5G Arrays for Lunar Relay Operations (FIGARO)

2022 STP Tech Expo presentation

June 8, 2022

Cooperative Agreement (CA) Partnerships with Universities and NASA Centers

Grant/Cooperative Agreement Number: 80NSSC20M0077

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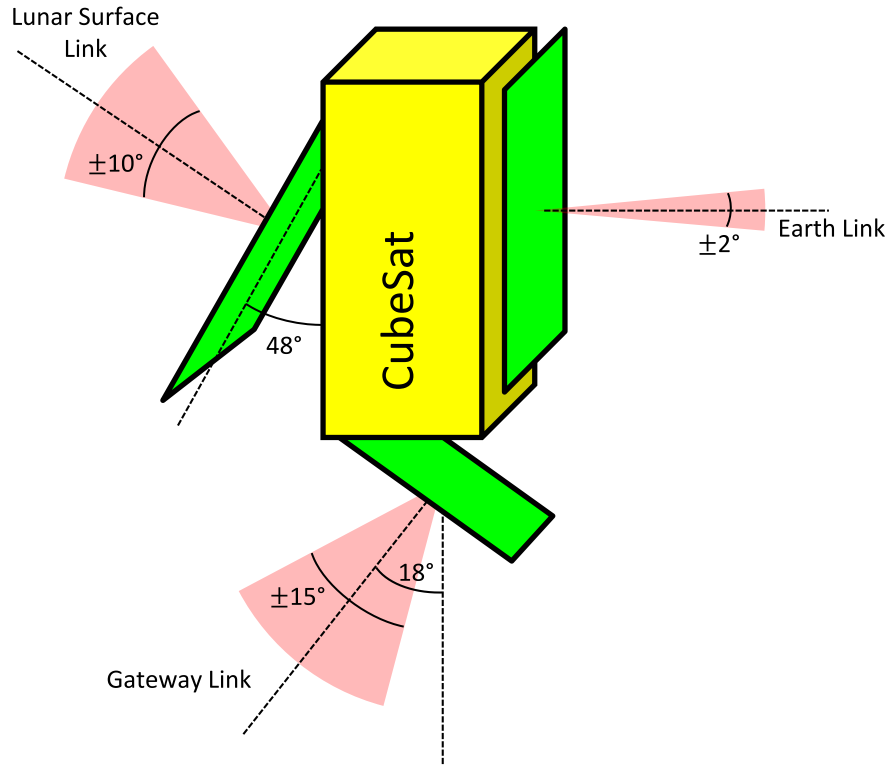
Introduction

- **Summary**: The objective of FIGARO is to design and build shared platform Ka-band phased array antennas (PAAs) utilizing commercial 5G Silicon RFIC beamformer technology for space-based relay applications. FIGARO will exploit the high volume production and commercial timescales of the 5G market to produce low cost, high performance systems.
- **Relevance and Impact:** The technology being developed through this effort will enable high gain, high data rate, multi-point communications for small satellites without the need for physical pointing mechanisms.
- **Technical Approach:** The approach requires design of a dual circularly polarized Ka-Band (25.5-27.5 GHz band (Rx/Tx) and 22.55-23.55 GHz band (Tx/Rx)) PAA payload with beam steering capability within ±60deg and minimal gain variation for a 6U Small Satellite.
- **FOMs:** Minimum data throughputs to SmallSat Relay (40 Msps), to the Lunar Surface (2 Msps), to Gateway (40 Msps), and to Earth (200 Msps)
- Anokiwave chip (**AWMF-0165**) employed for this project can feed four radiating elements, hence we need one chip for each 2x2 sub-array.

Introduction

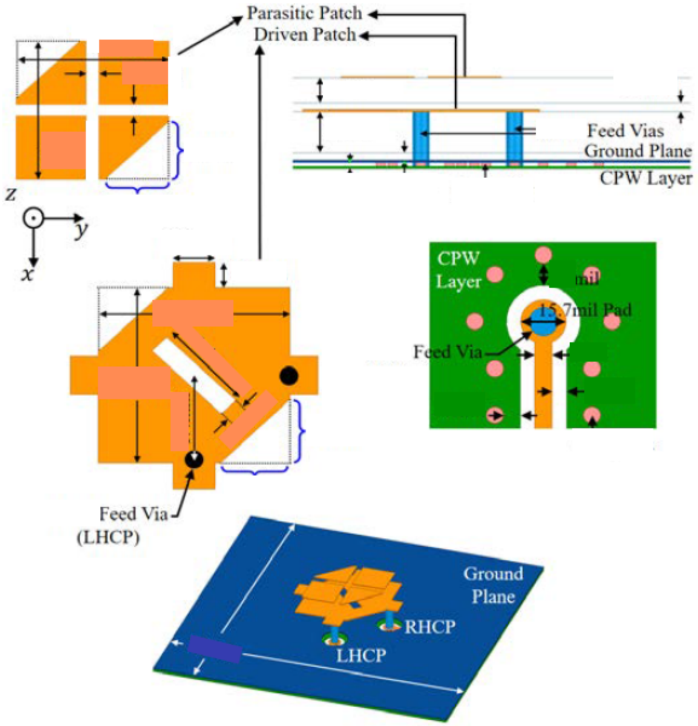
- Objective
  - Design flat-panel phased arrays for 6U CubeSats
    - As part of NASA's Artemis lunar mission
  - Specifications:
    - Operating bands: 22.55–23.55 GHz & 25.5–27.5 GHz (*K*/*Ka* band)
    - Dual-CP and Tx-Rx operations at both bands with stable performance

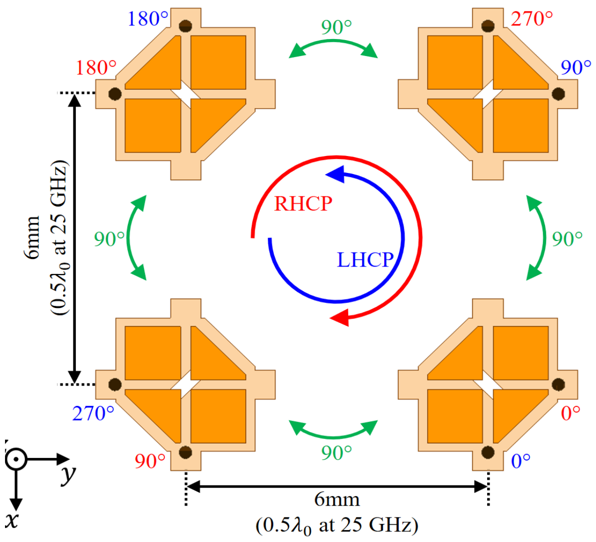


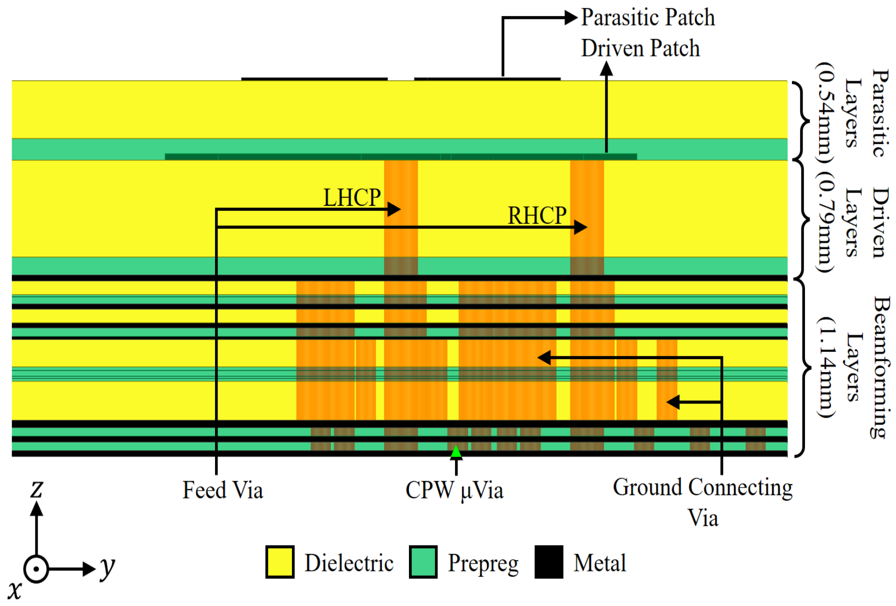
- Flat-panel electronically scanned phased array
  - Advantages
    - No mechanical steering required
    - Low-profile, consumes less volume, and lighter in weight
    - Fast electronic beam steering, flexibility and reliability
  - Circularly Polarized – To cope with signal fading
  - Microstrip Patch – Inexpensive, low profile, easy fabrication, and well-known radiation properties
  - It was decided that the array will have a wide impedance and axial-ratio bandwidth
    - Individual bands are very closely spaced – A single wideband design is preferred than a dual-band design
    - For wide impedance bandwidth – Stacked patch topology
    - Difficult to realize wide impedance and AR bandwidth in a simple element structure – Sequential rotation

Phased Array Designs: Approach I

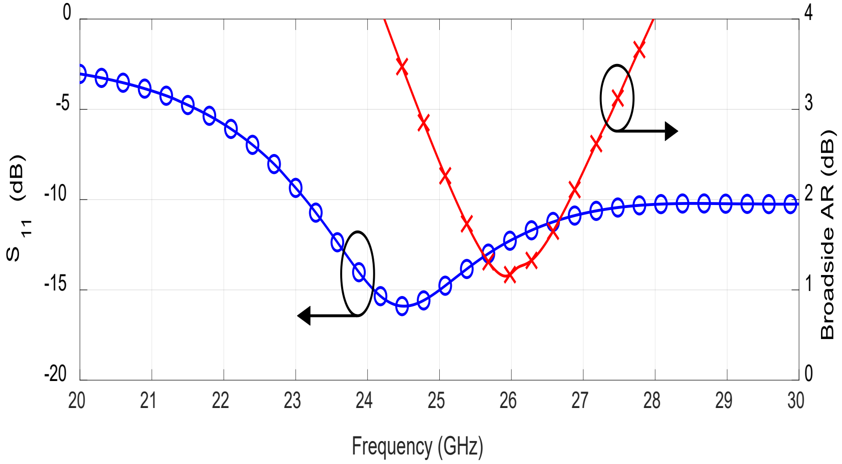
- Dual Circular Polarized wideband radiating element
- Narrow band circular polarization per radiating element
- Sequential rotation mechanism used to realize wideband circular polarization
- Multilayered printed circuit board (PCB) for implementing stacked microstrip patch radiating element along with beam forming network (BFN) layers

