KIEES 한국전자파학회

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Wide-Angle Scanning Flat-Panel Phased Array Antenna (WAS-FPAA)

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2) Dielectric grid layer based antenna

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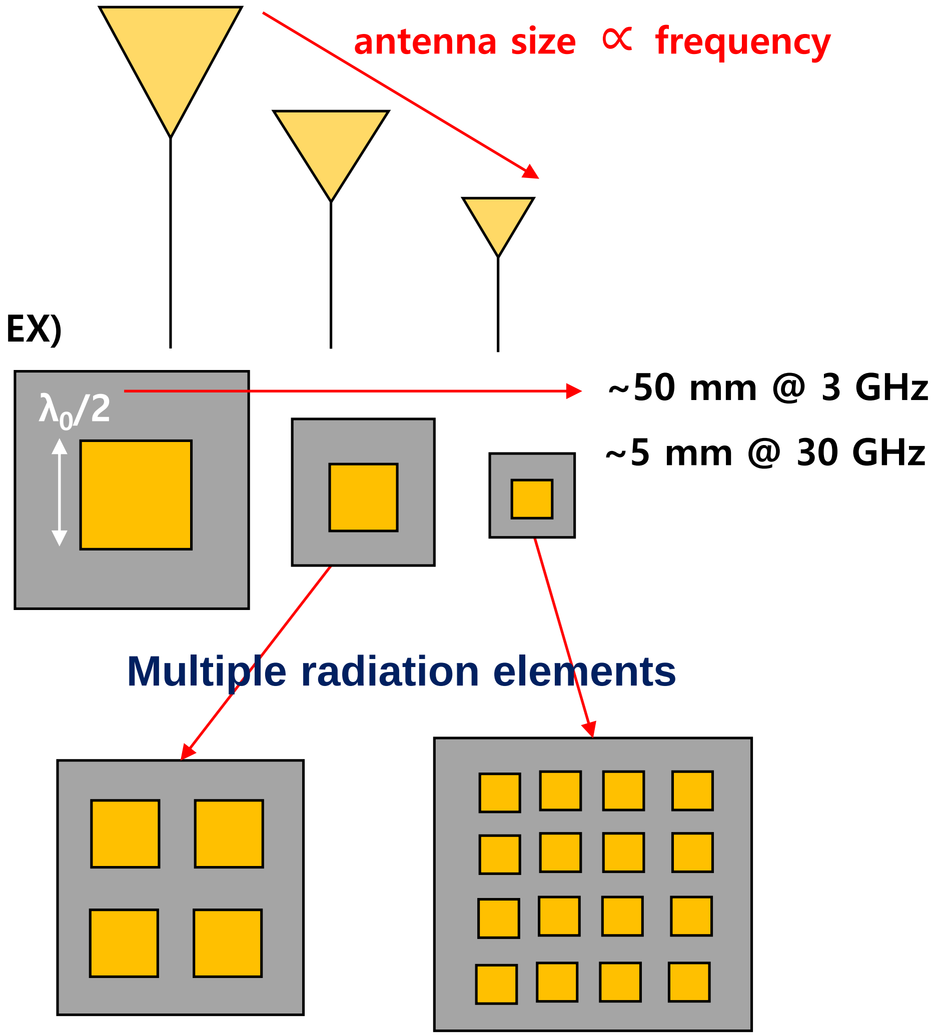
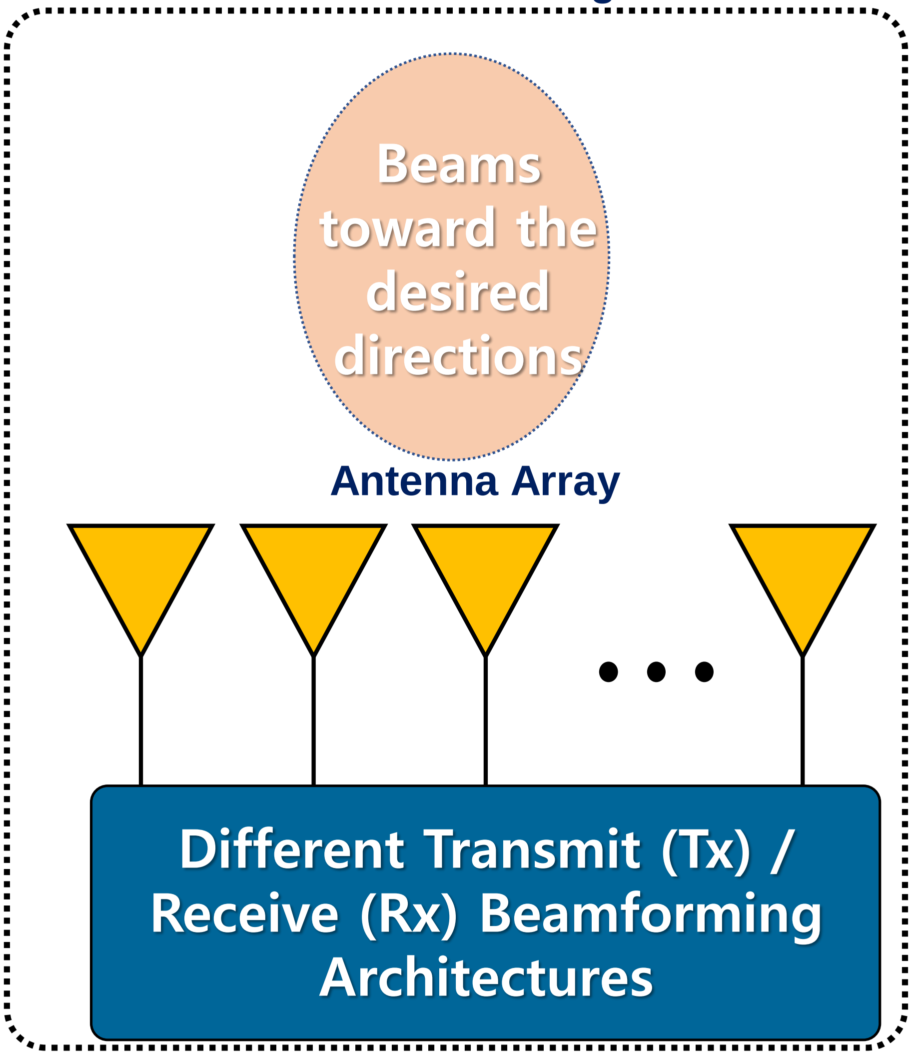
Fundamentals of Phased Array

- **Antenna Array**



mmWave beamforming antenna



Antenna Array : multiple antennas combined to enhance radiation and shape beam pattern

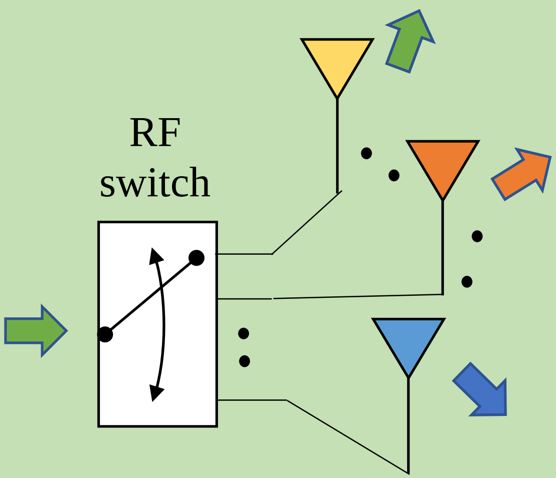
Fundamentals of Phased Array Tech.

Beamforming antenna structures

Beamforming Antenna Configurations

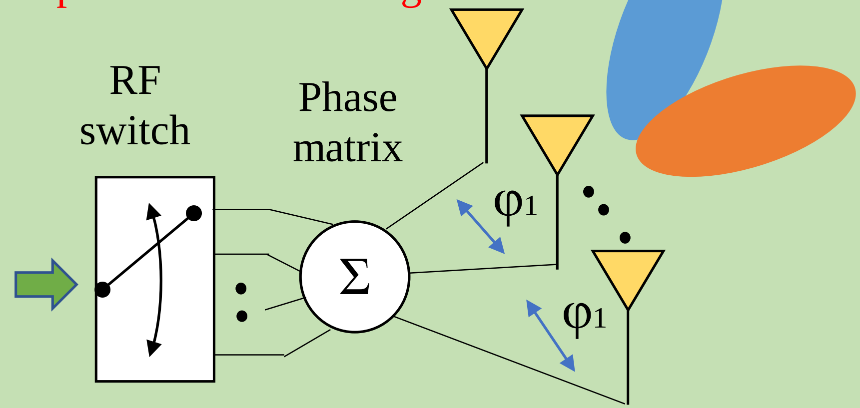
- **Switched Beamforming**
- **Phased Array Beamforming**

Switched Beamforming



Switch to select different antenna at a time

Phase matrix is usually passive, thus passive beamforming

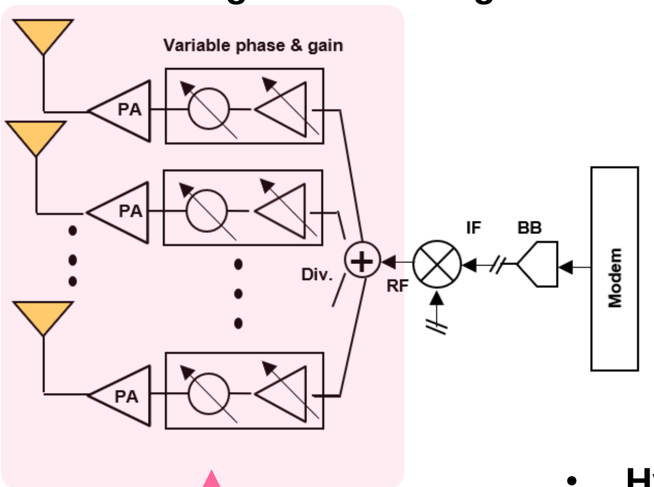


Switch to provide different phases to each antenna elements

Fundamentals of Phased Array Tech.

