EuCAP 2024

QUEEN'S UNIVERSITY BELFAST

Wideband Dual-Polarized 1-Bit Unit-cell Design For mmWave RIS

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SAND BOX

Ulster University

EuCAP 2024

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- Waveguide test
- Pathloss model
- Full RIS simulation
- Experimental results
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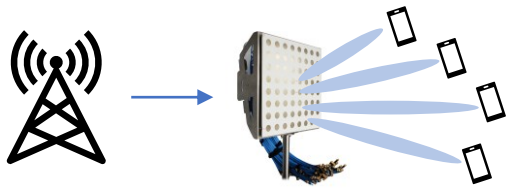
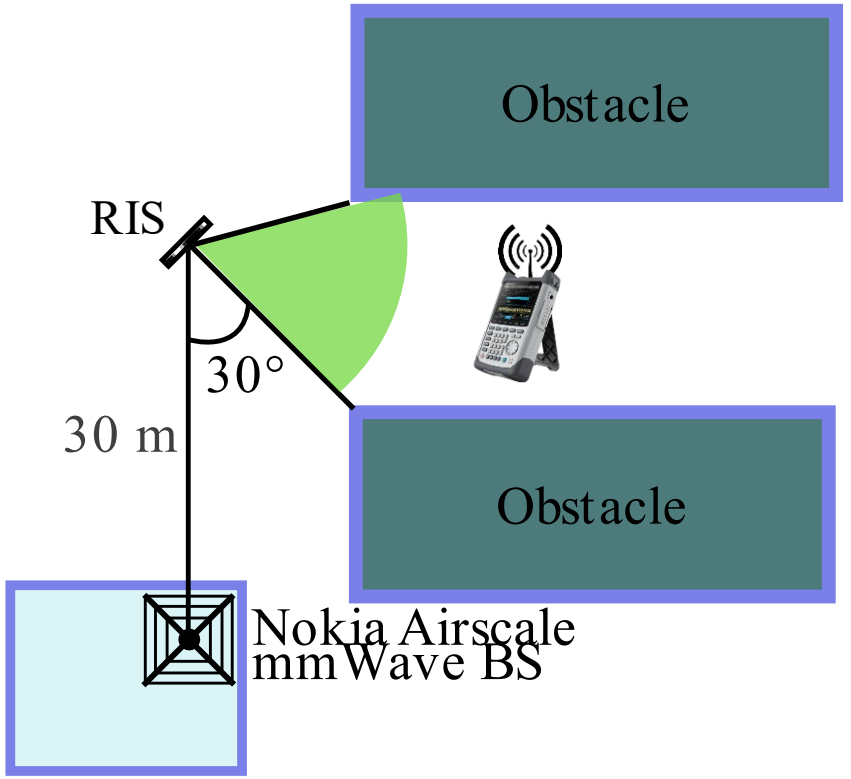
Introduction

- Millimetre wave communications ⟹ LoS
  - Massive MIMO arrays
  - Cell-free networks
  - Distributed antenna systems



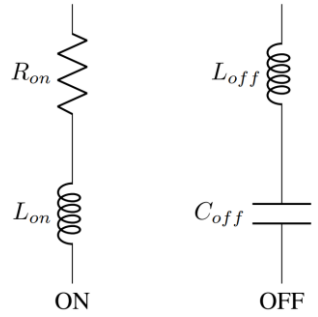
- Signals significantly degraded due to:
  - Pathloss
  - Obstacles
    - Buildings
    - Foliage
    - Other people
- Reconfigurable intelligent surfaces (RIS)
  - Dynamically reflect the signal towards UE
  - Potential to significantly improve the energy efficiency of the channel



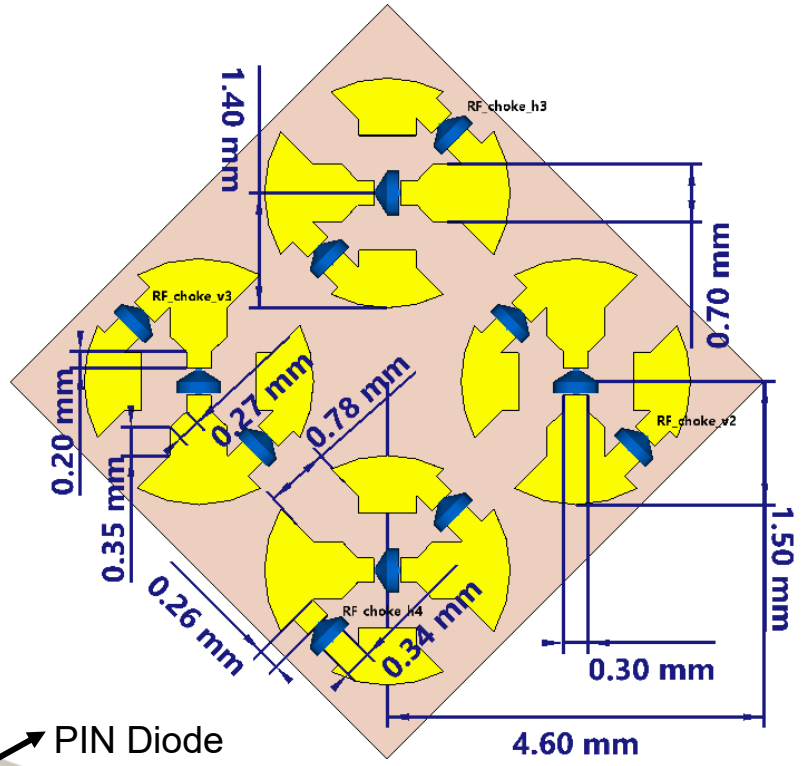
Unit-cell design

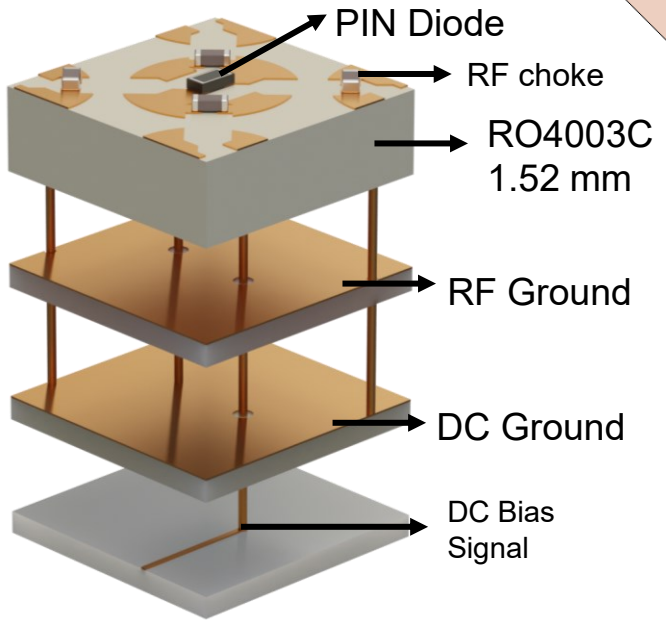
- Several design iterations
- Checker-board lattice
  - Contributes to both polarizations
- RF Chokes for bias
- Digitally controlled by p-i-n diodes
  - 1-bit per polarization
- Macom MADP-000907-14020P p-i-n diode

Diode state	L	R	C
On	30 pH	6 Ω	N/A
Off	30 pH	N/A	50 fF



Final iteration





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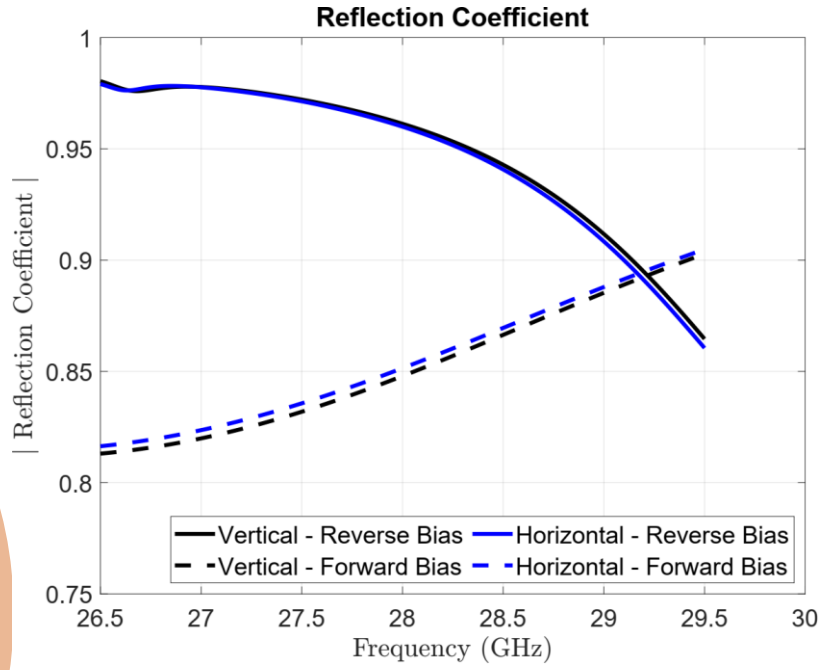
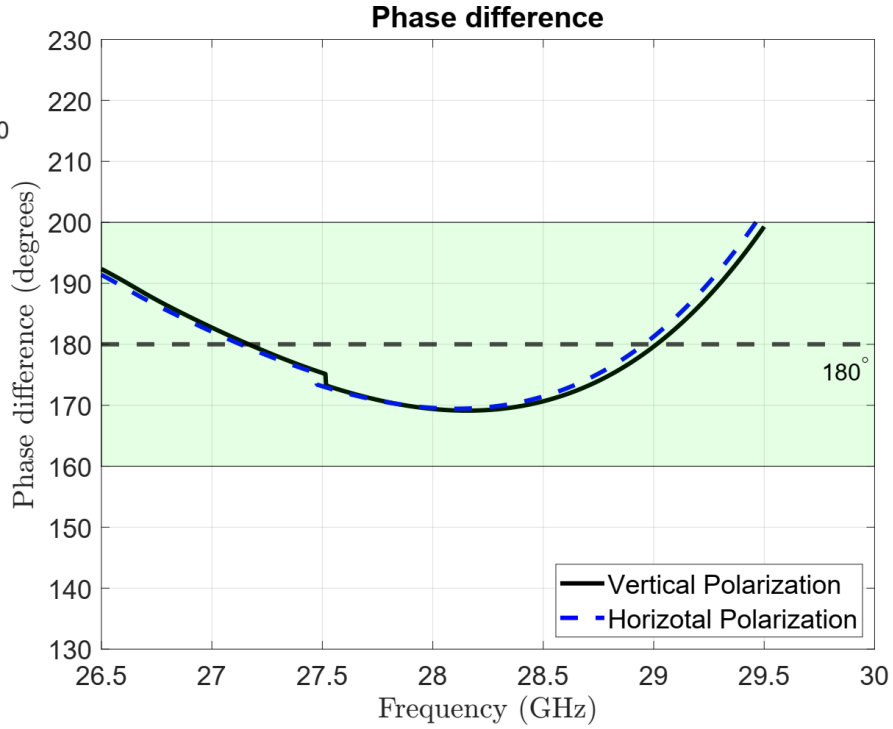
Numerical results