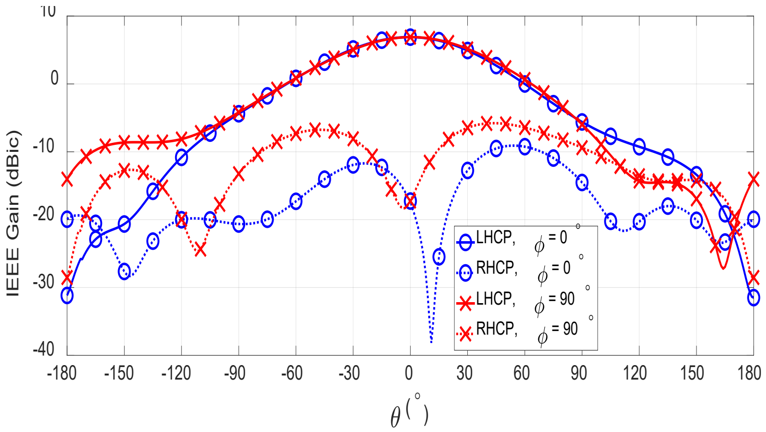


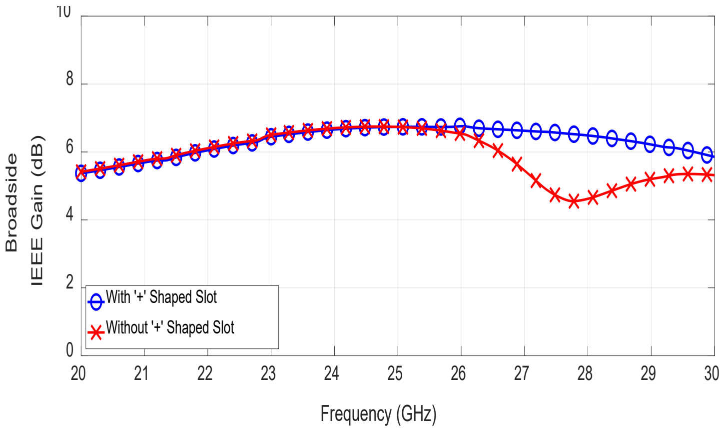


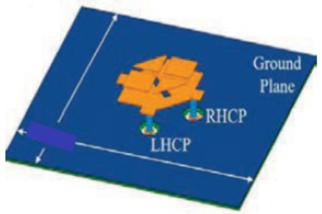


Phased Array Designs: Approach I

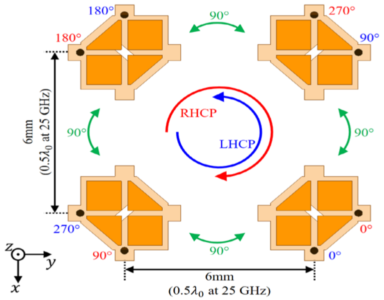




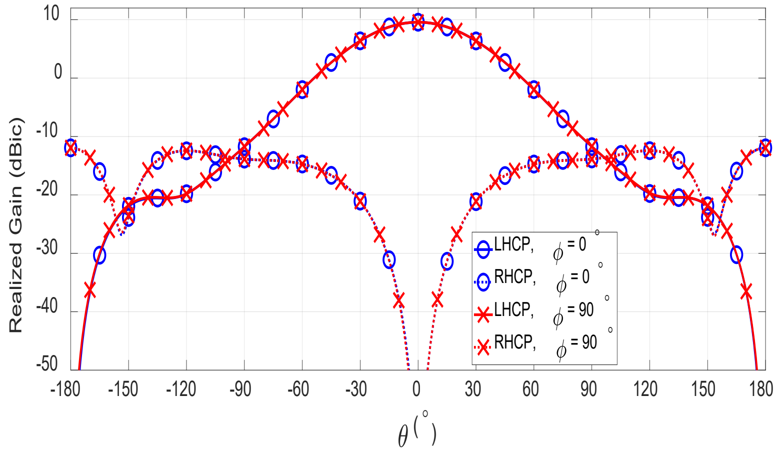


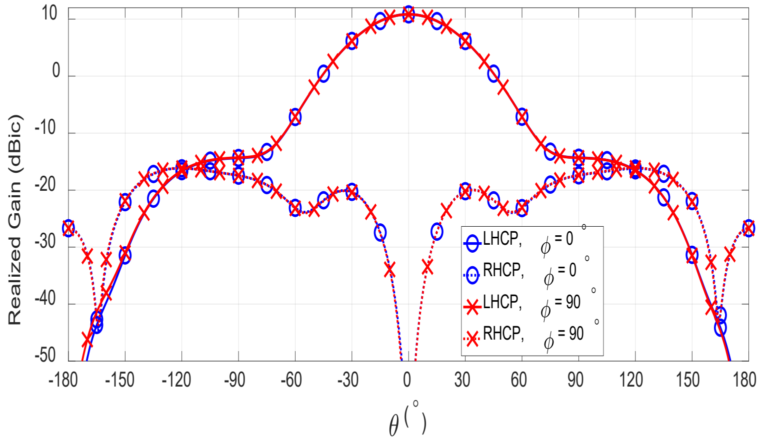


- Dual circular polarized wideband radiating element
- Narrow band circular polarization per radiating element



- Sequential rotation mechanism used to realize wideband circular polarization





Phased Array Designs: Approach I

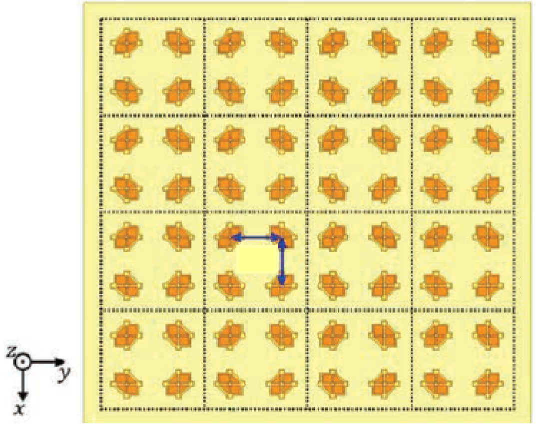
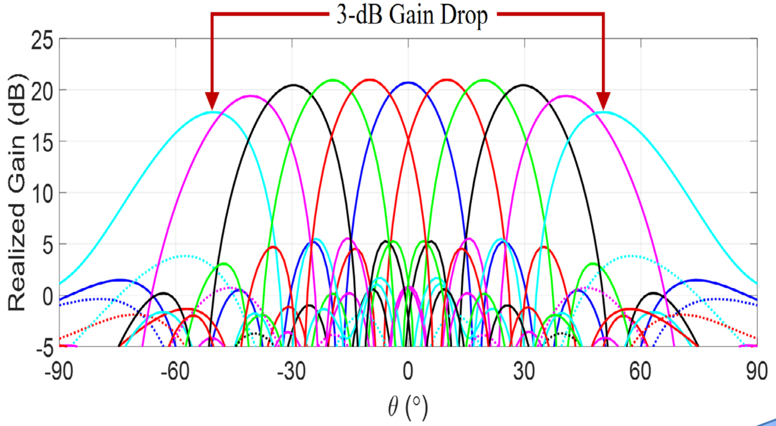


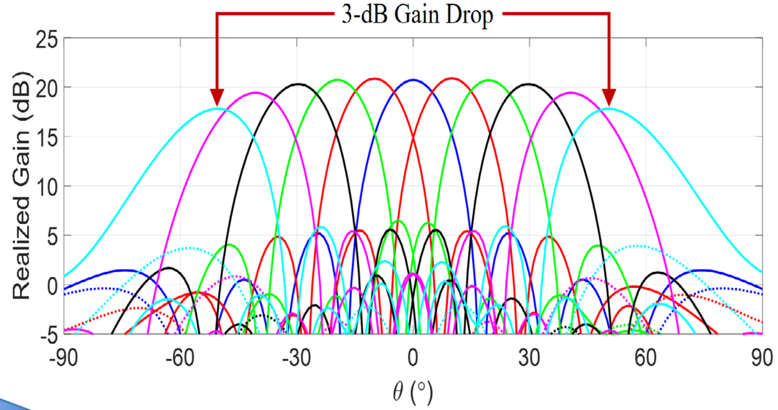
TABLE I

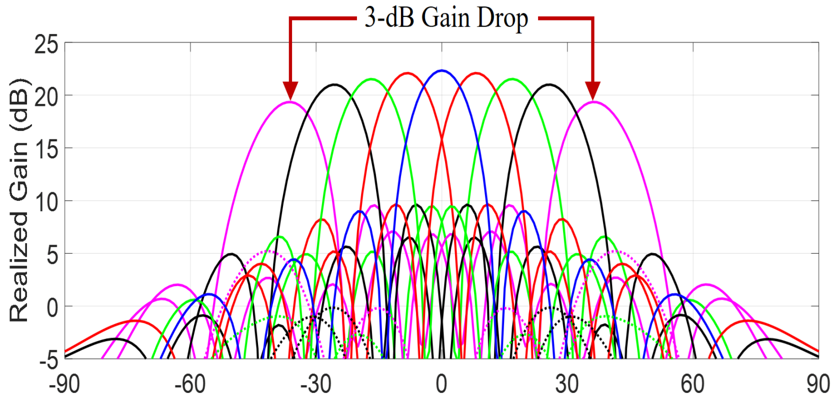
RADIATION PATTERN PARAMETERS FOR THE 8×8 PHASED ARRAY

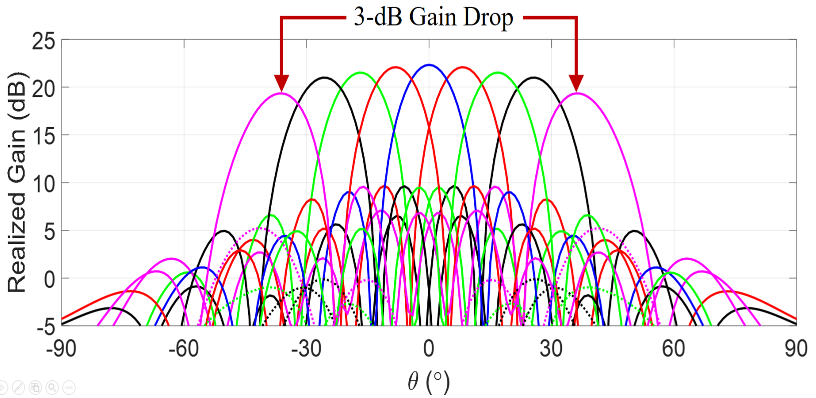
Parameter	23.05 GHz		26.5 GHz	
	$\phi = 0°$	$\phi = 90°$	$\phi = 0°$	$\phi = 90°$
Peak Gain	20.7 dBic		22.3 dBic	
HPBW	15°	15°	12°	12°
Sidelobe Level	15.5 dB	15.5 dB	13.3 dB	13.3 dB
Minimum Co-to-Cross Pol Separation*	21.1 dB	21.1 dB	29.6 dB	29.7 dB

*Obtained by estimating the difference between the maximum values of LHCP and RHCP gains.



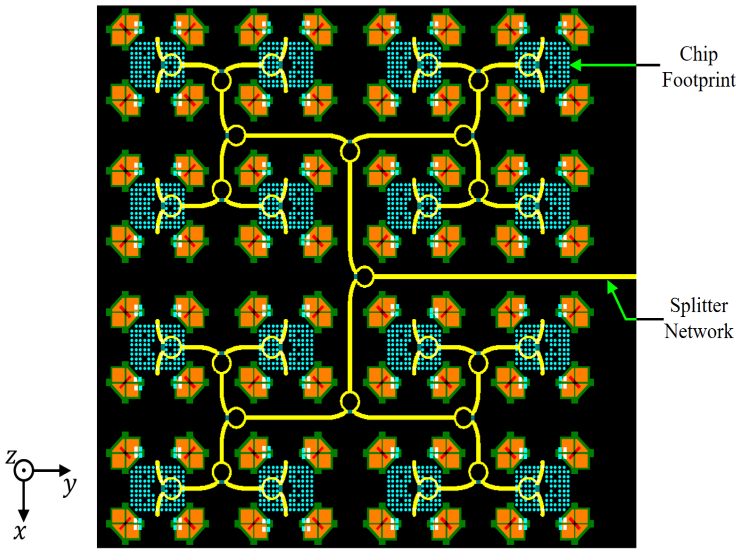


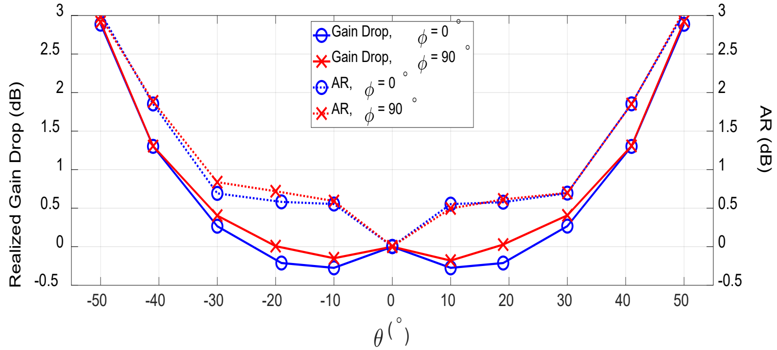


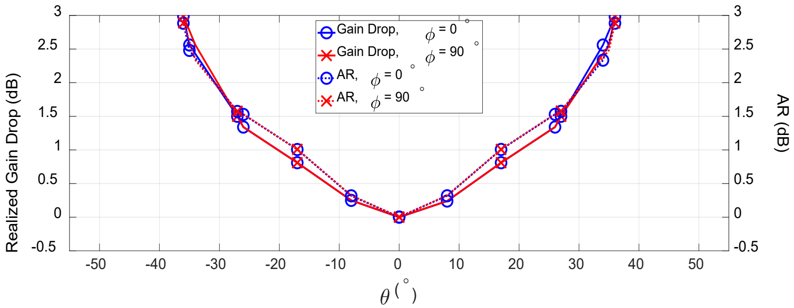


Realized gain scan patterns for the 8×8 phased array at: (a) 23.05 GHz, $\phi = 0°$, (b) 23.05 GHz, $\phi = 90°$, (c) 26.5 GHz, $\phi = 0°$, and (d) 26.5 GHz, $\phi = 90°$ (LHCP port excited, solid lines are co-pol and dotted lines are cross-pol).