Phased array antenna configuration (1)

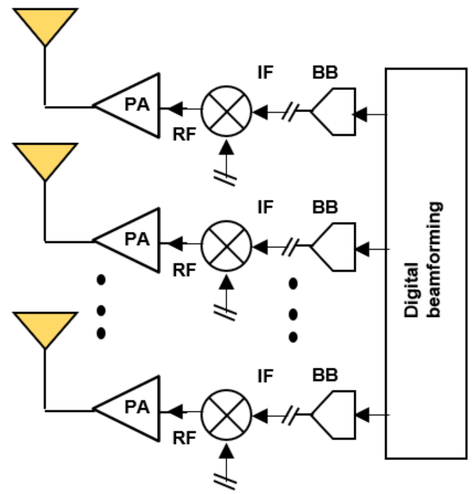
- Analog beamforming



- Simplest
- Lowest DC power consumption
- Requires RF phase shifters

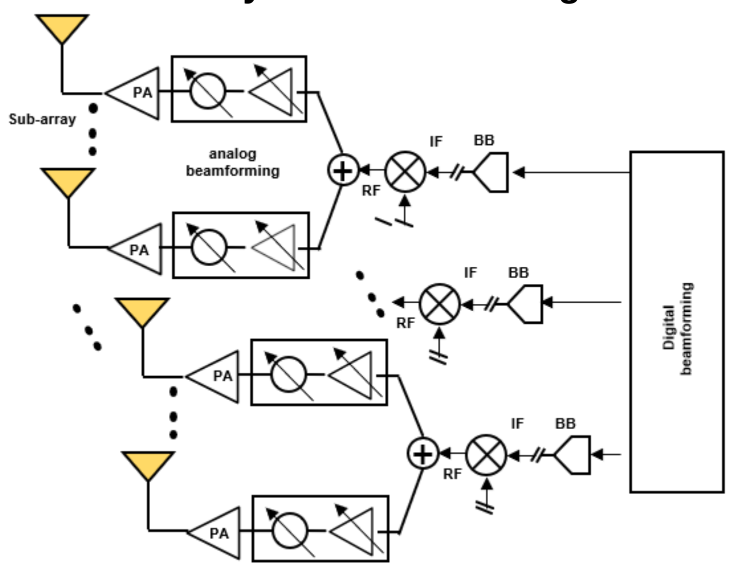
Key technology in mmWave applications

- Digital beamforming



- Flexible & programmable
- Highest number of beams can be generated
- Highest DC power consumption

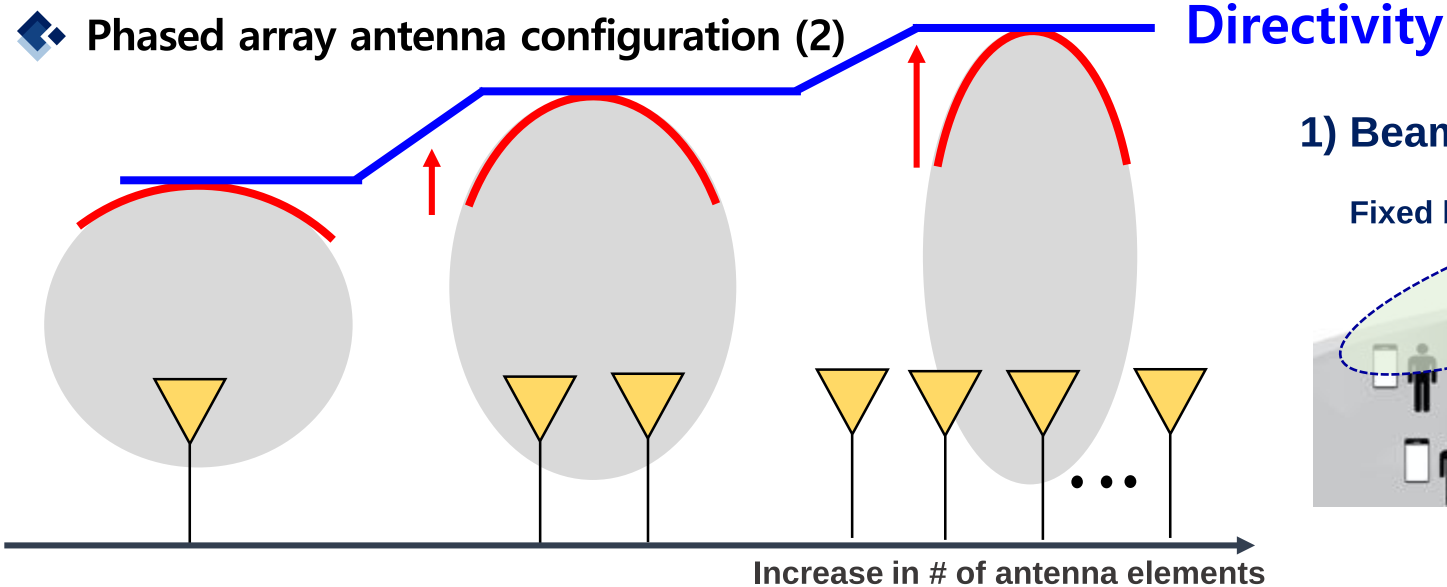
- Hybrid beamforming



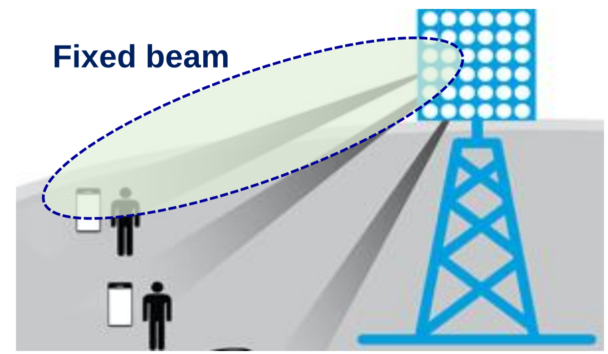
- Flexible with high number of beams
- Reasonable complexity
- Each beam only benefits from the subarray

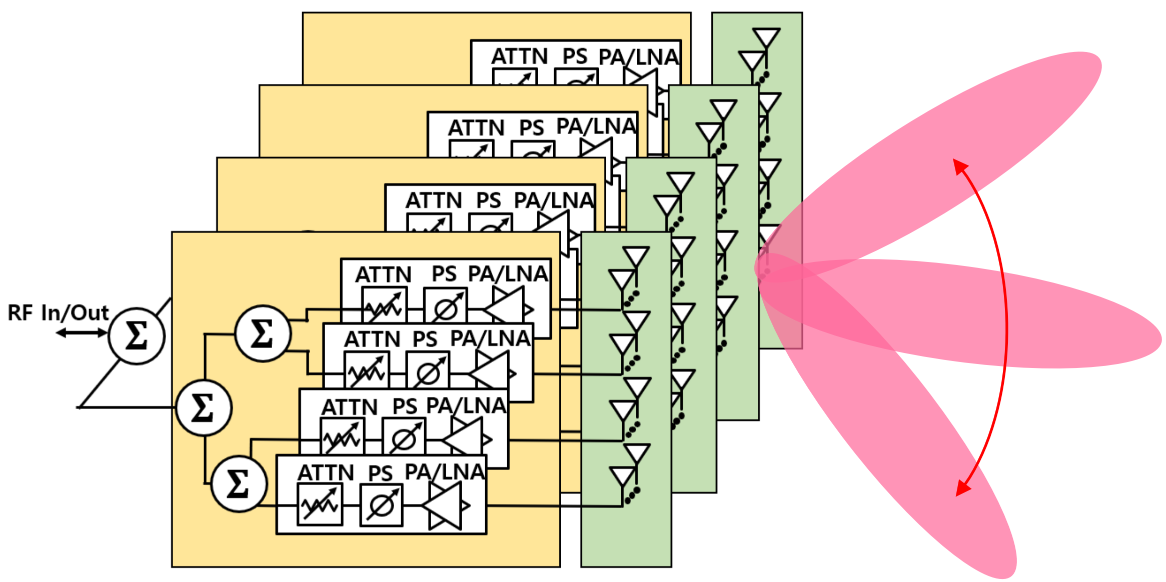
Fundamentals of Phased Array Tech.

- **Phased array antenna configuration (2)**

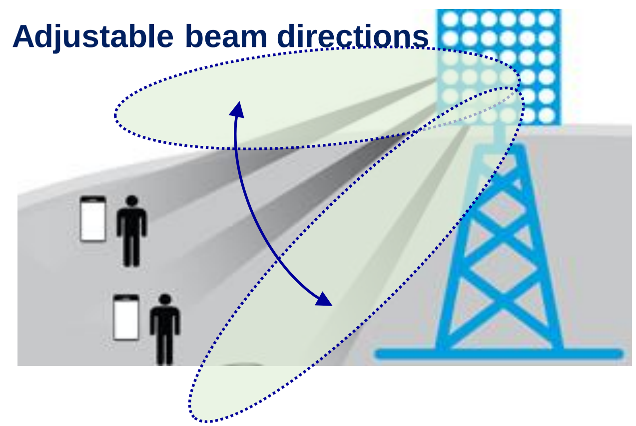


1) Beamforming





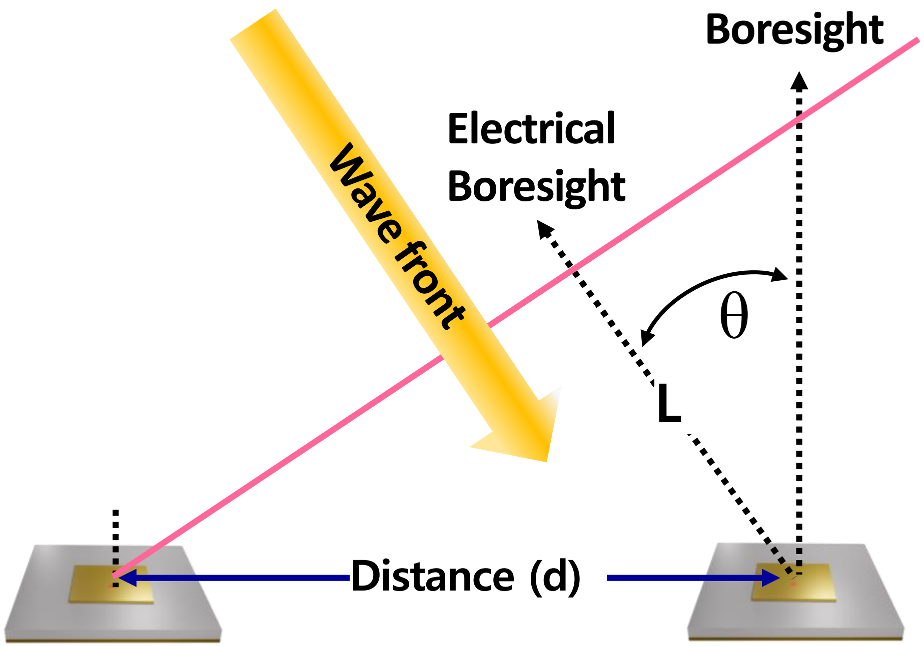
2) Beam-steering



Phased Array beamforming: radiation elements weighted by amplitude and phase

Fundamentals of Phased Array Tech.

