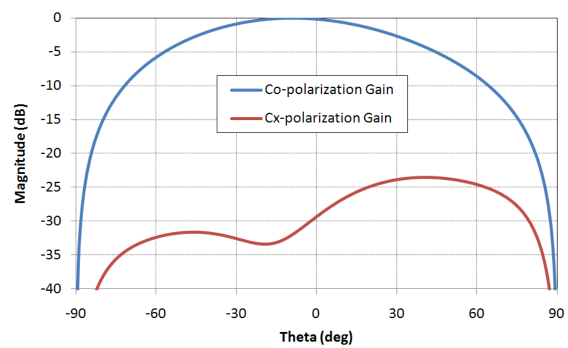


Return Loss

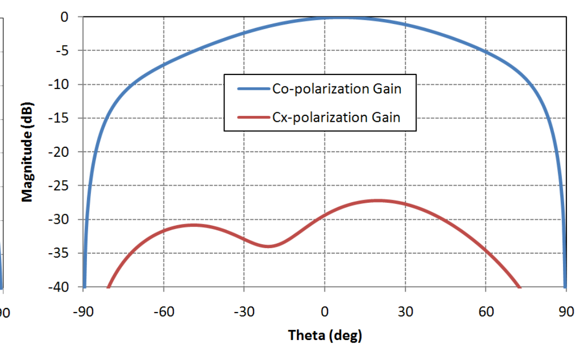




$E_\theta\,(\phi = 0°)$



$E_\theta\,(\phi = 90°)$



This radiator has considerable instantaneous bandwidth with cross-polarization levels on the order of 30 dB. Copper and substrate losses are included.

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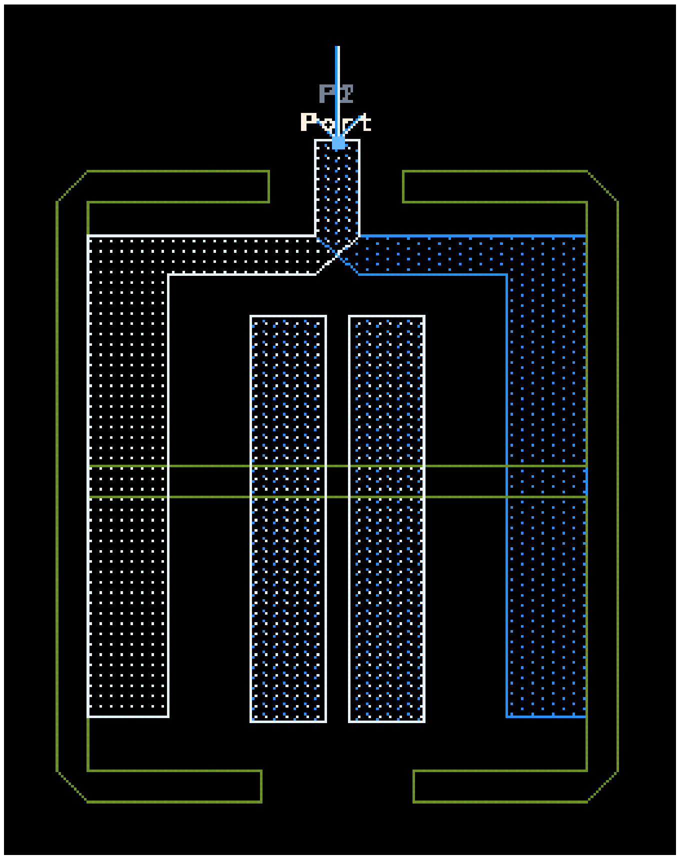
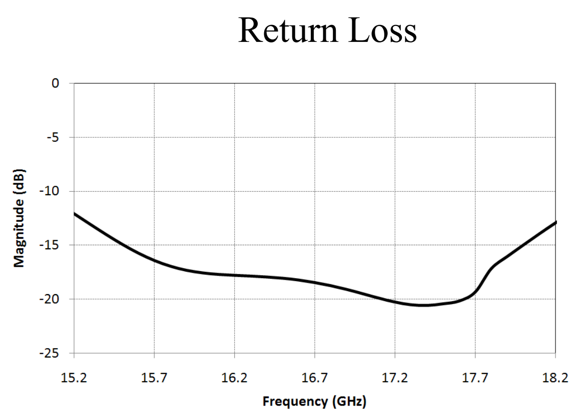
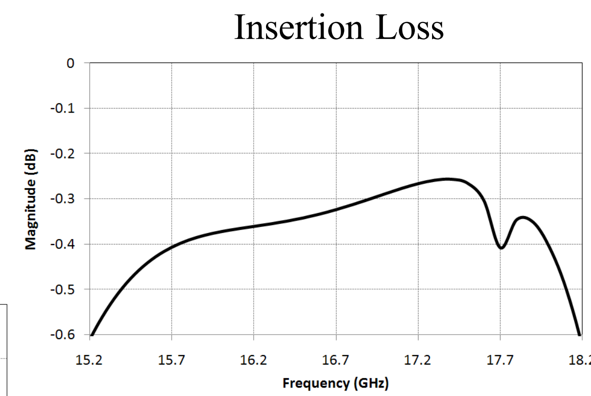
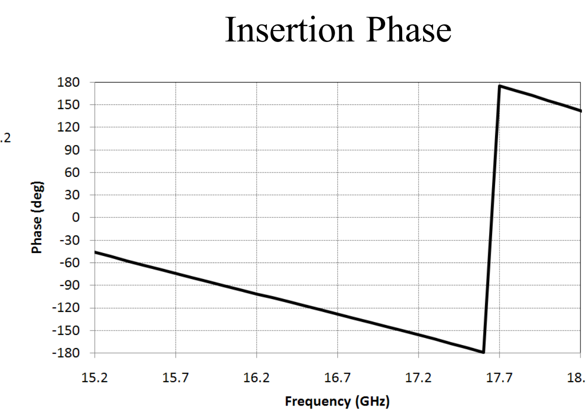
Stripline-to-Stripline Transition









This device eliminates the need for via-based interconnects, thereby increasing the array's manufacturing simplicity and operational reliability. Copper and substrate losses are included.