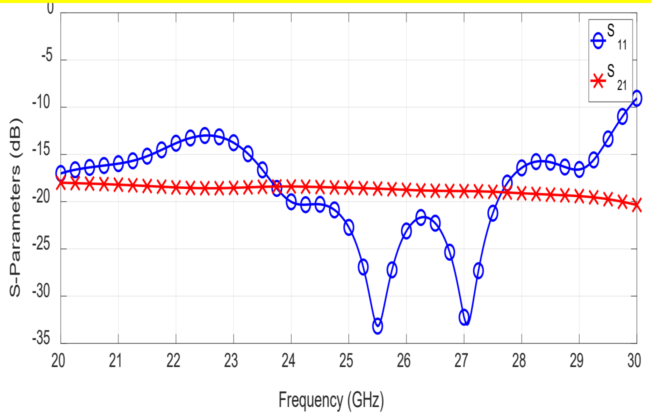
Phased Array Designs: Approach I



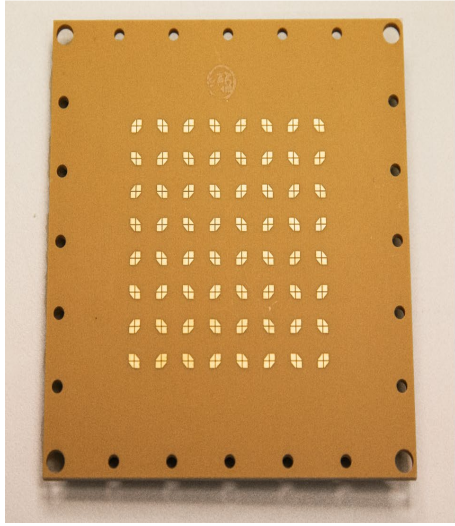


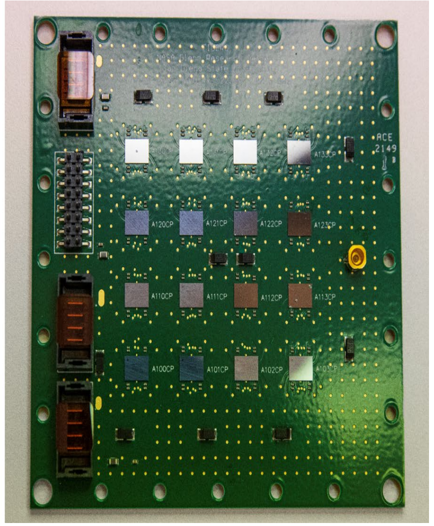


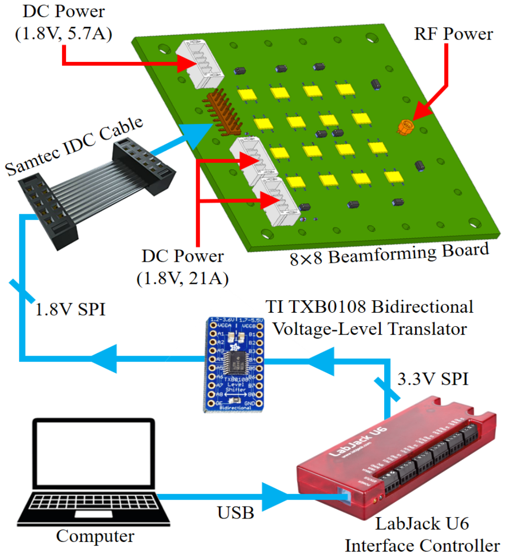
S-parameters of the 1-to-32 power splitter.

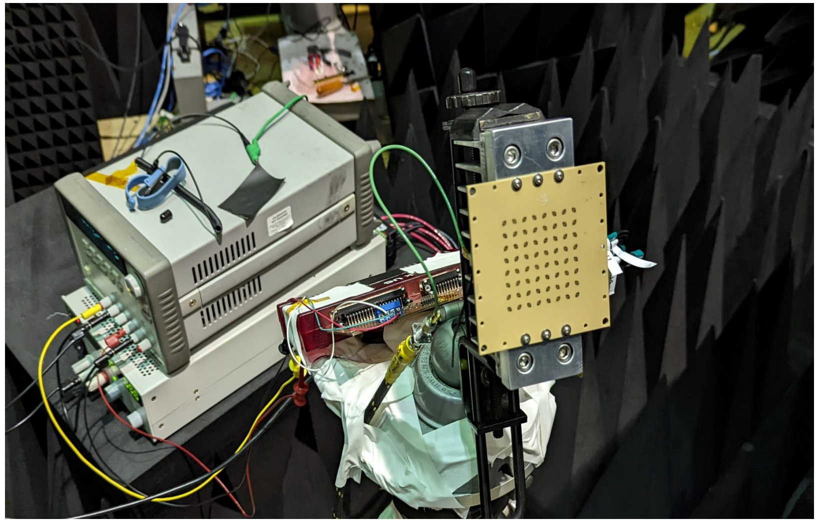


Gain drop and AR vs. scan angle at $\phi = 0°$ and $90°$ for (a) 23.05 GHz, and (b) 26.5 GHz.



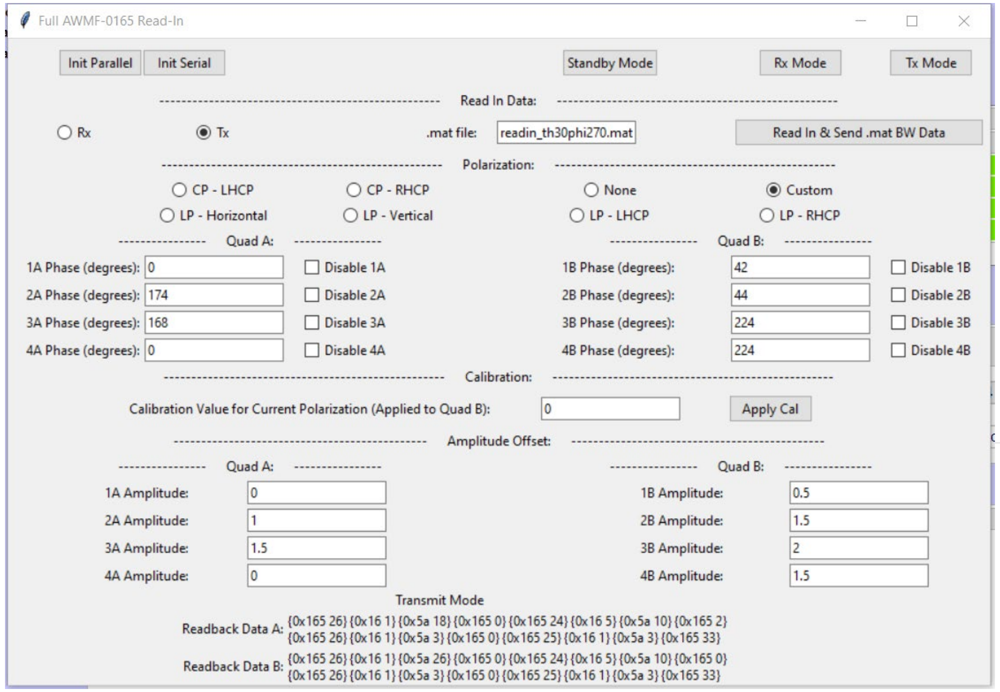


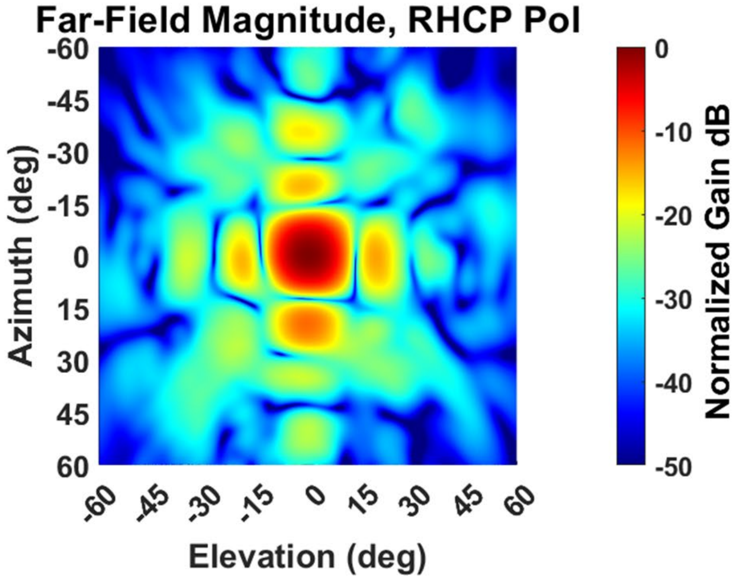


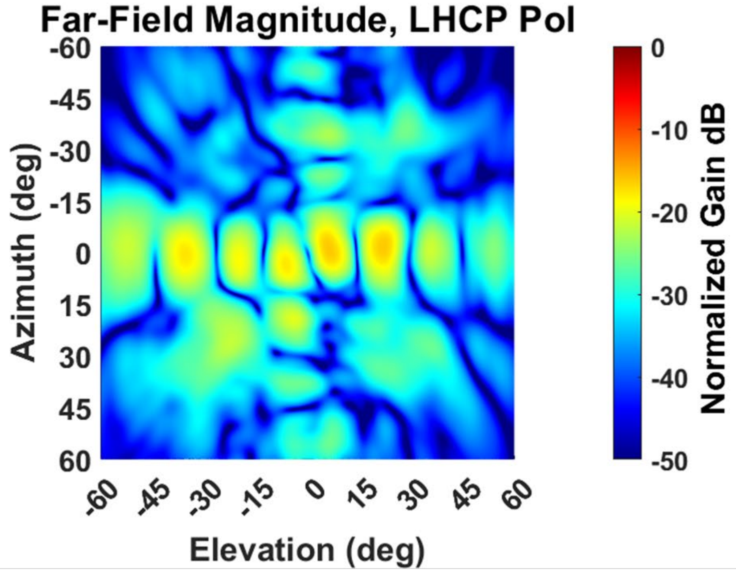


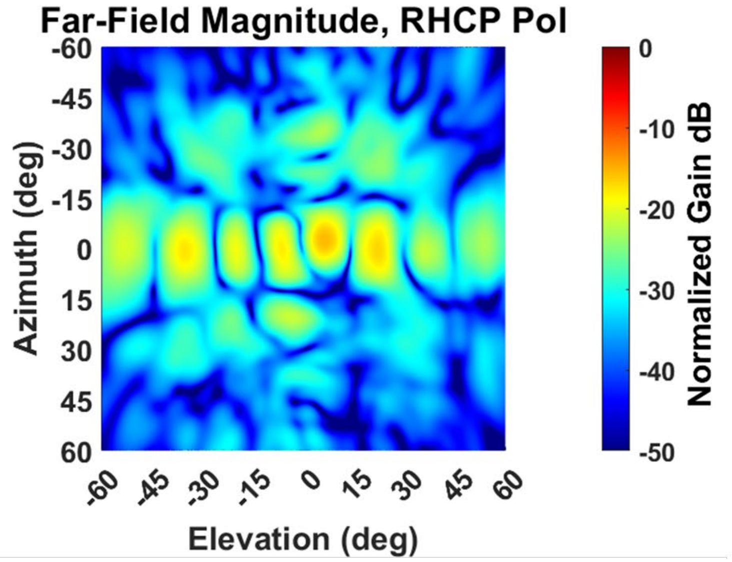
Phased Array Designs: Approach I

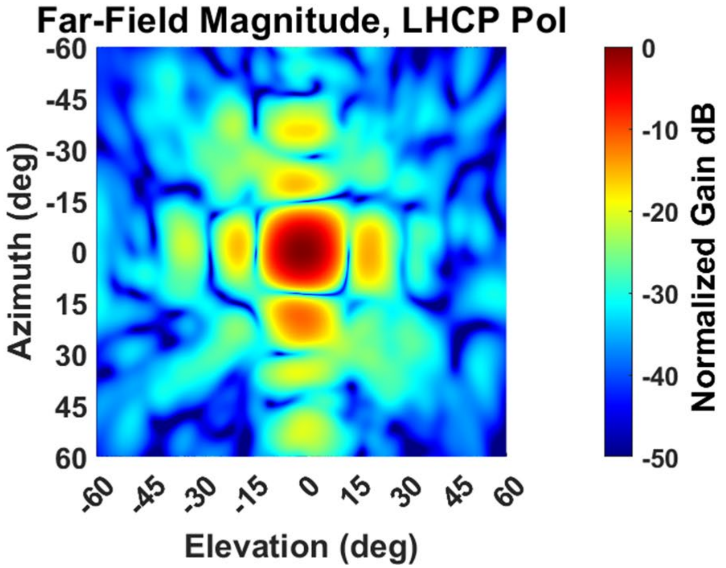
Beam forming algorithm has been applied through a GUI