Simulated in CST Microwave Studio

- Floquet ports and periodic boundary
- De-embedded to the surface of the unit-cell
- Optimised for 30° incidence





26.5 GHz ⟷ 29.5 GHz

n257 mmWave band,
n261 in particular

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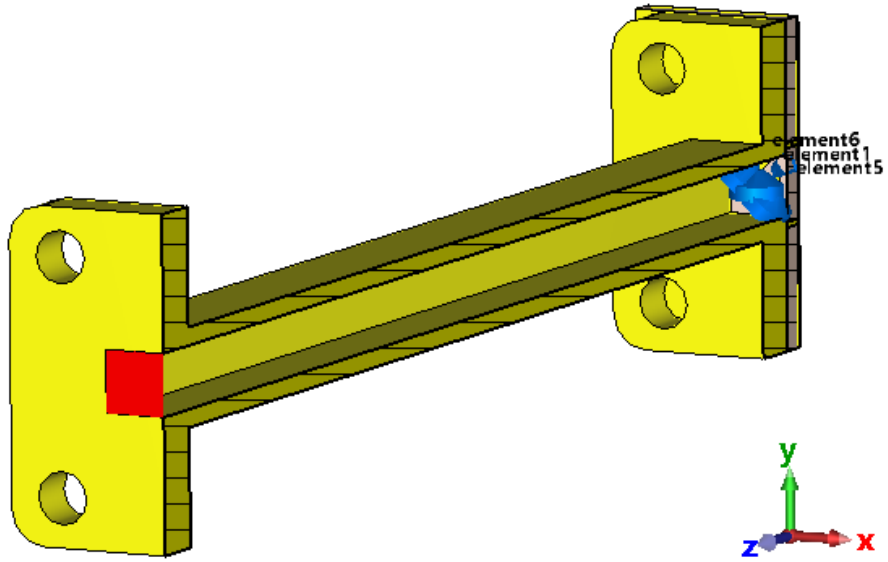
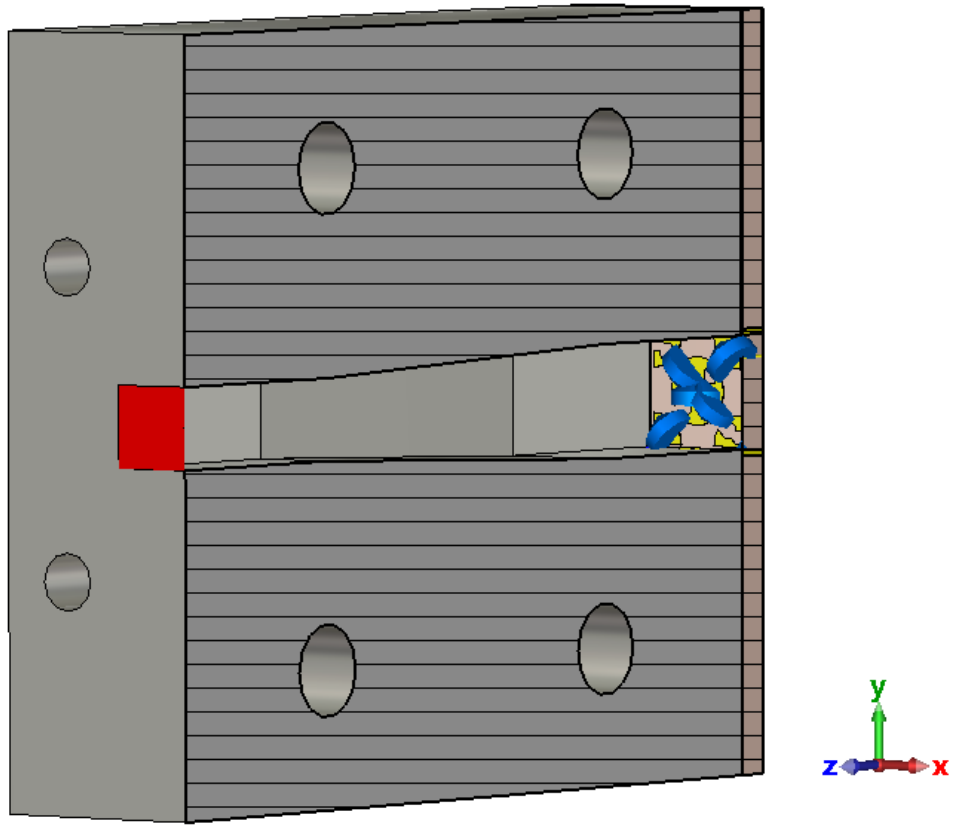
Waveguide tests



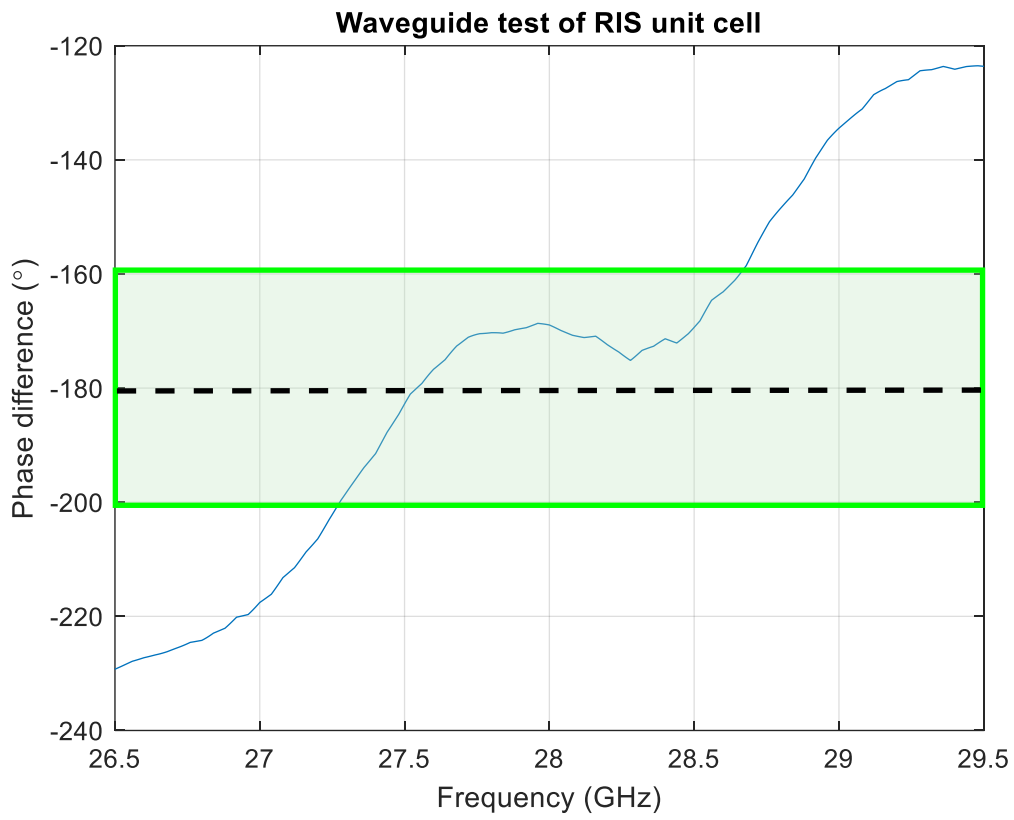


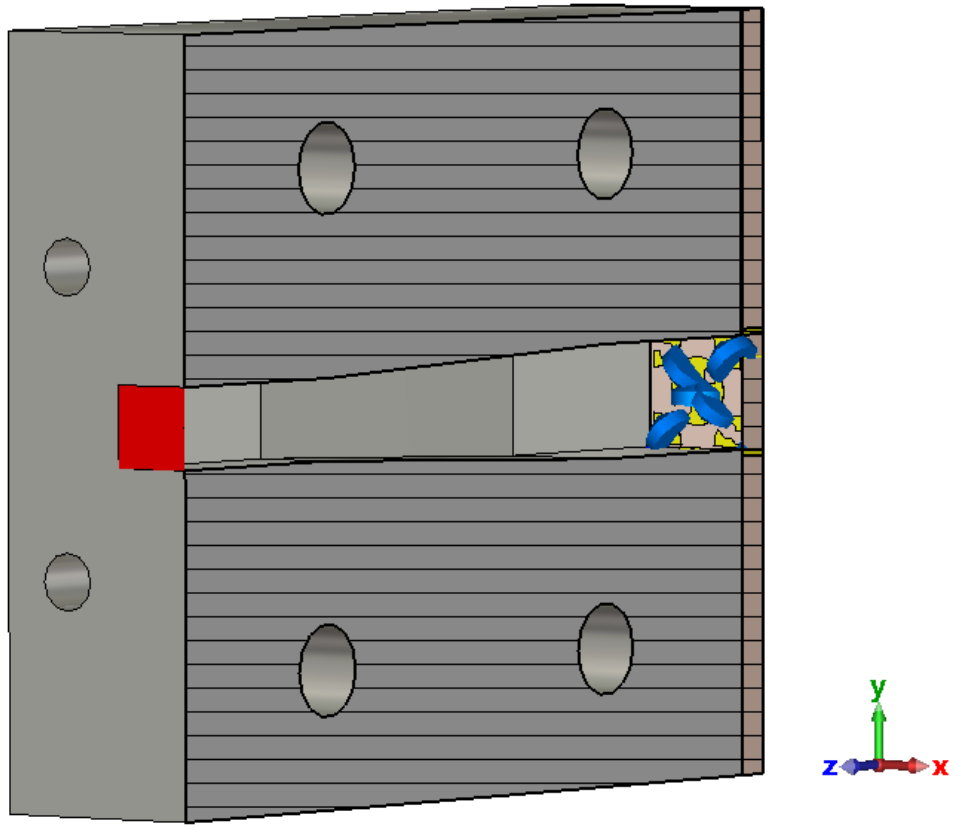
WR-28 waveguides have a rectangular cross-section
Width (a-dimension): 7.112 mm
Height (b-dimension): 3.556 mm

