CWI
CENTRE
FOR
WIRELESS
INNOVATION

Final Review

Conformal Antenna Array for Next Generation Launchers

esa

ESA AO/1-10149/20/NL/AS

QUEEN'S
UNIVERSITY
BELFAST

MAGISTER
SOLUTIONS

arianeGROUP

Final Review Meeting

- ESA, QUB, ArianeGroup, Magister
- Friday 5th December 2023

Outline

- Current Antenna Technology on Ariane 5
- S Band Antenna
- K_a Band Antenna
- Doppler Estimation and Throughput Simulations
- Practical Results

Ariane 5 - Current Antenna Technology

Antenna concept and architecture

- Quadrifilar helix
- 1 RHCP antenna and 1 LHCP antenna on the upper stage (not flush mounted)

Performances

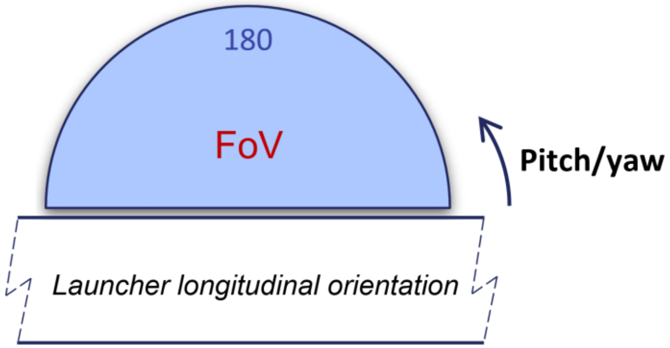
- Omnidirectional
- -6dBi in 99,5% of the surrounding sphere

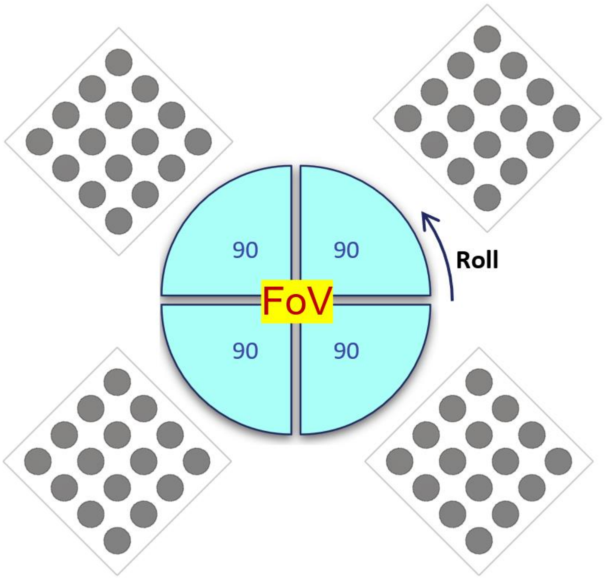
Telemetry services

- Straight to ground stations

S-Band Antenna

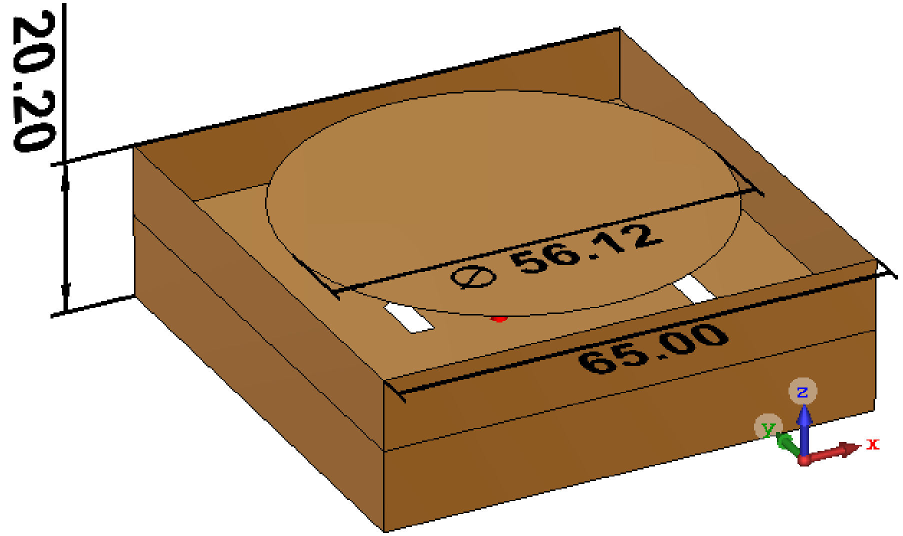
S Band system concept and sector definition

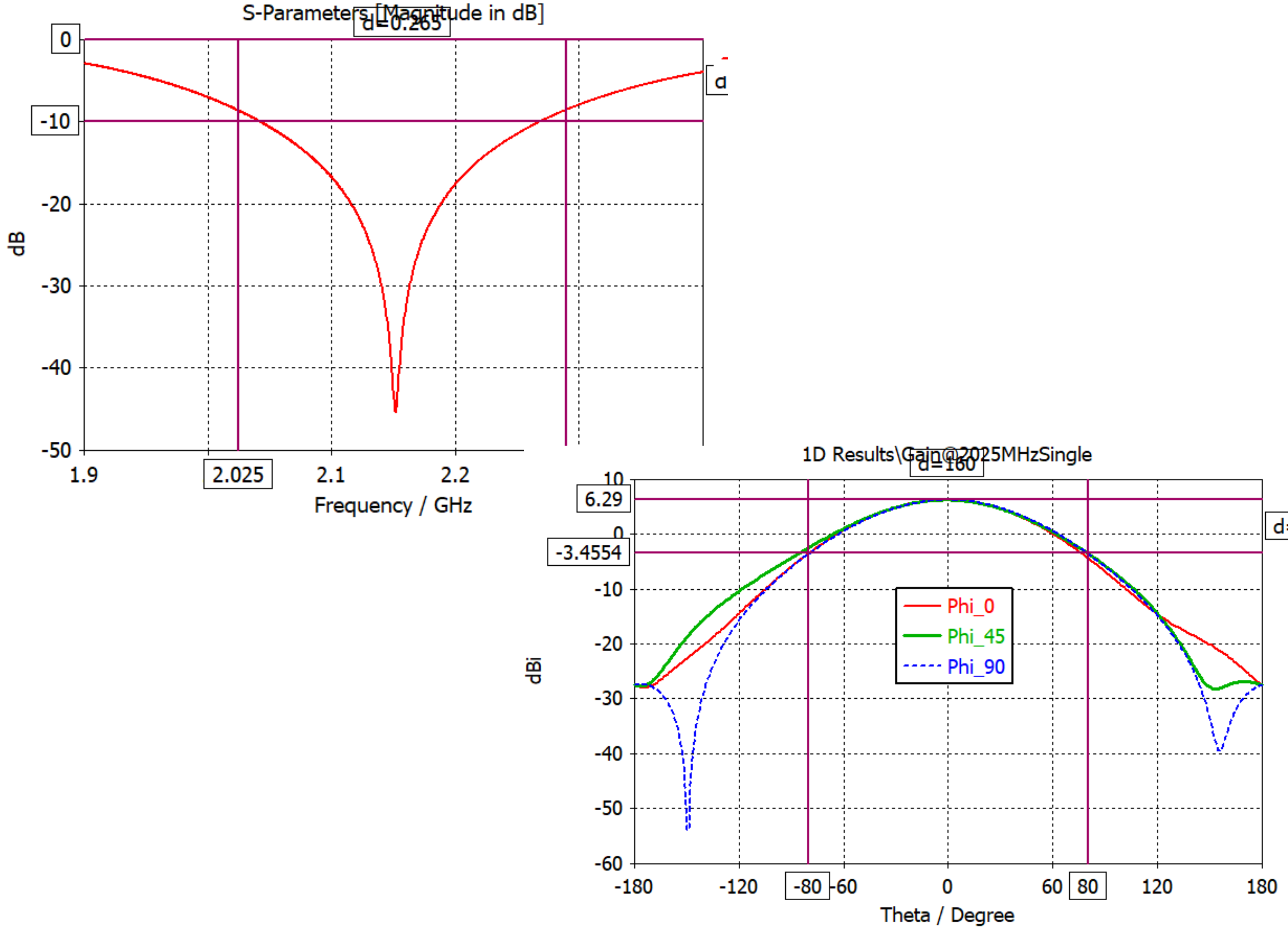




S Band Antenna Element Selected Concept

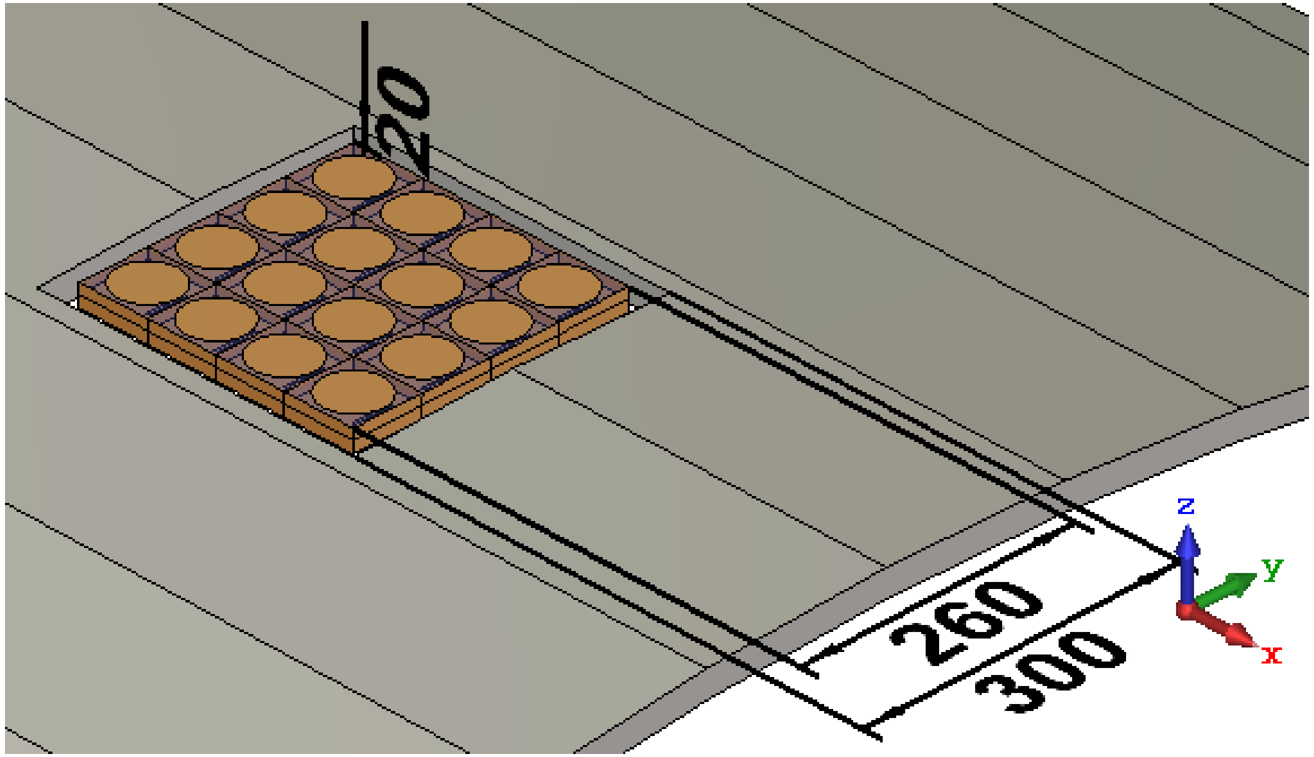
- air spaced patch
- no multilayer fabrication required