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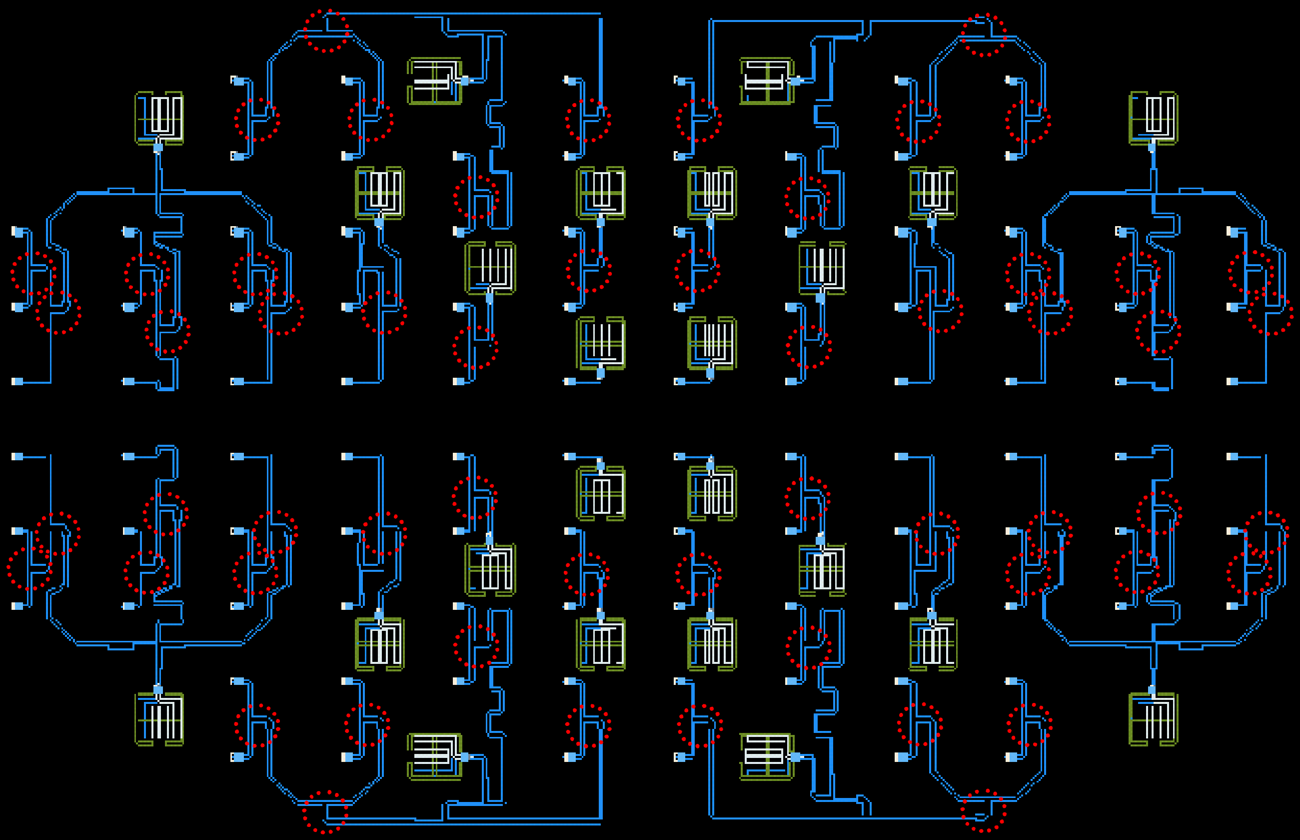
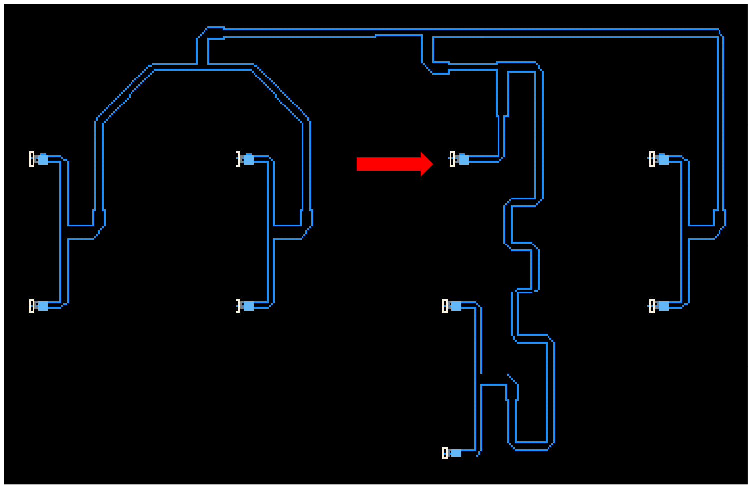
Post-T/R Feed Networks

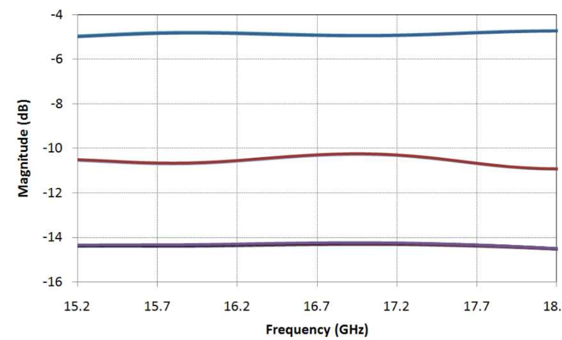


Identify 50/50 split locations. 50/50 splits are created with a T-splitter that has no magnitude or phase error from its input port to its two output ports. Mitigating phase error is very important in achieving low sidelobes.