WR-28 → 10mmx5mm tapered transition

The geometry of the scattering element is the same as in RIS modelling, yet periodicity is slightly changed to fit into the waveguide

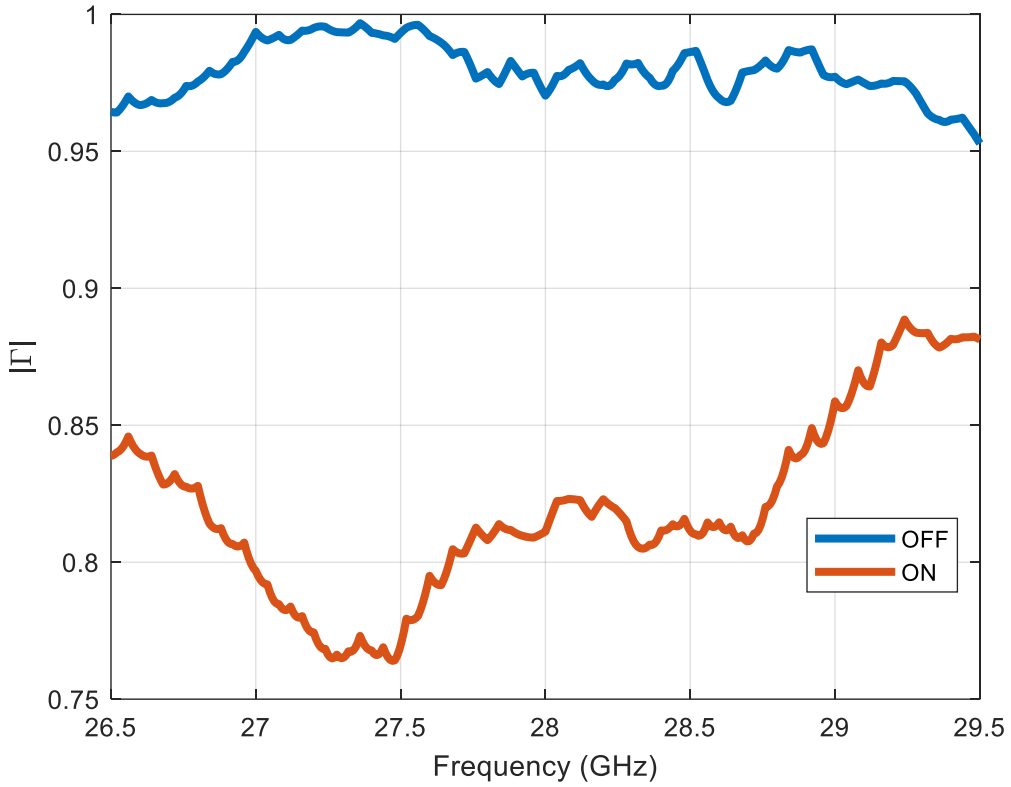
Waveguide test phase difference

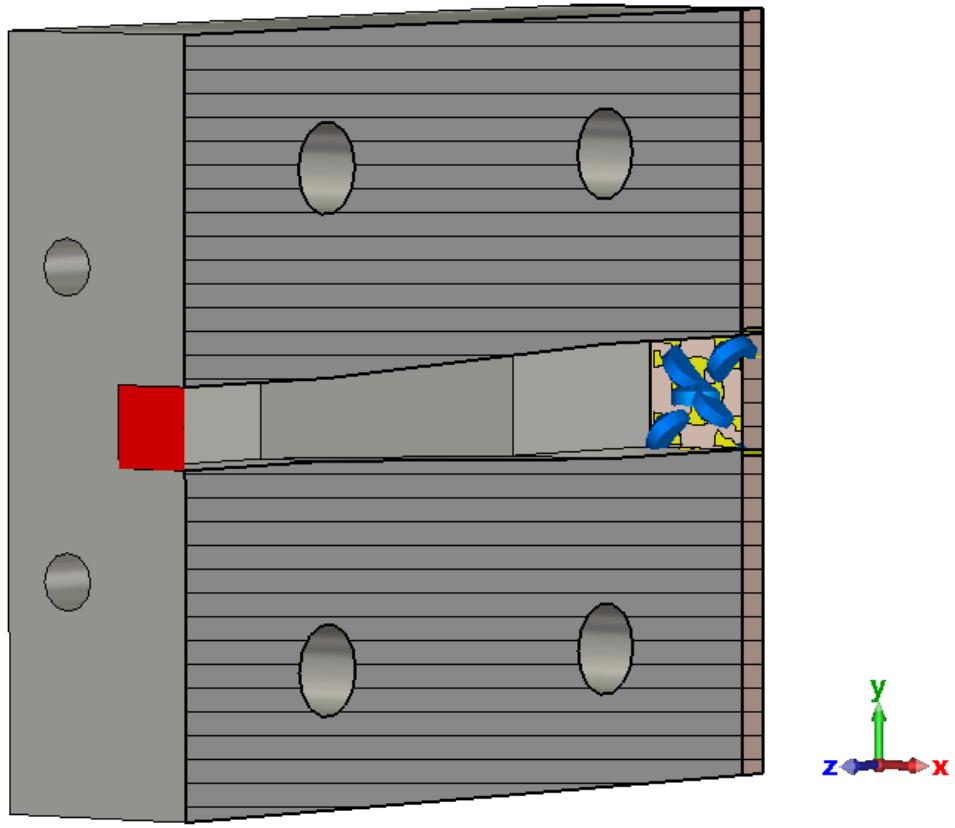




WR-28 → 10mmx5mm tapered transition

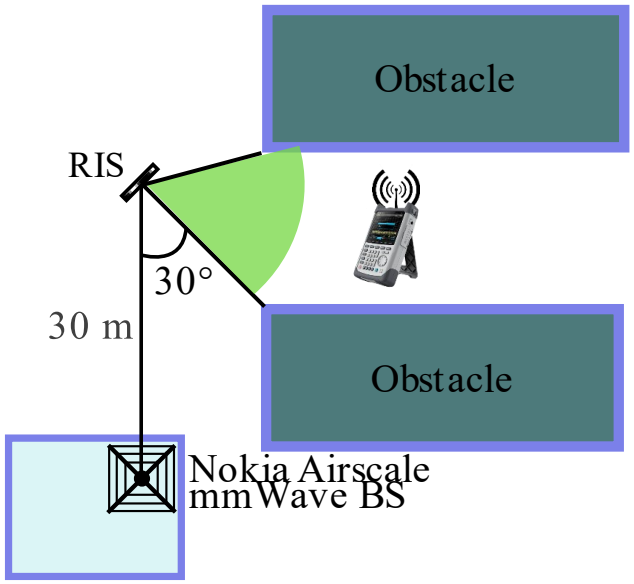
Waveguide test amplitude





WR-28 → 10mmx5mm tapered transition

Full RIS simulations

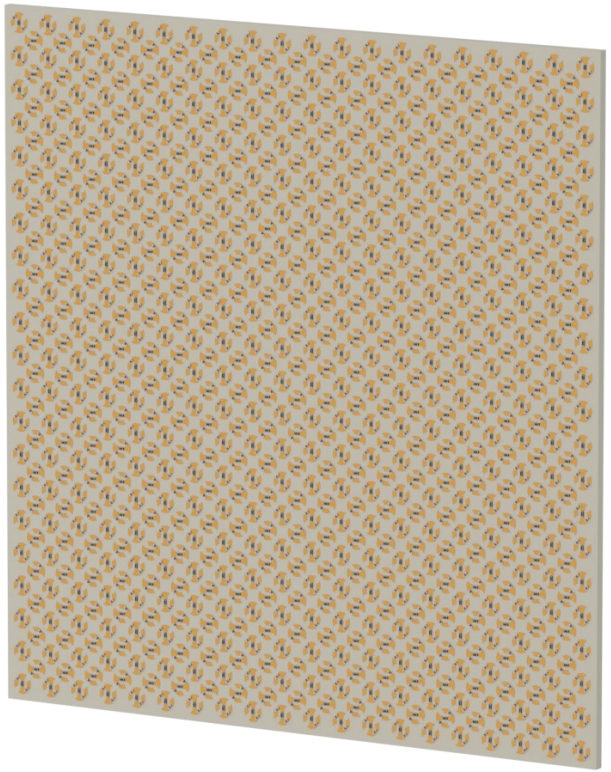


Pathloss estimation
- 2 distinct methodologies

Determine the dimension of the RIS

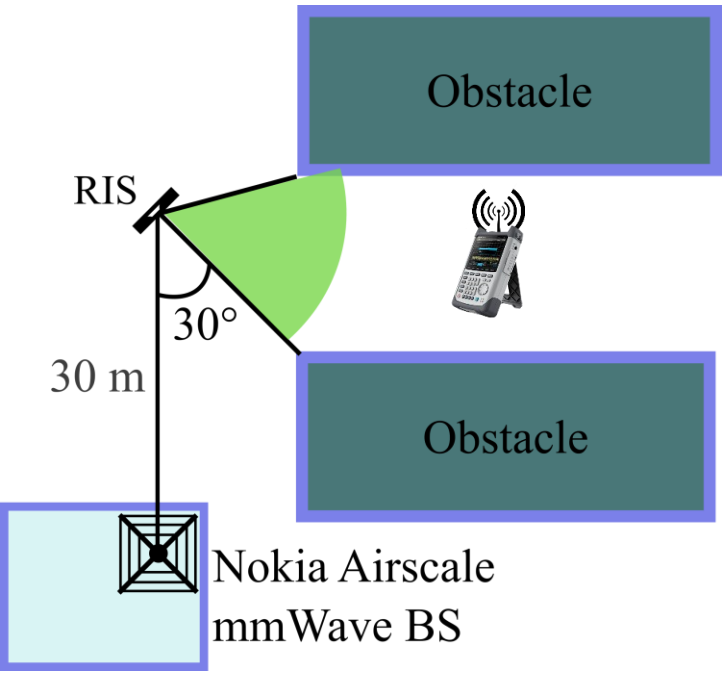
Find the number of required unit-cells

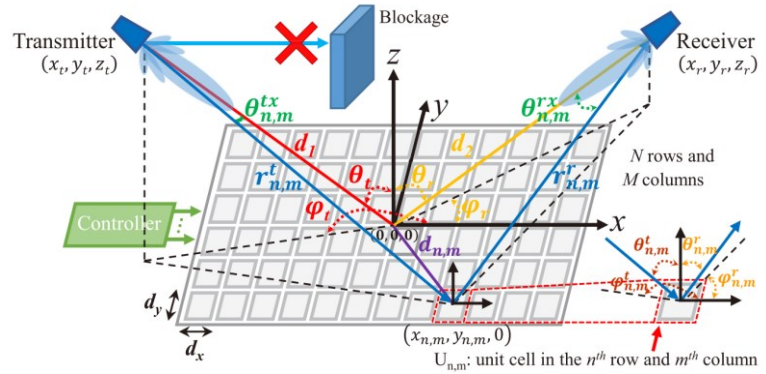
Build RIS Structure



Full RIS Simulation

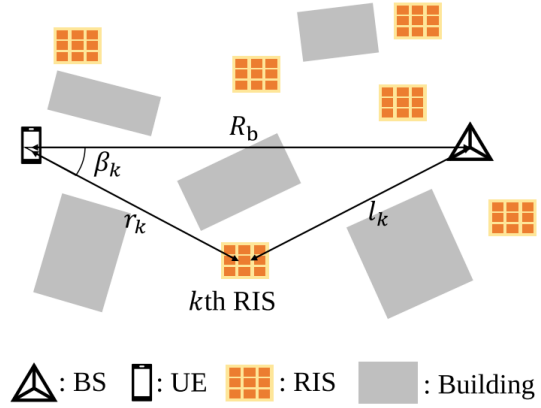
Pathloss models





$$PL_{general}^{refined} = \frac{P_t}{P_r} = \frac{16\pi^2}{G_t G_r (d_x d_y)^2} \times \frac{1}{\left| \sum_{m=1}^{M} \sum_{n=1}^{N} \frac{\sqrt{F_{n,m}^{combine}}\, \Gamma_{n,m}}{r_{n,m}^t r_{n,m}^r} e^{\frac{-j2\pi(r_{n,m}^t + r_{n,m}^r)}{\lambda}} \right|^2}$$

[1] W. Tang et al., "Path Loss Modeling and Measurements for Reconfigurable Intelligent Surfaces in the Millimeter-Wave Frequency Band," in IEEE Transactions on Communications, vol. 70, no. 9, pp. 6259-6276, Sept. 2022, doi: 10.1109/TCOMM.2022.3193400.