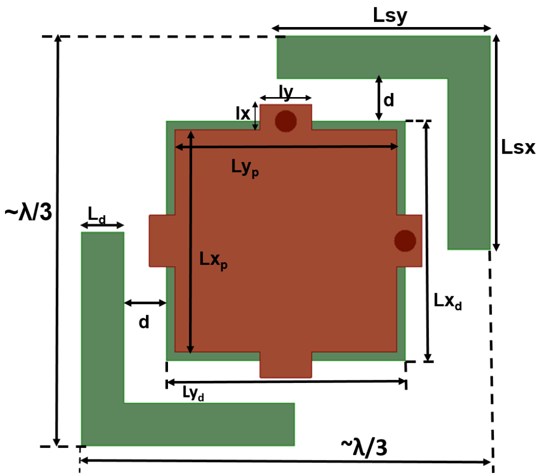


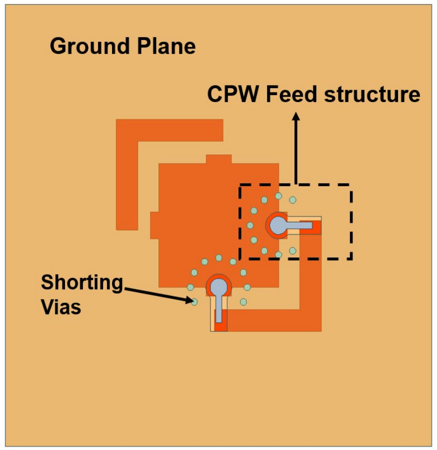


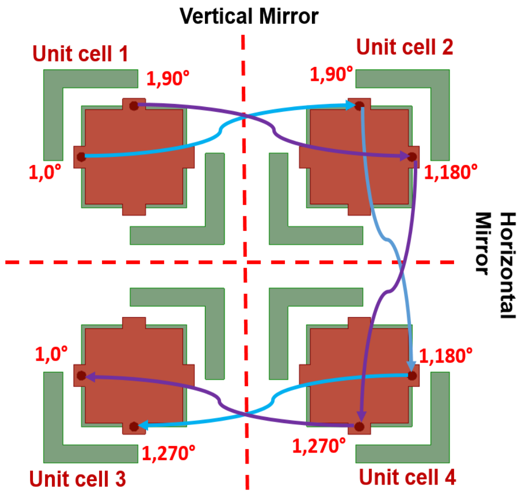
Beam scan radiation patterns are currently underway

Phased Array Designs: Approach II

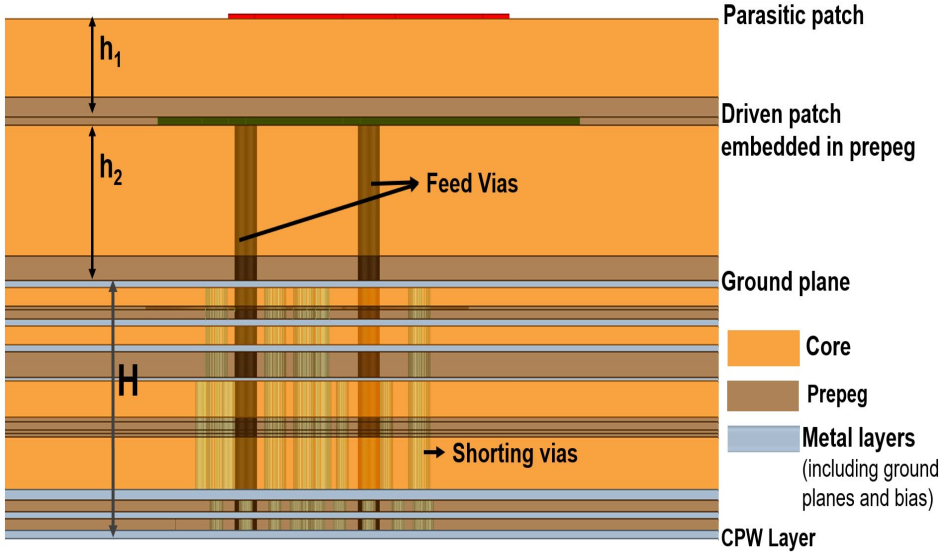
- Dual linear polarization wideband radiating element used for generating dual circular polarization using RFIC phase shifts
- Sequential rotation mechanism used to realize further wideband wideband circular polarization
- Overall reconfigurable polarization (vertical and horizontal linear, right and left hand circular polarization) phased array antenna design
- Multilayered printed circuit board (PCB) for implementing stacked microstrip patch radiating element along with beam forming network (BFN) layers



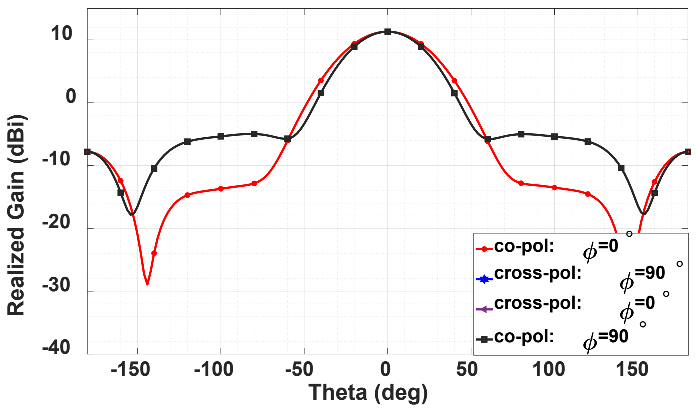


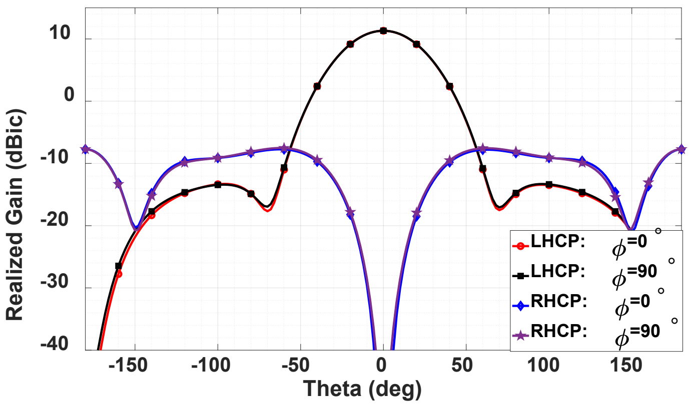


Sequential rotation in circularly polarized mode



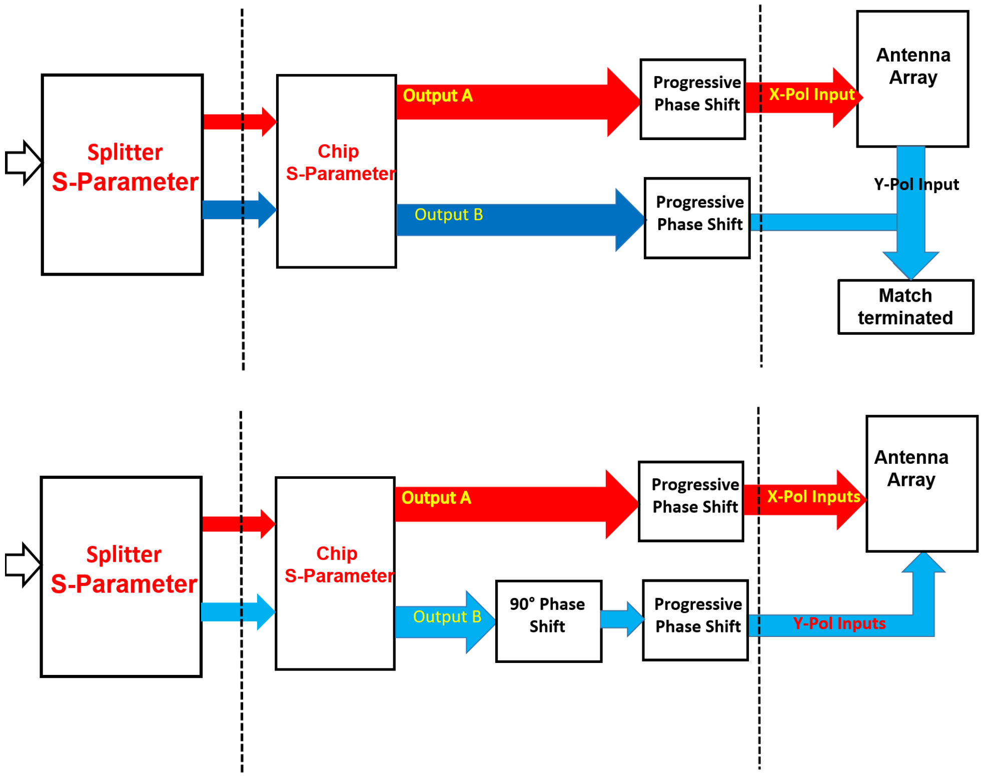
Phased Array Designs: Approach II

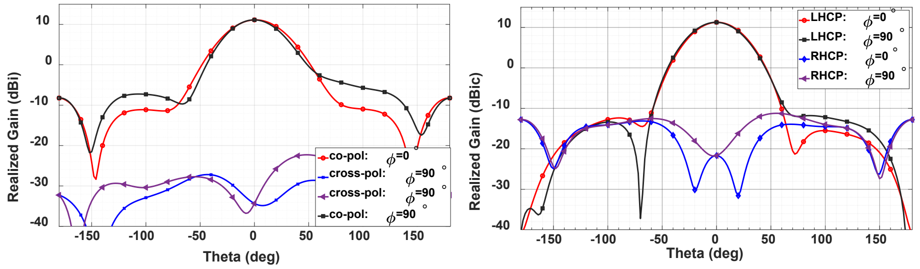




Radiation pattern at 25GHz for (top) Mirror for linear polarization (bottom) sequential for circular polarization

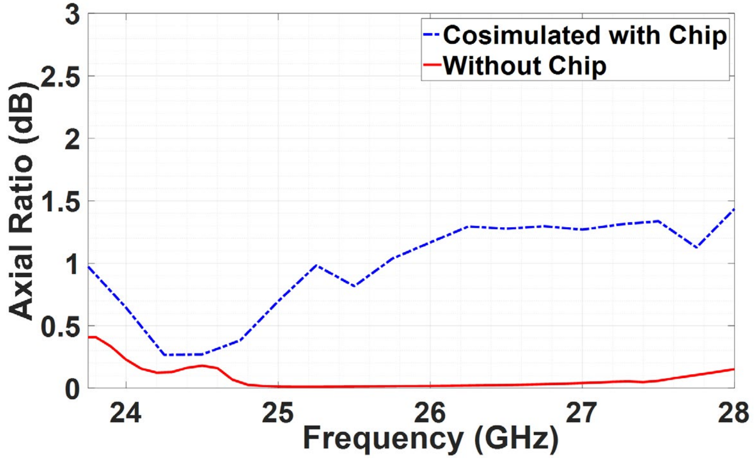
Schematic for EM co-simulation



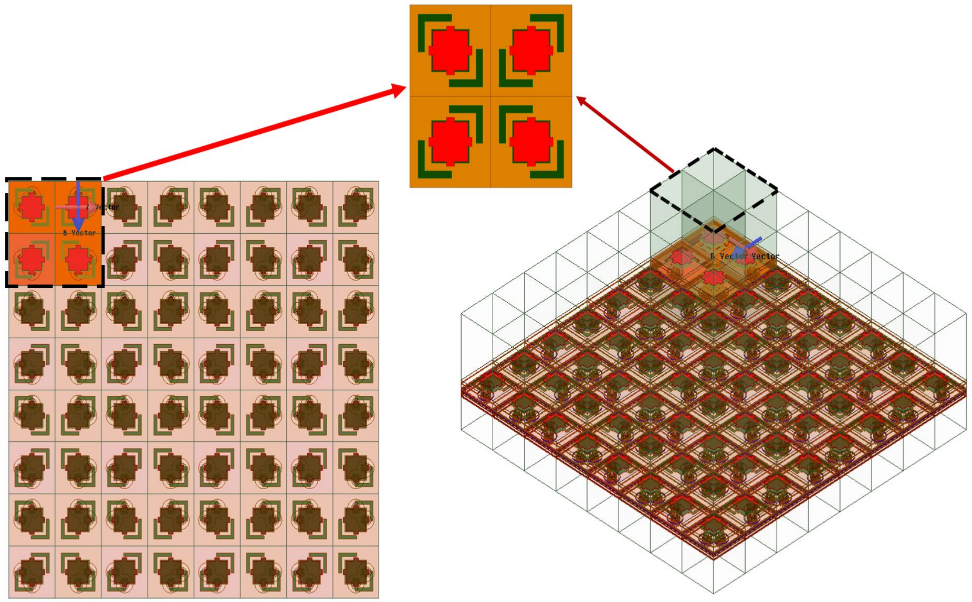


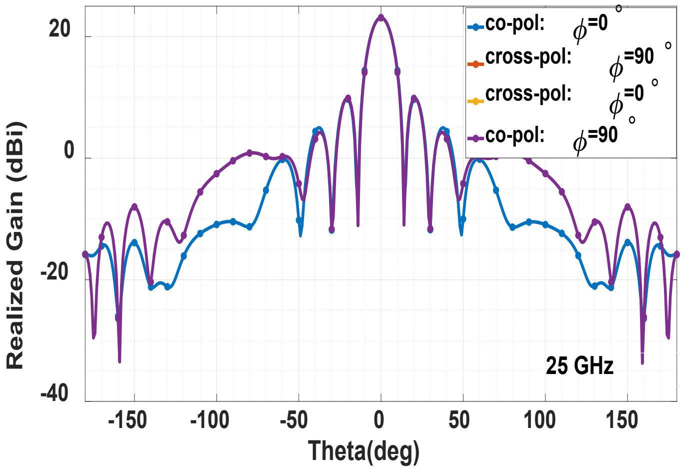
Radiation pattern at 25GHz (a) Mirror for linear polarization (b) sequential for circular polarization with co-sim

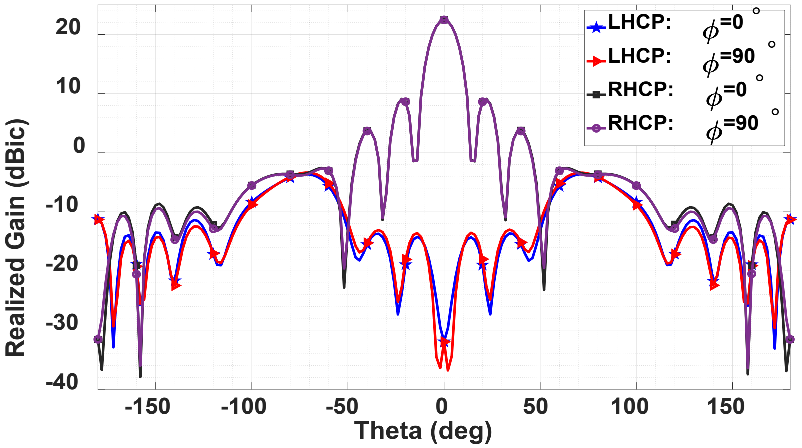
Anokiwave chip (AWMF-0165) employed for this project can feed four dual polarized antennas simultaneously. So we need one chip for each 2x2 sub-array.