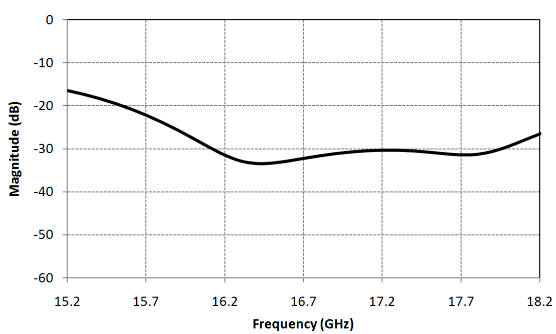
Post-T/R Eight-Element Feed-Network Example



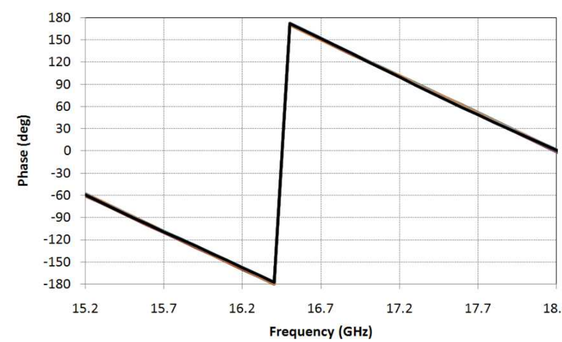
Insertion Loss



Return Loss



Insertion Phase



No phase error!

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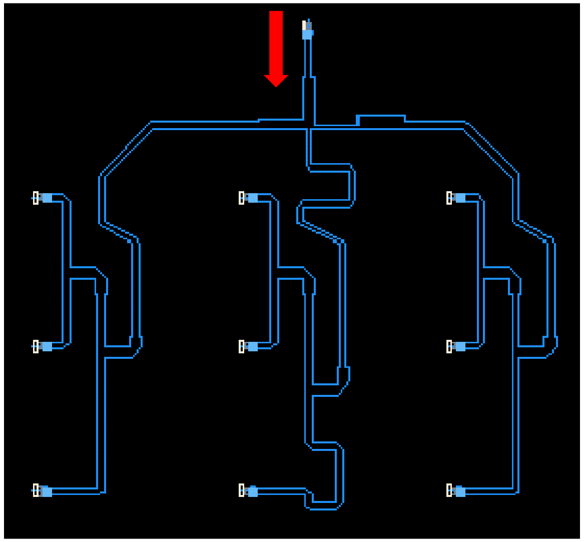
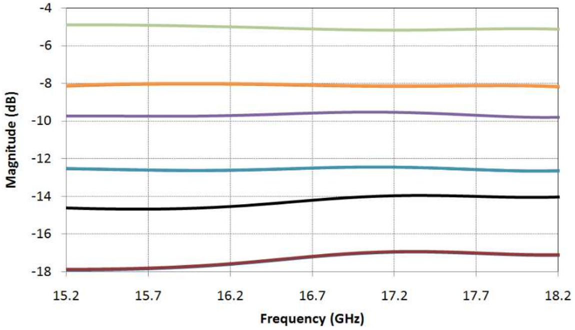
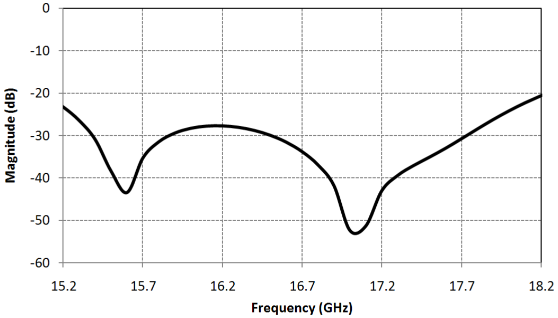
Post-T/R Nine-Element Feed-Network Example