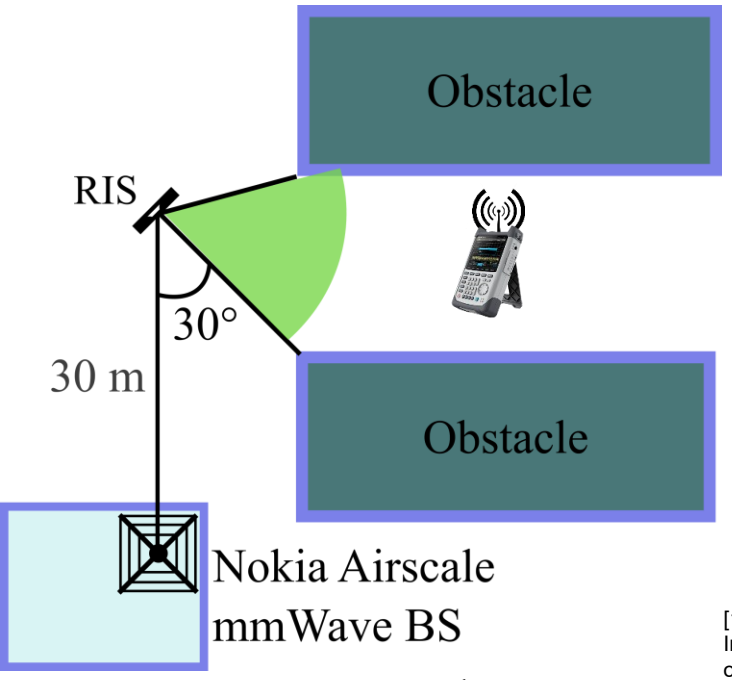


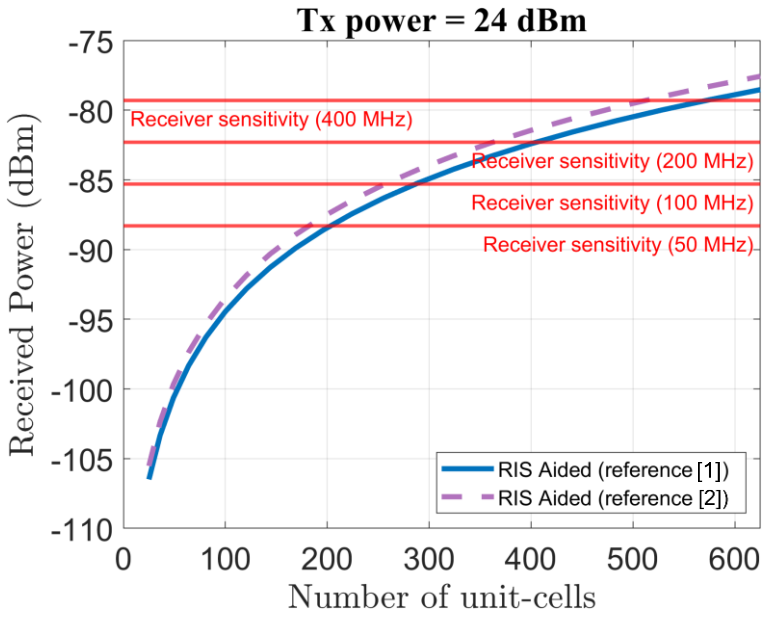
$$P_{rr} = \frac{P_t N_t^2 G_t M_d^2 N_d^2 l_u^2 \mu^2 \rho^2}{64\pi^3 (\tilde{l_k} \tilde{r_k})^\alpha},$$

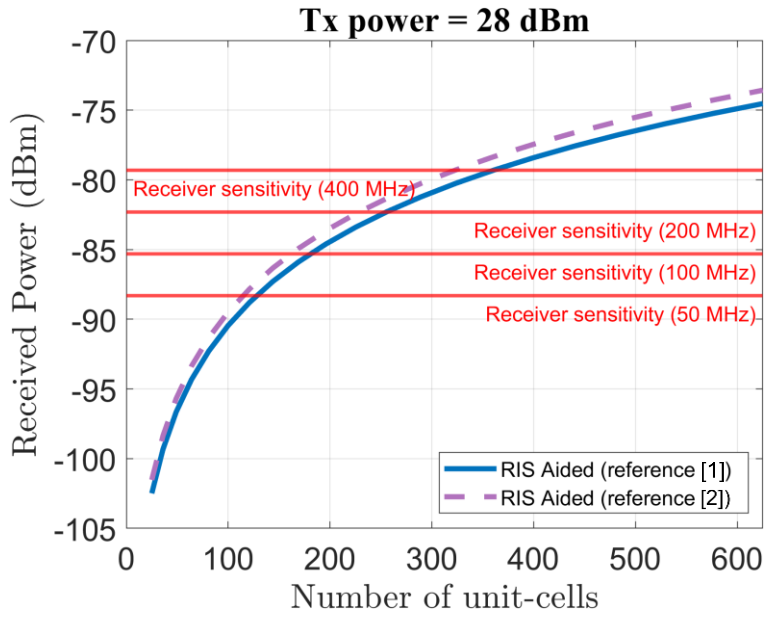
[2] Z. Li, H. Hu, J. Zhang and J. Zhang, "RIS-Assisted mmWave Networks With Random Blockages: Fewer Large RISs or More Small RISs?," in IEEE Transactions on Wireless Communications, vol. 22, no. 2, pp. 986-1000, Feb. 2023, doi: 10.1109/TWC.2022.3200157.

Full RIS Simulation

Determining the number of Unit-cells







$f_0 = 27.275$ GHz, $P_x = P_y = 4.6$ mm – 30 meters
$G_t = 29$ dBi, $G_r = 2$ dBi

[1] W. Tang et al., "Path Loss Modeling and Measurements for Reconfigurable Intelligent Surfaces in the Millimeter-Wave Frequency Band," in IEEE Transactions on Communications, vol. 70, no. 9, pp. 6259-6276, Sept. 2022, doi: 10.1109/TCOMM.2022.3193400.

[2] Z. Li, H. Hu, J. Zhang and J. Zhang, "RIS-Assisted mmWave Networks With Random Blockages: Fewer Large RISs or More Small RISs?," in IEEE Transactions on Wireless Communications, vol. 22, no. 2, pp. 986-1000, Feb. 2023, doi: 10.1109/TWC.2022.3200157.