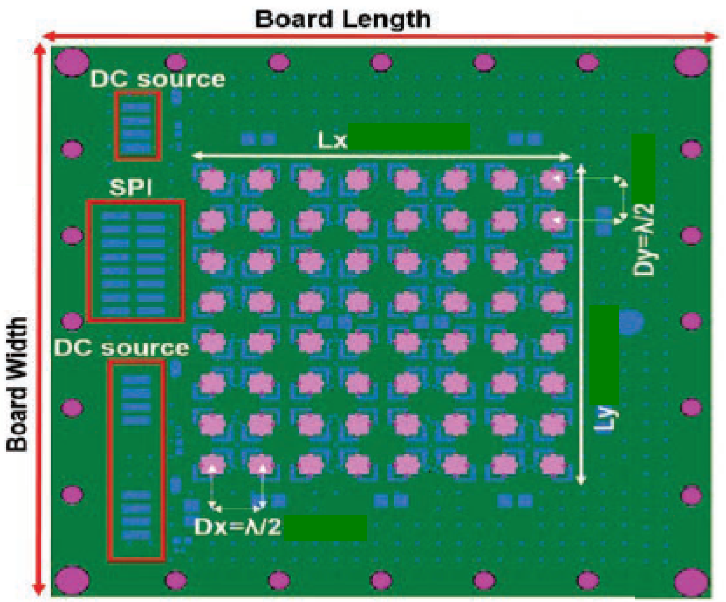


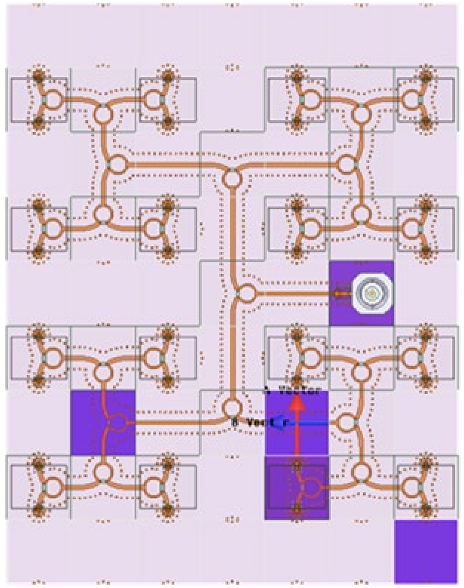
Phased Array Designs: Approach II

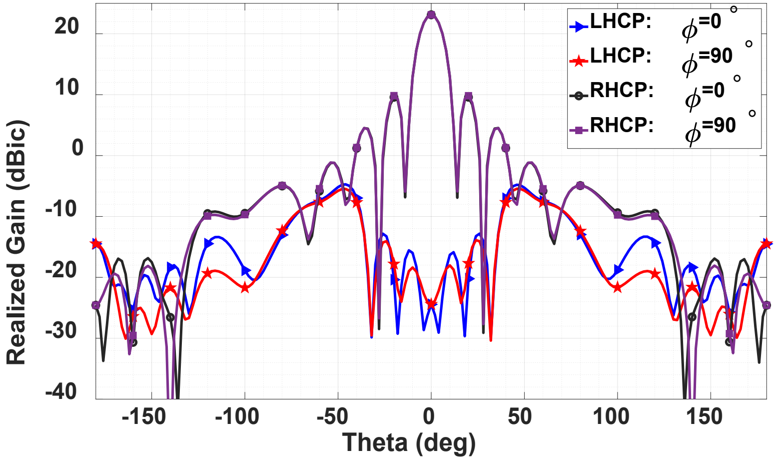




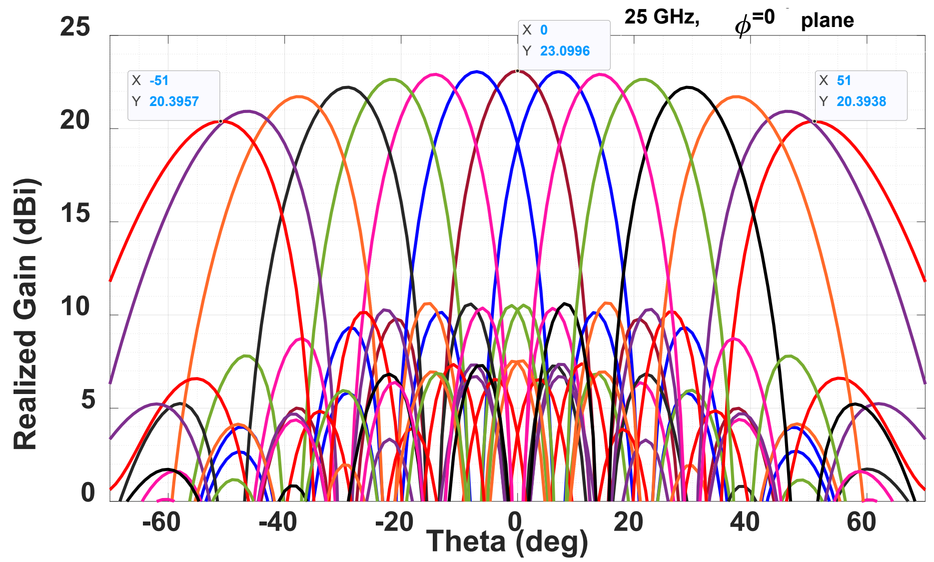


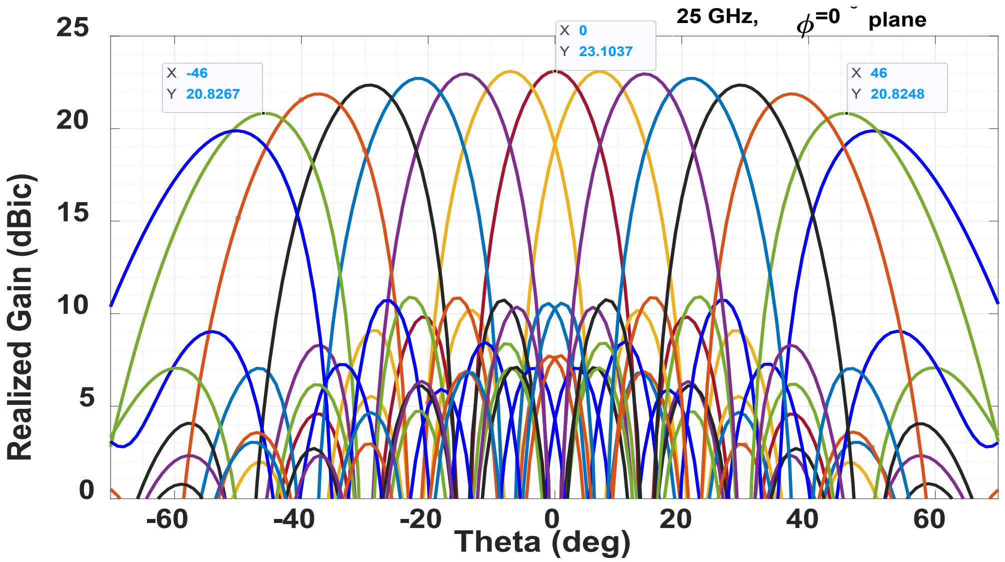


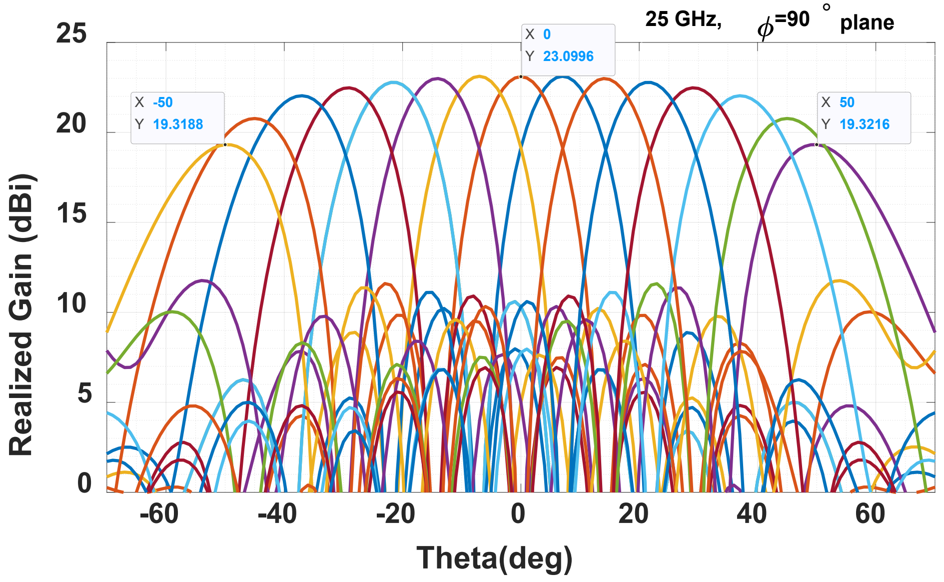


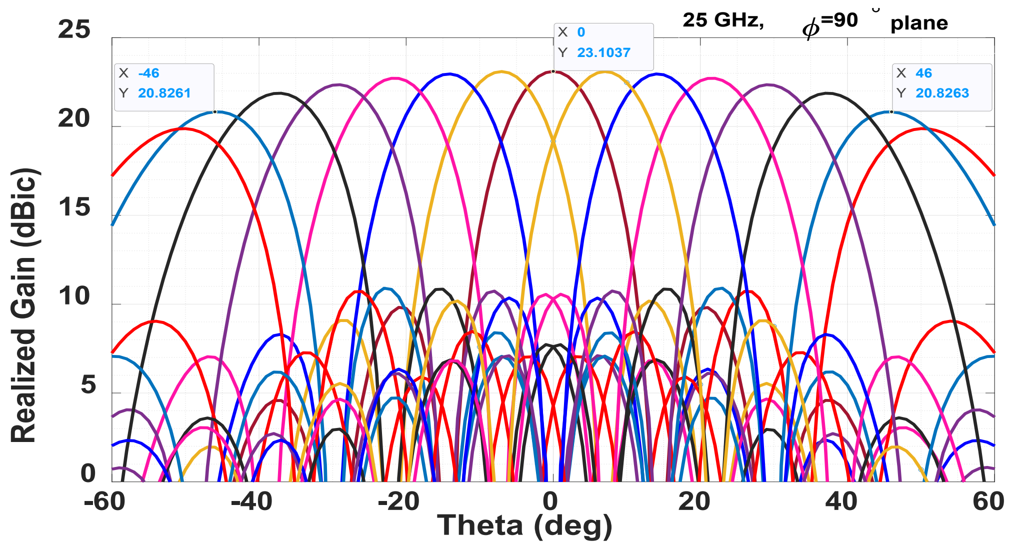


Phased Array Designs: Approach II

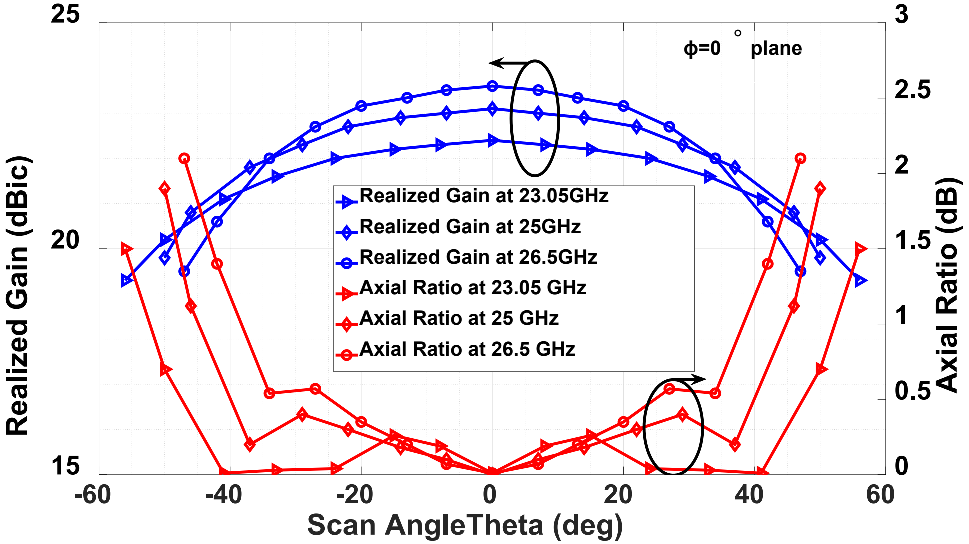


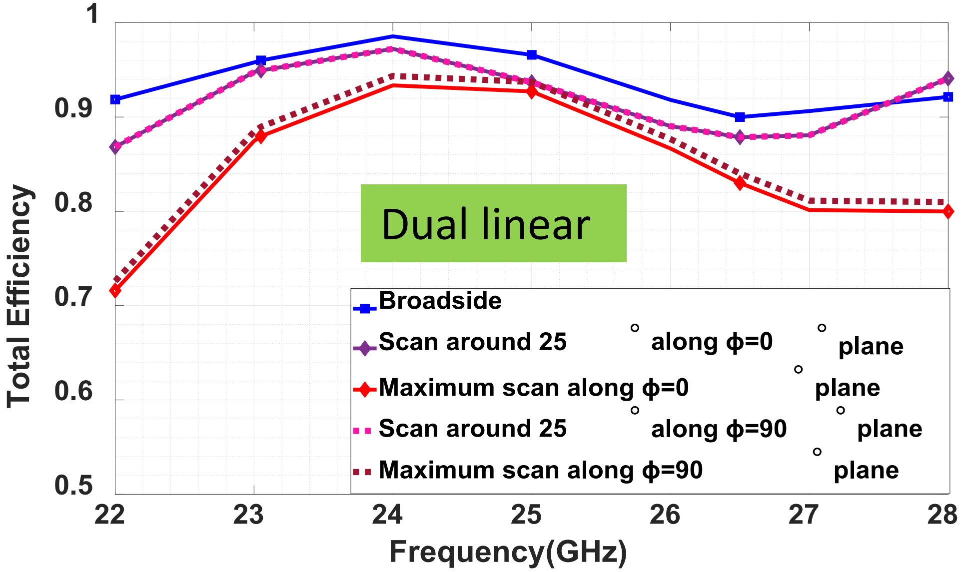