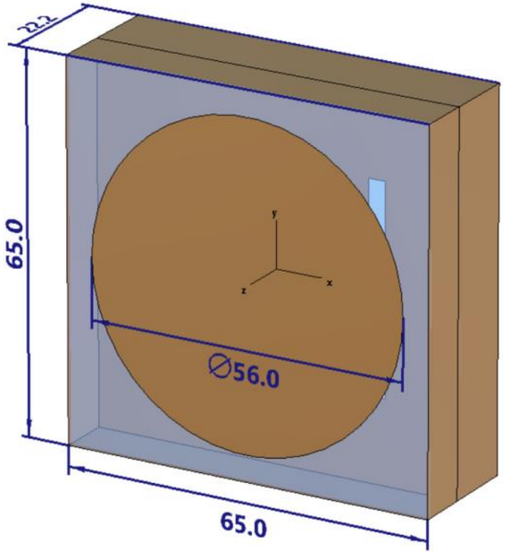


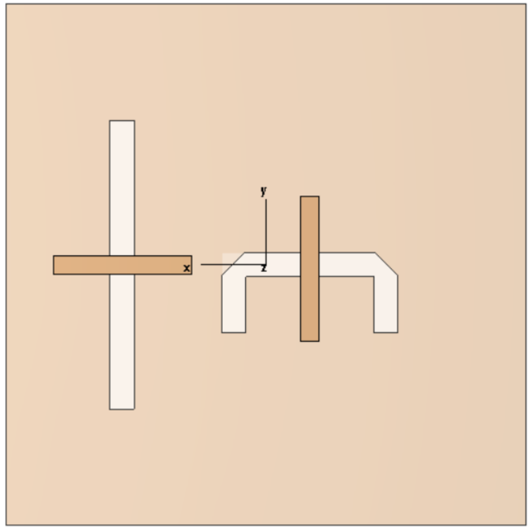
CENTRE FOR WIRELESS INNOVATION

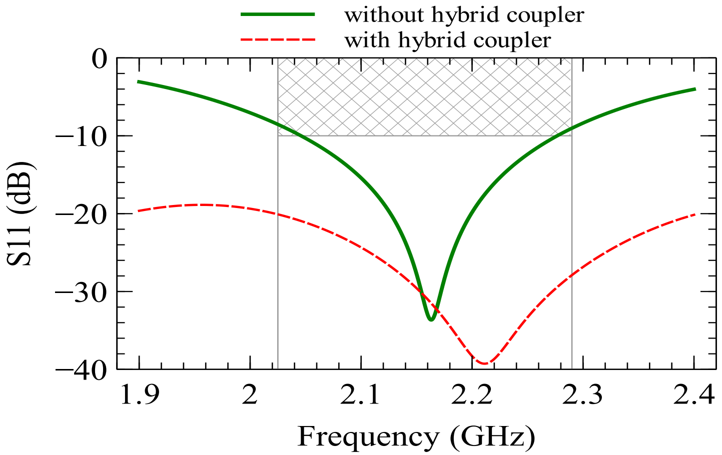
S-Band Array – Launcher Accommodation

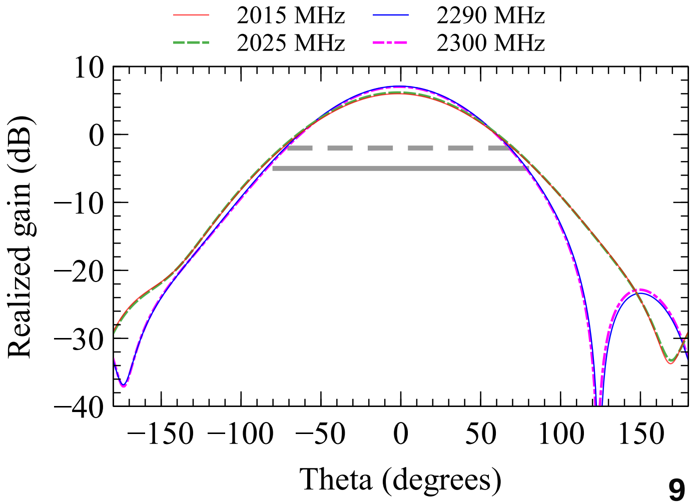


S Band Optimized antenna structure



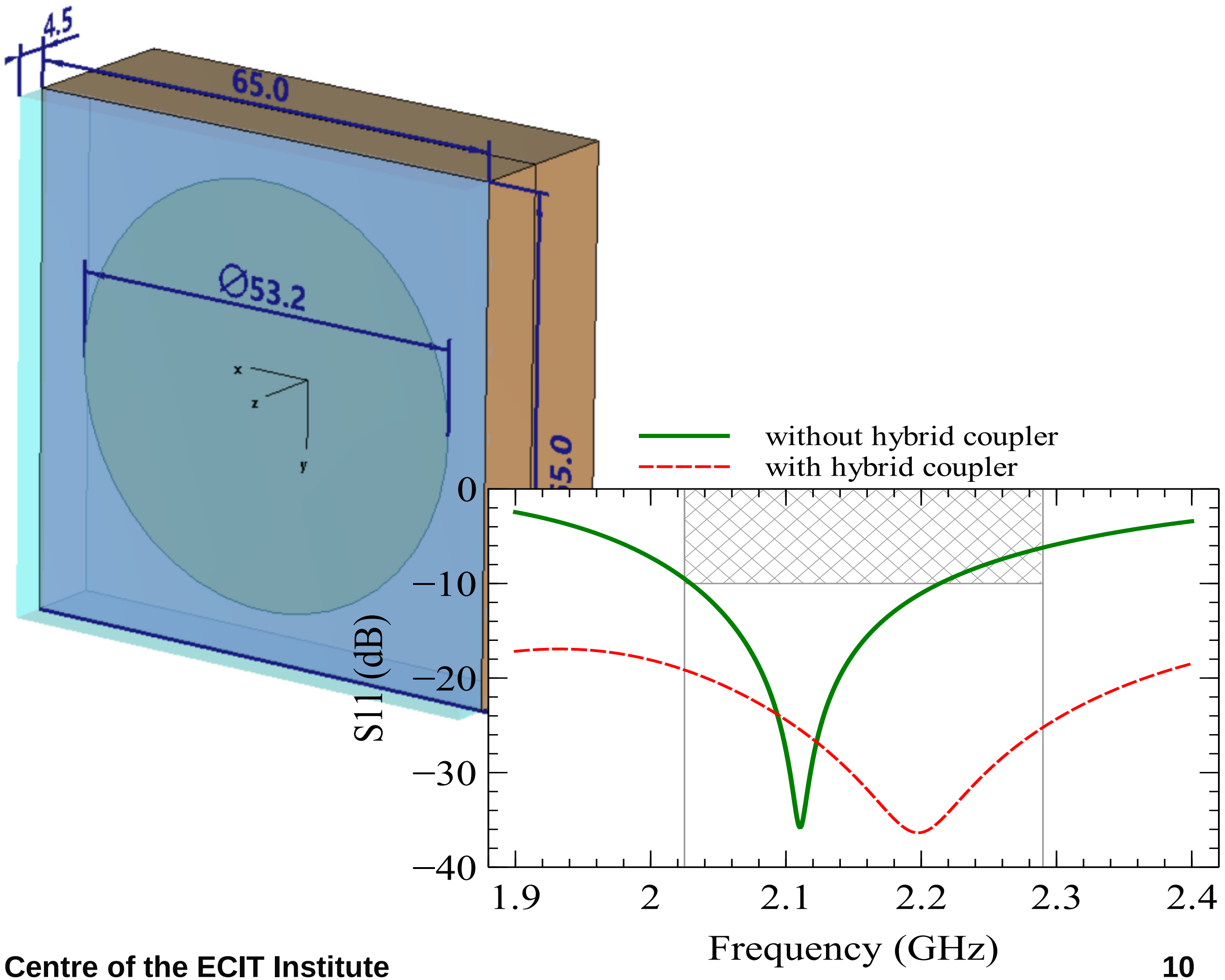




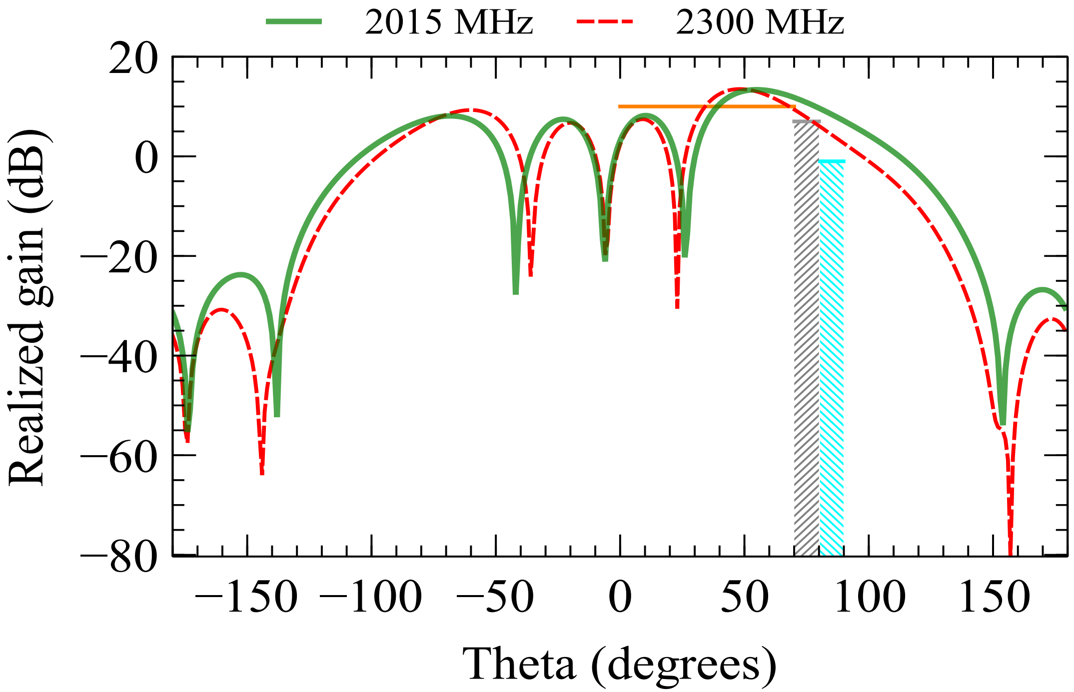


Antenna simulation with thermal protection

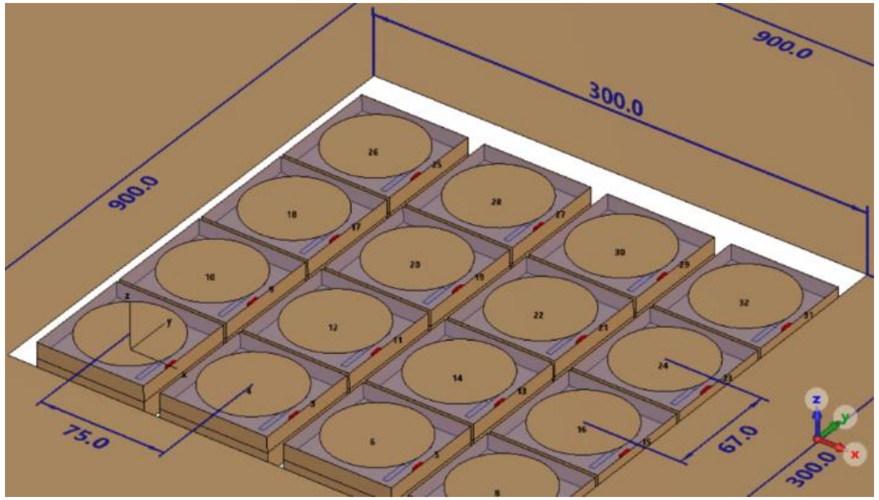
- Dielectric sheet of 4.5mm thickness is placed on top of the antenna.
- Dielectric constant of 2.24 and loss tangent of 0.02

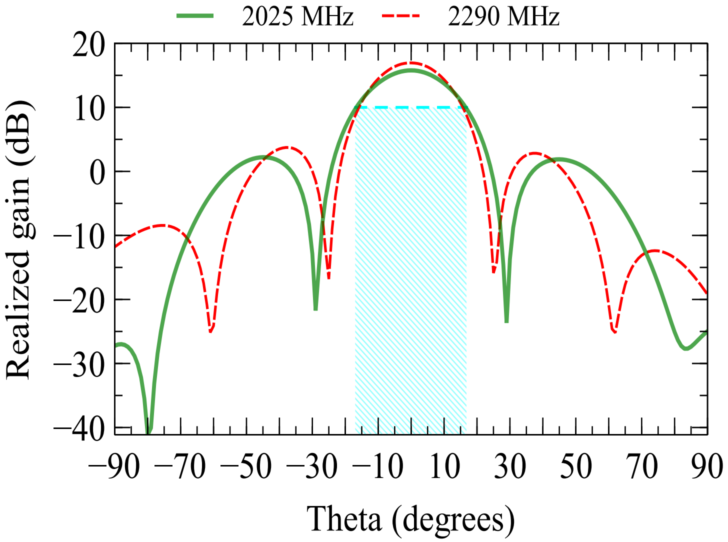


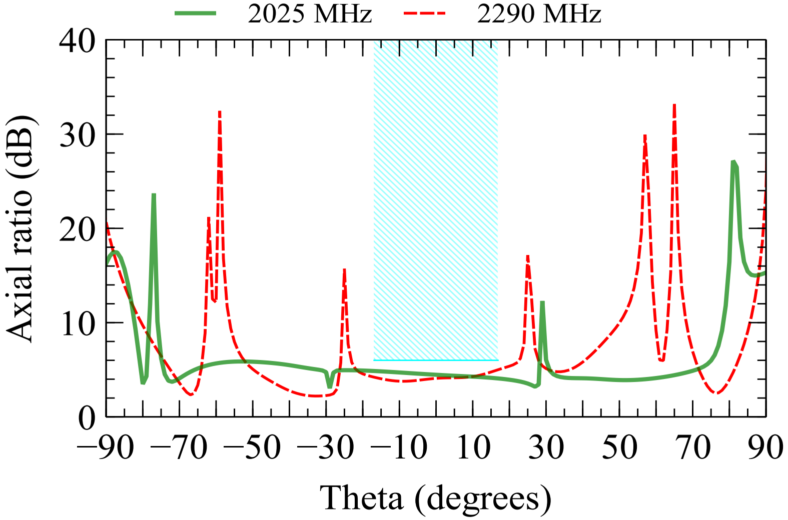
Scanning performance of the a 4x4 array with thermal protection



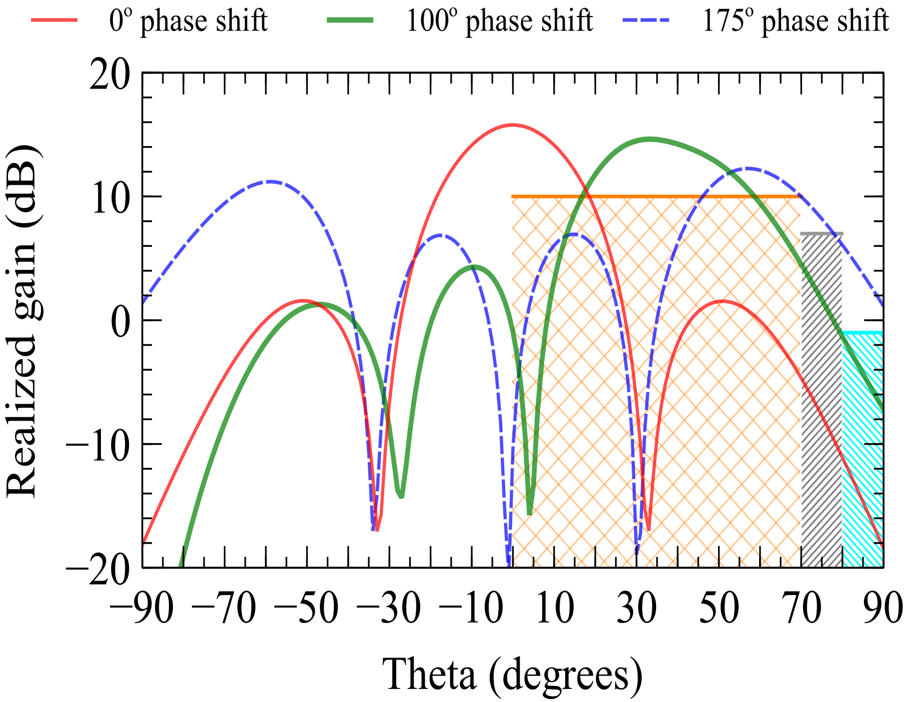
S Band Antenna Array System Design and Analyses

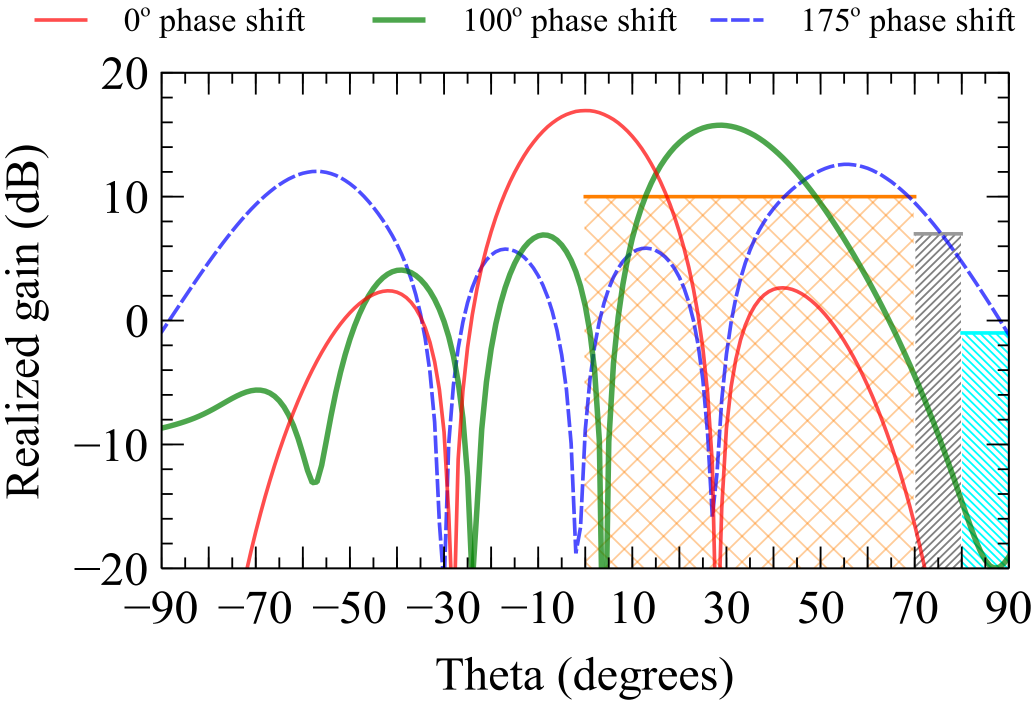






S Band Antenna Array – scanning performance



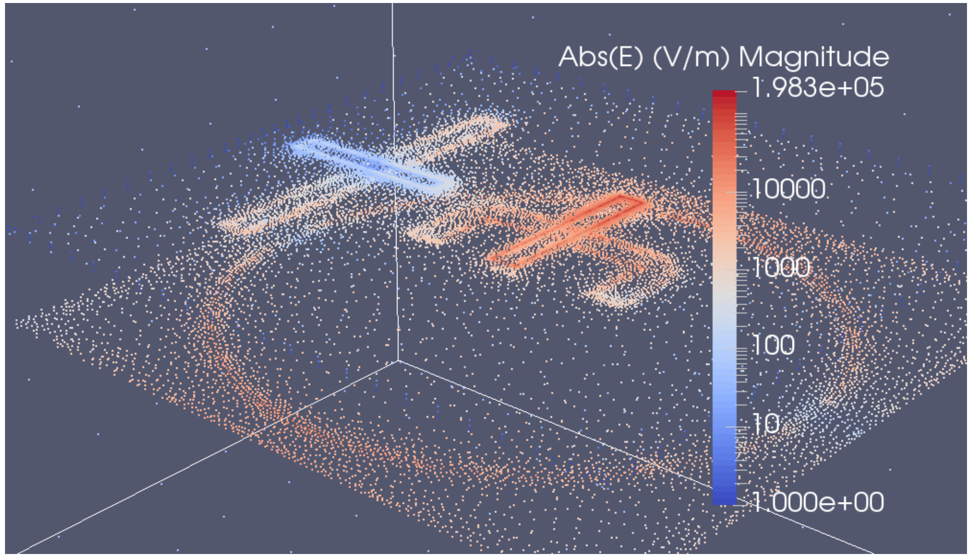


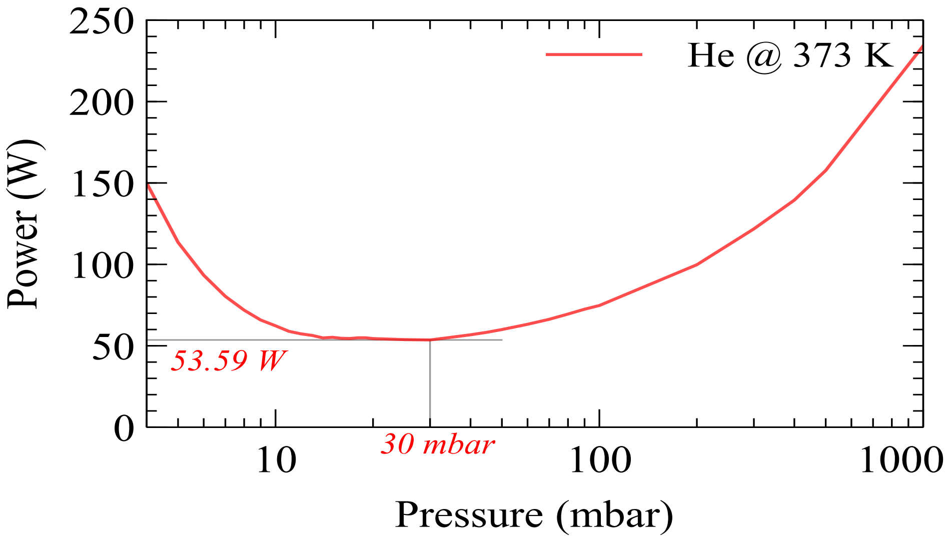
S Band Antenna Array – scanning performance

		|θ| < 70°	70°< |θ| < 80°	80°< |θ| < 90°
S-Band - Rlz. Gain (required)		> 10 dBi	> 7 dBi	> -1 dBi
S-Band - Rlz. Gain (Simulated)	2.025 GHz	> 9.98 dBi	> 6.10 dBi	> +1.12 dBi
	2.290 GHz	> 9.51 dBi	> 4.73 dBi	> -1.14 dBi

		|θ| < 70°	70°< |θ| < 80°	80°< |θ| < 90°
S-Band – AR (required)		< 6 dB	< 9 dB	< 11 dB
S-Band – AR (simulated)	2.025 GHz	< 5.1 dB	< 8.5 dB	< 17.4 dB
	2.290 GHz	< 7.7 dB	< 11.7 dB	< 33.4 dB

S Band Antenna Element Corona discharge simulation





Breakdown power due to Corona discharge for S-band antenna (simultaneous excitation), at 2.2 GHz and using He at 373 K

Link Budget (for corona discharge validation)