Phase shifting



- Incremental distance to travel

$$L = d \sin\theta$$

- Time delay between the elements

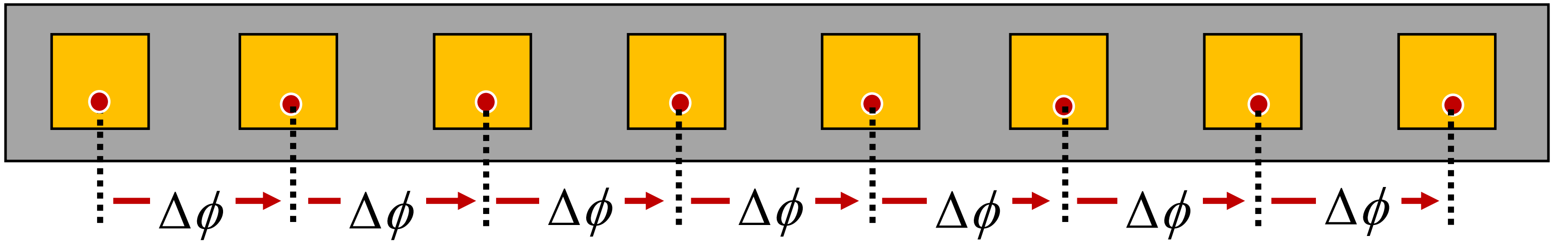
$$\Delta t = L / c = d \sin\theta / c$$
$$\rightarrow \theta = \sin^{-1}(\Delta t\, c / d)$$

- Phase shift between the elements

$$\Delta\phi = 2\pi L / \lambda = 2\pi f L / c$$
$$\rightarrow \Delta\phi = 2\pi f d \sin\theta / c$$
$$\boxed{\Delta\phi = \frac{2\pi d \sin\theta}{\lambda}}$$
$$\theta = \arcsin\left(\frac{\Delta\phi}{2\pi} \times \frac{\lambda}{d}\right)$$
$$\rightarrow \theta = \sin^{-1}(\Delta\phi\, c / (2\pi f d))$$

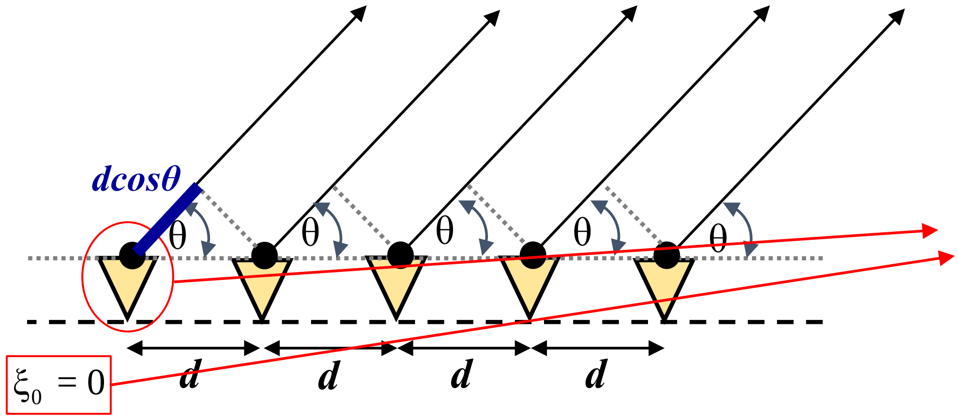
- Typically, $d = \frac{\lambda}{2} \rightarrow \boxed{\Delta\phi = \pi\sin\theta}$

- Electrical boresight steering by $\Delta\phi$



Fundamentals of Phased Array Tech.

1-D Array Factor (AF) (1)



$$AF = e^{j\xi_0} + e^{j\xi_1} + e^{j\xi_2} + \cdots + e^{j\xi_{N-1}}$$

ξ_m are the phases of an incoming plane wave at the element locations $m = 0, 1, \ldots,$

$$AF = 1 + e^{jkd\cos\theta} + e^{jk2d\cos\theta} + \cdots e^{jk(N-1)d\cos\theta}$$

$$= \sum_{m=0}^{N-1} \mathrm{e}^{jkmd\,\cos\theta} = \sum_{m=0}^{N-1} \mathrm{e}^{jkm\frac{d}{N-1}\cos\theta}$$

- define $\psi = kd\cos\theta,\quad AF = \sum_{m=0}^{N-1} e^{jm\psi} = 1 + e^{j\psi} + e^{j2\psi} + \cdots e^{j(N-1)\psi}$ ①

- Multiply by $e^{j\psi}$

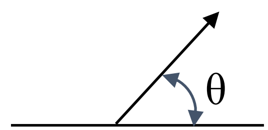
$$AF \cdot e^{j\psi} = e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \cdots + e^{jN\psi} \quad ②$$

① − ② : $\boxed{AF(1-e^{j\psi}) = 1-e^{jN\psi}}$

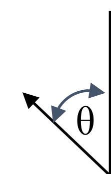
- Rearrange

$$AF = \frac{1-e^{jN\psi}}{1-e^{j\psi}} = \frac{e^{jN\psi/2}}{e^{j\psi/2}} \frac{e^{jN\psi/2} - e^{-jN\psi/2}}{e^{j\psi/2} - e^{-j\psi/2}}$$

$$= e^{j(N-1)\psi/2} \frac{\sin(N\psi/2)}{\sin(\psi/2)} \rightarrow f(\psi) = \frac{\sin(N\psi/2)}{N\sin(\psi/2)} \rightarrow \boxed{(AF)_N = \frac{\sin(\frac{N}{2}kd\cos\theta)}{N\sin(\frac{1}{2}kd\cos\theta)}}$$



or, $\boxed{(AF)_N = \frac{\sin(\frac{N}{2}kd\sin\theta)}{N\sin(\frac{1}{2}kd\sin\theta)}}$