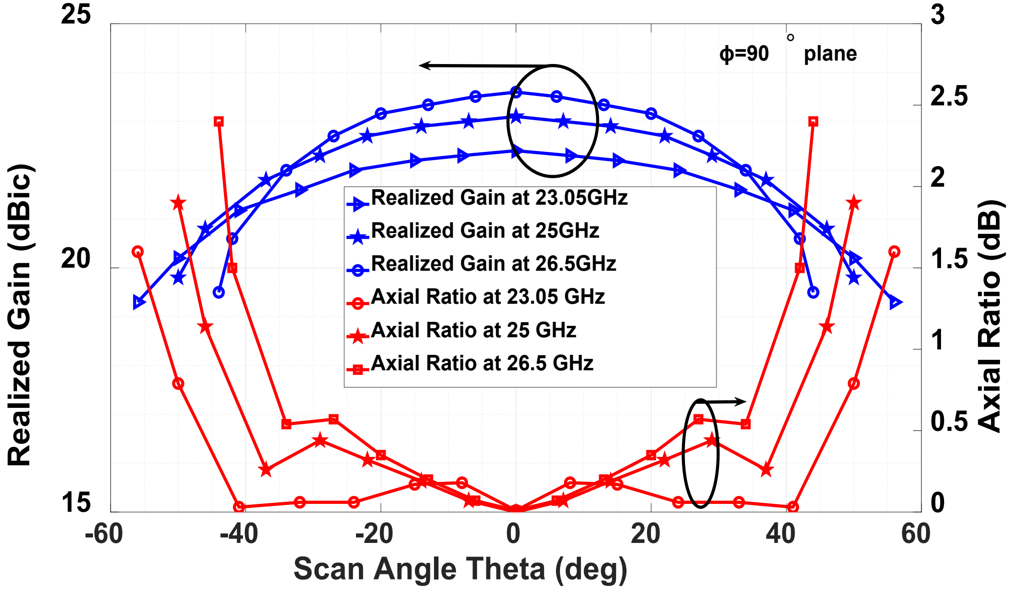


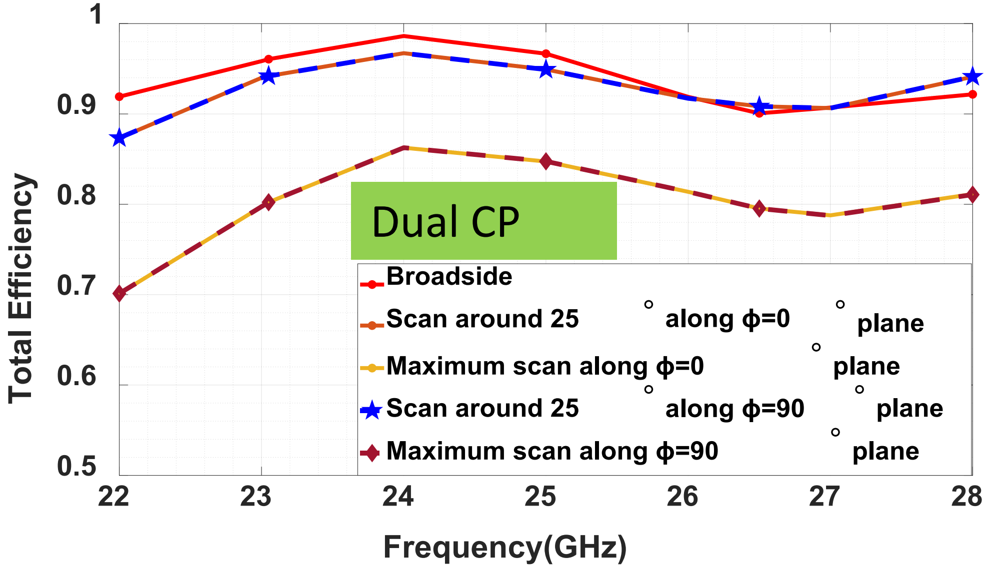


Phased Array Designs: Approach II

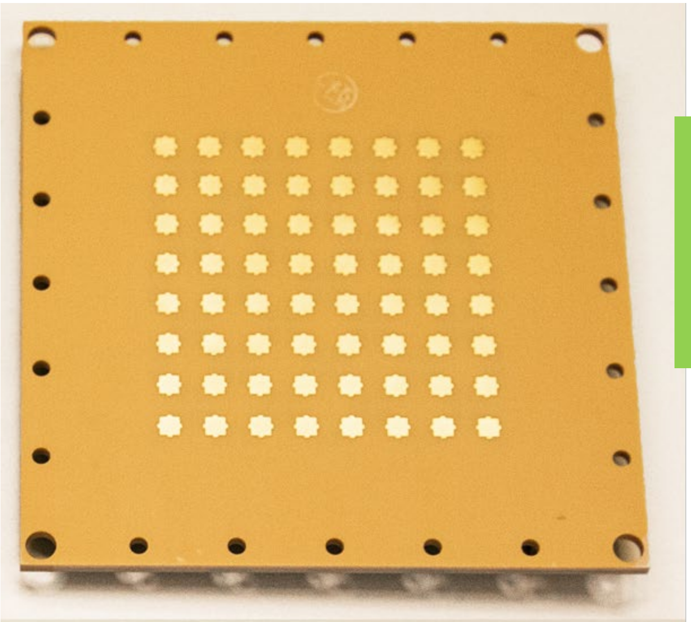




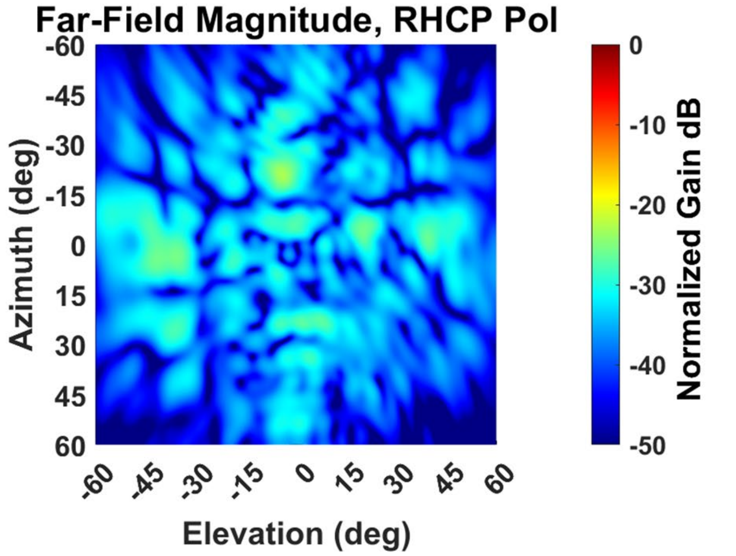


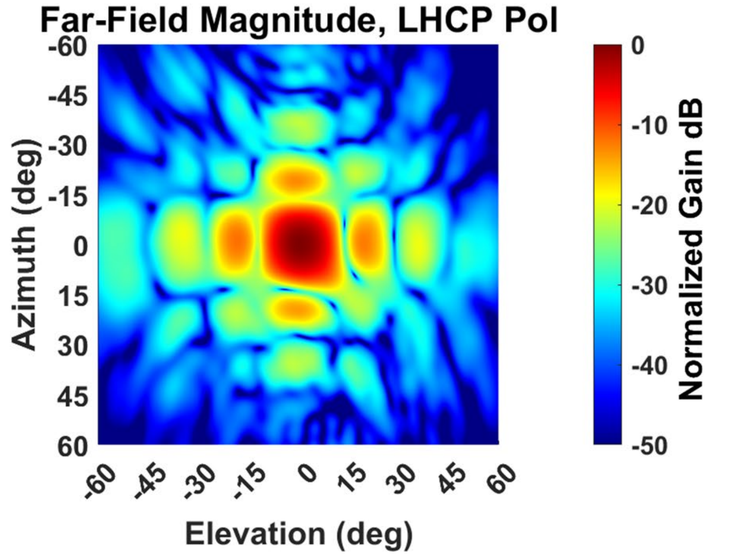


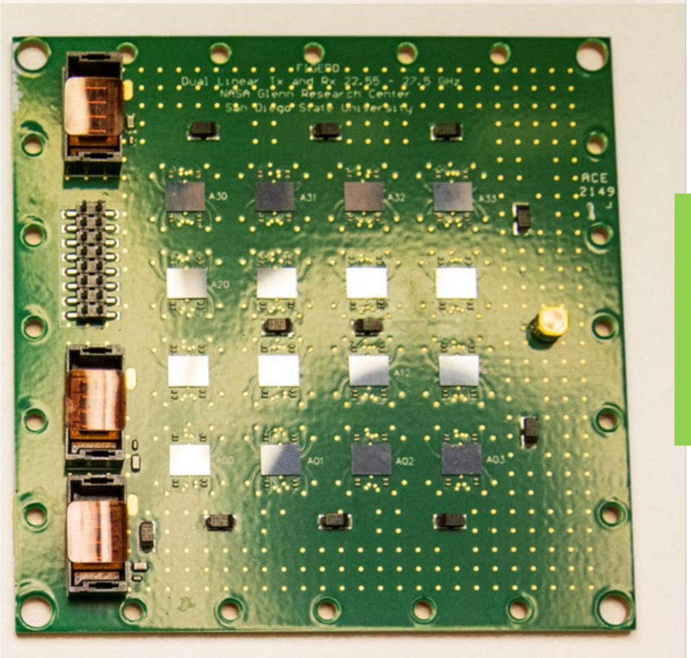
Phased Array Designs: Approach II



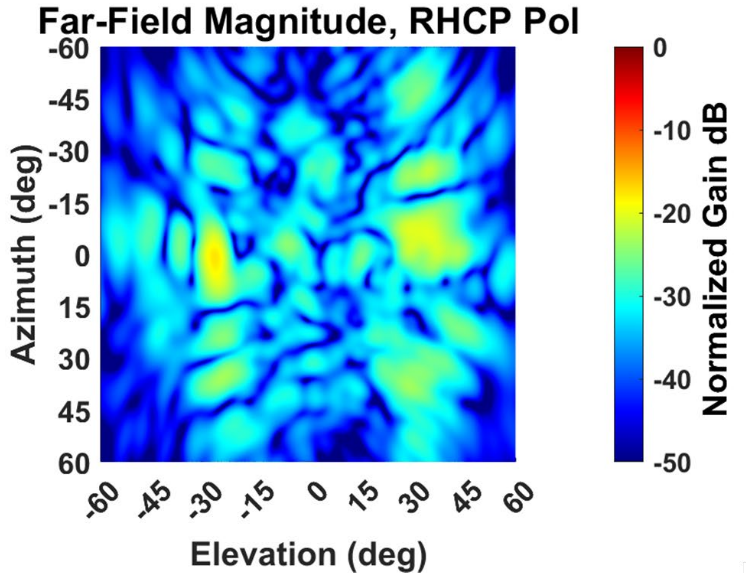
Directivity est: 20.5 dBic
Axial Ratio: 0.12 dB