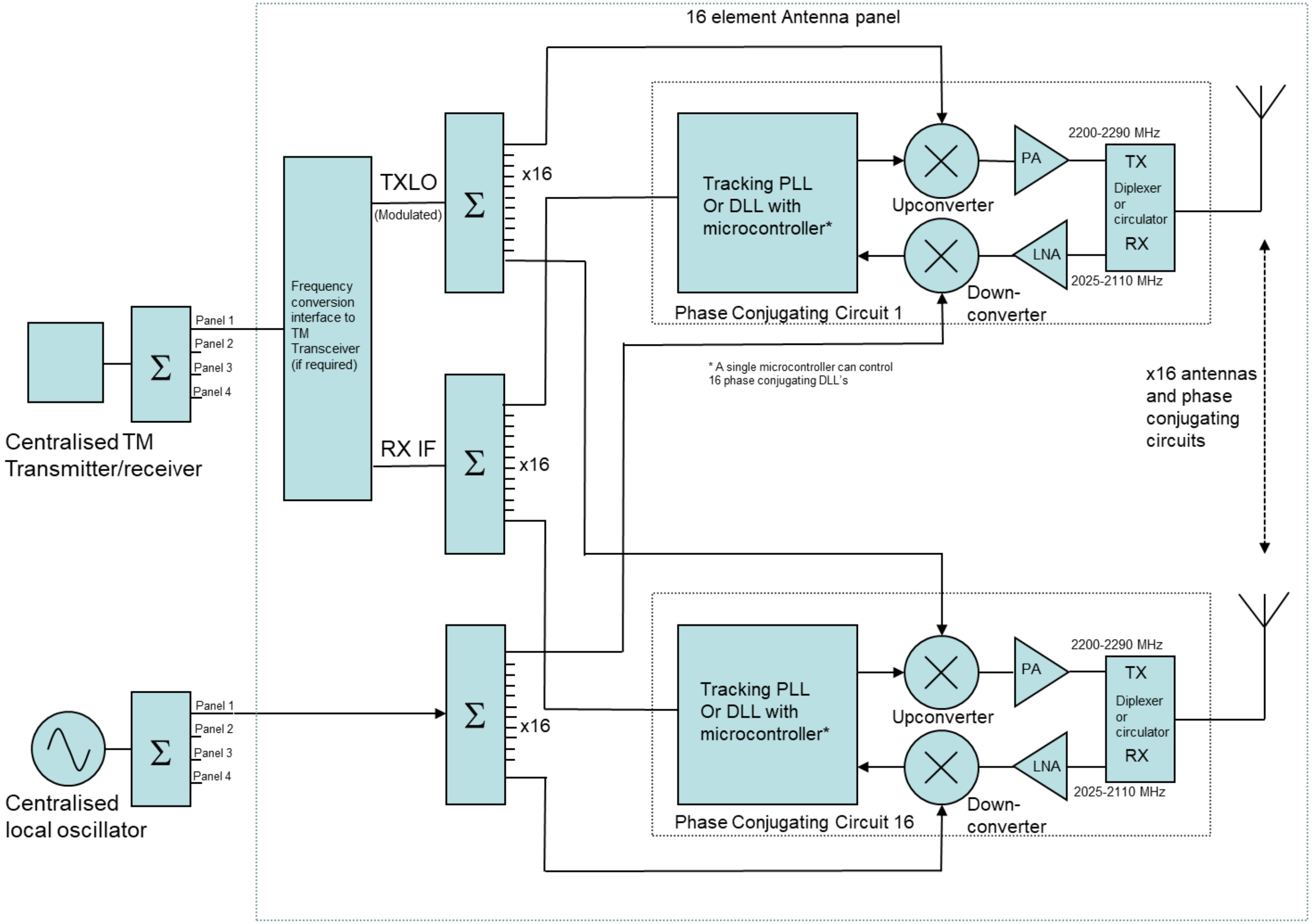
	nominal	intermediate	critical
Transmission chain		≈300W EIRP	
emitted power	30W	30W	30W
Transmission losses	< 2dB	< 2dB	< 2dB
Antenna gain	10dBi	**7dBi**	**-1dBi**
Communication path			
Space losses	191dB	191dB	191dB
Polarization losses	< 1dB	**1,5dB**	**2,5dB**
Incidence angle	70°	**80°**	**90°**
Telemetry performances			
data rate	1Mbps	1Mbps	**100kbps**
Link margin	3dB w/o R-S coding	**1dB with R-S coding**	**1dB w/o R-S coding**

Assuming 300W EIRP (30W into 10dBi antenna), and 16 element array with 15 dBi gain, the power per element would be:

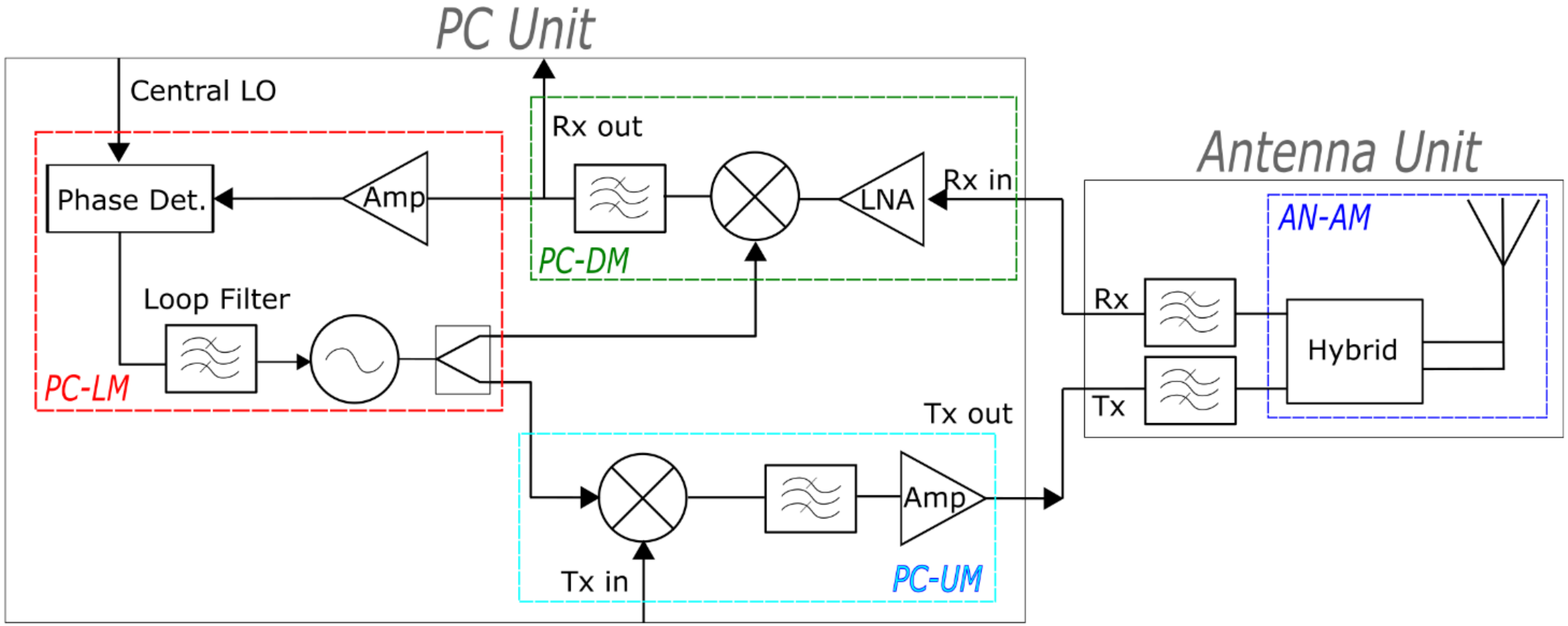
$10\log(P_{ELE} x16) + 15 = 10\log(300)$

$P_{ELE} =$ 0.6 W (total 9.48W for 16 elements), Corona discharge predicted breakdown at 53.59 W/element