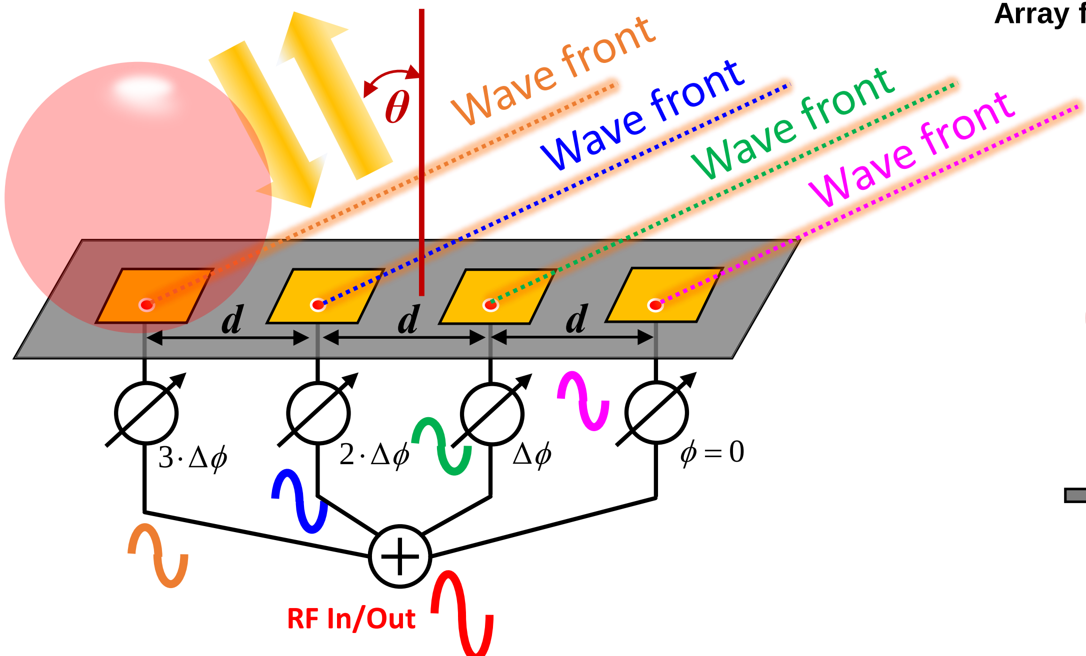


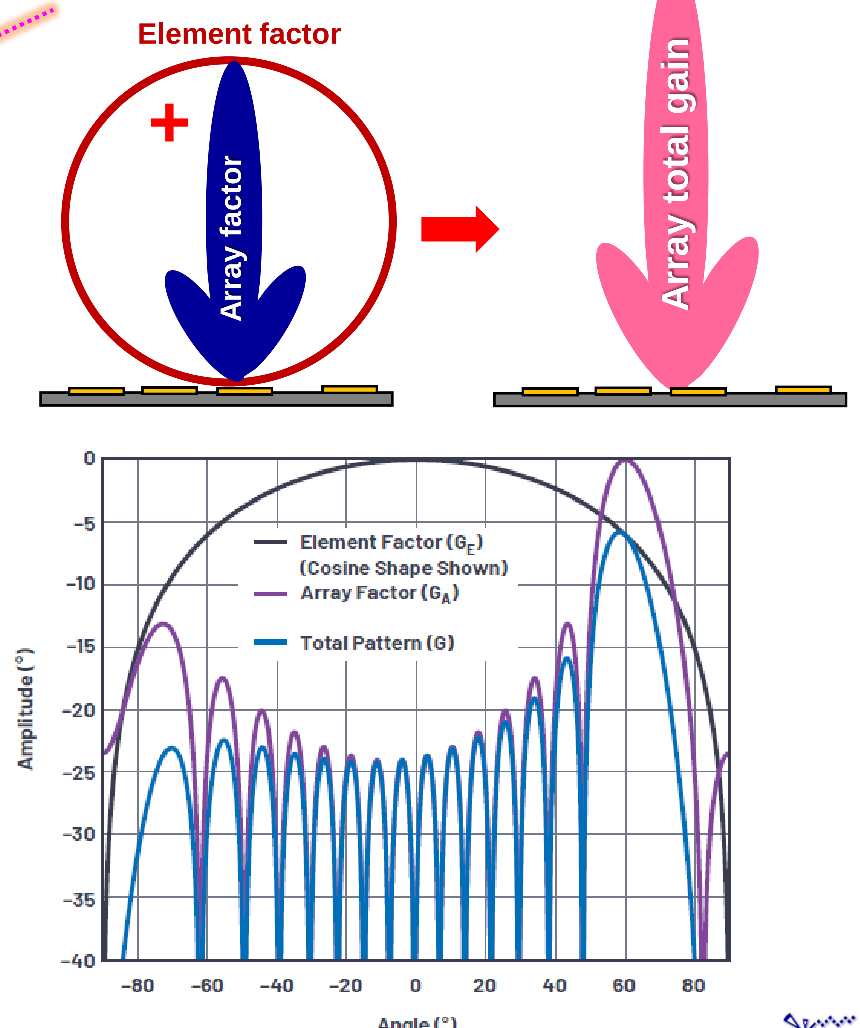
Fundamentals of Phased Array Tech.

1-D Array Factor (AF) (2)

Element factor: radiation pattern produced by a single element

Array factor: response of an array of isotropic element





$$\boxed{AF_N(\theta) = \frac{\sin(\frac{N}{2}kd\sin\theta)}{N\sin(\frac{1}{2}kd\sin\theta)}} = \frac{\sin(\frac{N\pi d}{\lambda}\sin\theta)}{N\sin(\frac{\pi d}{\lambda}\sin\theta)}$$

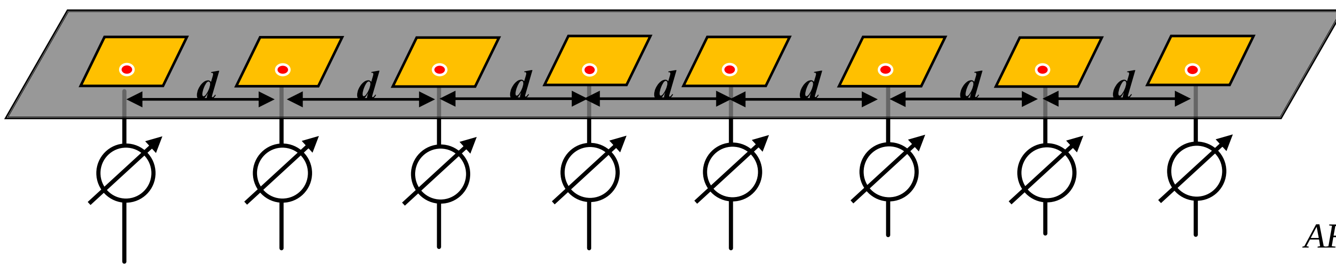
$$\Rightarrow \quad \Delta\phi = \frac{2\pi d\sin\theta}{\lambda}$$

$$\Delta\phi = \pi\sin\theta \ \text{ for } \ d = \frac{\lambda}{2}$$

$$\boxed{AF_N(\theta, \Delta\phi) = \frac{\sin\left(\frac{N\Delta\phi}{2}\right)}{N\sin\left(\frac{\Delta\phi}{2}\right)}}$$

Fundamentals of Phased Array Tech.

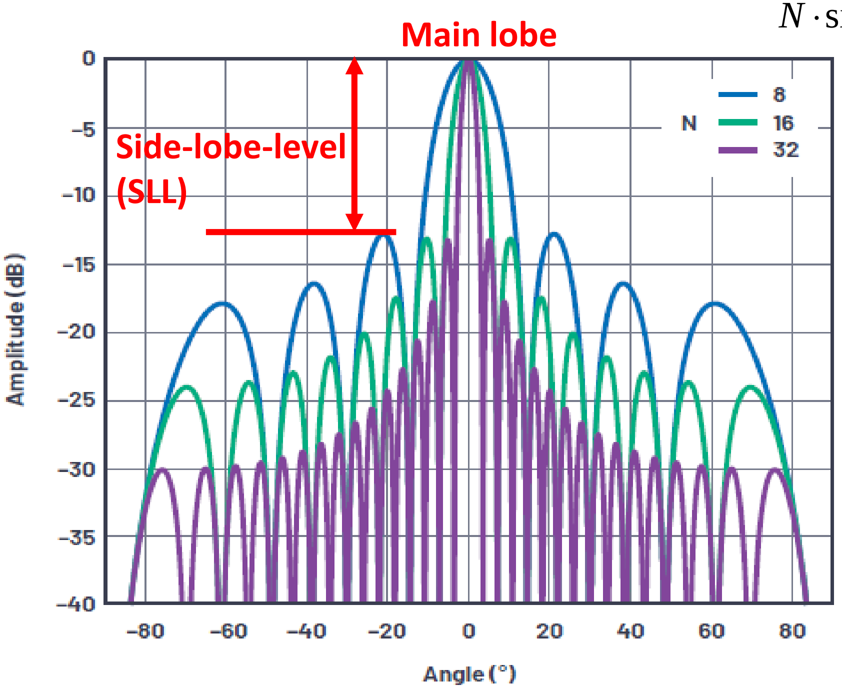
1-D Phased array patterns (1)

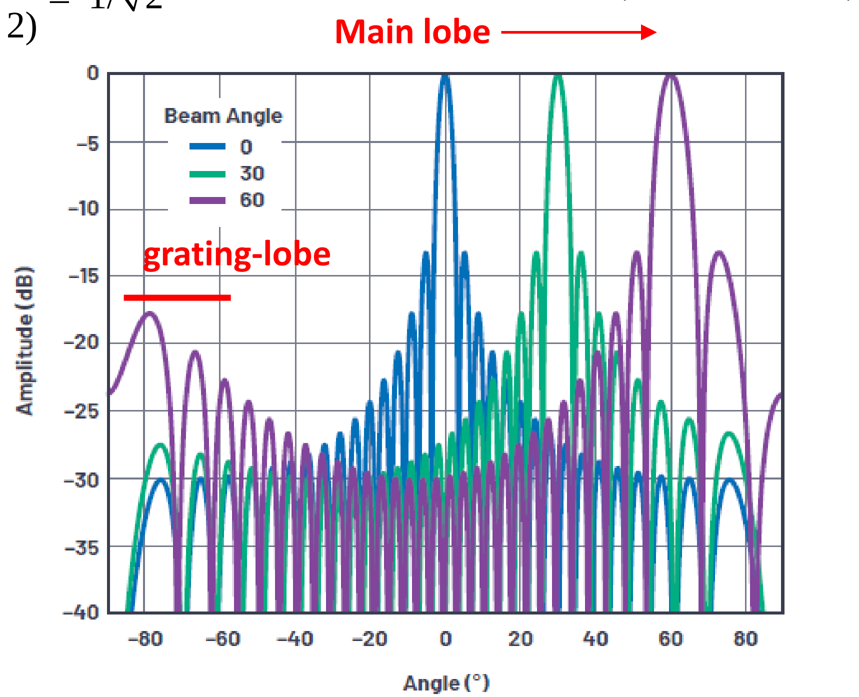


$$AF_N(\theta) = \frac{\sin\left(\frac{N\pi d}{\lambda}[\sin\theta - \sin\theta_0]\right)}{N\sin\left(\frac{\pi d}{\lambda}[\sin\theta - \sin\theta_0]\right)}$$

$$AF_N(\theta, \Delta\phi) = \frac{\sin\left(N\left[\frac{\pi d}{\lambda}\sin(\theta) - \frac{\Delta\phi}{2}\right]\right)}{N\sin\left(\frac{\pi d}{\lambda}\sin(\theta) - \frac{\Delta\phi}{2}\right)}$$

$$HPBW: \frac{\sin(N\cdot\Delta\phi/2)}{N\cdot\sin(\Delta\phi/2)} = 1/\sqrt{2}$$





1) Main-lobe narrows by $2\pi/N$, 2) # of side-lobe increases, 3) SLL decreases

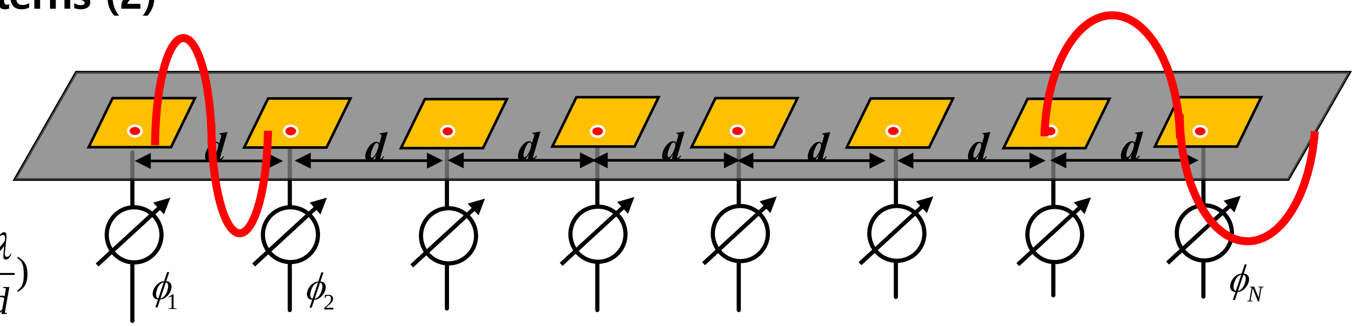
Fundamentals of Phased Array Tech.