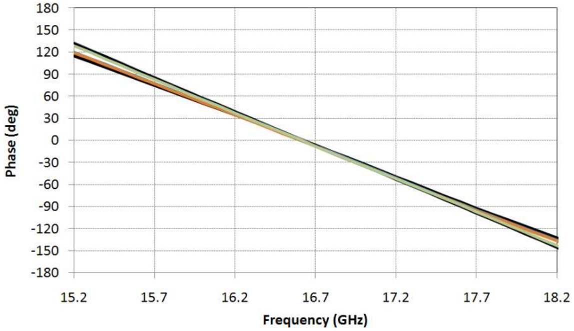
Insertion Loss



Return Loss



Insertion Phase



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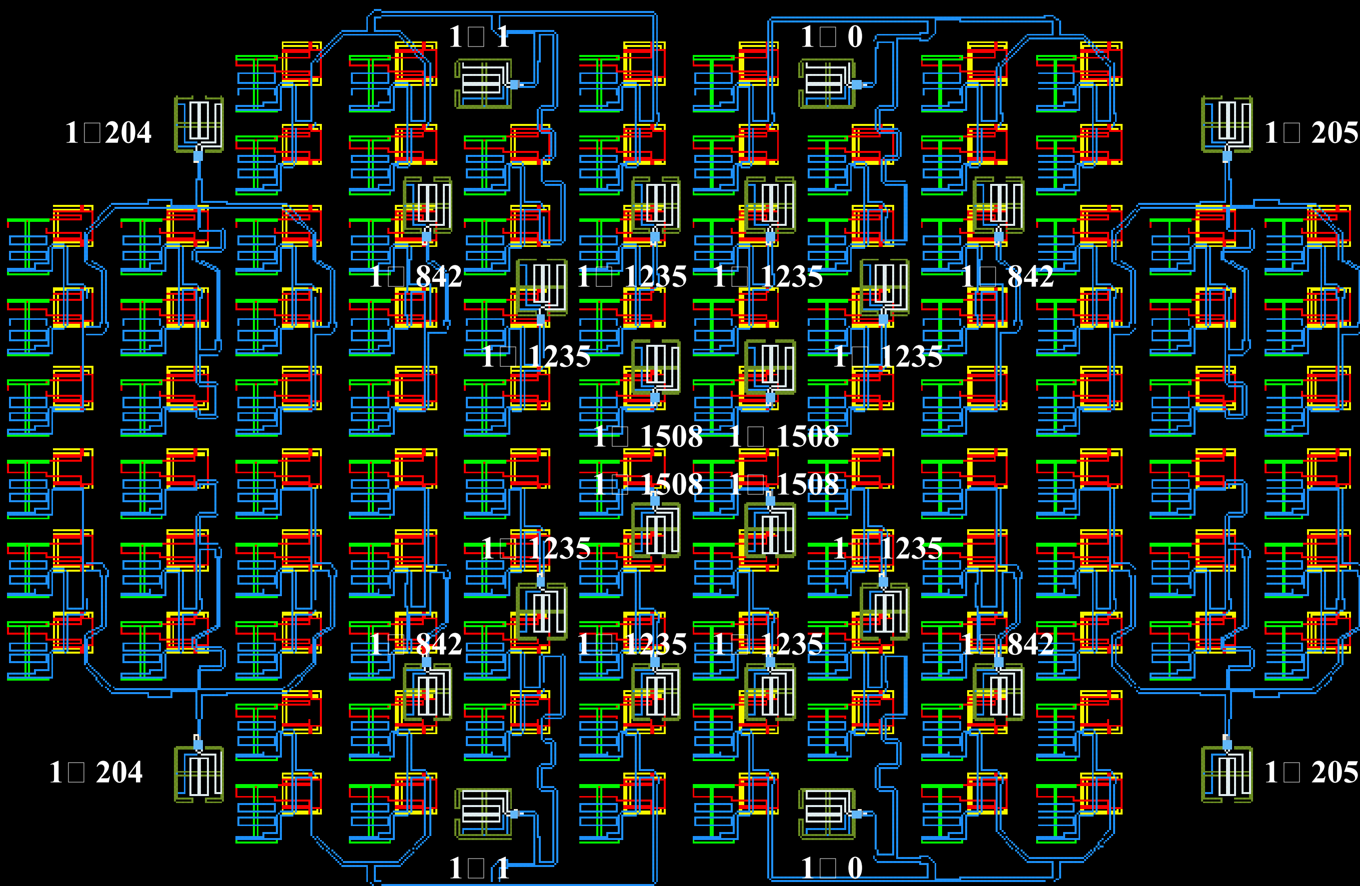
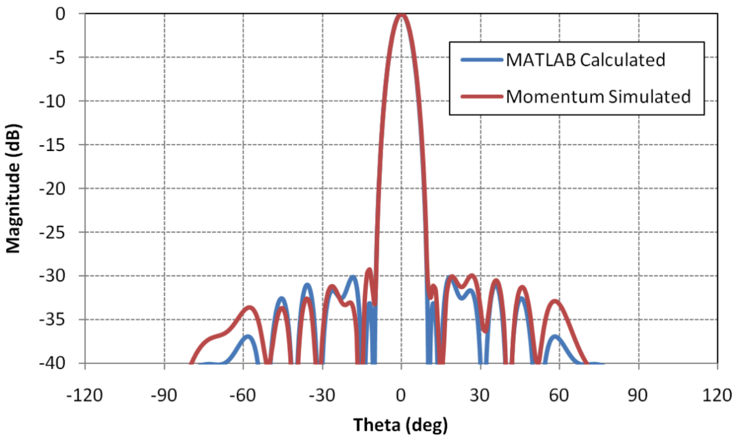
Simulated Array with 16.7 GHz Phase Compensations Shown