S Band Retrodirective System Concept

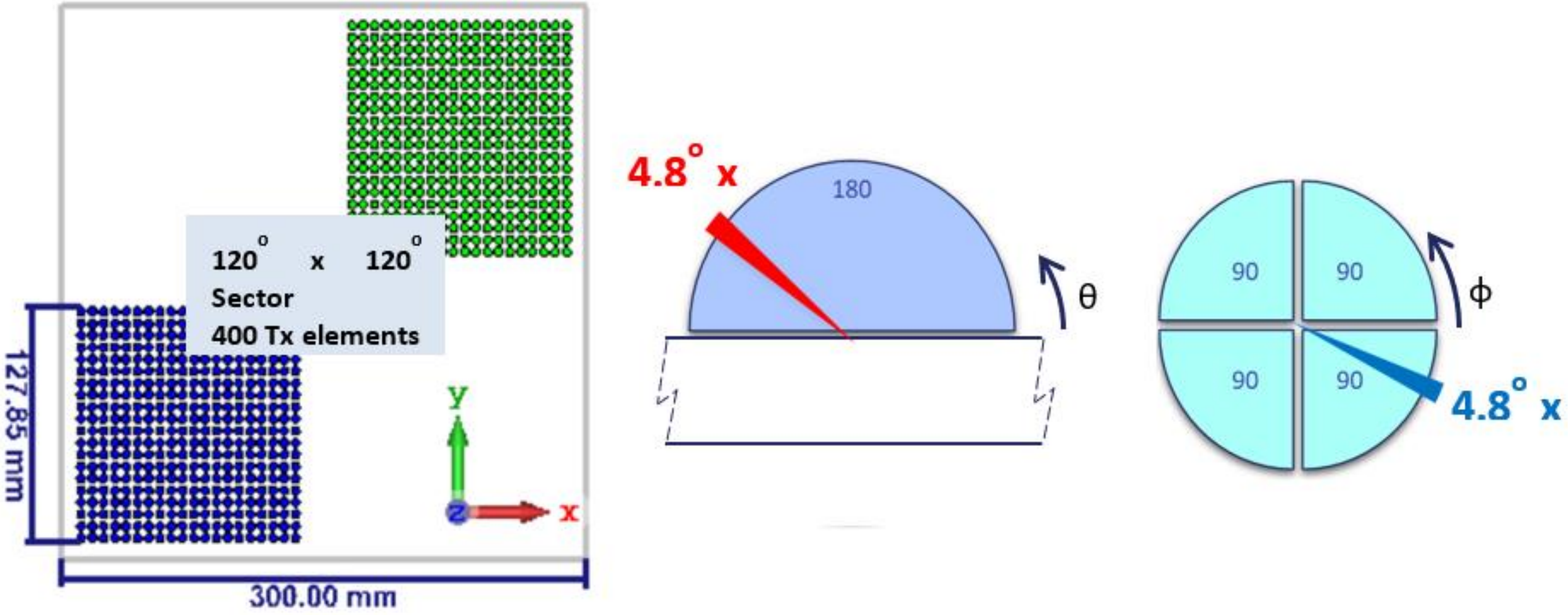


S Band Phase Conjugating Unit

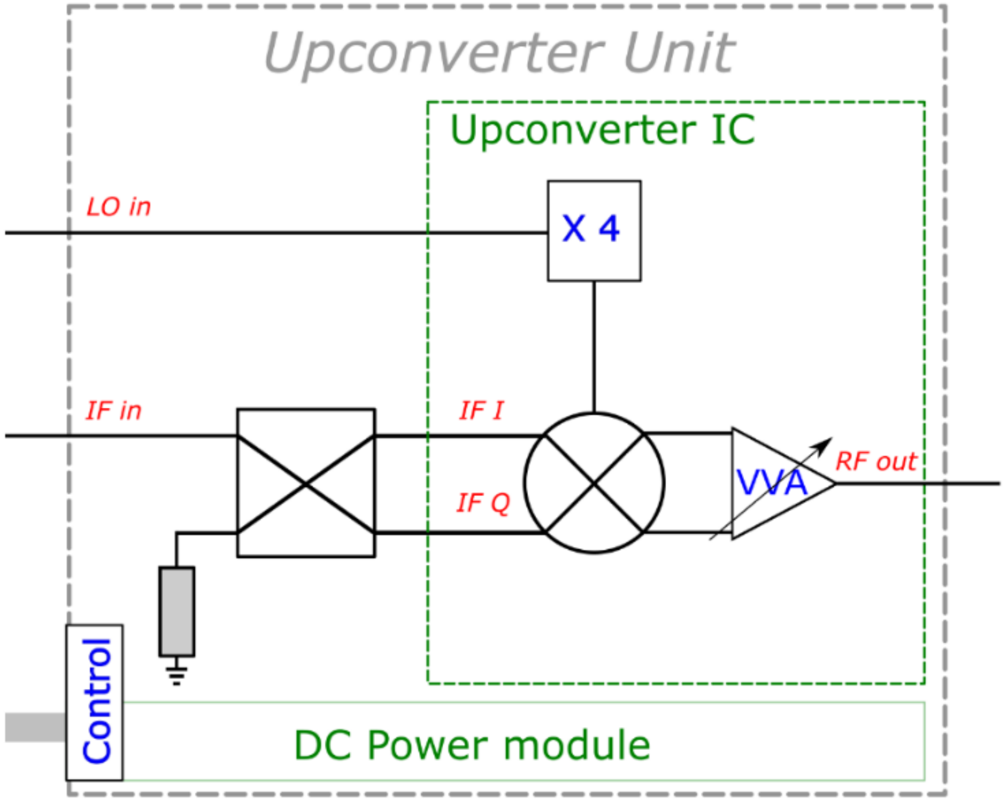


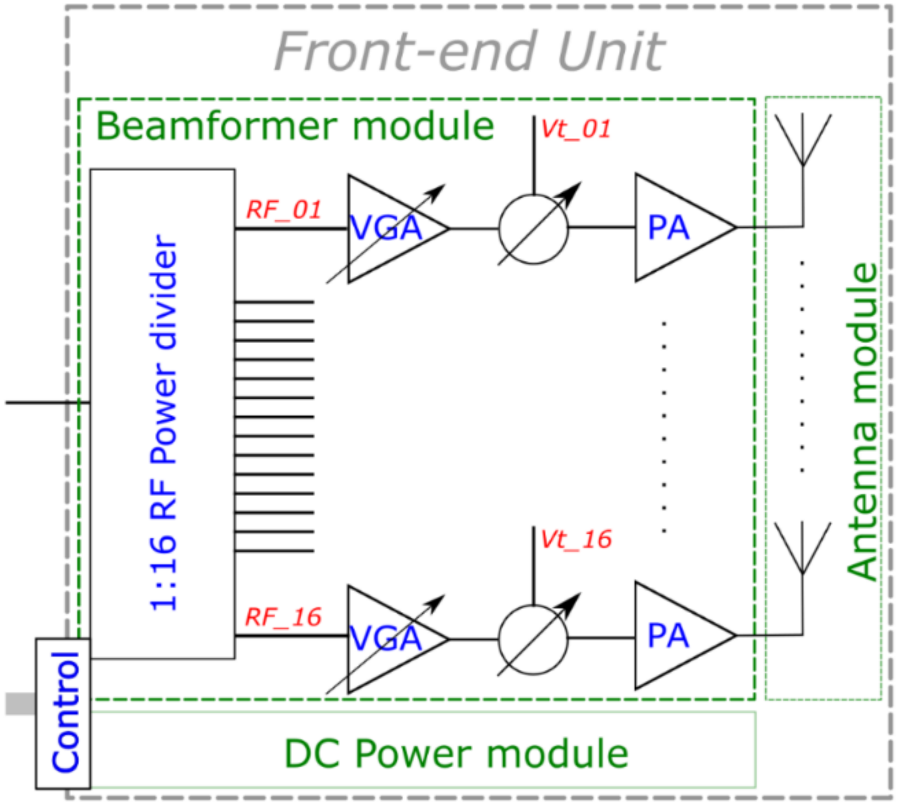
Ka Band Antenna

Array layout and sector definition for one antenna panel for Ka band



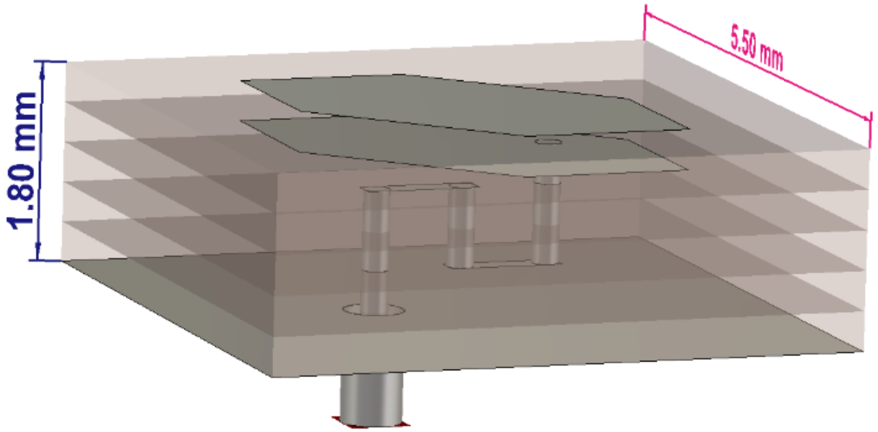
Ka Band Architecture

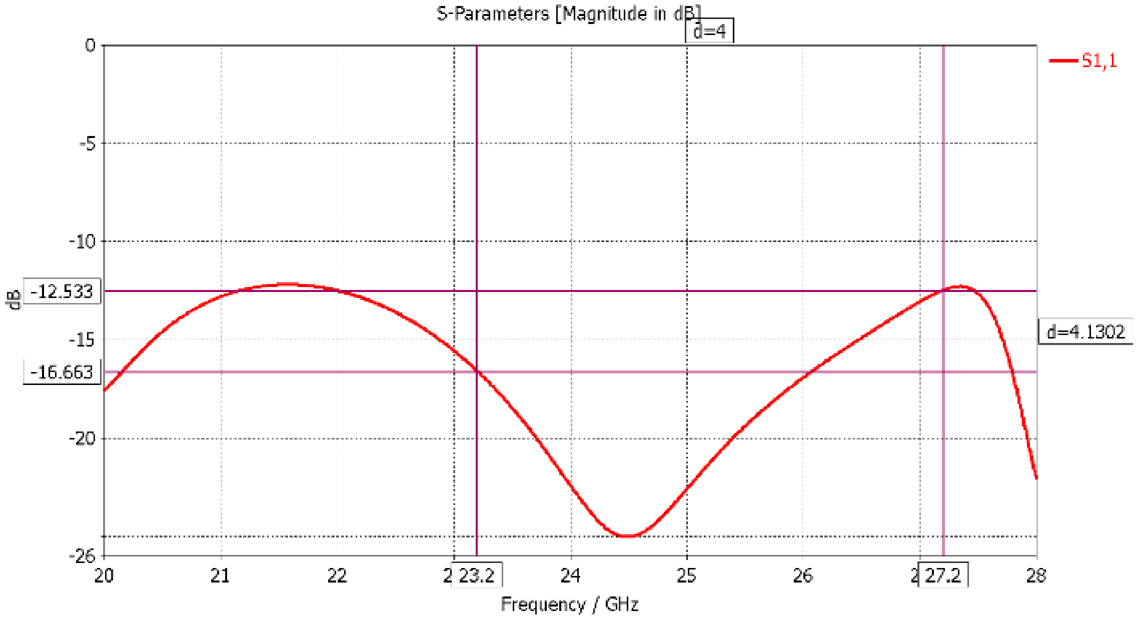




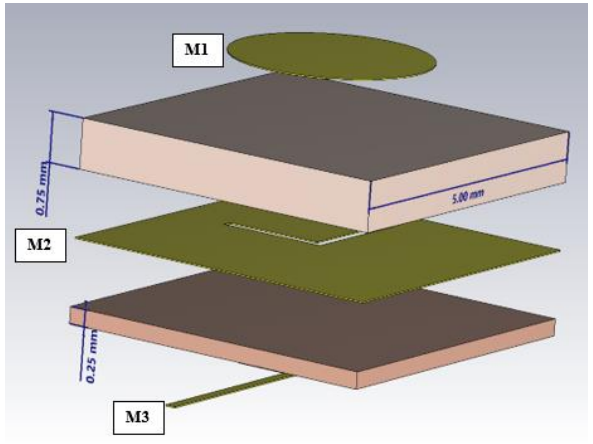
Ka band Antenna Element Selected Concept

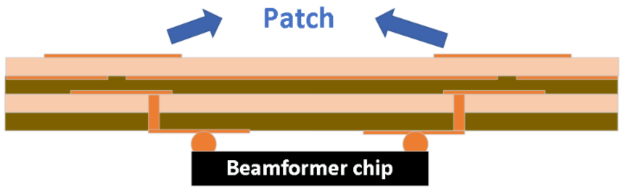
- Five-layer structure
- Significantly improved manufacturability
- 0.36 mm layer thickness - available on the market

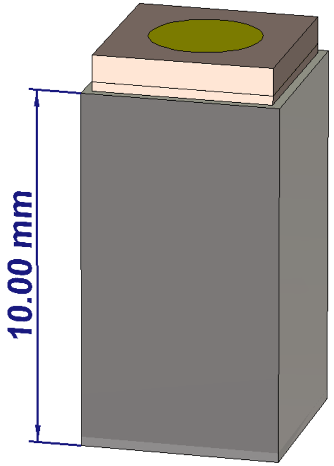




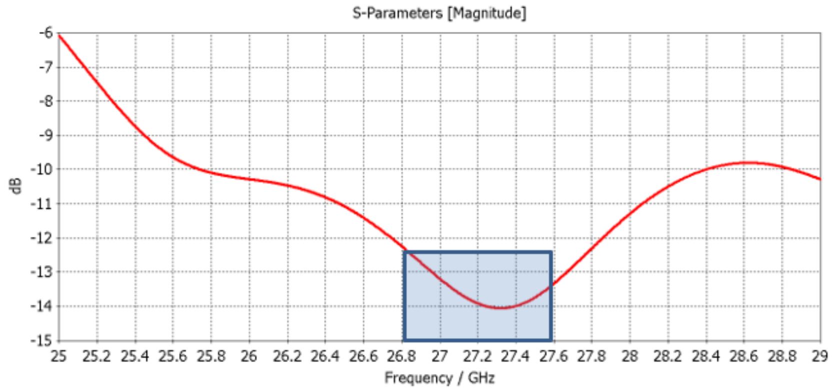
Optimized Ka band antenna

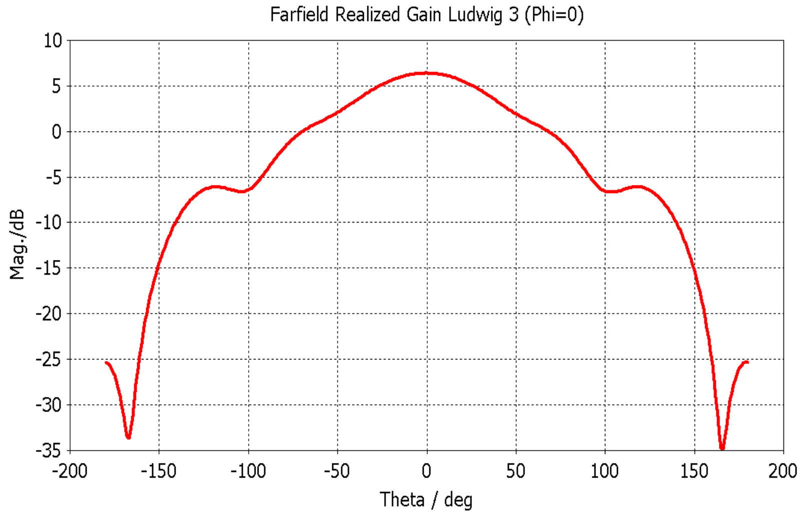




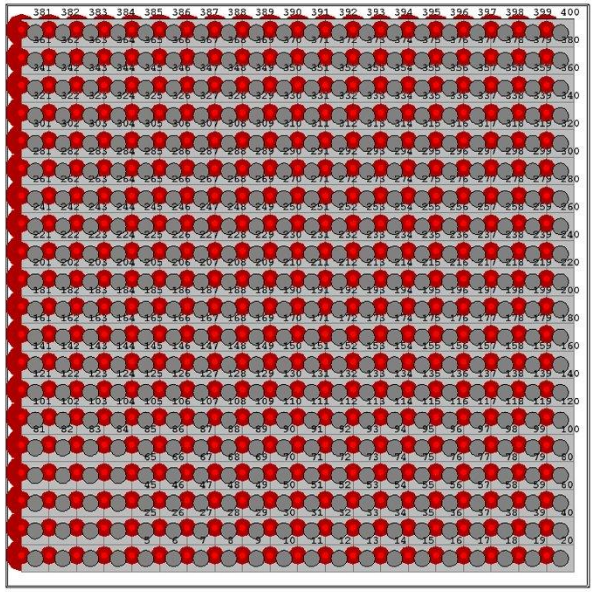


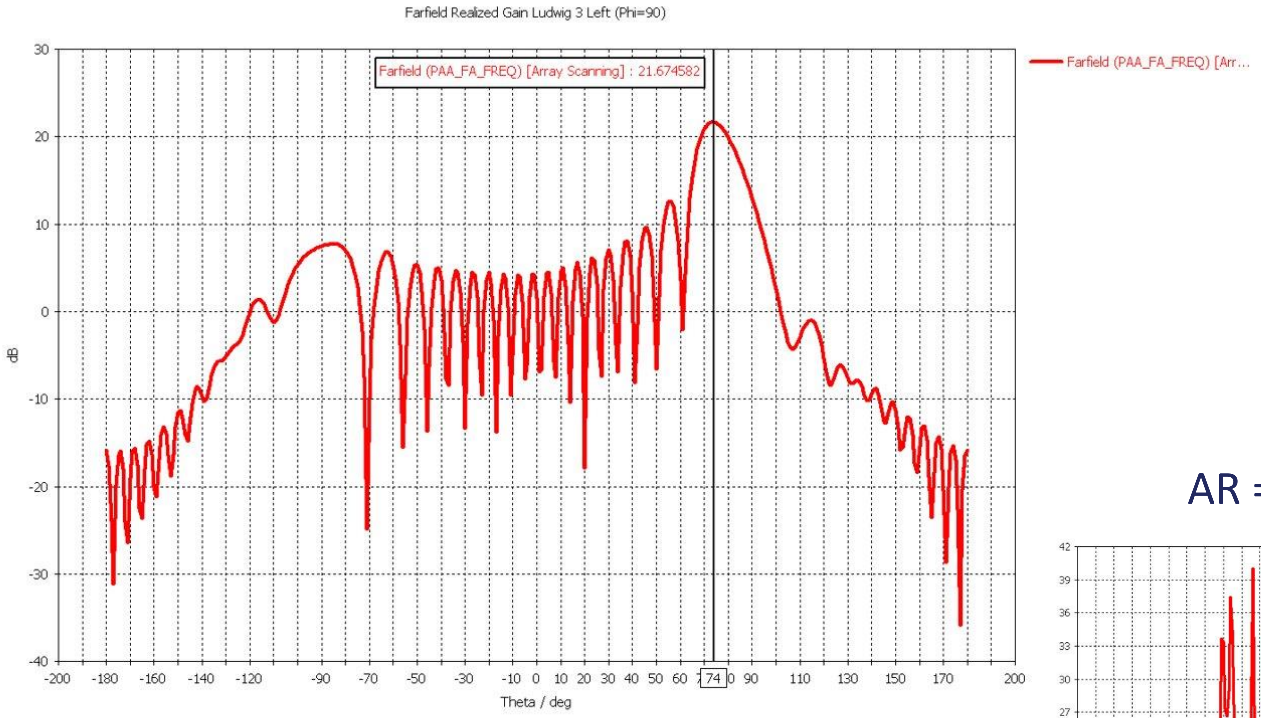
Metal Cavity





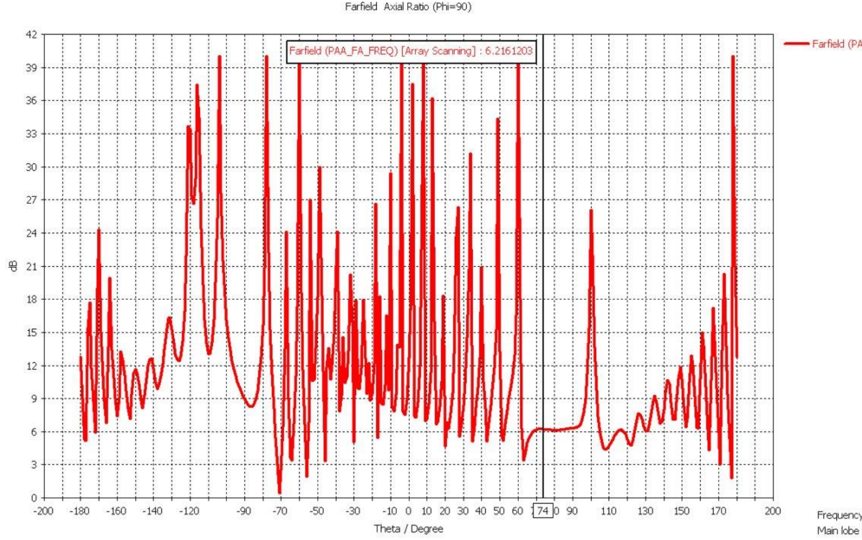
Ka band 20×20-element array full-wave simulation at extreme scan angle



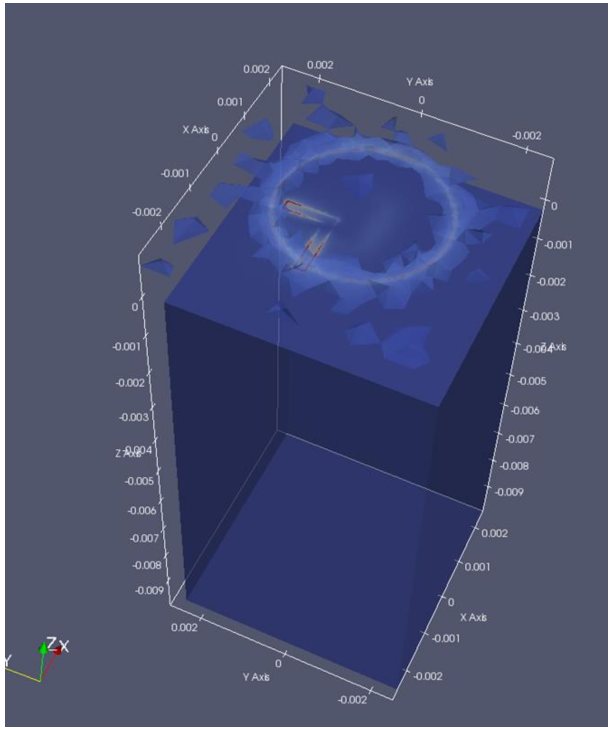


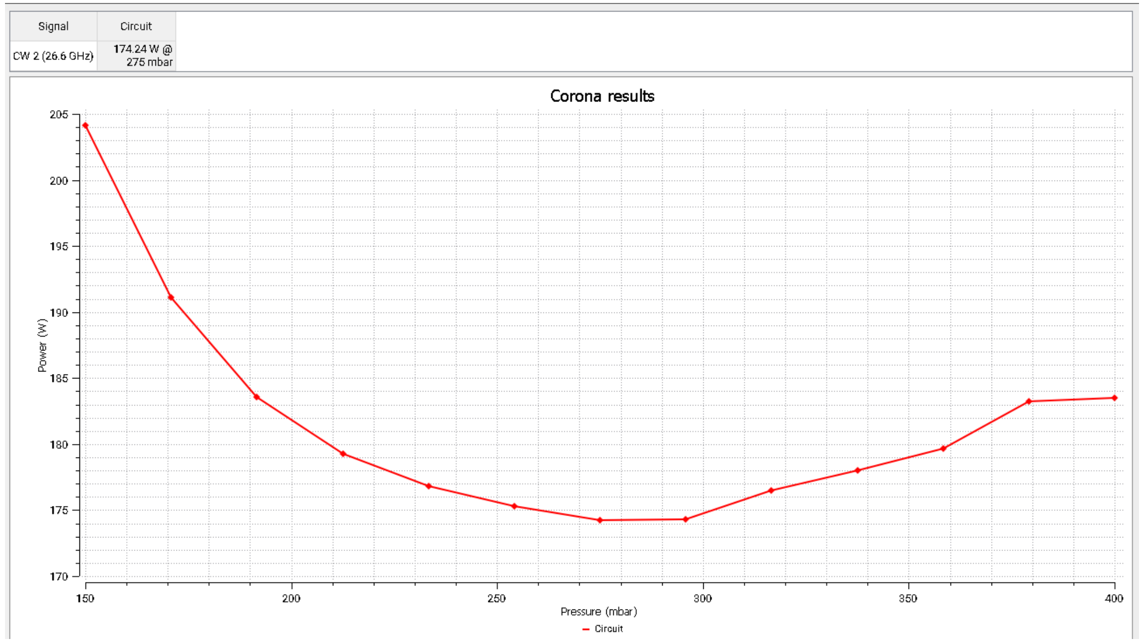
Scan at 74°, 21.67 dBi gain

AR = 6dB at 74° scan angle



Ka band Antenna Corona discharge simulation





Signal	Circuit
CW 2 (26.6 GHz)	174.24 W @ 275 mbar

Corona discharge results of Ka-band antenna unit, for Helium at 100 °C and 26.6 GHz

Ka band emitted power is 50W overall (from link budget) Corona discharge predicts breakdown at 174 W/element

Doppler Estimation and Throughput Simulations

Doppler Estimation for LV accelerations

Consider a velocity of 6000 m/s at 20900s, (Dtmin-1, 1st trajectory, Figure 40). At this point assume the longitudinal acceleration is 40 m/s^2. At 20900s, the Doppler frequency will be:

$F\ Doppler$ = 2(6000) 2.1X10^9 / c= 84000 Hz or 84 KHz

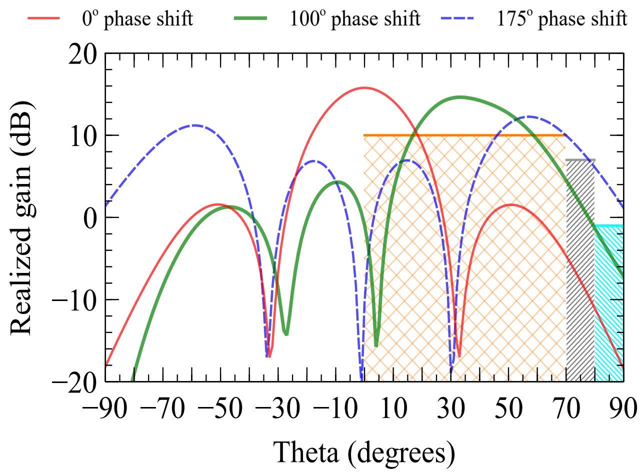
At 20901s, assuming an acceleration of 40 m/s^2 has occurred the velocity becomes 6040 m/s, the Doppler frequency becomes:

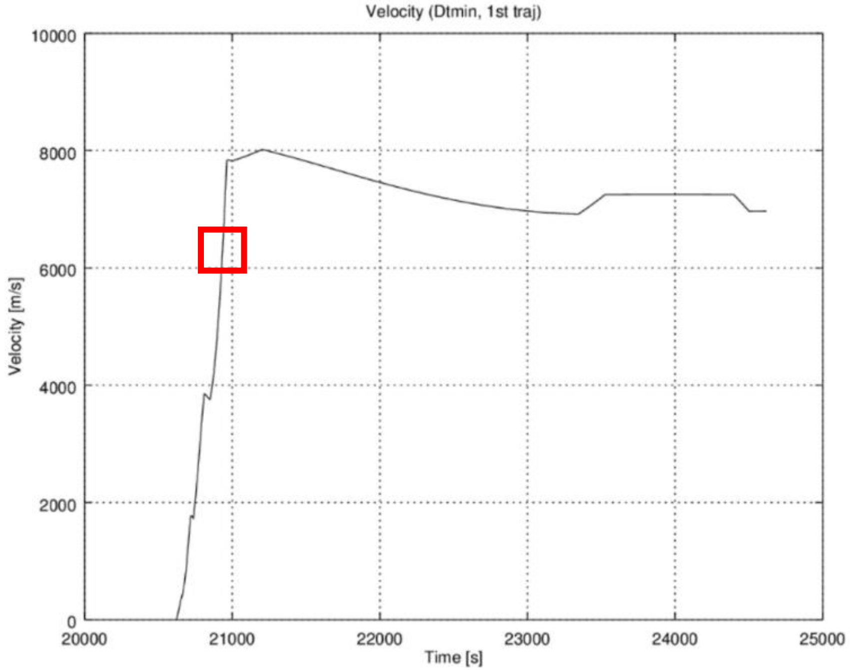
$FDoppler$ = 2(6040) 2.1X10^9 / c = 84560 Hz or 84.56 KHz

This corresponds to a linear frequency ramp of 560Hz/s^2, or 3158 Rad/s^2.