1-D Phased array patterns (2)

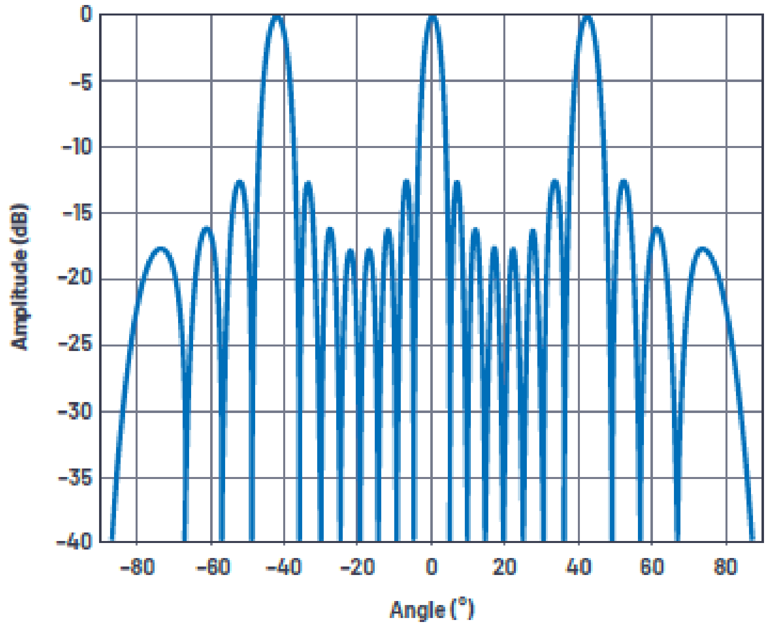
$$\theta = \sin^{-1}\left(\frac{\Delta\phi}{2\pi} \times \frac{\lambda}{d}\right)$$

Considering periodicity,

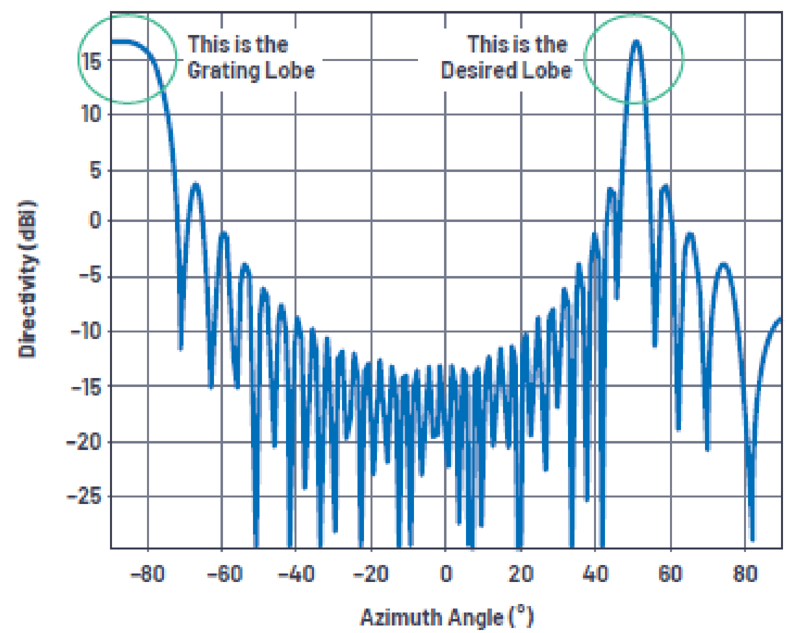
$$\theta = \sin^{-1}\left(\frac{m \times 2\pi + \Delta\phi}{2\pi} \times \frac{\lambda}{d}\right)$$



$d > \lambda$



$\lambda/2 < d < \lambda$



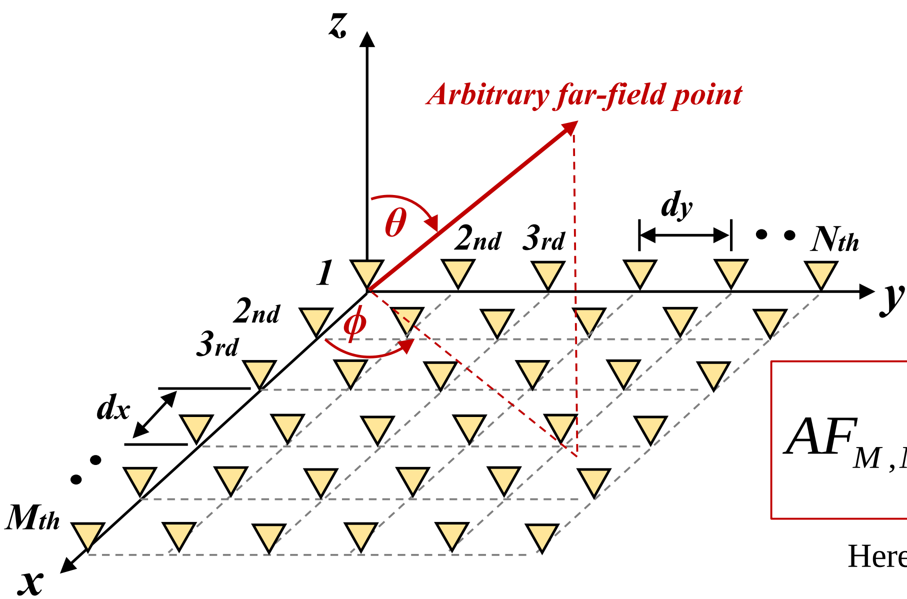
$$d_{max} = \frac{\lambda}{1+|\sin\theta_{max}|} \text{ for } \theta_{max} \textit{ from } 0 \text{ to } \pm\pi/2 \Rightarrow \boxed{d = \frac{\lambda}{2}}$$

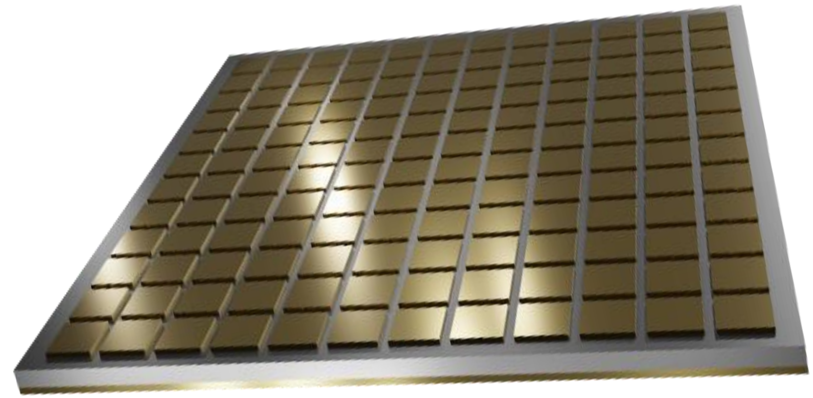
- **d < λ/2 : no grating lobe occurs**
- **d > λ/2 : grating lobe appears at the opposite horizon**

Fundamentals of Phased Array Tech.

2-D Phased array antenna

- Similar to 1-D planar array, but expanded to two-axes





$$AF_{M,N}(\theta,\phi) = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} I_{mn} e^{jk(md_x \sin\theta\cos\phi + nd_y \sin\theta\sin\phi)}$$