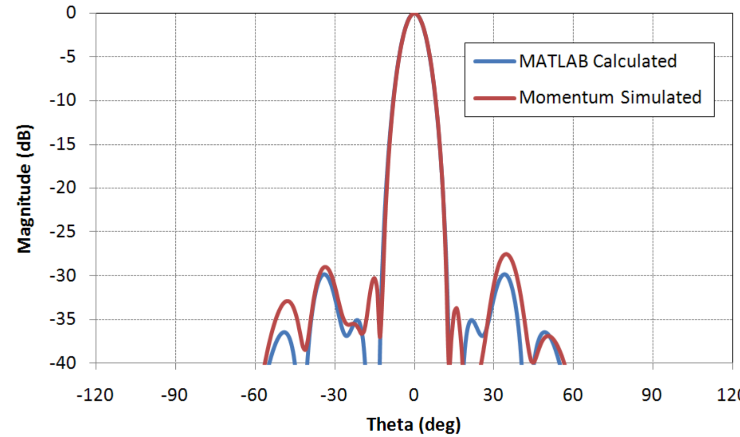


Simulated vs. Predicted Patterns at 16.7 GHz Using Phase Compensation

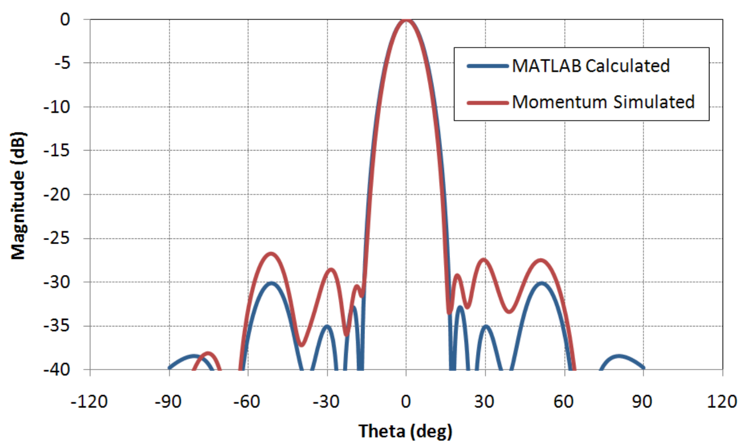
$E_\theta\ (\phi = 0°)$



$E_\theta\ (\phi = 45°)$



$E_\theta\ (\phi = 90°)$



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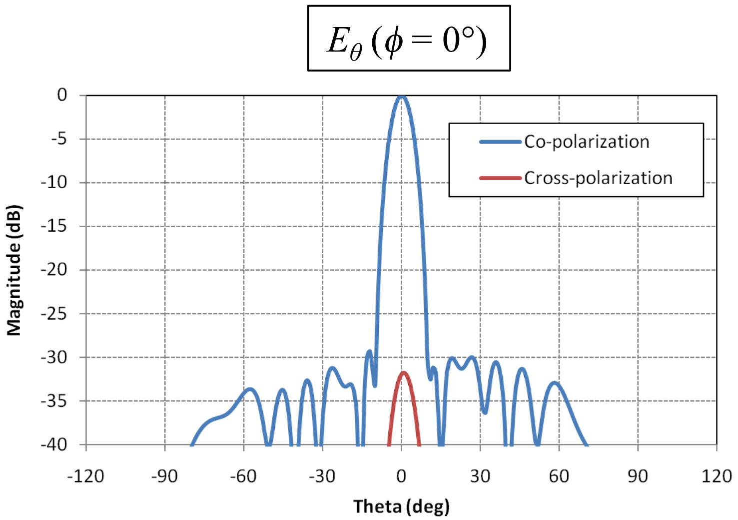
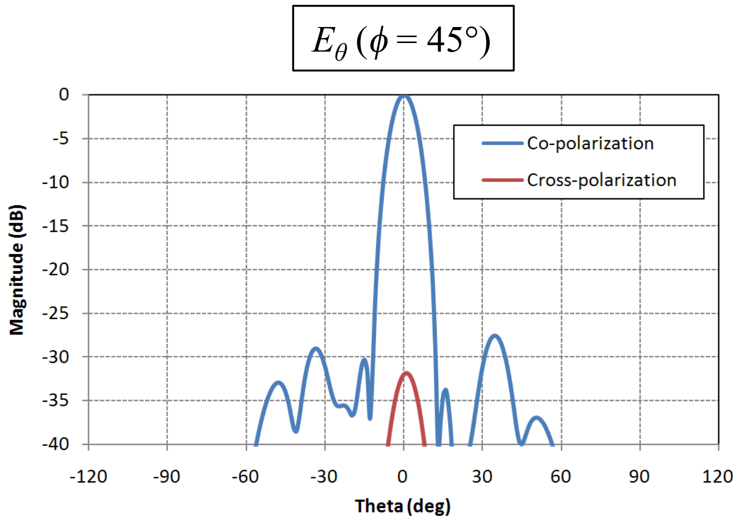
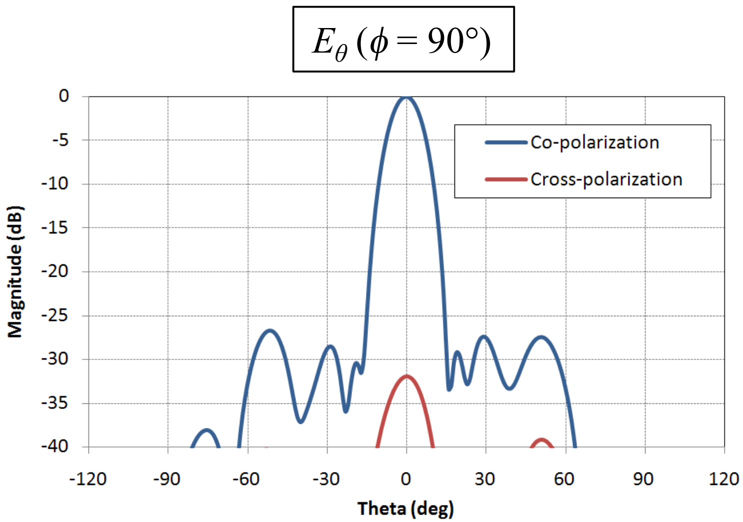
Simulated 16.7 GHz Pattern Data Using Phase Compensation