For a second order PLL this gives a static phase error of **0.91°** [Conformal Antenna Array for Next Generation Launchers, AO/1-10149 Final Report]

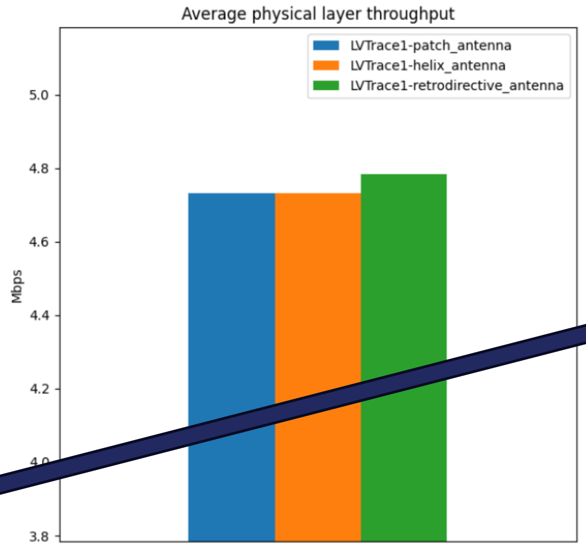
For the S band 4x4 array a 100° phase shift caused a 30° shift in beam, so 0.91° would cause a **0.27°** shift in beam



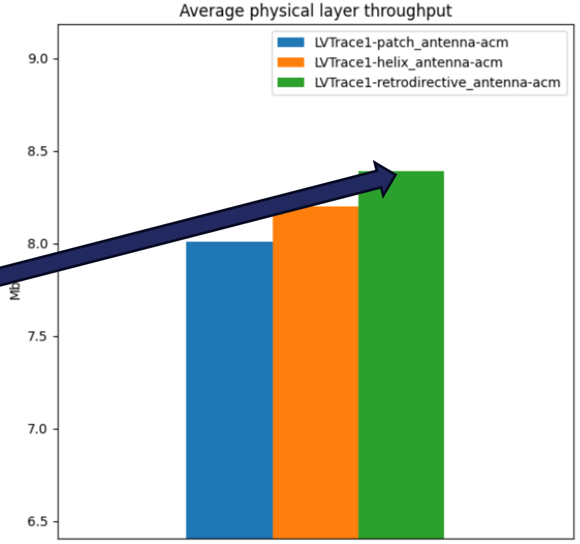


Retrodirective gain pattern in NTM-Simulator - Magister

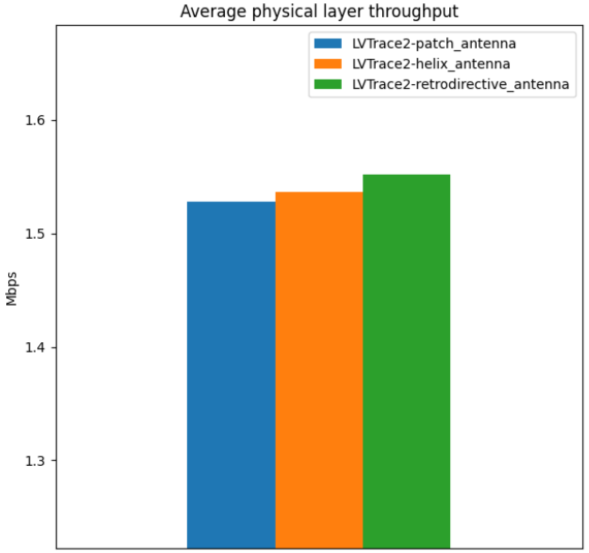
- Retrodirective system showed an increased average physical layer throughput.
- The most notable of these being an 8.4 Mbps average throughout for Dtmin-1 with ACM