Here, I_{mn} denotes the excitation amplitude of the *mn*th element of the array

- This can be viewed as the product of two linear array factors

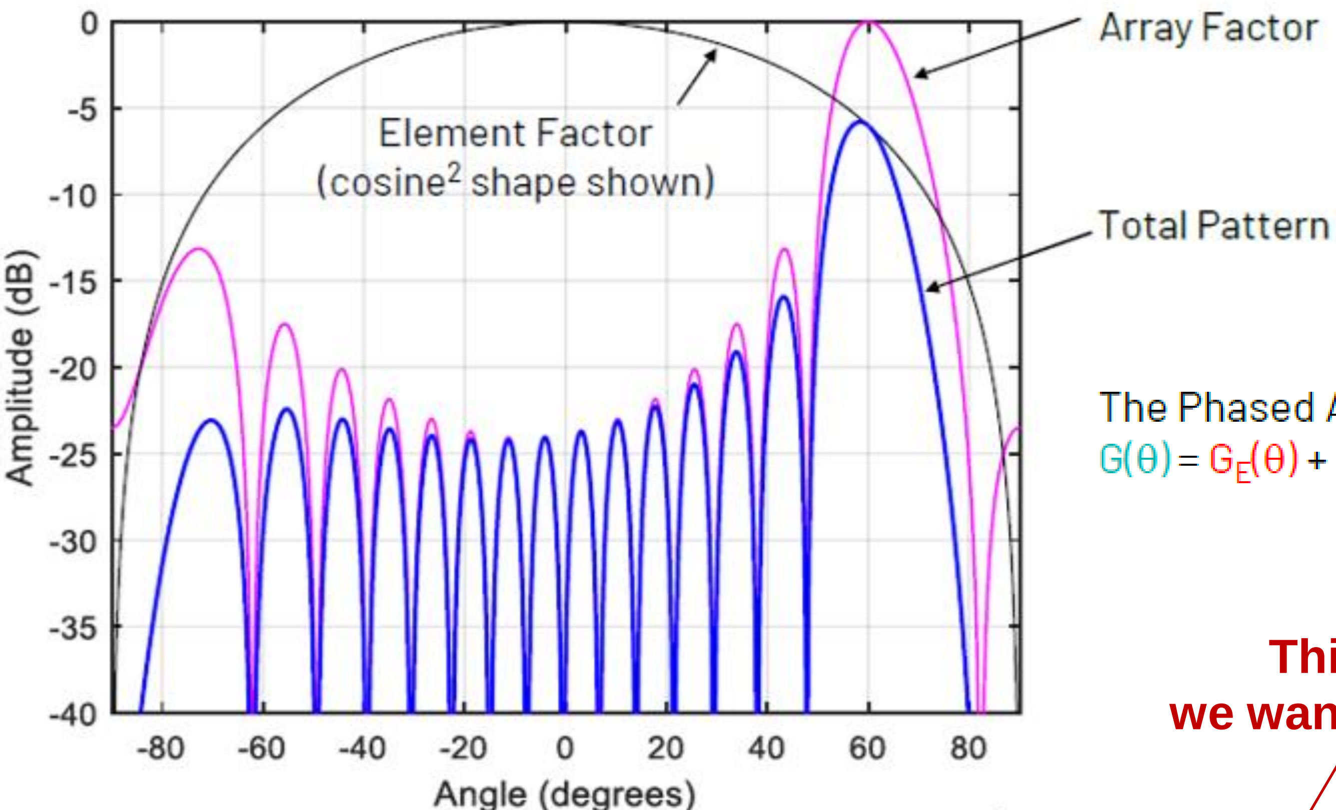
$$I_{mn} = I_{mx} I_{yn} \longrightarrow \begin{aligned} I_{mx} &= I_0 e^{jma_x} \\ I_{yn} &= I_0 e^{jna_y} \end{aligned}$$

where α_x and α_y are the phase gradients in the respective directions

$$AF_{M,N}(\theta,\phi) = I_0 \sum_{m=0}^{M-1} e^{jk(md_x \sin\theta\cos\phi + a_x)} \sum_{m=0}^{N-1} e^{jk(nd_y \sin\theta\sin\phi + a_y)}$$

Fundamentals of Phased Array Tech.

Key consideration in shaping EM propagation of phased array antenna (1)



The Phased Array Gain (dB)

$G(\theta) = G_E(\theta) + G_A(\theta)$

This is what we want to focus on!

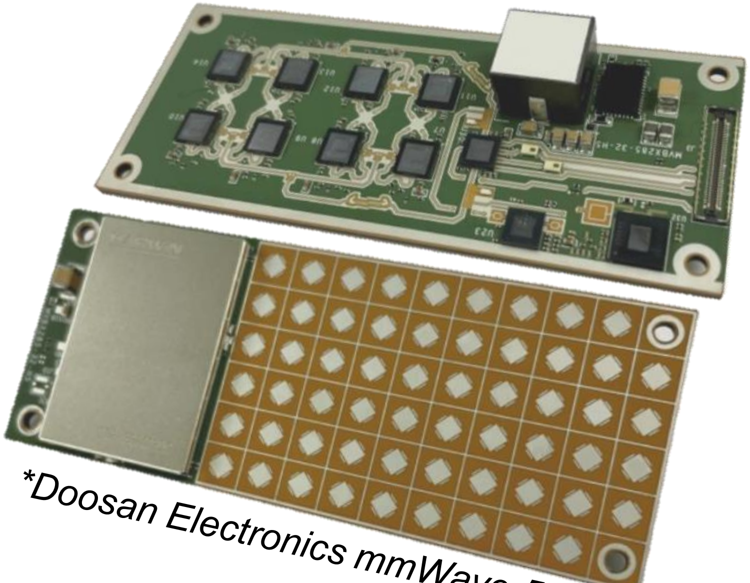
1) The main beam loses amplitude accordingly to the "element factor"

2) The side-lobe have no amplitude loss on the boresight

3) SLL performance gets degraded off boresight

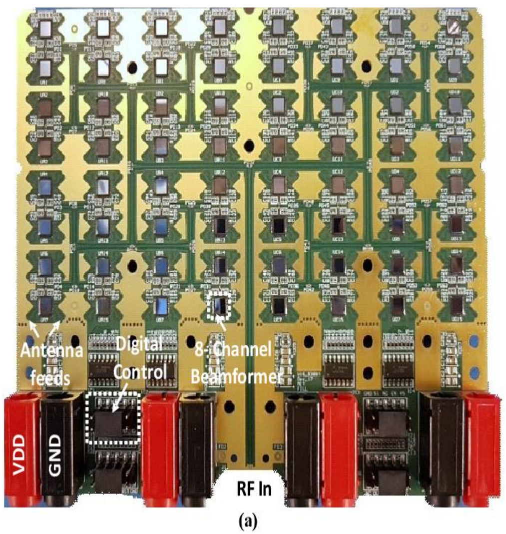
Fundamentals of Phased Array Tech.

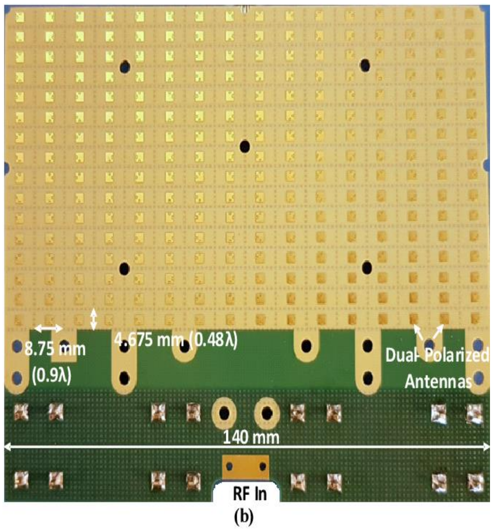
Key consideration in shaping EM propagation of phased array antenna (2)

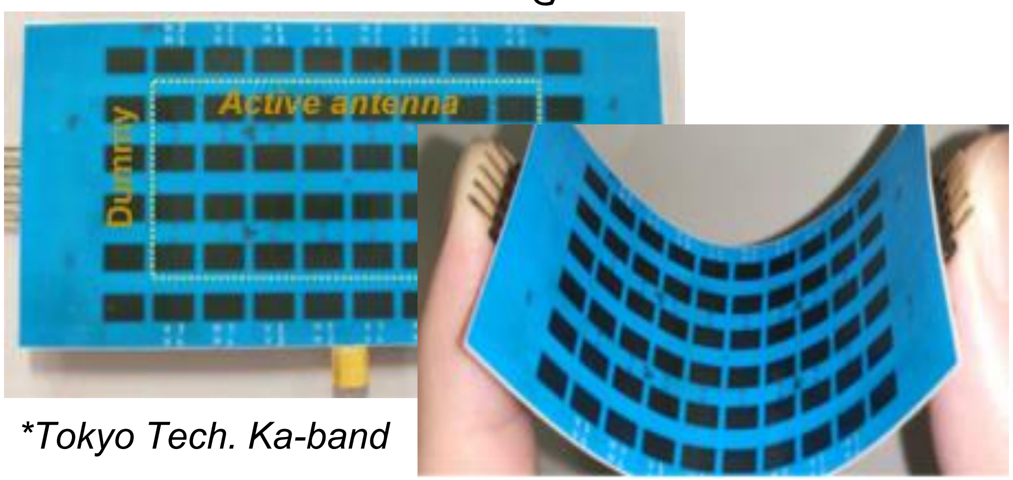


*Doosan Electronics mmWave-5G

*UCSD K-band SatCom. (2022)

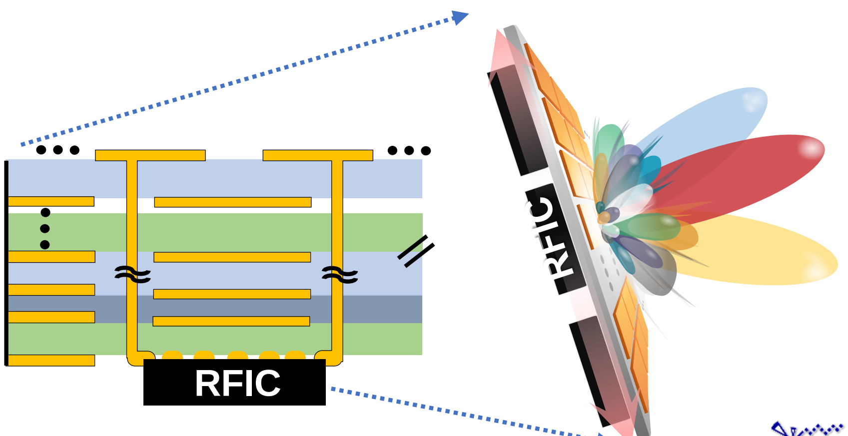






*Tokyo Tech. Ka-band LEO SatCom. (2023)

Fabrication & active integration!



Fundamentals of Phased Array Tech.