Table 7.3.2.3-1: Reference sensitivity

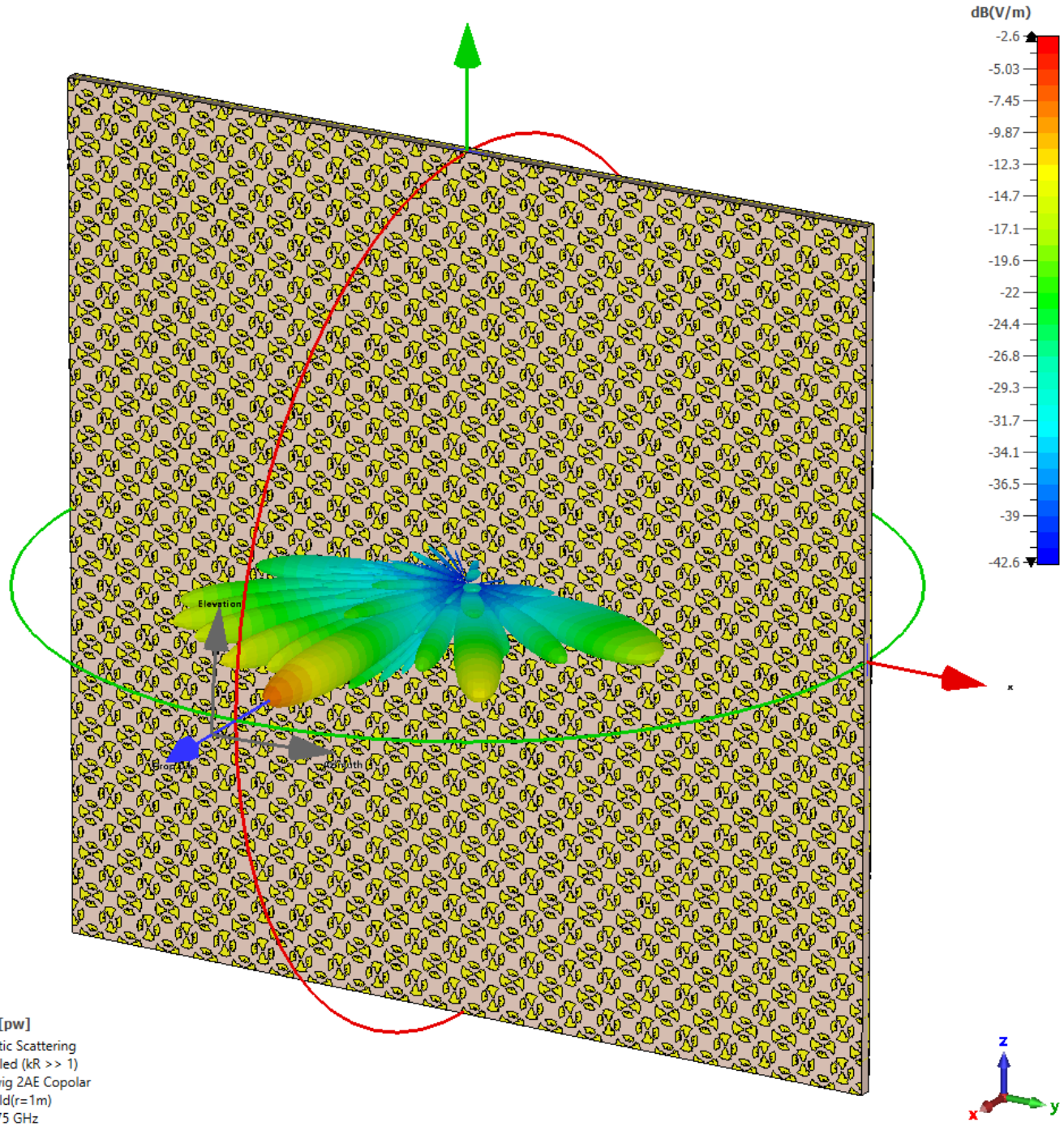
Operating band	REFSENS (dBm) / Channel bandwidth			
	50 MHz	100 MHz	200 MHz	400 MHz
n257	-88.3	-85.3	-82.3	-79.3
n258	-88.3	-85.3	-82.3	-79.3
n260	-85.7	-82.7	-79.7	-76.7
n261	-88.3	-85.3	-82.3	-79.3
NOTE 1: The transmitter shall be set to P_{UMAX} as defined in clause 6.2.4				

3GPP

Full RIS Simulation

Numerical results

$-30°$ Incidence
$+0°$ reflection
Co-polar



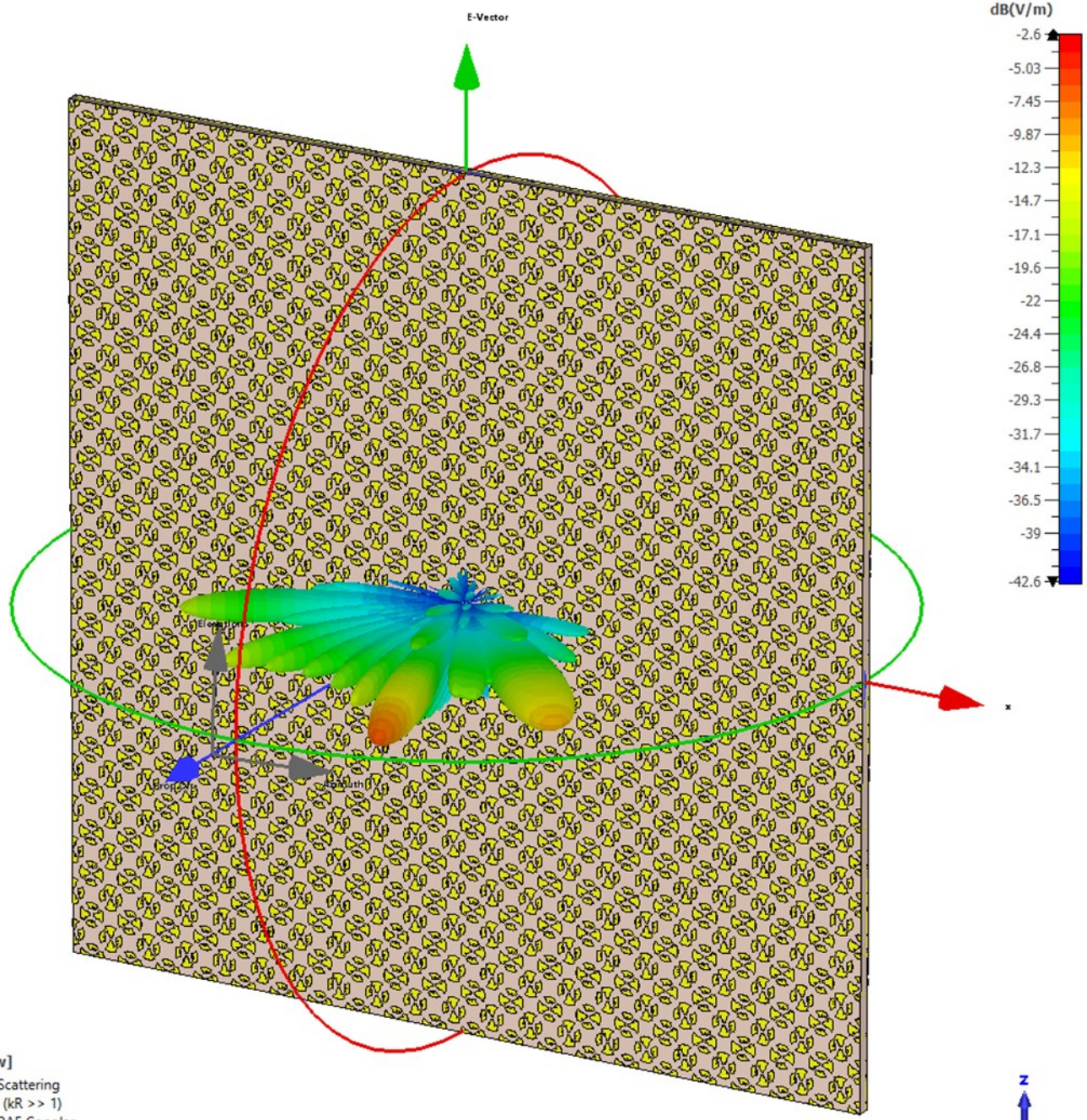
farfield (f=27.275) [pw]

Type	Bistatic Scattering
Approximation	enabled (kR >> 1)
Component	Ludwig 2AE Copolar
Output	E-Field(r=1m)
Frequency	27.275 GHz
Emax (Abs)	-1.959 dB(V/m)
Emax (Copolar)	-1.959 dB(V/m)

Full RIS Simulation

Numerical results

$-30°$ Incidence
$+45°$ reflection
Co-polar



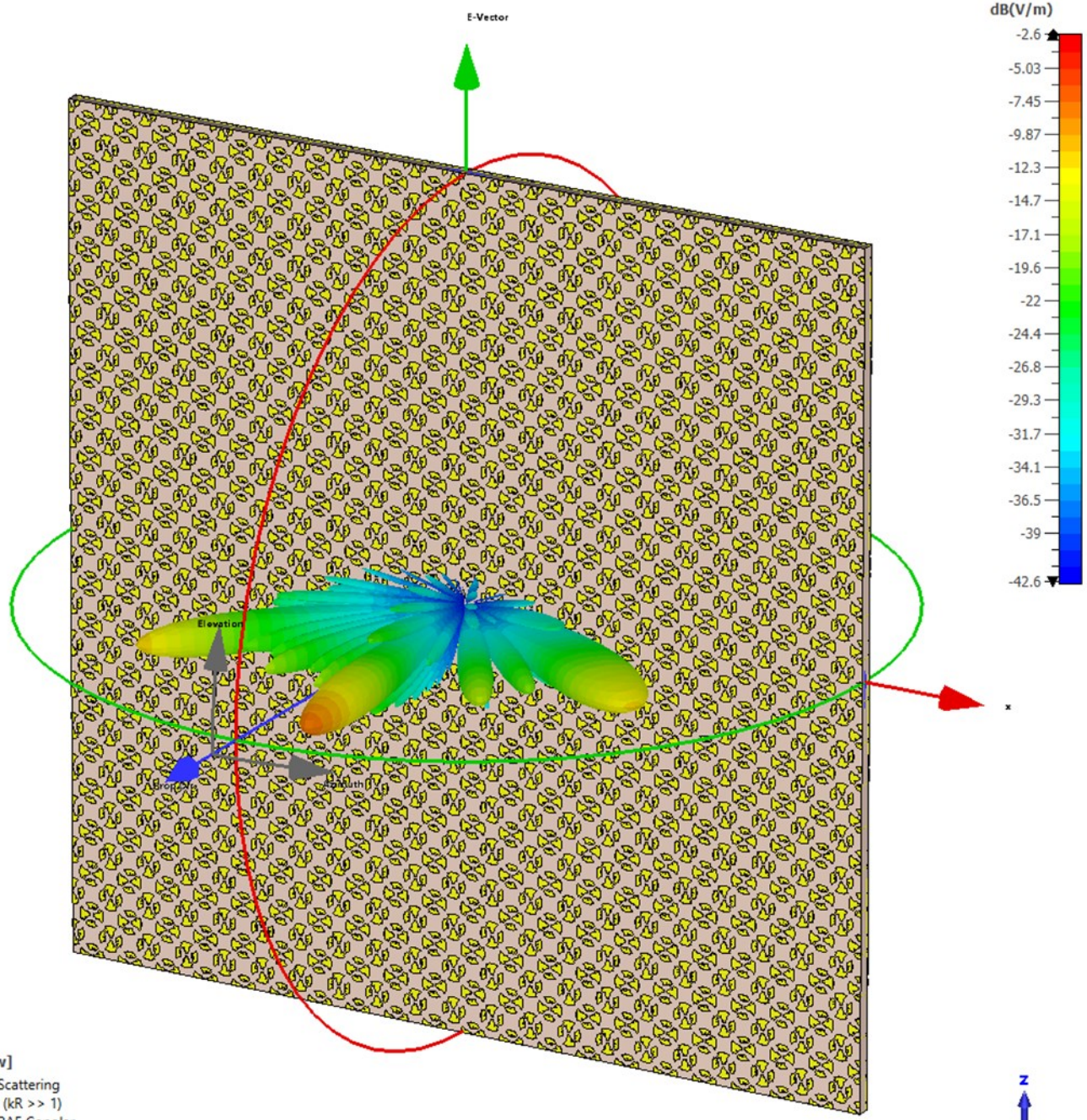
farfield (f=27.275) [pw]