Cross-polarization levels better than 30 dB

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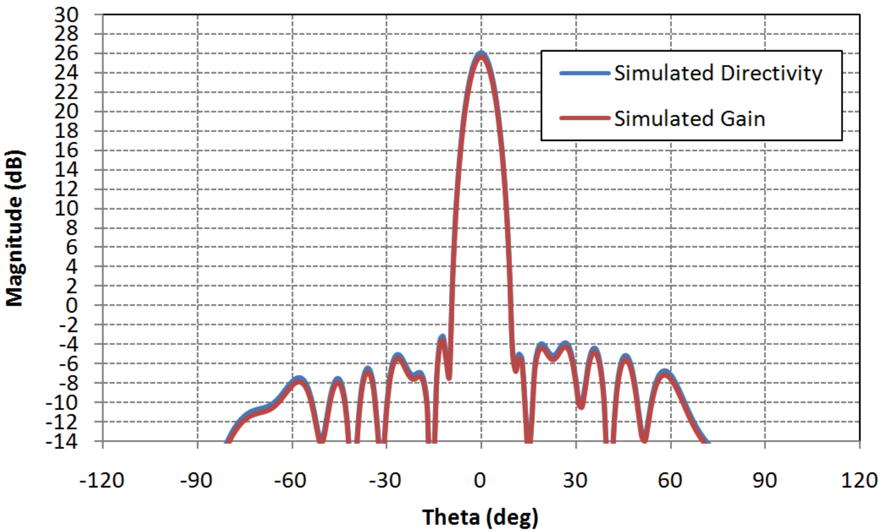
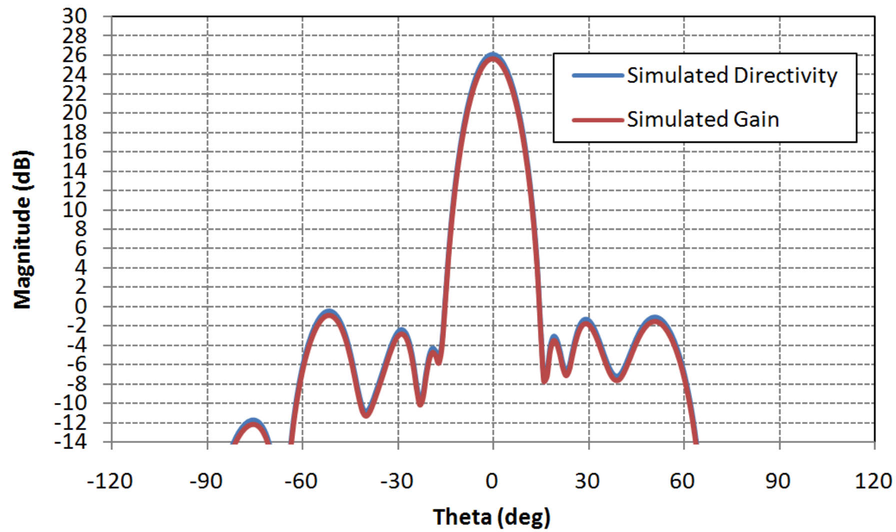
Momentum-Generated Directivity and Gain Using Phase Compensation

$E_\theta\ (\phi = 0°)$



$E_\theta\ (\phi = 90°)$



Antenna gain at 16.7 GHz is just below 26 dB. This however excludes pre-T/R feed network losses.

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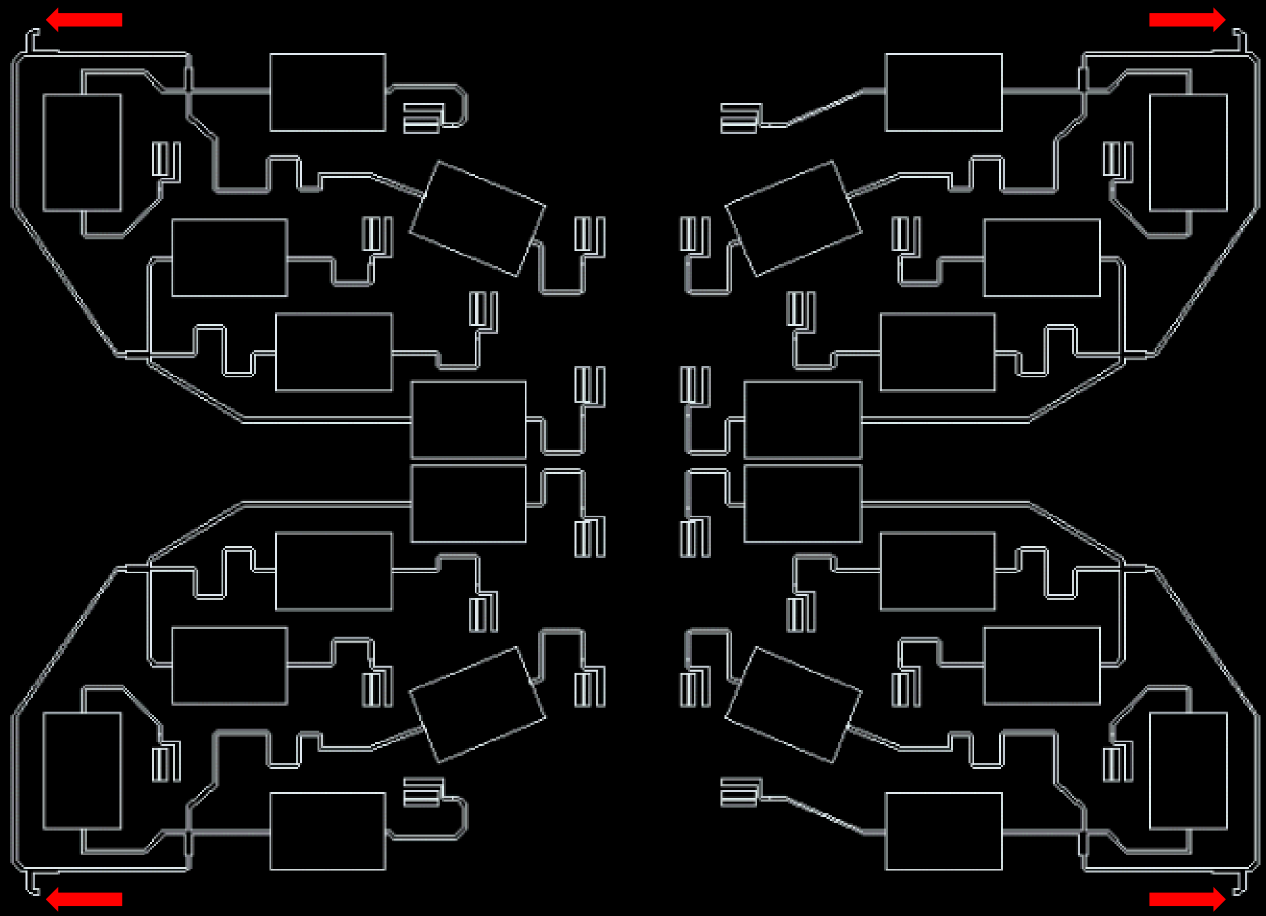
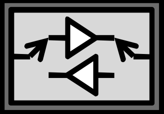
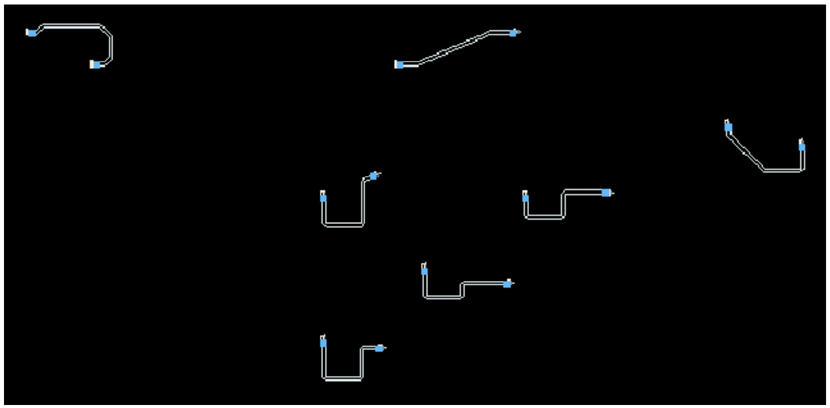
Pre-T/R Phase-Compensating Feed Network and the 24 Amplifier Area Locations