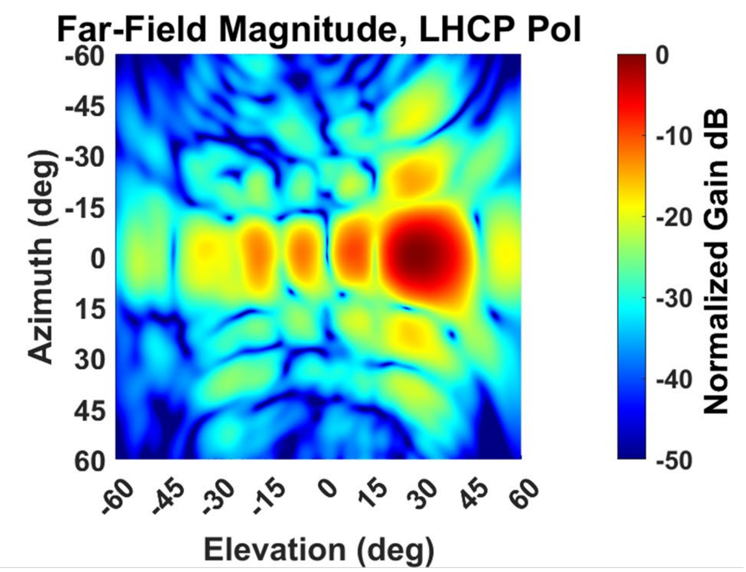




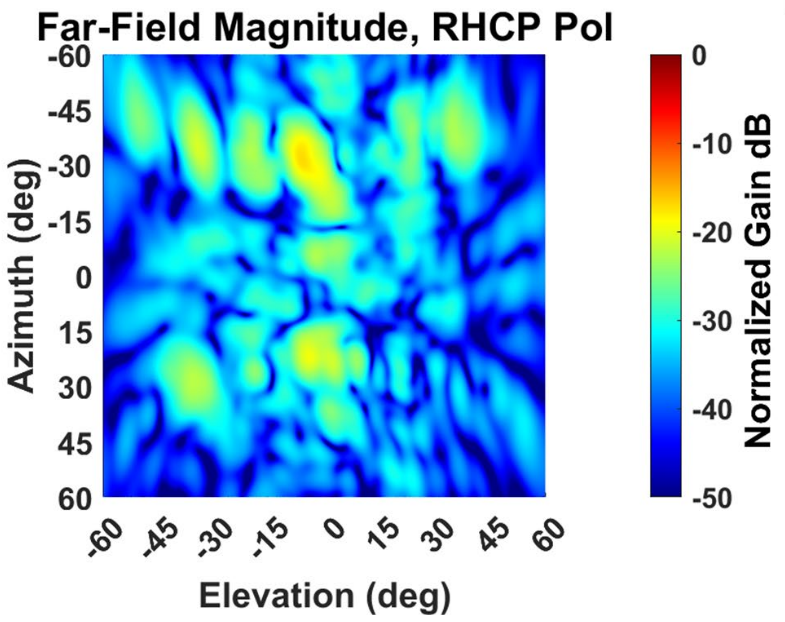


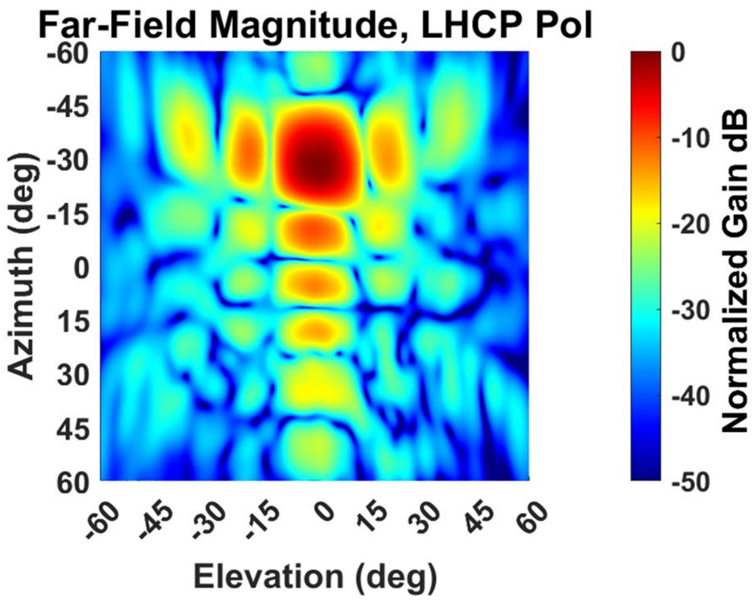
Directivity est: 20.4 dBic
Axial Ratio: 1.42 dB



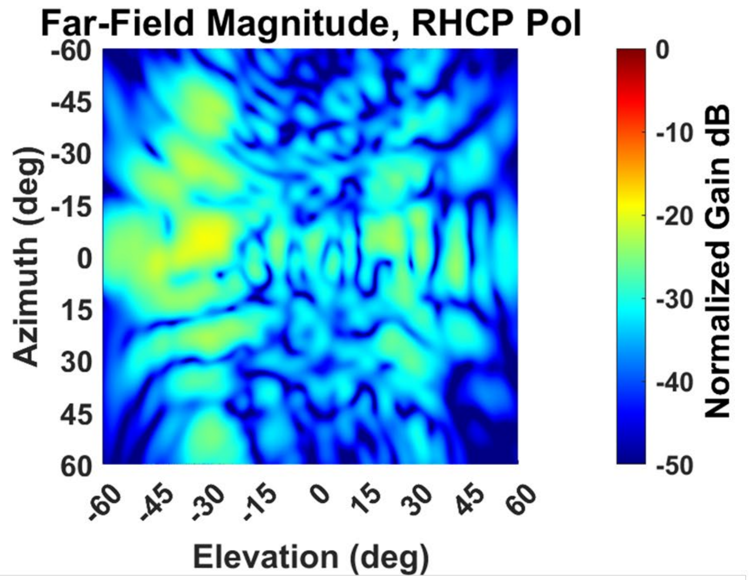


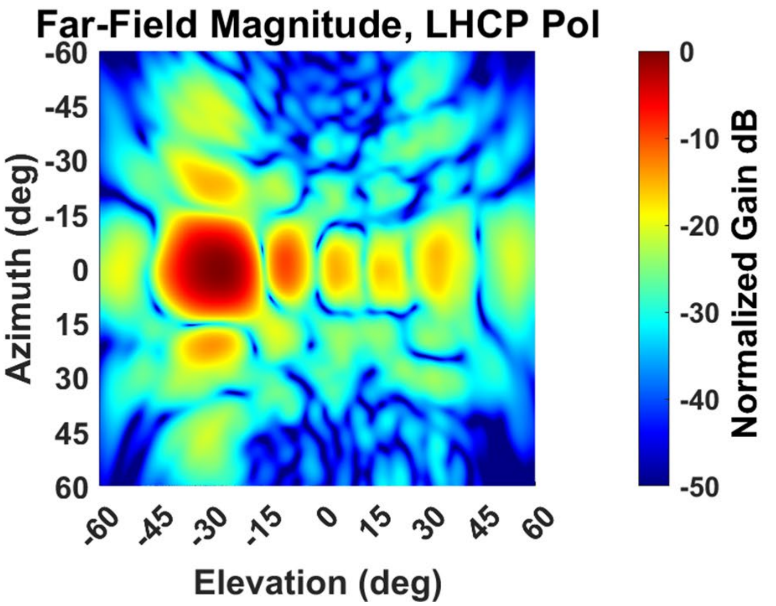
Phased Array Designs: Approach II





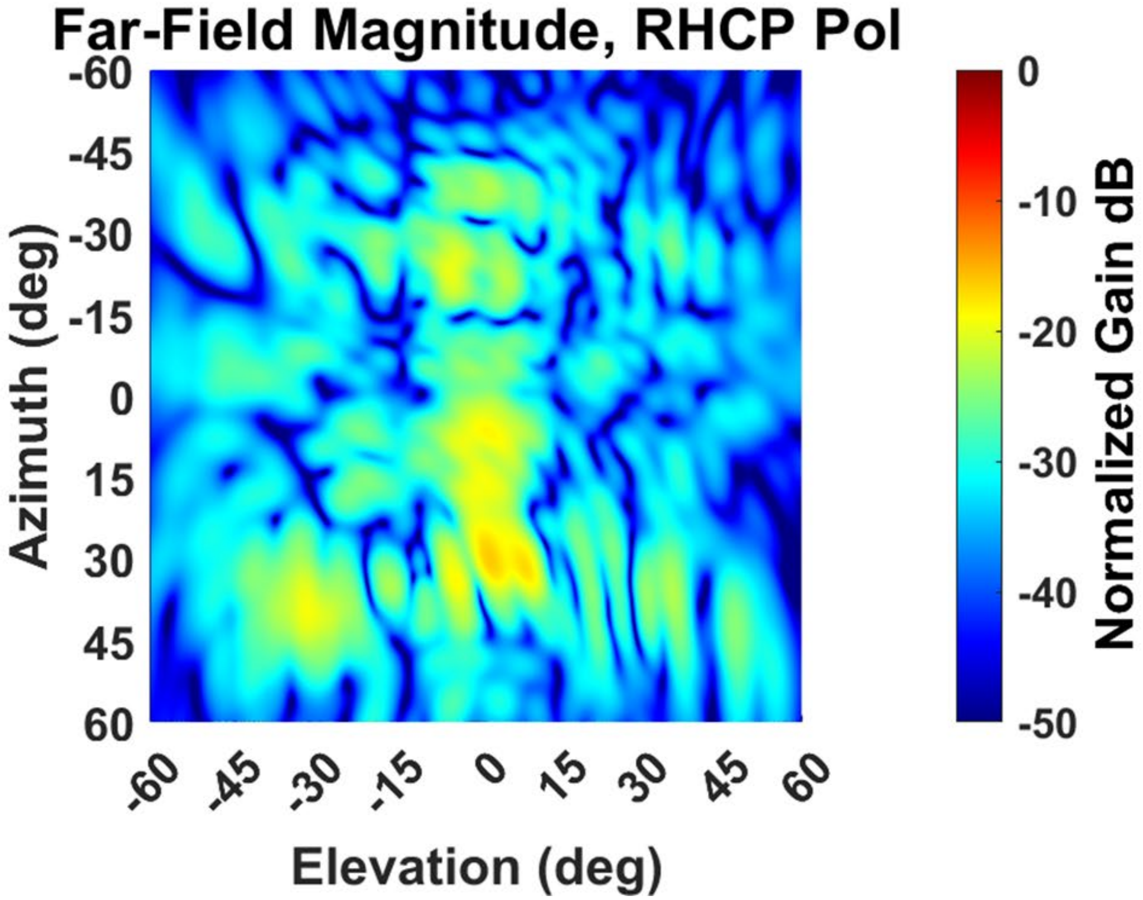
Directivity est: 20.4 dBic
Axial Ratio: 1.57 dB