Type	Bistatic Scattering
Approximation	enabled (kR >> 1)
Component	Ludwig 2AE Copolar
Output	E-Field(r=1m)
Frequency	27.275 GHz
Emax (Abs)	-2.115 dB(V/m)
Emax (Copolar)	-2.115 dB(V/m)

Full RIS Simulation

Numerical results

$-30°$ Incidence
$+60°$ reflection
Co-polar

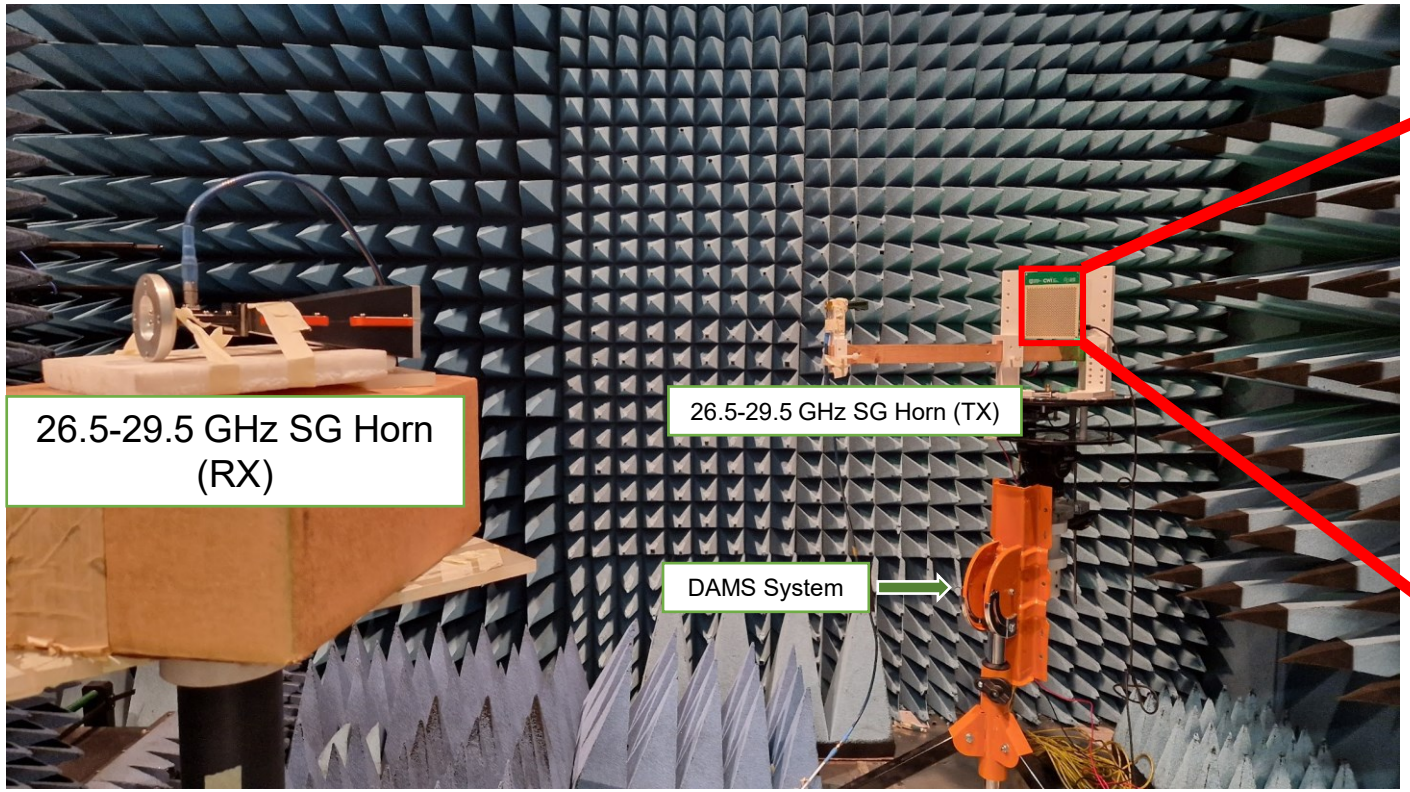


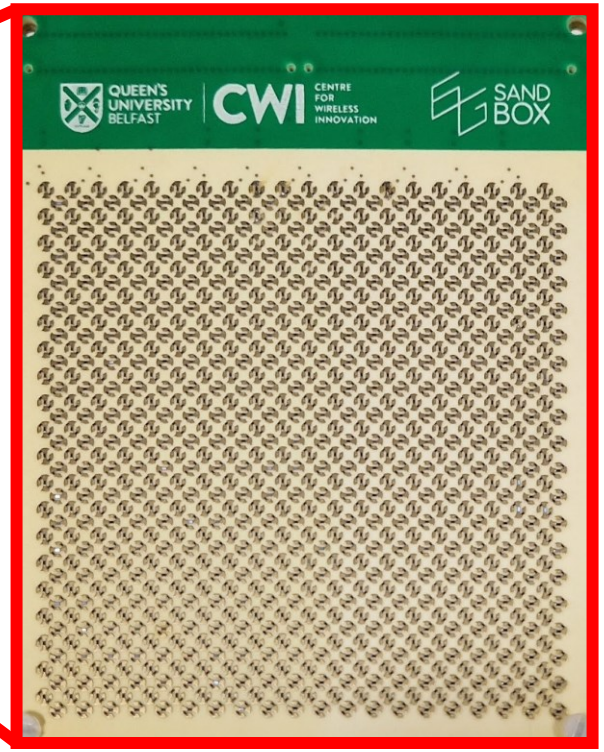
farfield (f=27.275) [pw]

Type	Bistatic Scattering
Approximation	enabled (kR >> 1)
Component	Ludwig 2AE Copolar
Output	E-Field(r=1m)
Frequency	27.275 GHz
Emax (Abs)	-2.044 dB(V/m)
Emax (Copolar)	-2.044 dB(V/m)