❒ Planar microstrip antenna (Patch antenna)

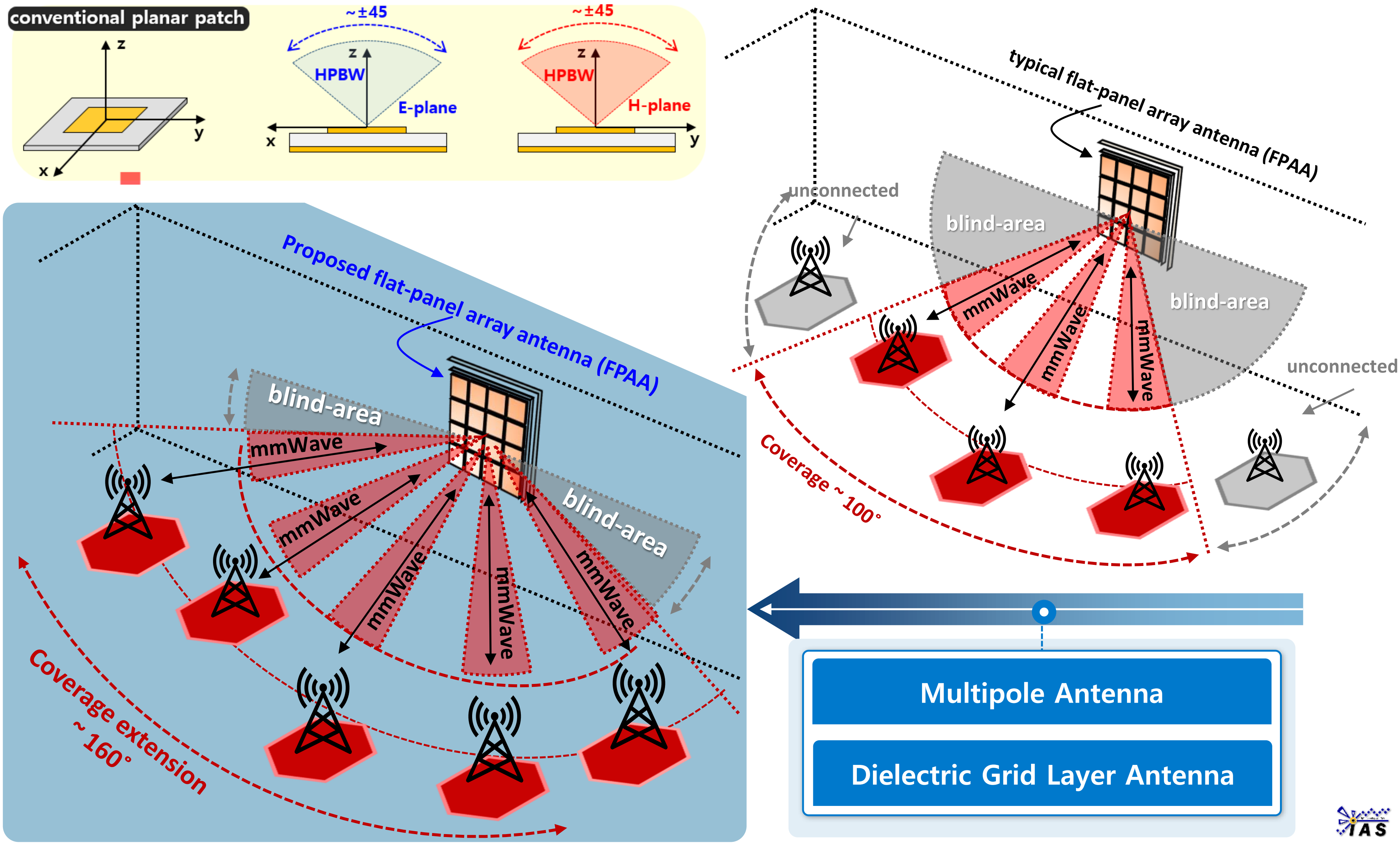
- One of the most useful antennas at microwave frequencies ($f > 1$ GHz).
- It usually consists of a metal "patch" on top of a grounded dielectric substrate.
- The patch may be in a variety of shapes, but rectangular and circular are the most common.

❒ Advantages of microstrip patch antennas

- Low profile (can even be "conformal," i.e. flexible to conform to a surface).
- Easy to fabricate (use etching and photolithography).
- Easy to feed (coaxial cable, microstrip line, etc.).
- Easy to incorporate with other microstrip circuit elements and integrate into systems.
- Patterns are somewhat hemispherical, with a moderate directivity (about 6-8 dB is typical).
- Easy to use in an array to increase the directivity.

Fundamentals of Phased Array Tech.

Limited coverage by the typical patch-based antenna



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1) Multipole based antenna

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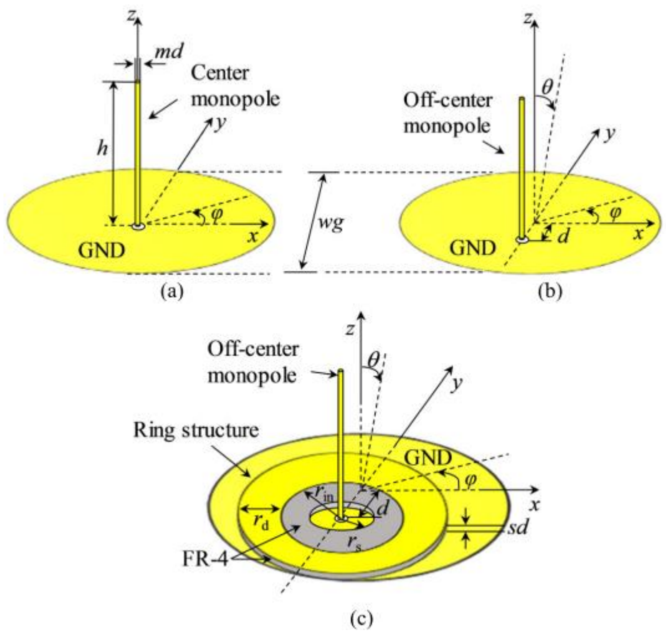
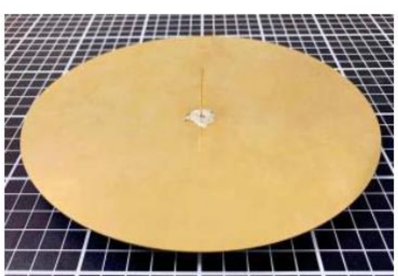
4 Conclusion

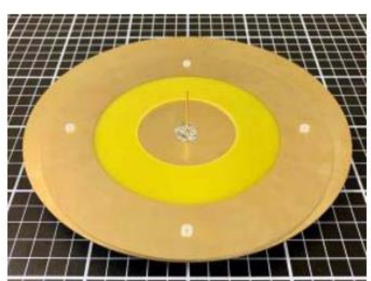
Wide-Angle Antennas

Monopole or dipole based structure

① H. Sheng and Z. N. Chen, "Improving Radiation Pattern Roundness of a Monopole Antenna Placed Off-Center Above a Circular Ground Plane Using Characteristic Mode Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 2, pp. 1135-1139, Feb. 2021.







Operation Freq. : 2.45 GHz

Performance	Total antenna size (λ_0^3)	1.6 x 1.6 x 0.23
	Peak gain (dBi)	3.5
	3dB beamwidth (deg)	360, *
	Impedance bandwidth (%)	81
Pros.	Wide Beamwidth & bandwidth	
Cons.	High profile , Low gain, Not suitable for array implementation	

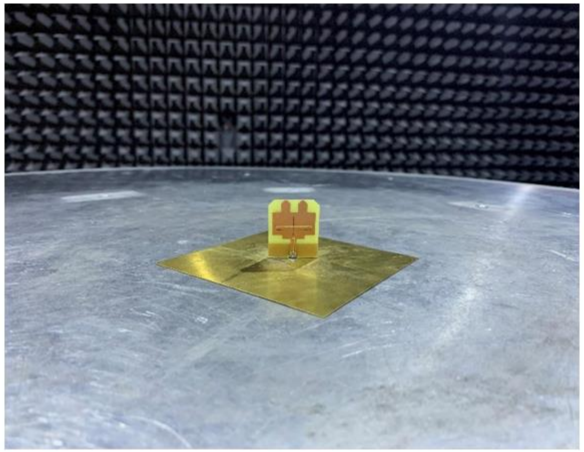
Wide-Angle Antennas

Monopole or dipole based structure

② A. M. Yacoub, M. O. Khalifa and D. N. Aloi, "Wide Band Raised Printed Monopole for Automotive 5G Wireless Communications," *IEEE Open Journal of Antennas and Propagation*, vol. 3, pp. 502-510, 2022.

(a) front view

(b) back view



Operation Freq. : 3.5 GHz

Performance	Height (λ_0)	0.7
	Peak gain (dBi)	3.2
	3dB beamwidth (deg)	360, 80
	Impedance bandwidth (%)	101
	Radiation efficiency (%)	74.4
Pros.	Wide Beamwidth & bandwidth	
Cons.	High profile , Complex structure, Not suitable for array implementation	

Wide-Angle Antennas

Monopole or dipole based structure

③ Y. Zhang and Y. Li, "Scalable Omnidirectional Dual-Polarized Antenna Using Cavity and Slot-Dipole Hybrid Structure," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 6, pp. 4215-4223, June 2022.

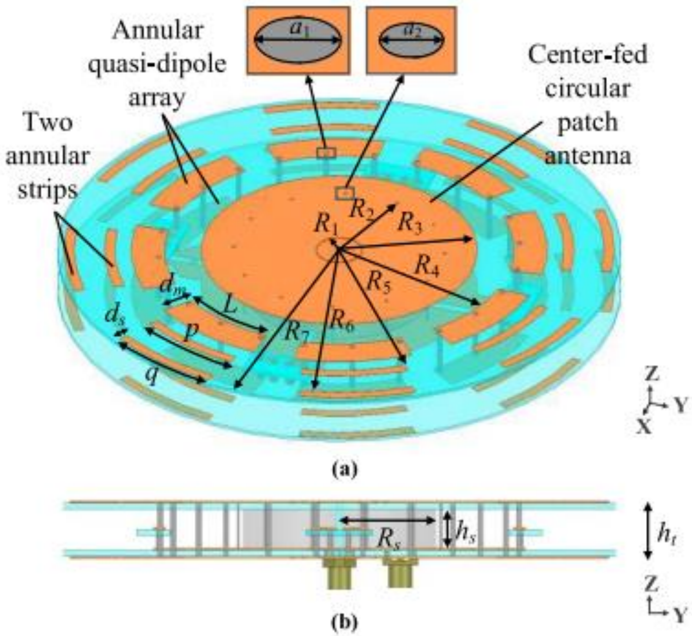
Operation Freq. : 2.45 GHz

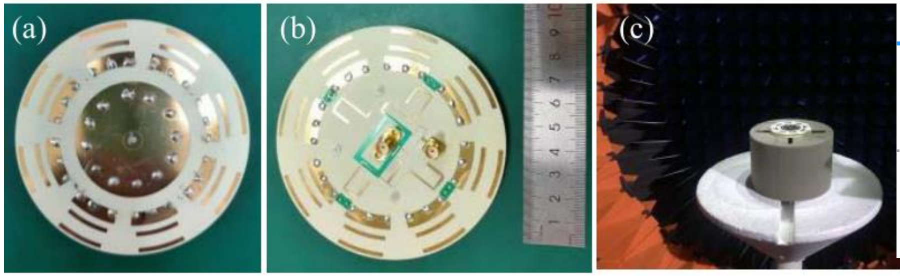
Performance	Total antenna Size ($\lambda_0{}^3$)	1 x 0.16 x 0.66
	Peak gain (dBi)	2.7
	3dB beamwidth (deg)	320, *
	Impedance bandwidth (%)	0.8
	Radiation efficiency (%)	83
Pros.	Wide Beamwidth, Dual polarization	
Cons.	High profile, Narrow bandwidth, Not suitable for array implementation	

Wide-Angle Antennas

Monopole or dipole based structure

④ Z. Zhang, S. Liao, Y. Yang, W. Che and Q. Xue, "Low-Profile and Shared Aperture Dual-Polarized Omnidirectional Antenna by Reusing Structure of Annular Quasi-Dipole Array," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 9, pp. 8590-8595, Sept. 2022.