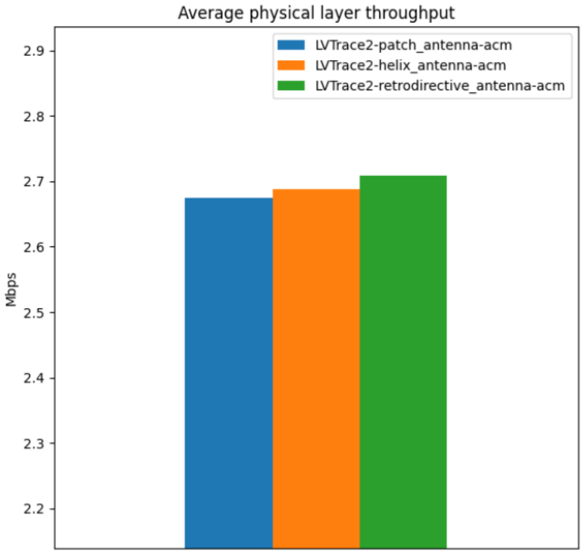
Dtmin-1 launch phase, No ACM



Dtmin-1 launch phase, with ACM



MT3 launch phase, No ACM

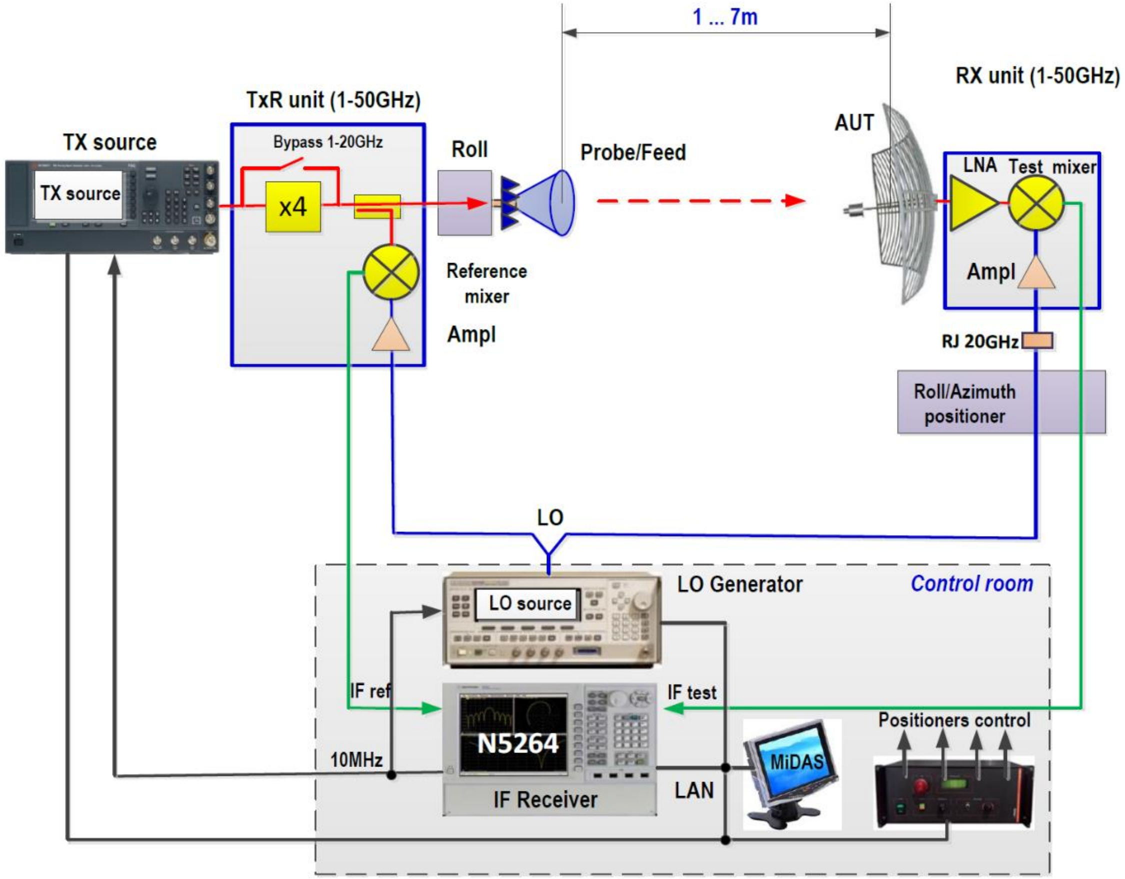


MT3 launch phase, with ACM

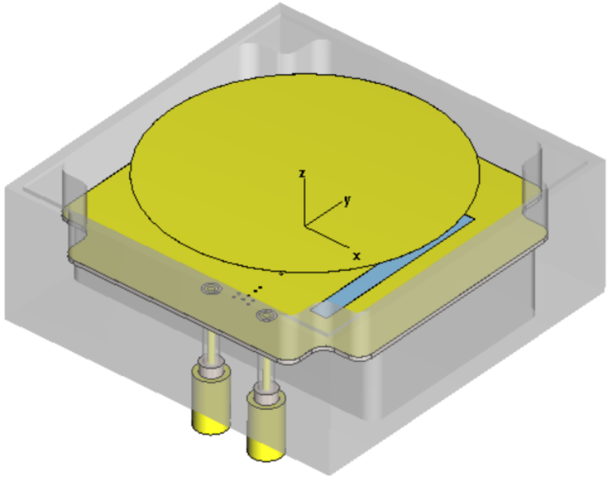
CENTRE
FOR
WIRELESS
INNOVATION

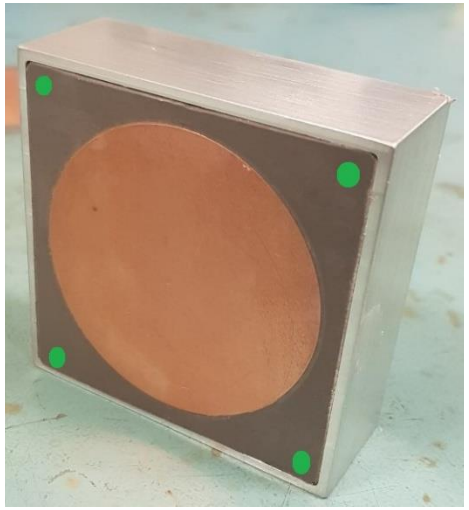
Practical Results

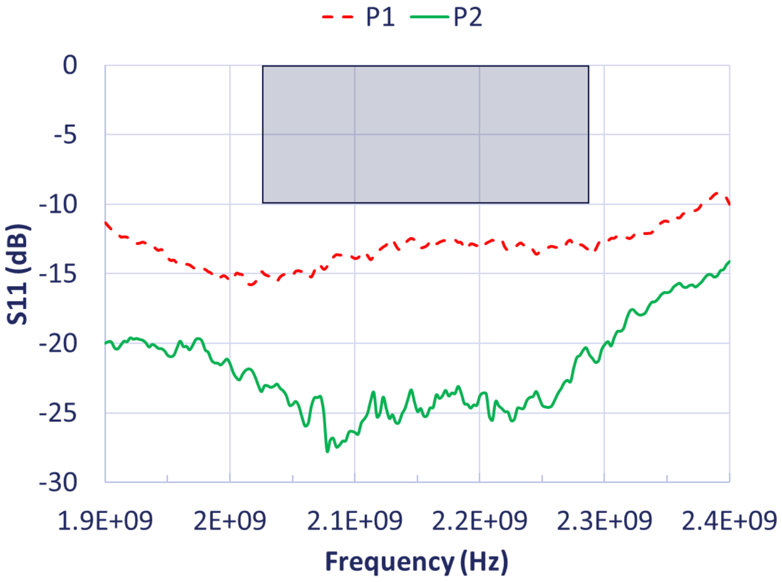
Practical Results

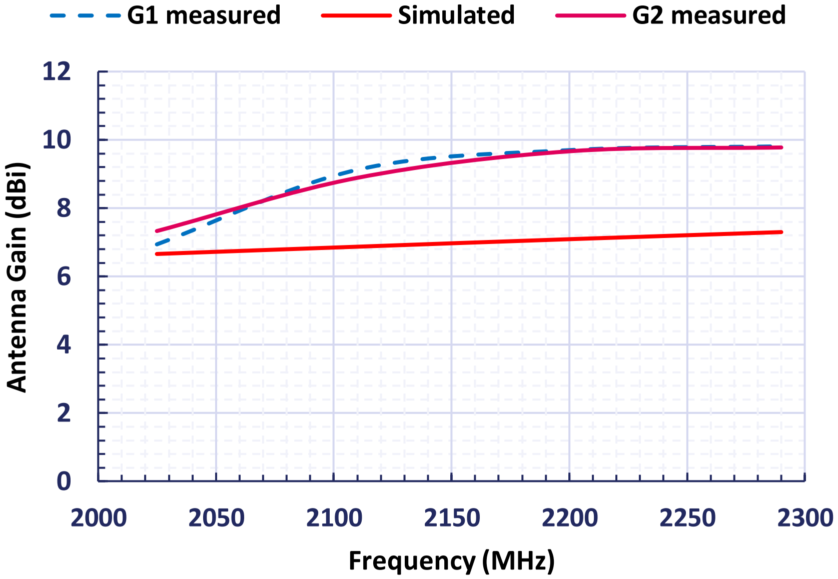


Testing of antenna unit – Return loss & Gain

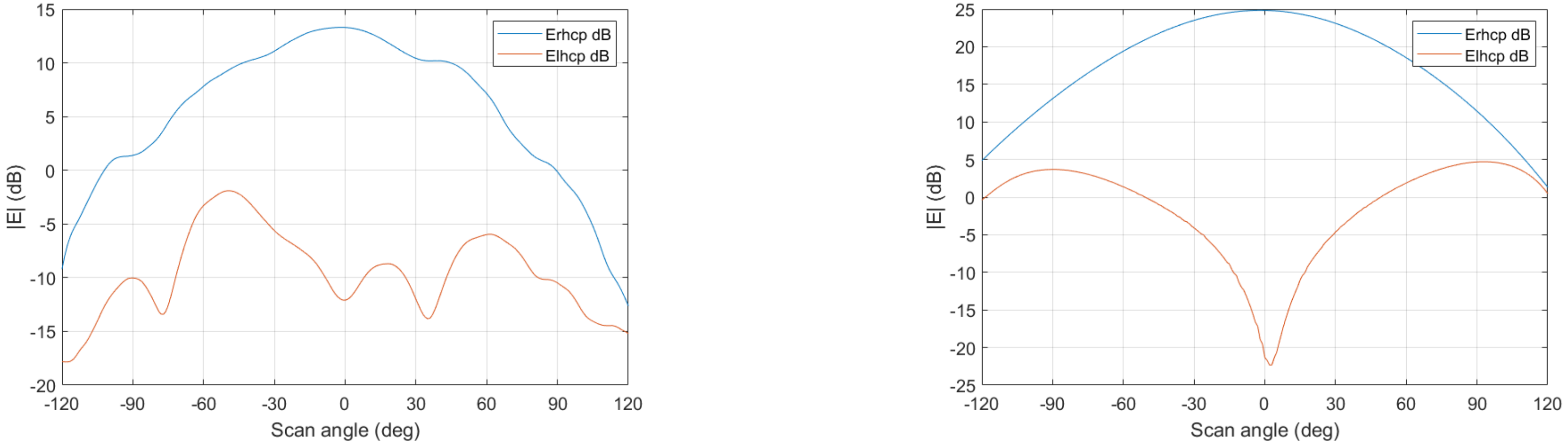




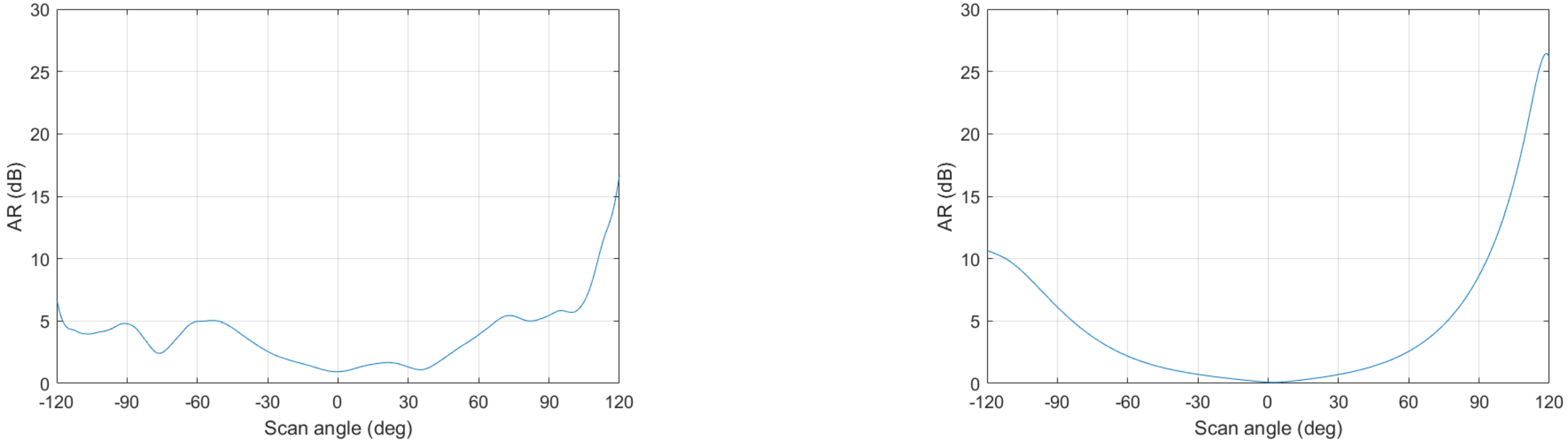




Testing of antenna unit – Radiation Patterns

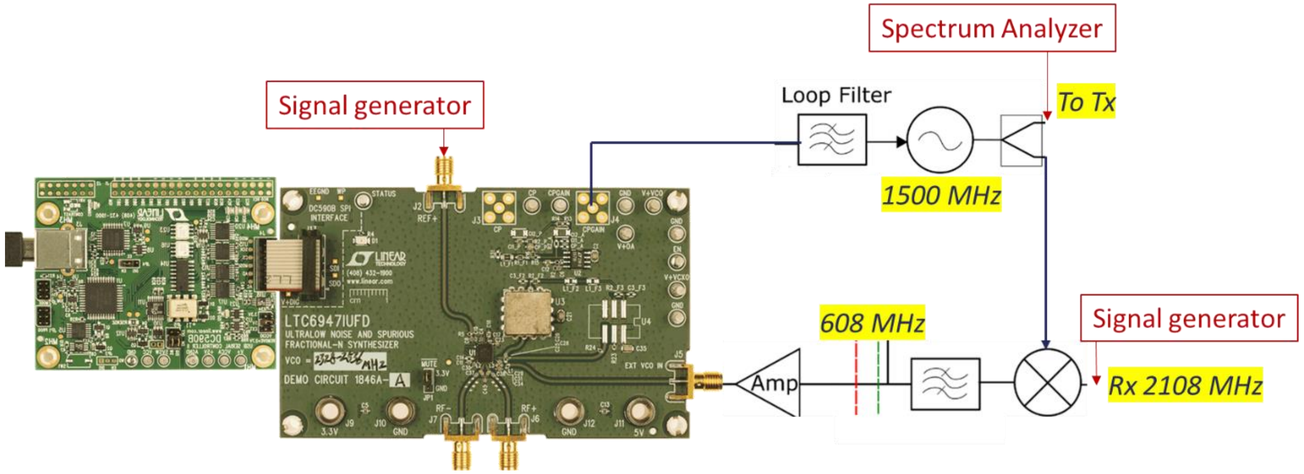


Measured and simulated radiation patterns at 2200 MHz

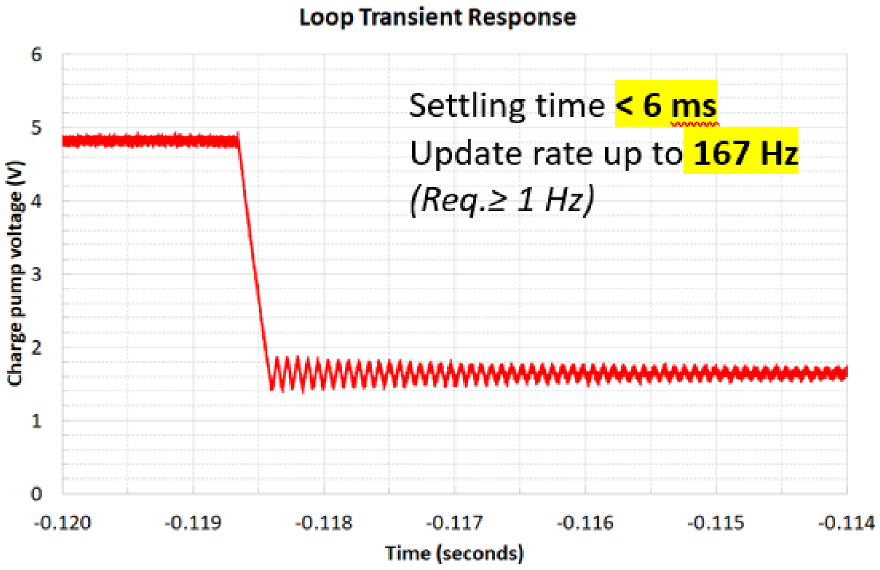


Measured and simulated Axial Ratio at 2200 MHz

Phase Conjugating Loop tracking Measurement



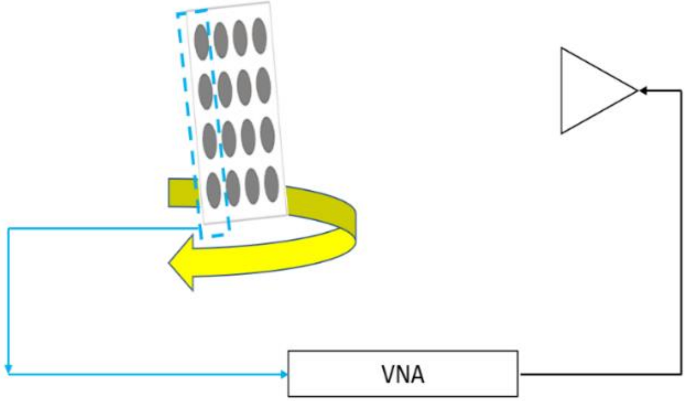
$$Update\ Rate\ (Hz) = \frac{1}{Loop\ Seetling\ Time}$$

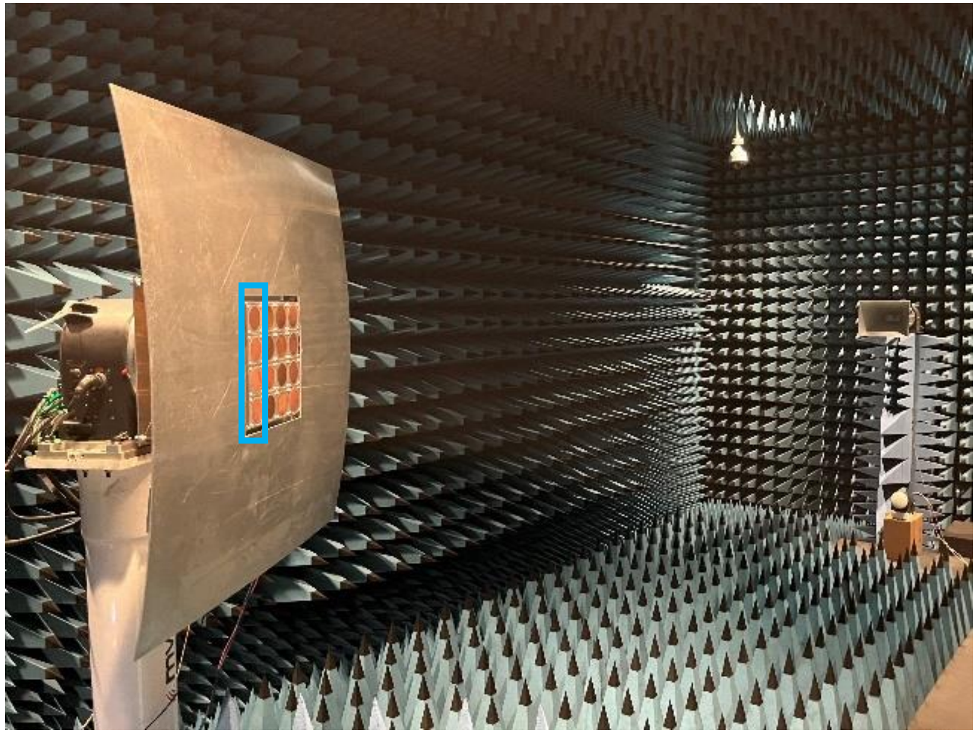


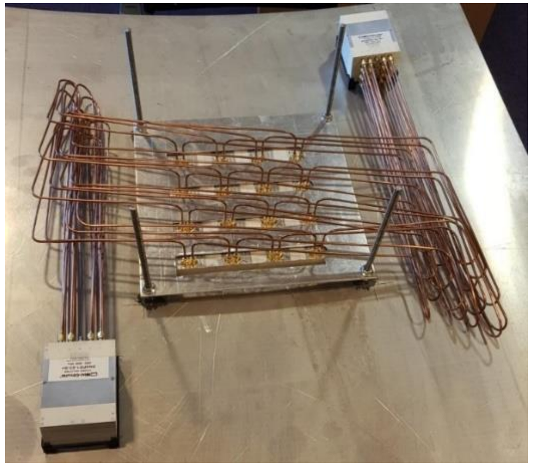
Settling time **< 6 ms**
Update rate up to **167 Hz**
(Req.≥ 1 Hz)

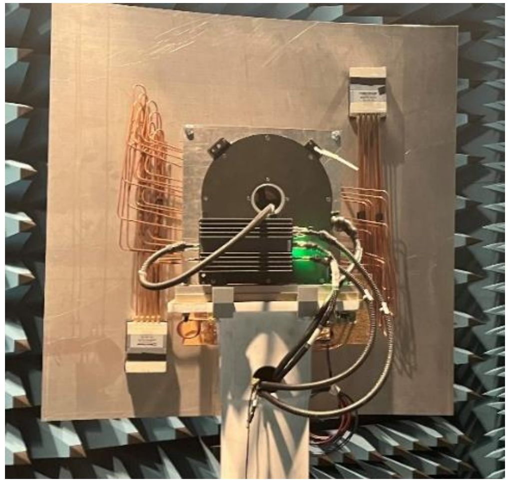
U. Naeem and N. Buchanan, "Conformal Retrodirective TM System for Future Generation Launch Vehicles," 2023 IEEE Wireless and Microwave Technology Conference (WAMICON), Melbourne, FL, USA, 2023, pp. 89-92, doi: 10.1109/WAMICON57636.2023.10124919.