Experimental Results

Set-up

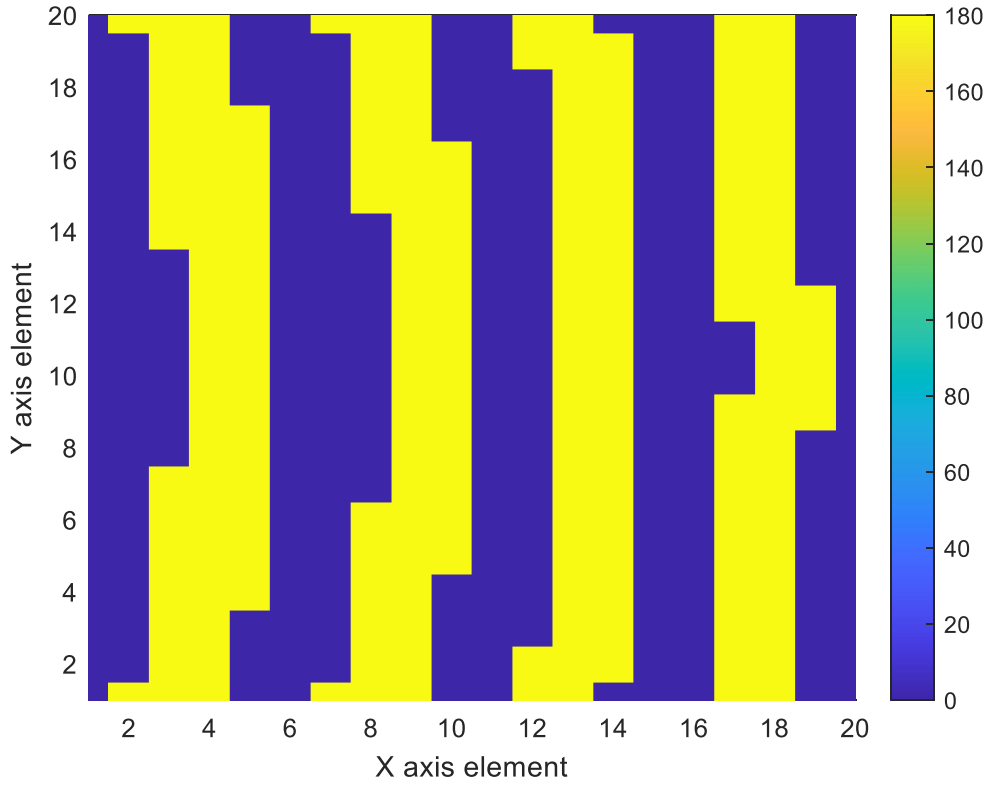


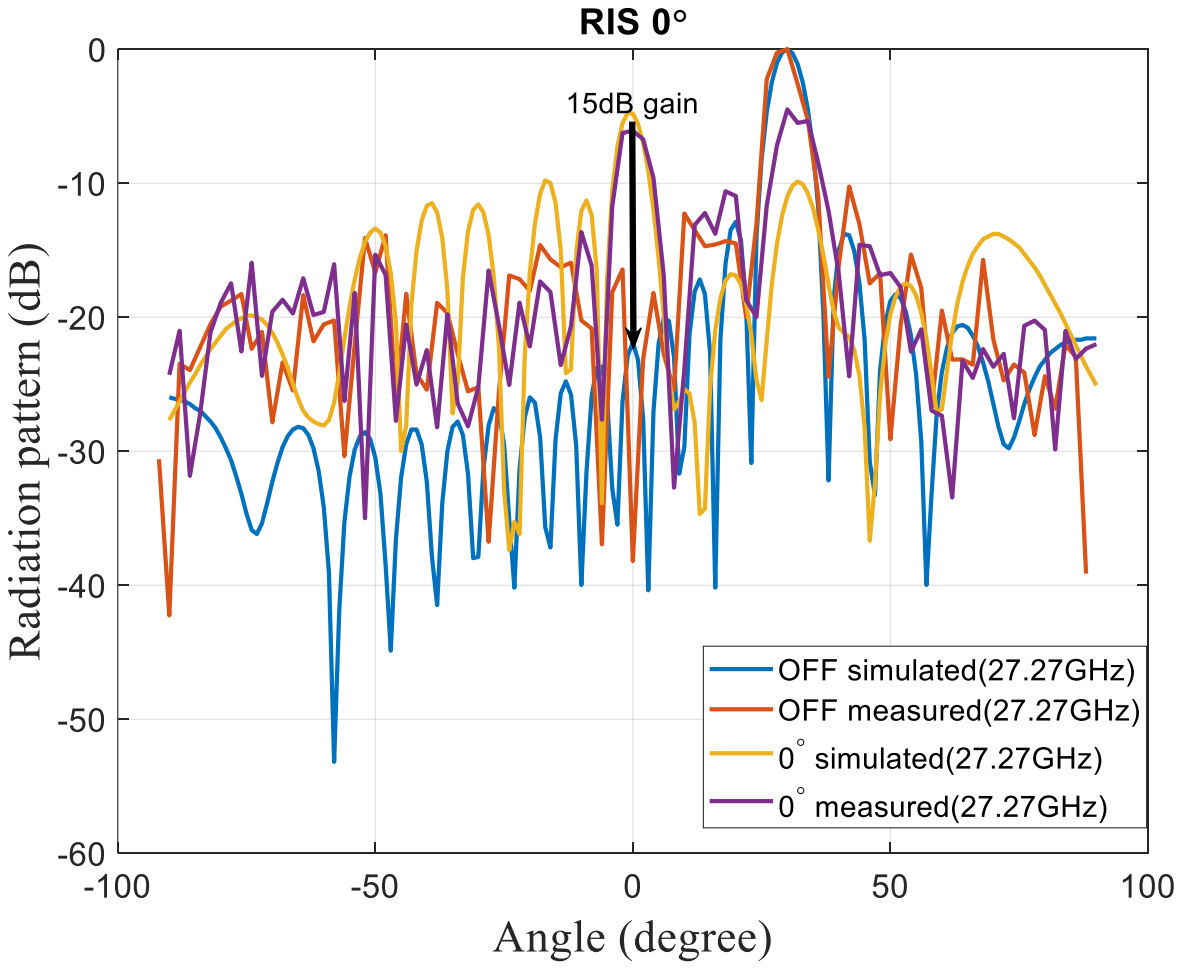


Tx-RIS distance is 40cm
RIS-Rx distance is 2m

Experimental Results

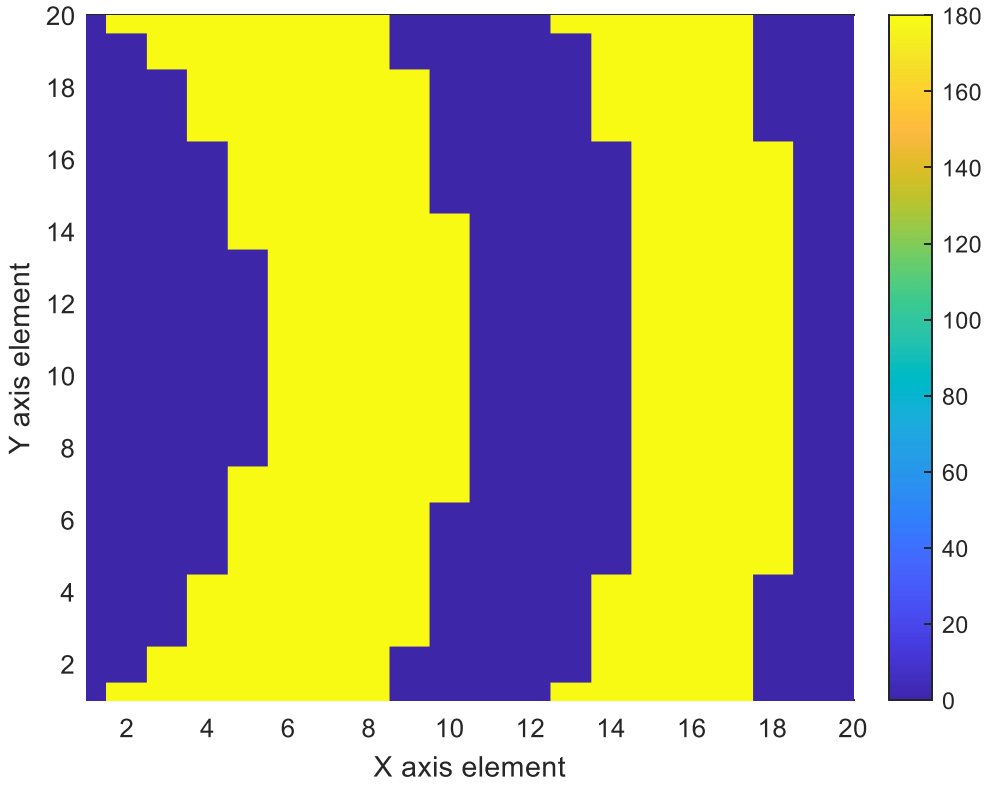
0 degree direction

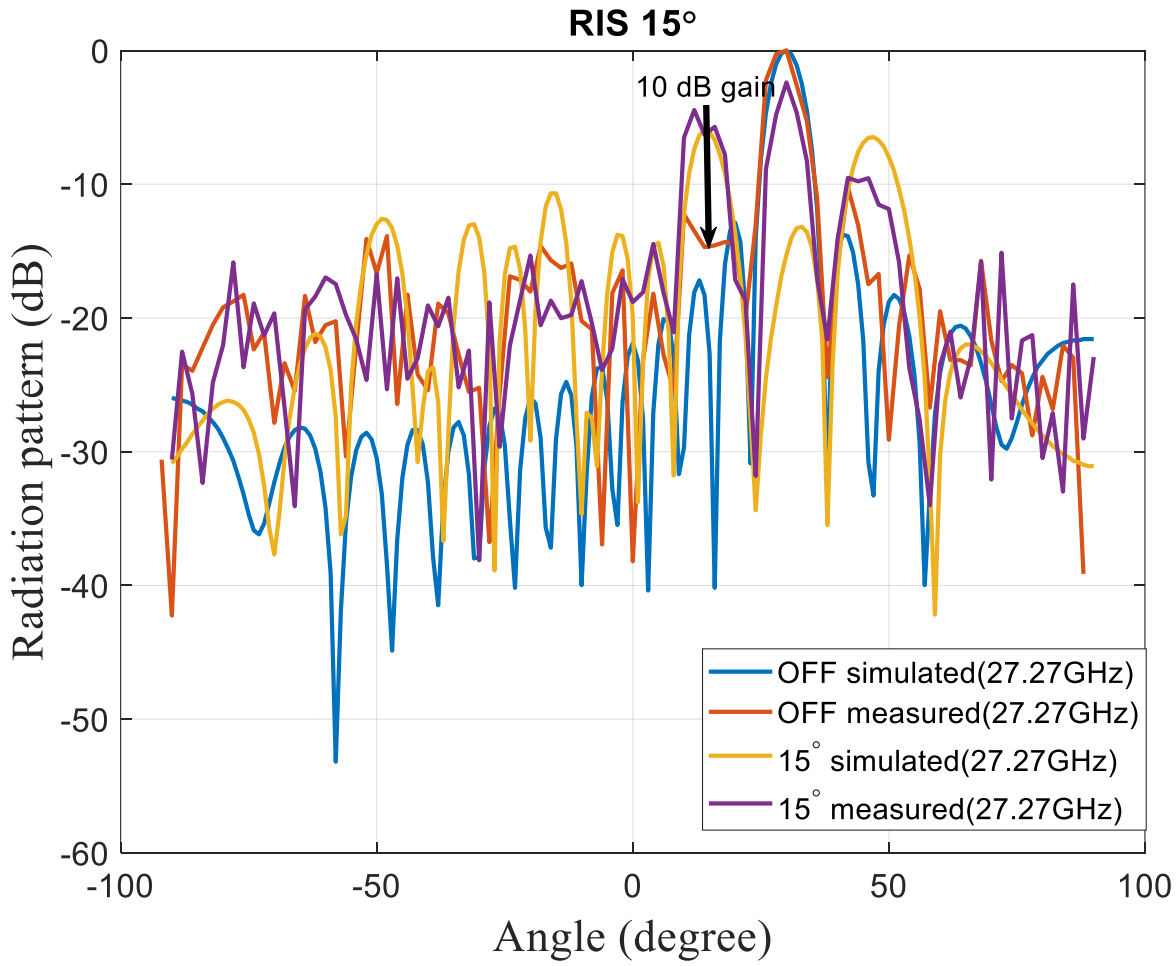




Experimental Results

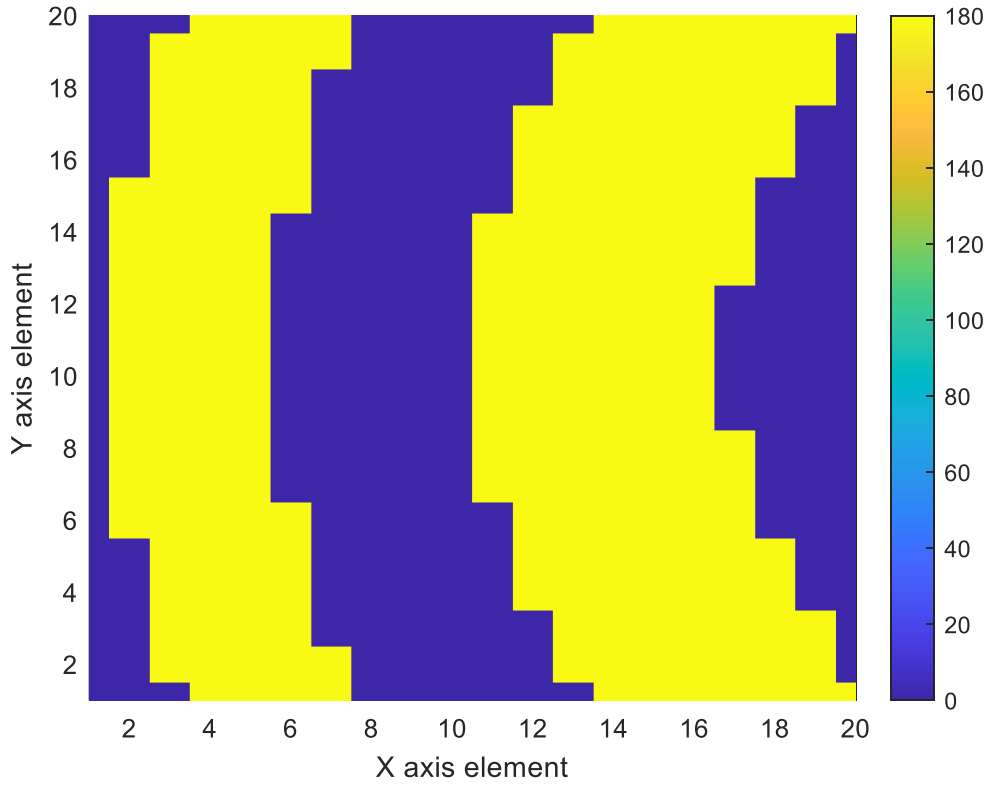
15 degree direction

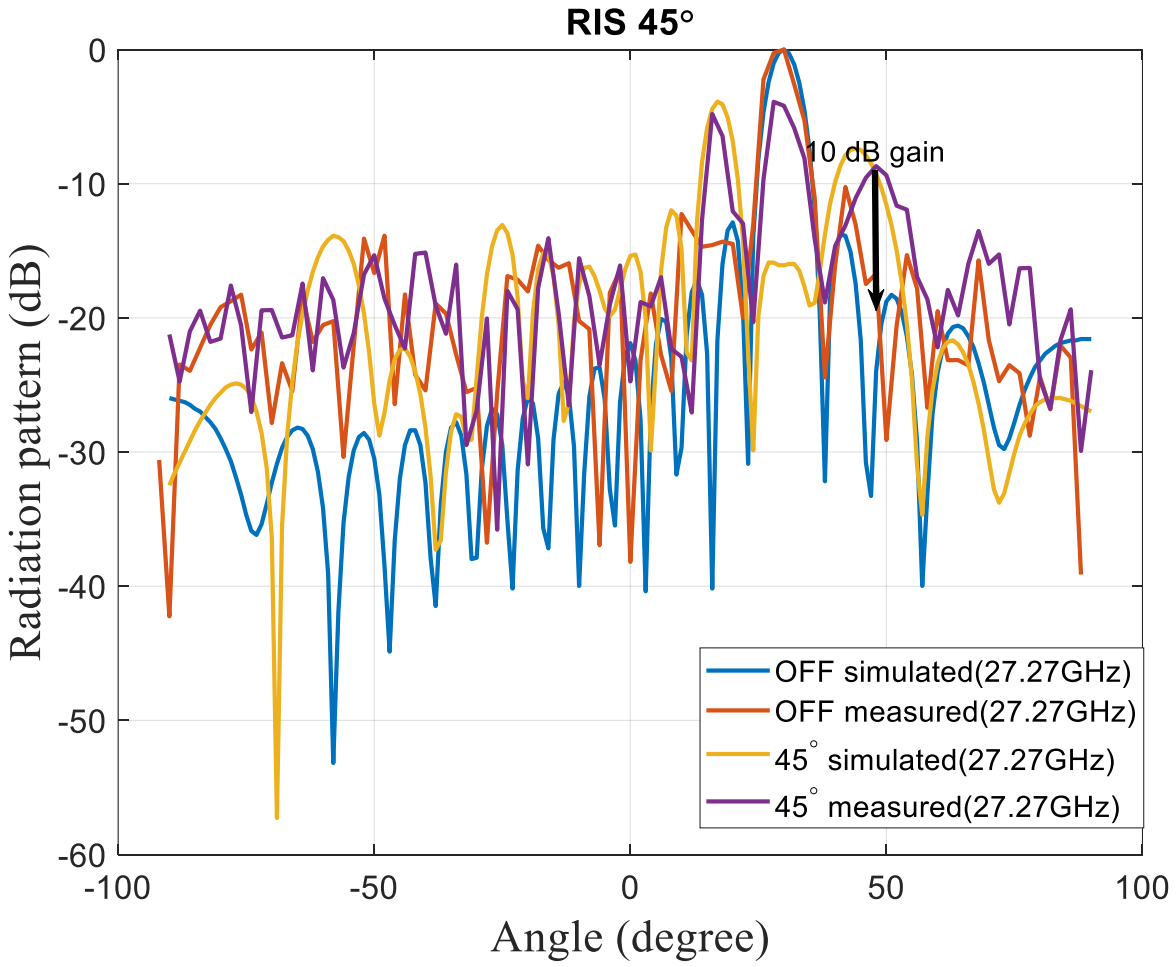




Experimental Results

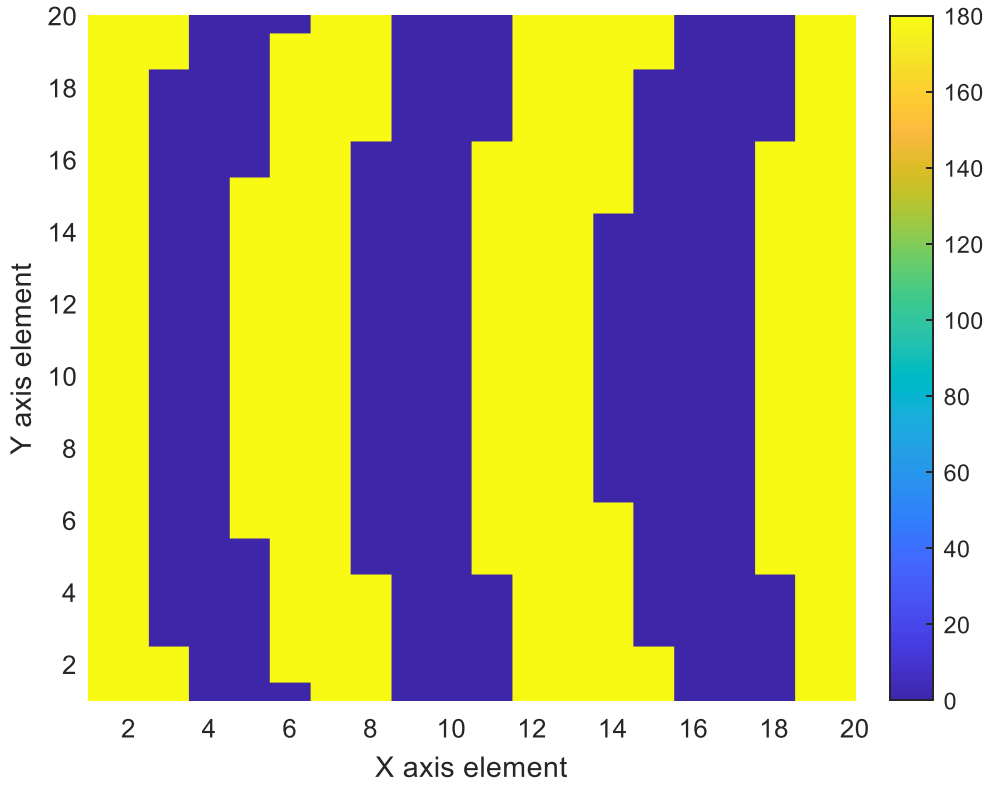
45 degree direction

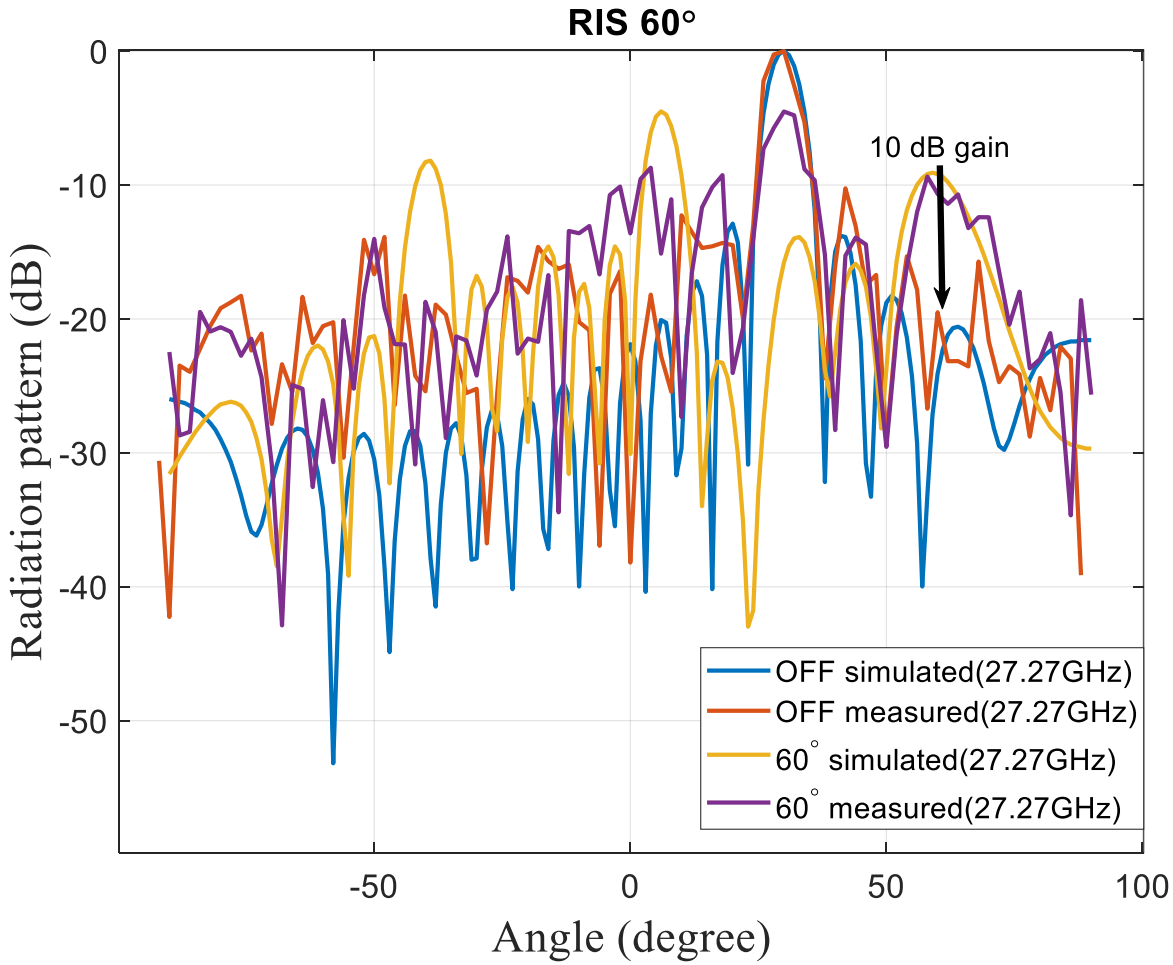




Experimental Results

60 degree direction





Conclusions

A novel unit-cell for RIS has been presented

Coverage of the entire n257 5G mmWave band

Final dimensions obtained based on the scenario it will be used

- Considered 2 pathloss models

Simulations of the full RIS show specular reflection and some grating lobes

- Quantization
- Spacing between unit-cells to provide dual-polarization capability

Initial measurement stages

- Needs refinement
- Results are encouraging

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