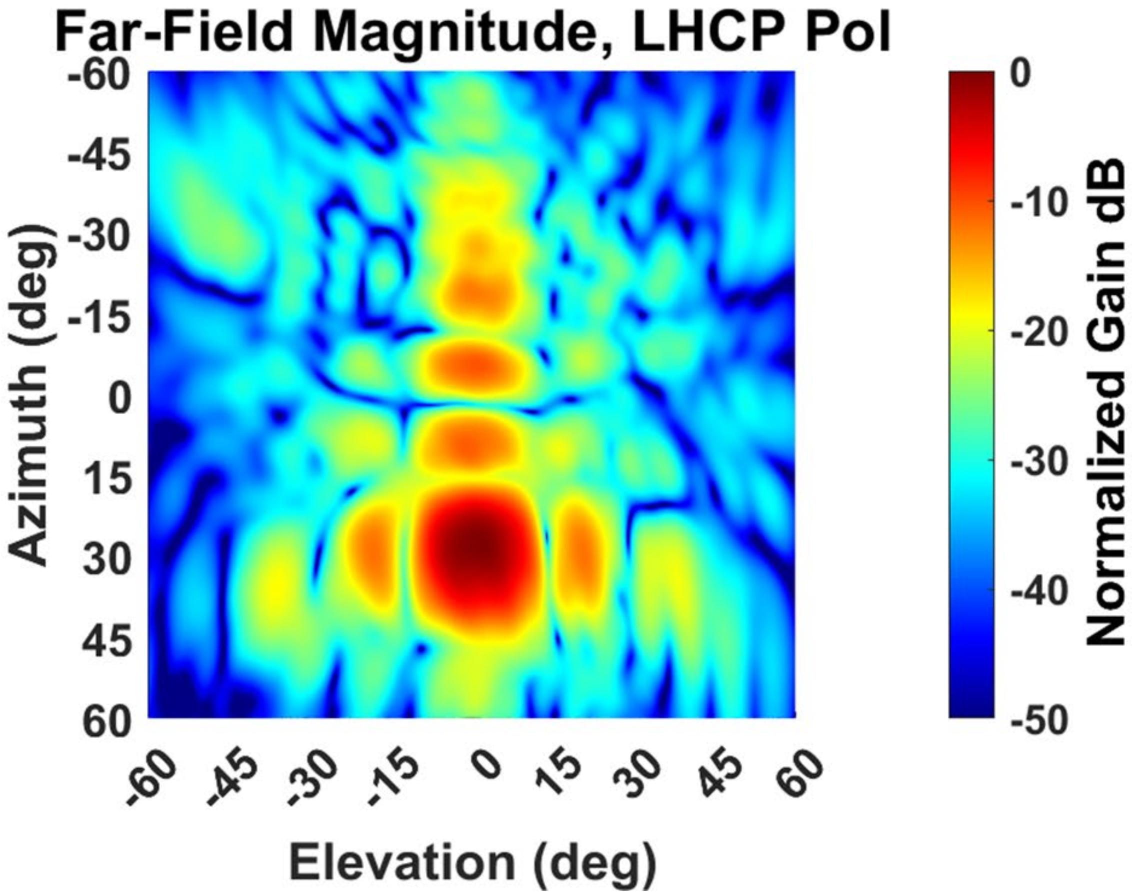




Directivity est: 20.1 dBic
Axial Ratio: 1.26 dB

Phased Array Designs: Approach II



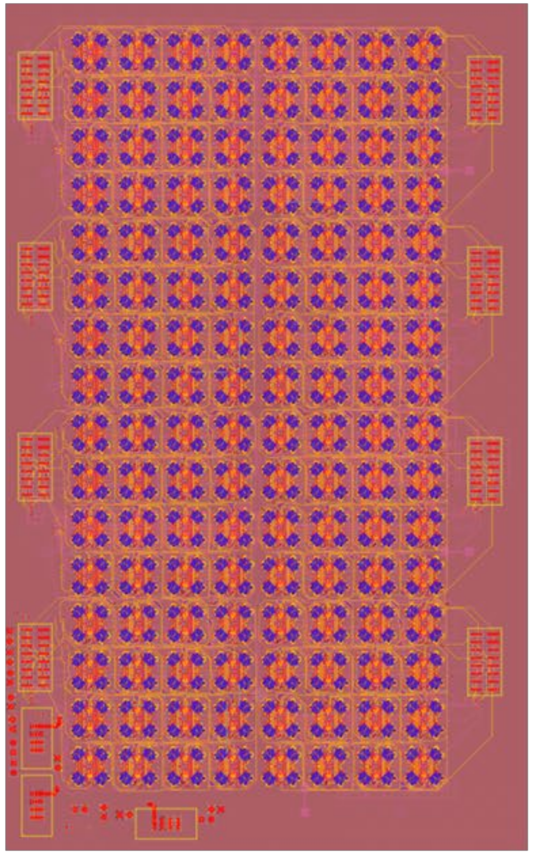


Directivity est: 19.8 dBic
Axial Ratio: 2.6 dB

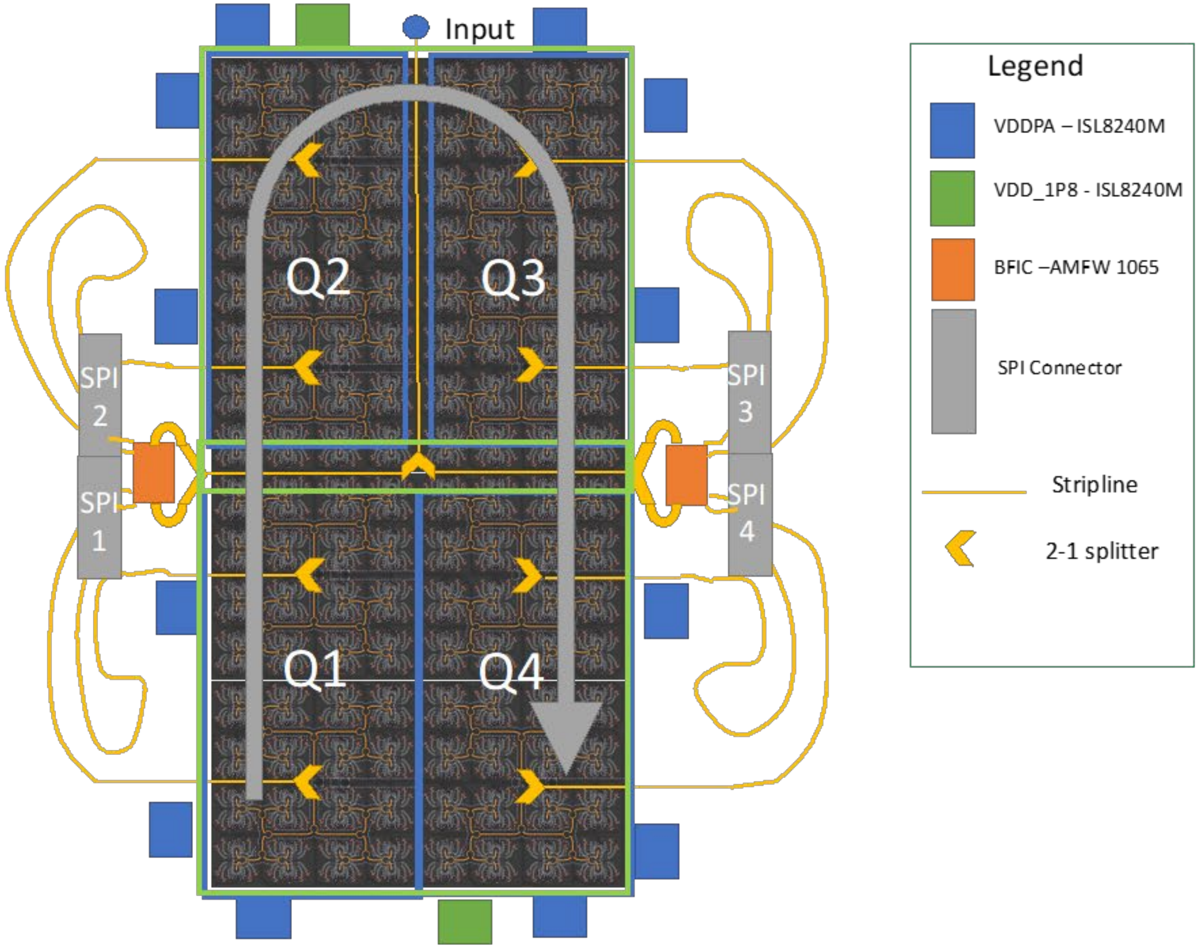
Additional measurement are in process and will be available in couple of week!

Conclusions and Future Study

- Full 512-element FIGARO array PCB layout currently being developed.
- Scaled layout complete and undergoing performance analysis.



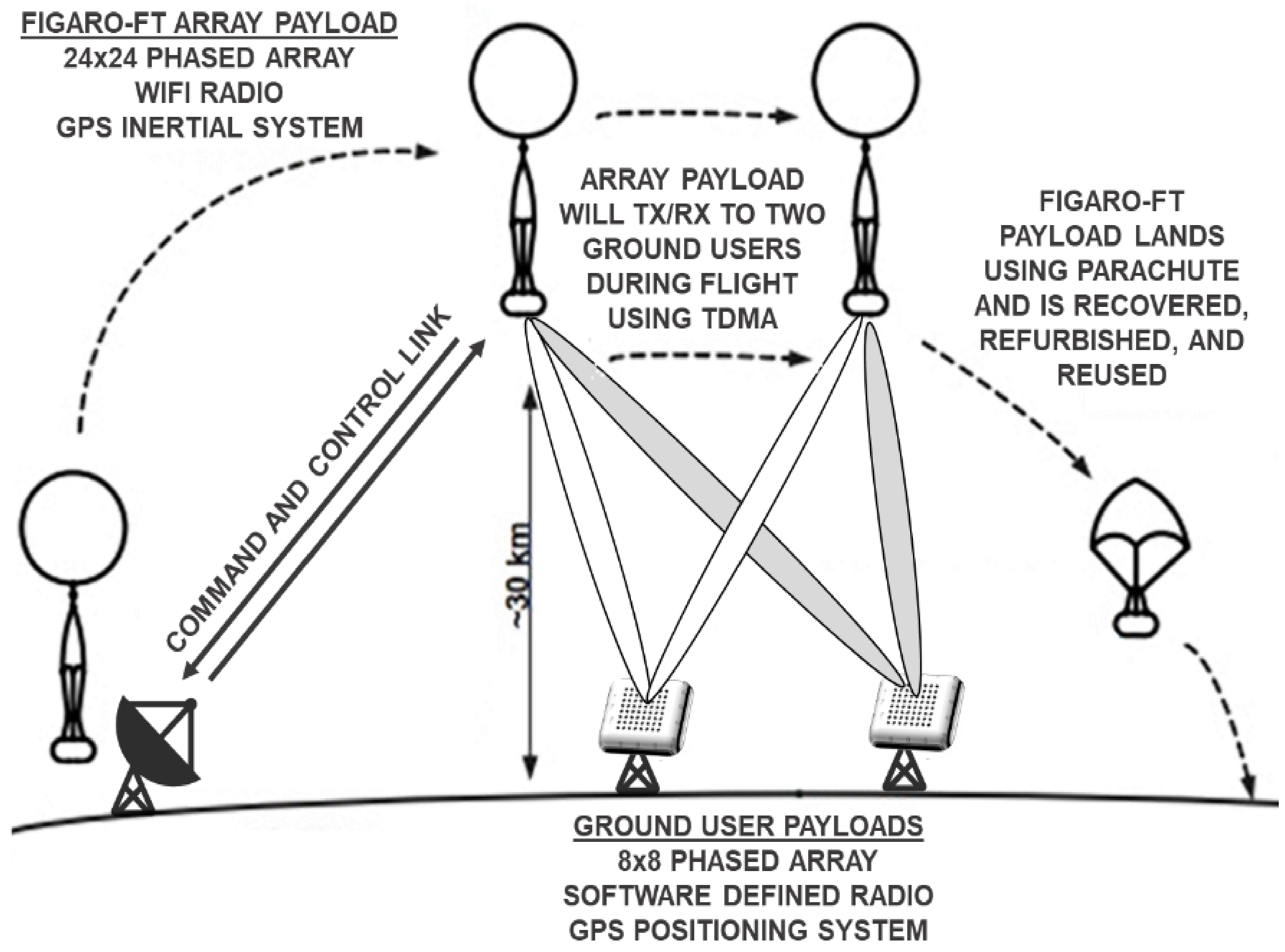
2D PCB layout (32x16 array)



Full 512-element FIGARO layout with power regulators and SPI.

Conclusions and Future Study

5G Array for Lunar Relay Operations – Flight Test (FIGARO-FT)



Depiction of proposed high altitude balloon experiment architecture

Link Budget	FIGARO-FT Forward Link			FIGARO-FT Return Link		
Carrier Frequency (GHz)	23			27		
Tx Antenna Angle (off boresight)	0°	30°	60°	0°	30°	60°
EIRP (dBW)	40	39	36	29	28	25
Slant Path Distance (km)	30	34.6	60	30	34.6	60
Rx Antenna G/T (dB/K)	-5.0	-9.0	-6.0	4.0	0.0	3.0
Modulation	QPSK			QPSK		
Bit Error Rate	10^{-7}			10^{-7}		
Information Rate (Gbps)	10	2.4	0.8	4.6	1.1	0.4
Link Margin (dB)	3.0	3.0	3.0	3.0	3.0	3.0

Link budget calculations for a 30-km altitude balloon link