Passive subarray measurements

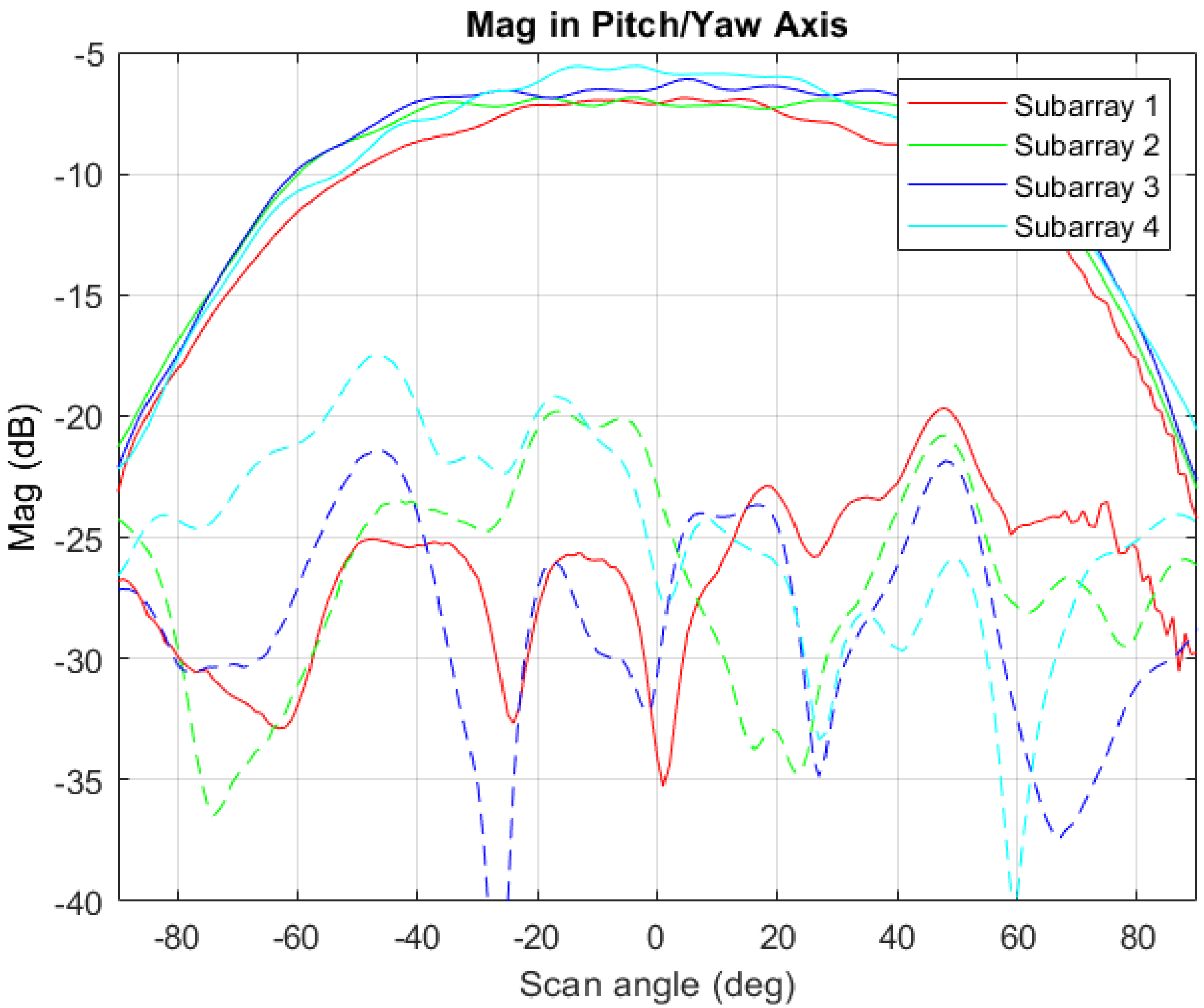




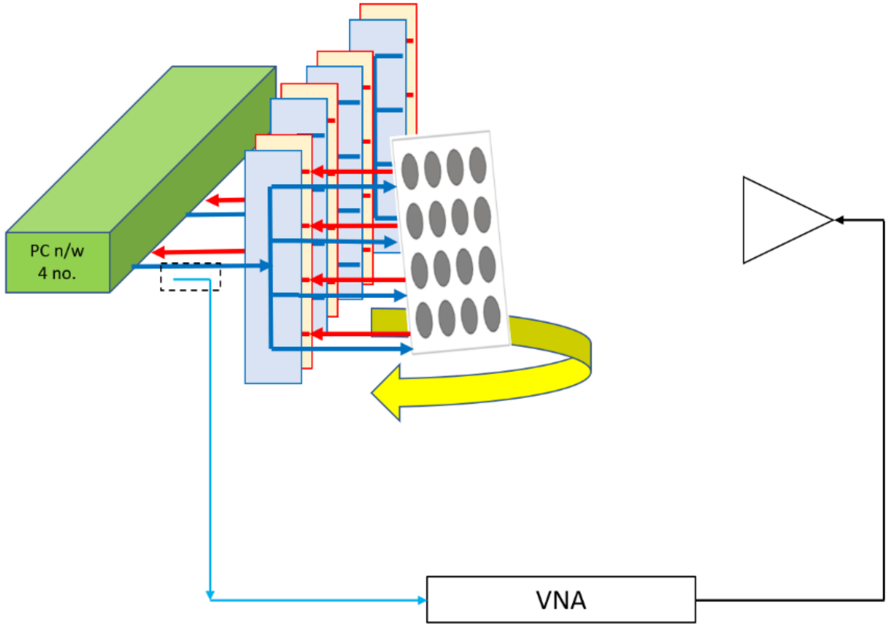


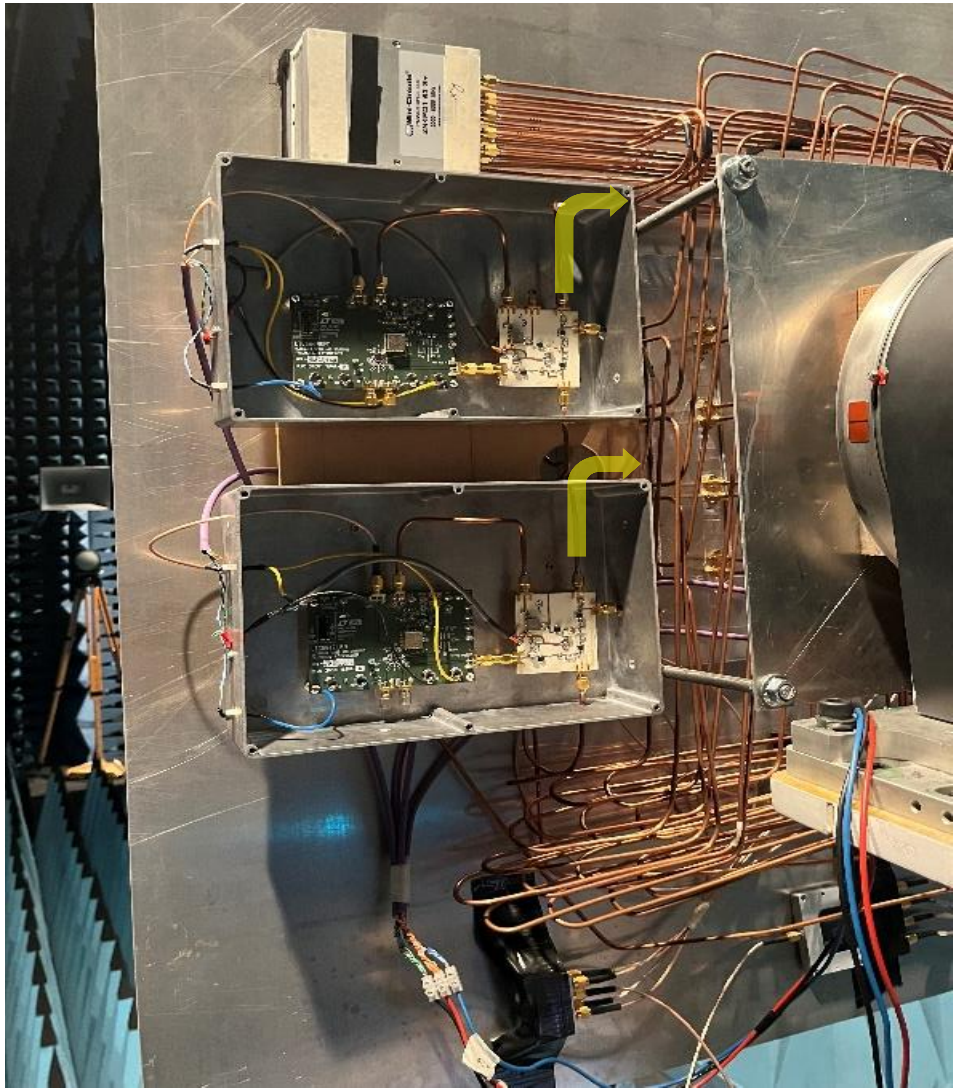


Passive subarray measurements

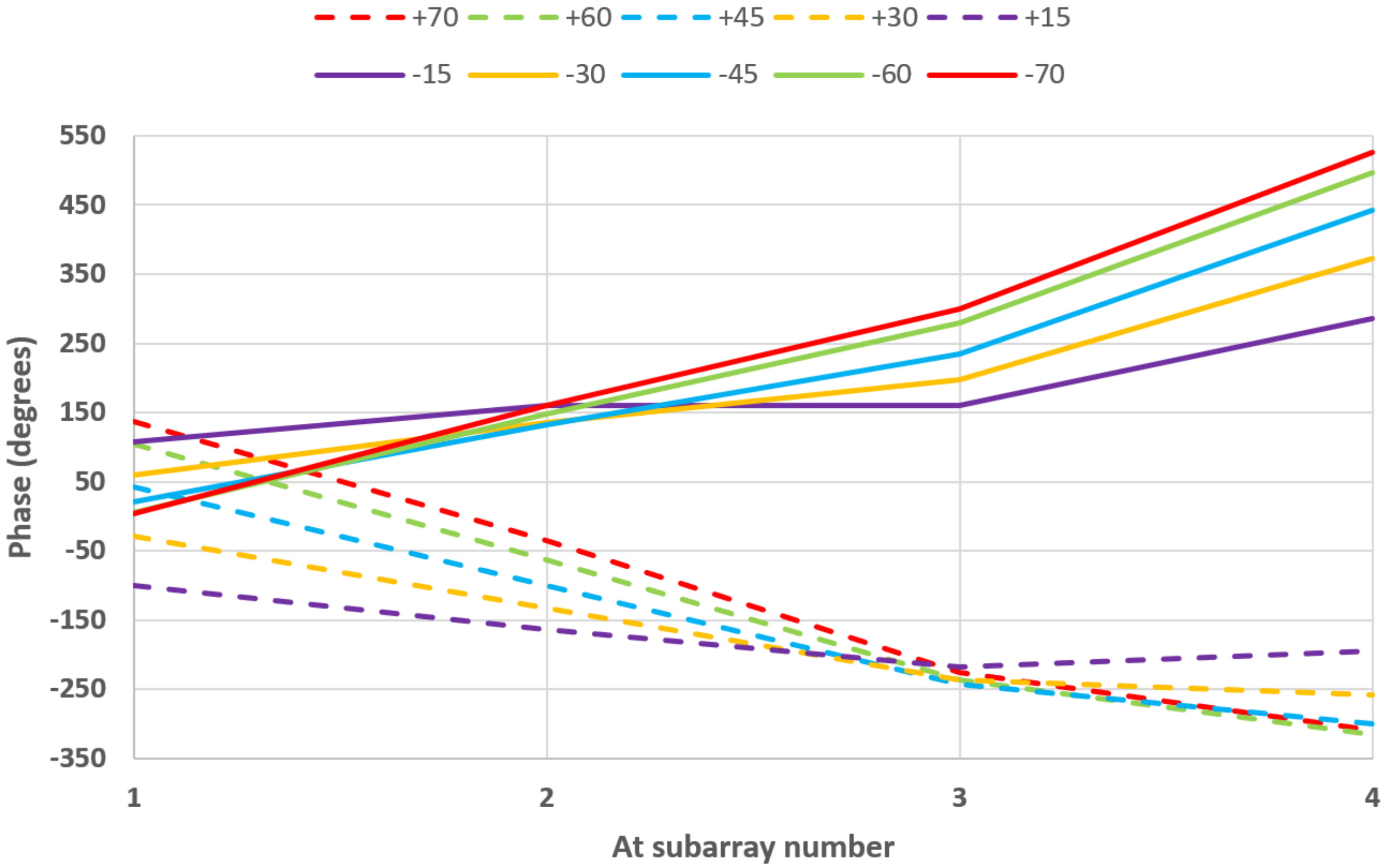


Phase measurements at subarrays to determine phase conjugation



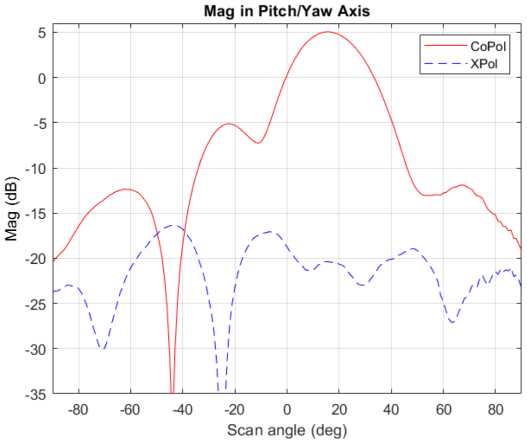


Phase measurements at subarrays to determine phase conjugation

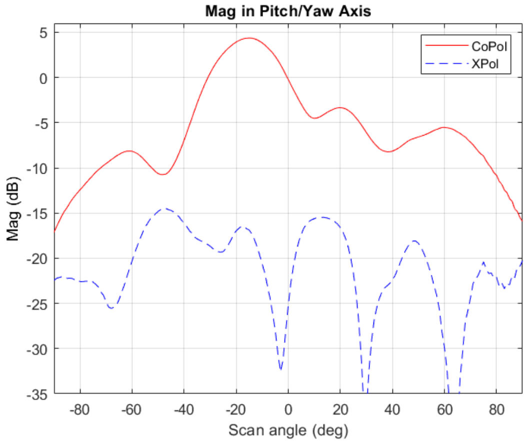


- Unwrapped phase at each subarray transmit port for different azimuth angles
- Higher value of progressive phase is seen for steering angles further from boresight
- Subarrays further from centre of rotation have higher phase shift