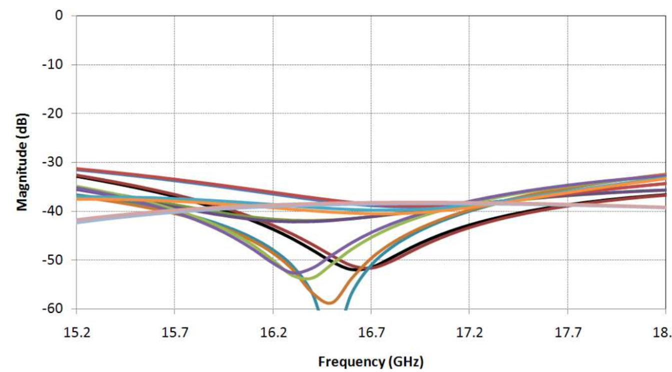


Each rectangular area is 15 mm x 10 mm.
All T/R components must be placed within these spaces.

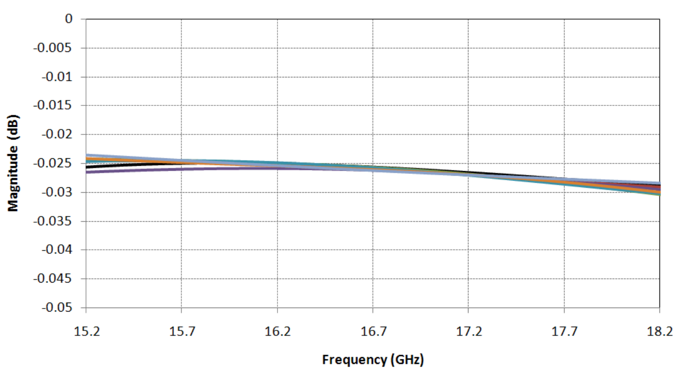
Short Sections Between T/Rs and Their Respective Stripline-to-Stripline Transitions