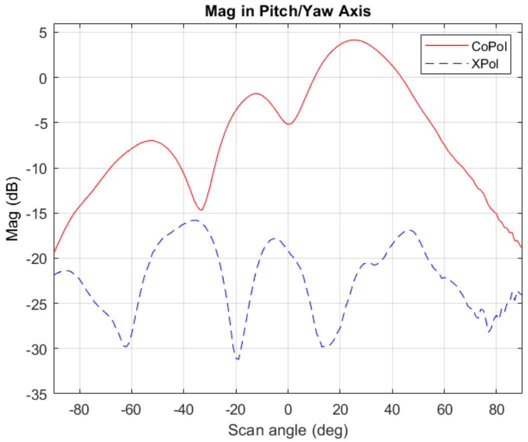
Bistatic Radiation Patterns



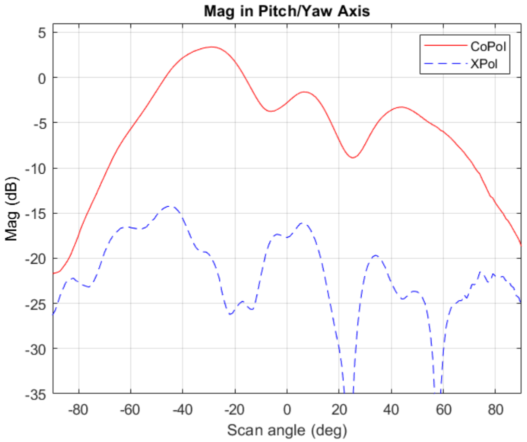
φ =+15 degrees



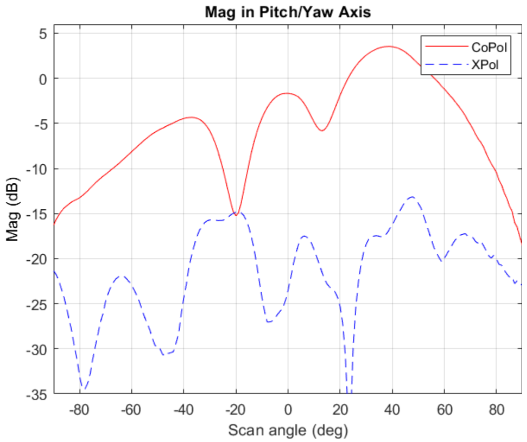
φ =-15 degrees



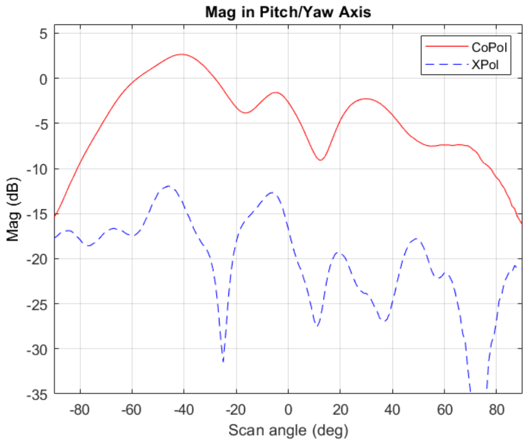
φ =+30 degrees



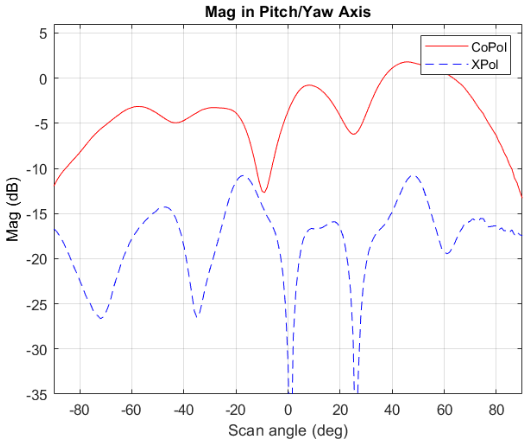
φ =-30 degrees



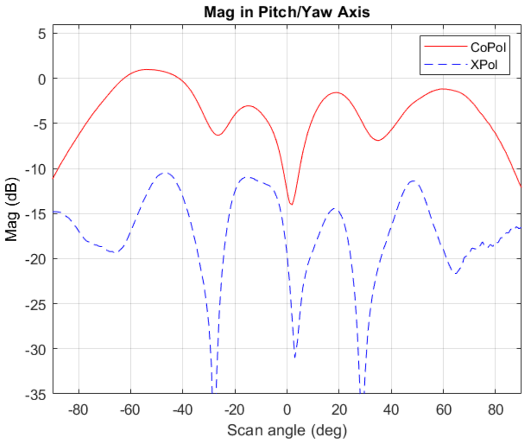
φ =+45 degrees



φ =-45 degrees



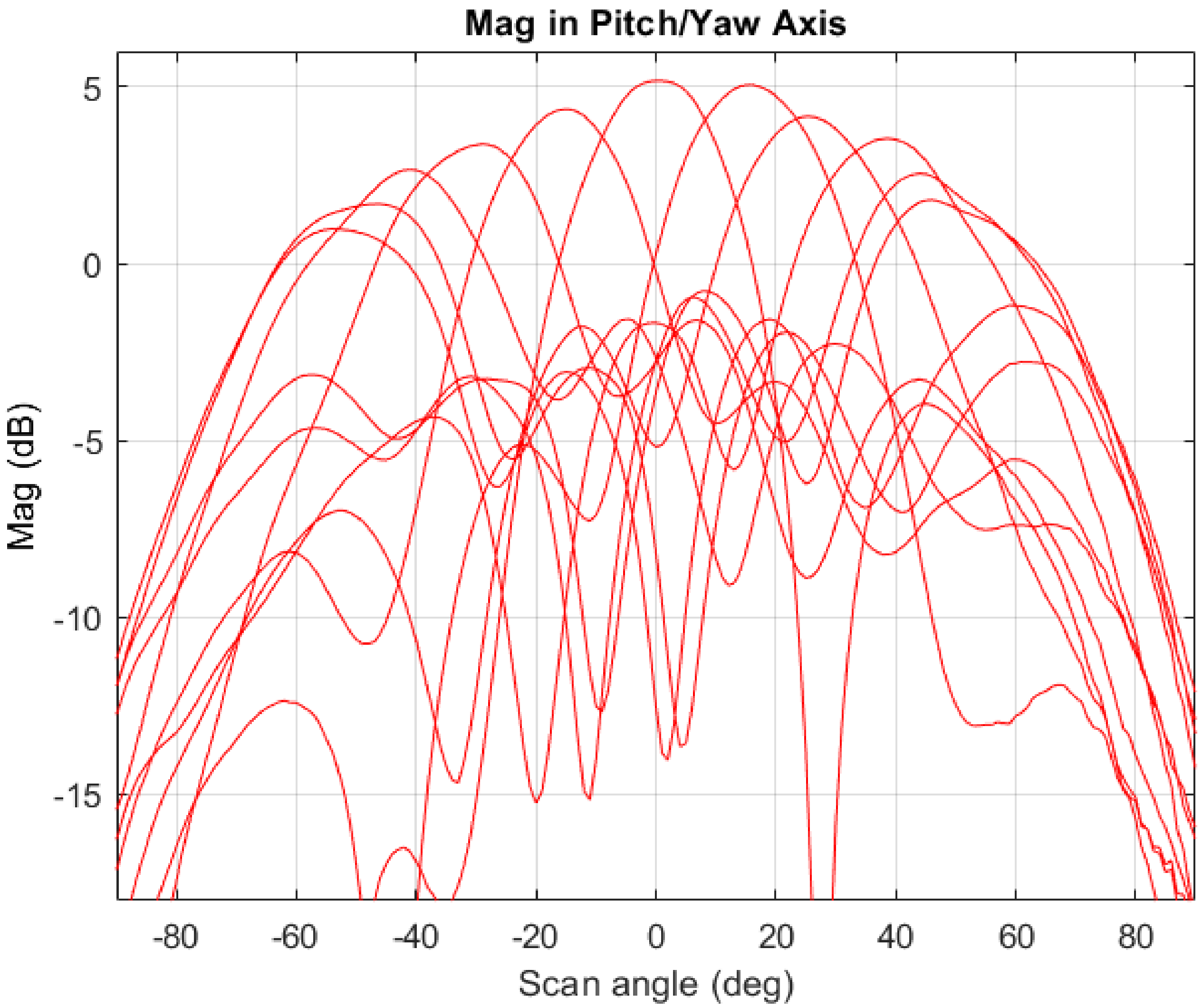
φ =+75 degrees



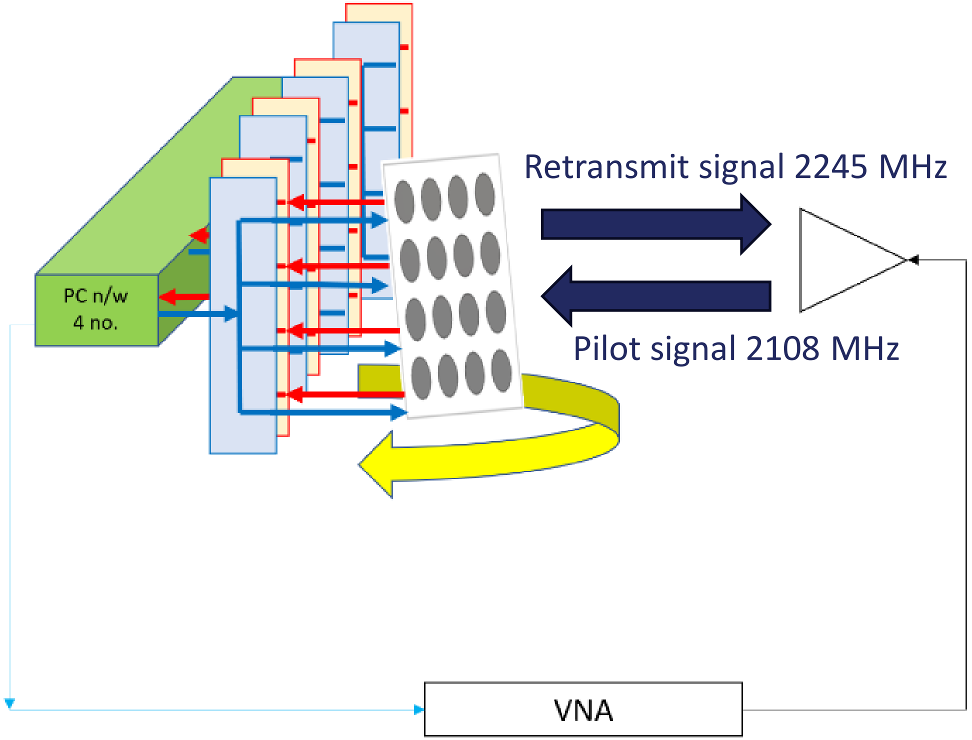
φ =-75 degrees

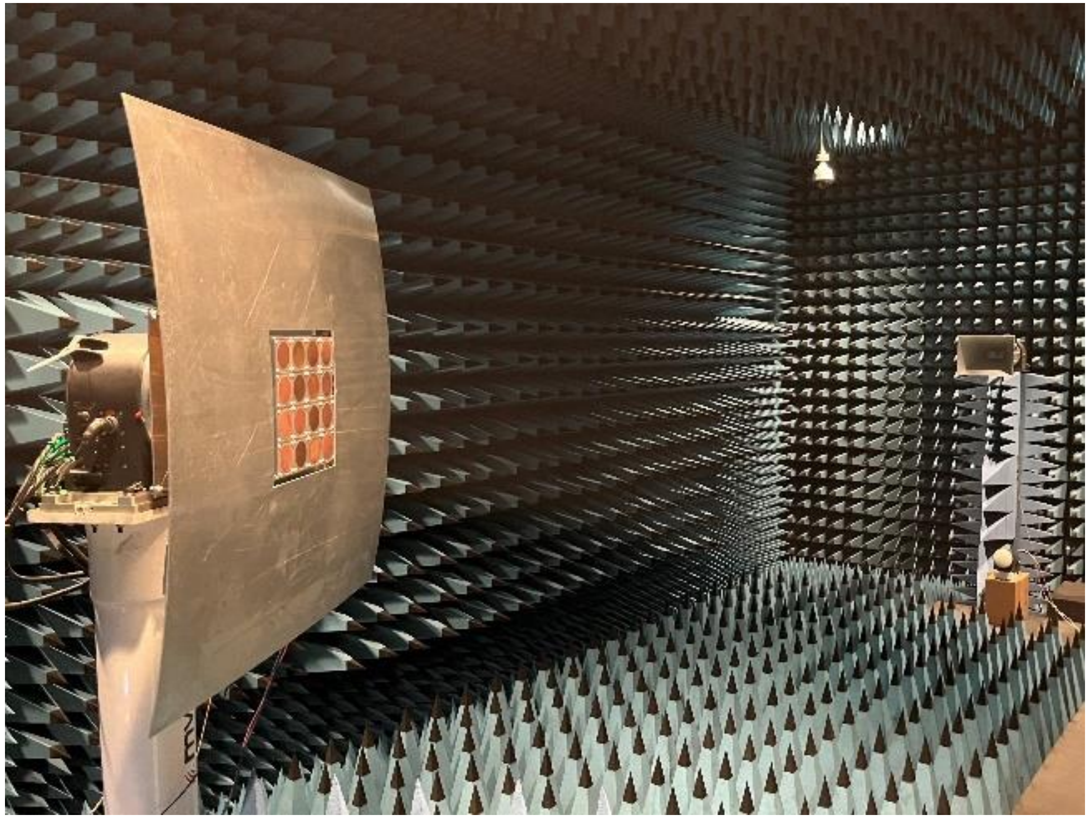
Calculated using the method of: N. B. Buchanan and V. F. Fusco, "A Simple Measurement Technique for Accurate Bistatic Retrodirective Radiation Pattern Calculation Based on the Active Element Pattern Method," in IEEE Transactions on Antennas and Propagation, vol. 66, no. 1, pp. 472-475, Jan. 2018, doi: 10.1109/TAP.2017.2776611

Bistatic Radiation Patterns

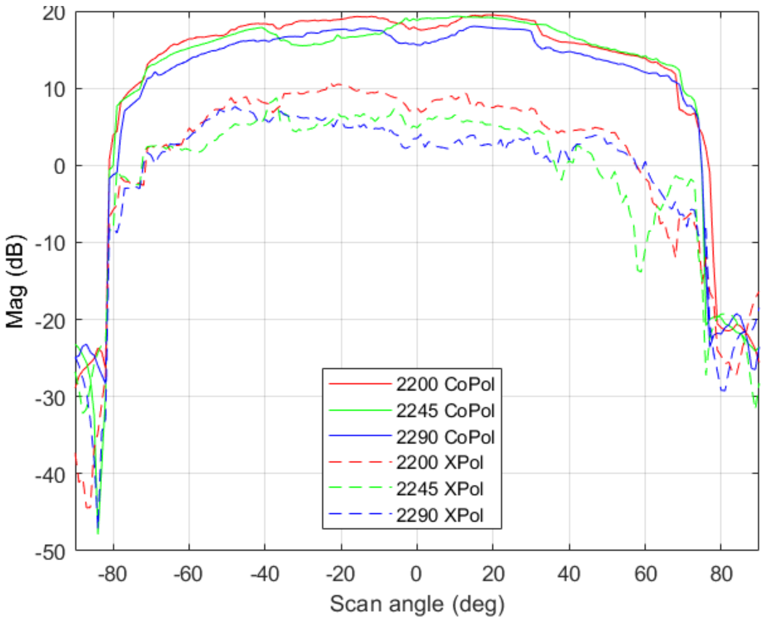


Monostatic Measurements

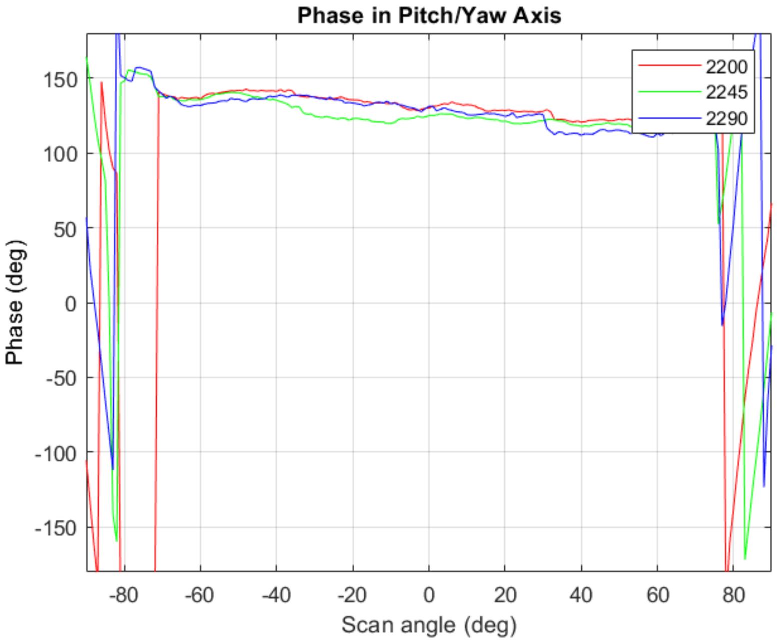




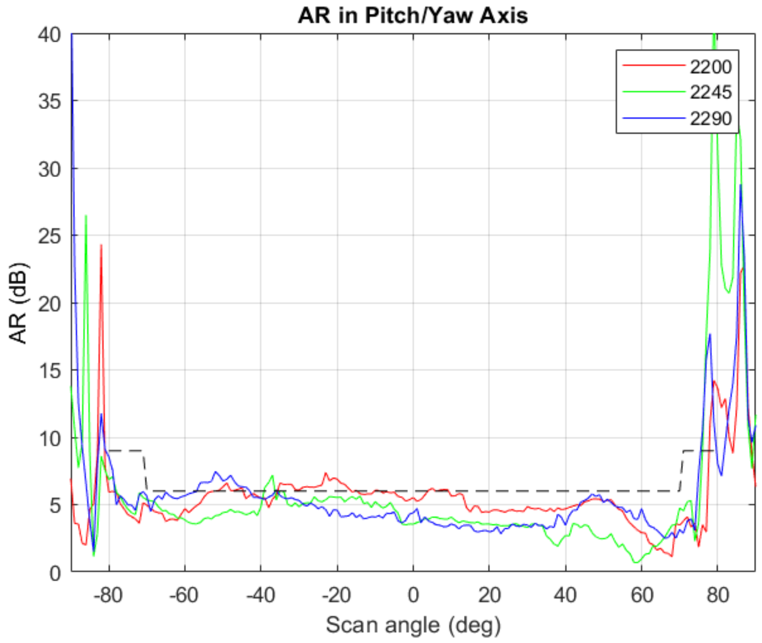
Monostatic Radiation Patterns - Azimuth



Magnitude

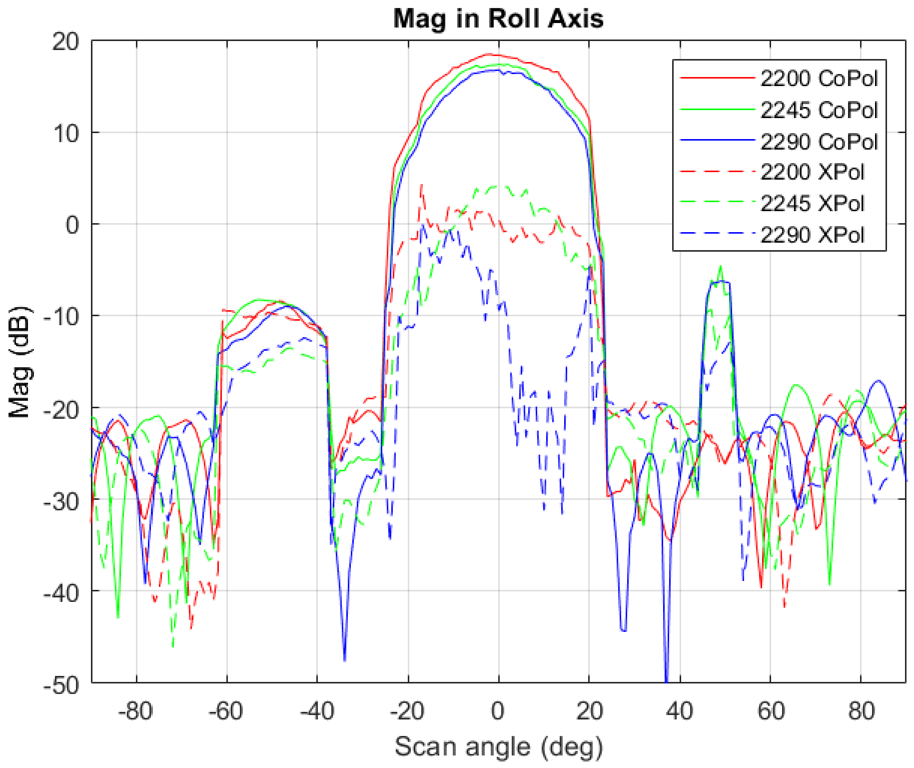


Phase

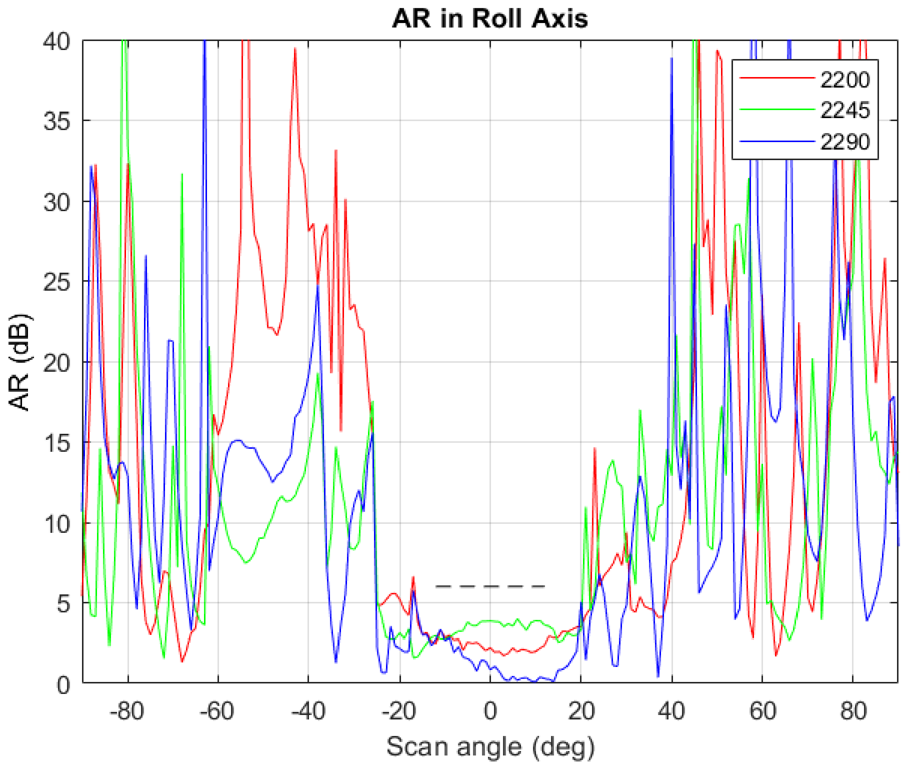


Axial Ratio

Monostatic Radiation Patterns - Elevation



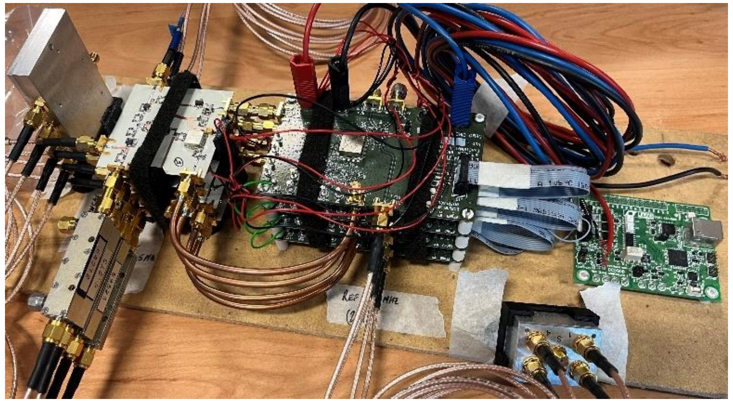
Magnitude



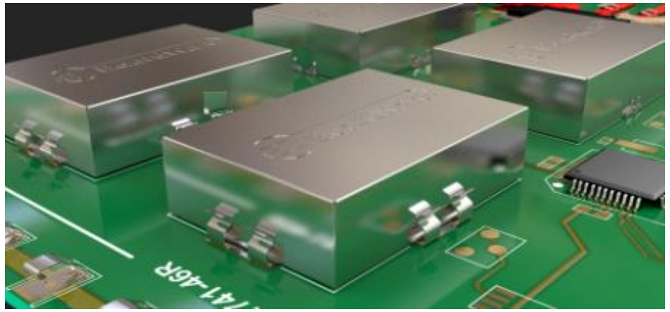
Axial Ratio

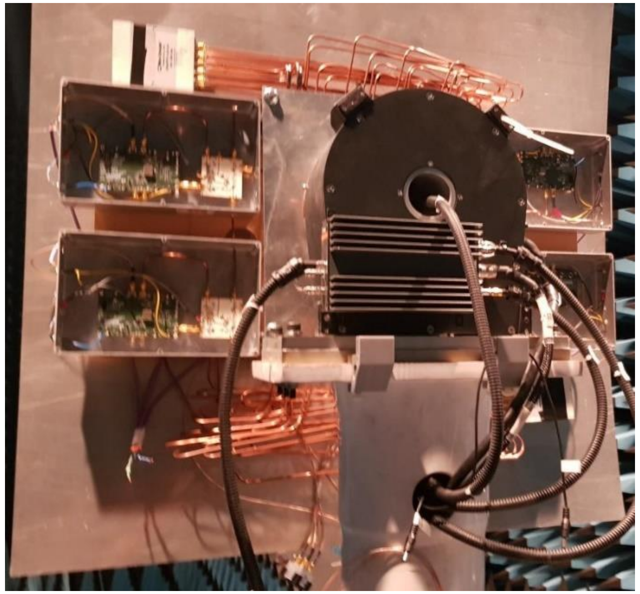
Challenges faced With Final Breadboard Measurements

- EMC issues were experienced
- PLLs of the same frequency can produce unwanted injection locking to each other
- This is counterproductive to the phase conjugation
- Future tracking PLLs must be designed with an emphasis on EMC reduction
- For example, EMC sensitive circuits should be designed in screening cans



PCBs co-located - Bad





PCBs Separated - Good

Conclusions

- Successful practical demonstration produced of a 4x4 S band retrodirective antenna
- S band was chosen for further development
- Ka band was taken to simulation stage with detailed designs of a 20x20 array
- Full compliance was reached for most of the S band antenna steering range with partial compliance for axial ratio in the region of $80° < |\theta| < 90°$
- Retrodirective tracking PLL showed ability to operate with high rates of doppler frequency and high update rates
- Additional simulations were carried out including corona discharge, sensitivity to temperature and manufacturing tolerance