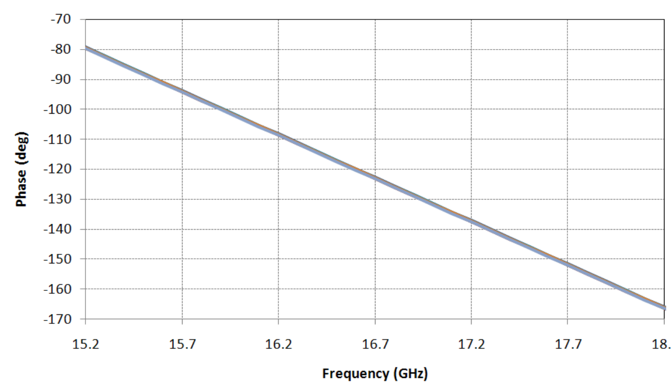
Return Loss



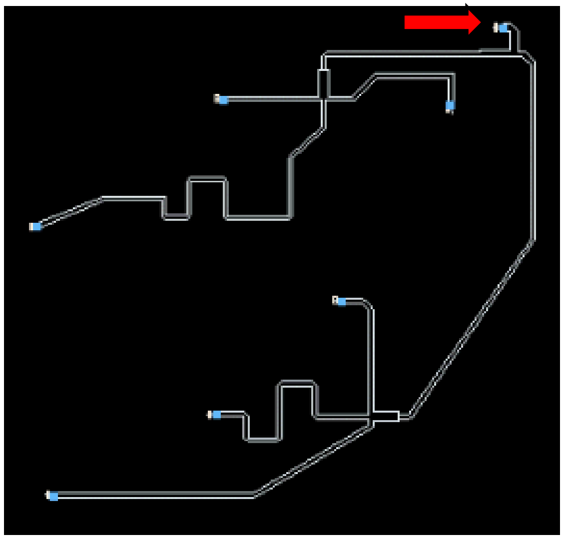
Insertion Loss



Insertion Phase

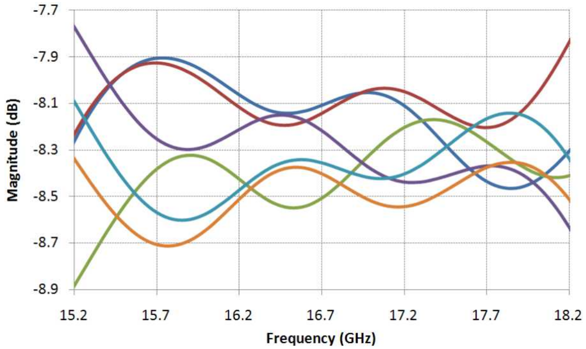


Pre-T/R Feed Network

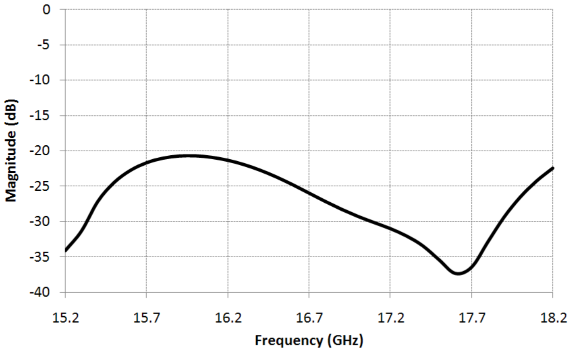


Needs some work to reduce ripple

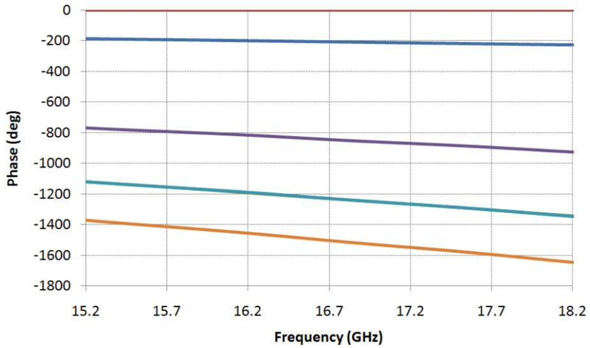
Insertion Loss



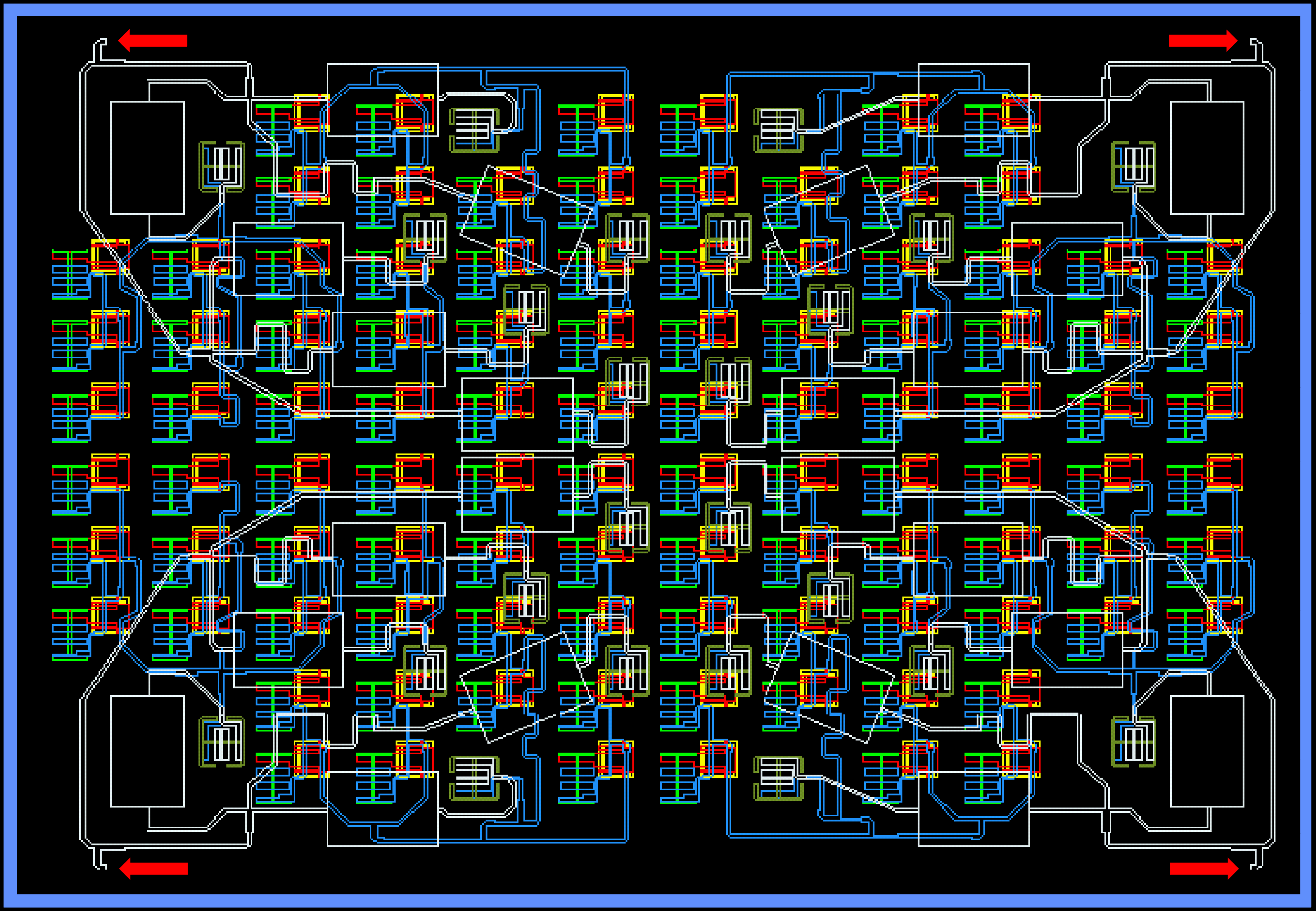
Return Loss



Insertion Phase



Quadrant Profile Lends Itself to Monopulse Functionality



Conclusions

The irregular subarray amplifier array concept shows considerable promise for achieving taper on transmit without throwing away lots of RF power. Using 24 1 W amplifiers seems to be sufficient in replacing the MPM. This approach also allows for similar part-numbered amplifiers to be used, thereby mitigating temperature, phase, and magnitude variations over the large instantaneous bandwidth desired. This array is also very lightweight and low profile.

Questions?