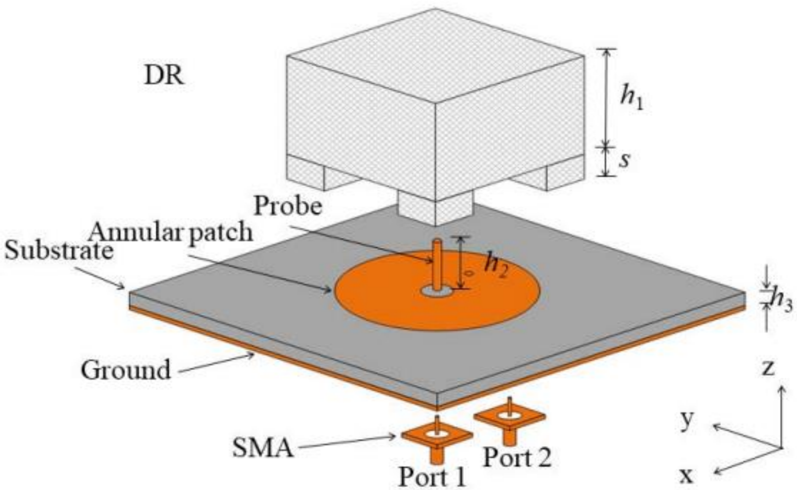
Operation Freq. : 4.6 GHz

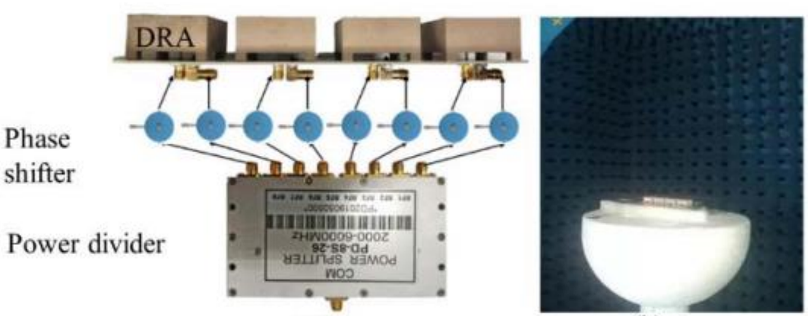
Performance	Total antenna size ($\lambda_0{}^3$)	0.8 x 0.8 x 0.13
	Peak gain (dBi)	1.8
	3dB beamwidth (deg)	360, 83
	Impedance bandwidth (%)	20
	Radiation efficiency (%)	80
	Isolation (dB)	-36
Profit	Wide Beamwidth, Dual polarization, High isolation	
Weakness	High profile , Complex structure, Not suitable for array implementation	

Wide-Angle Antennas

Dielectric resonator (DR) based structure

① Z. Chen, Z. Song, H. Liu, X. Liu, J. Yu and X. Chen, "A Compact Phase-Controlled Pattern-Reconfigurable Dielectric Resonator Antenna for Passive Wide-Angle Beam Scanning," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 5, pp. 2981-2986, May 2021.





(a) (b)

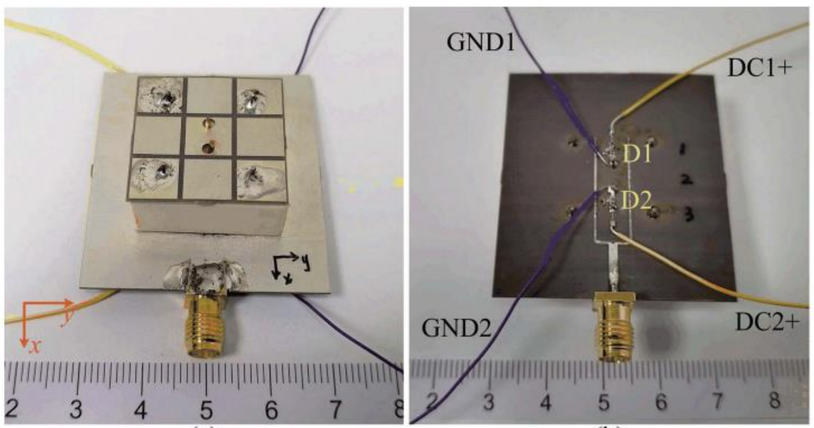
Operation Freq. : 3 GHz

Performance	Total antenna size (λ_0^3)	0.7 x 2.25 x 0.38
	Array size	1 x 4
	Peak gain (dBi)	3.5
	Main lobe angle (deg)	±81 (E-p.), ±66 (H-p.)
	Impedance bandwidth (%)	3.3
Pros.	Wide 1-D beam scanning	
Cons.	High profile , Low gain, High SLL	

Wide-Angle Antennas

Dielectric resonator (DR) based structure

② Z. Wang, Y. Dong, Z. Peng and W. Hong, "Hybrid Metasurface, Dielectric Resonator, Low-Cost, Wide-Angle Beam-Scanning Antenna for 5G Base Station Application," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 9, pp. 7646-7658, Sept. 2022.



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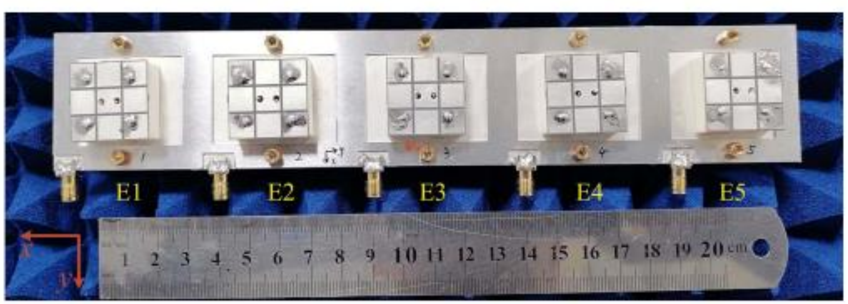


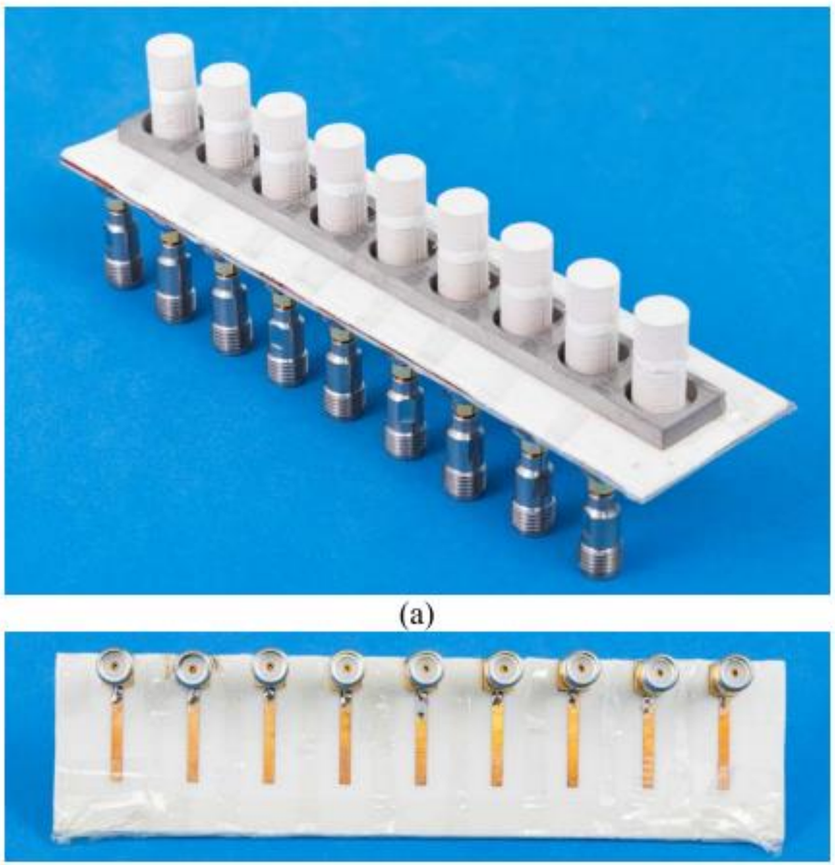
Operation Freq. : 3.5 GHz

Performance	Total Antenna Size (λ_0^3)	2.45 x 0.5 x 0.11
	Array size	1 x 5
	Peak Gain (dBi)	10.5
	Main lobe angle (deg)	±70 (E-p.)
	Impedance Bandwidth (%)	14.1
	Radiation Efficiency (%)	90
Pros.	Wide 1-D beam scanning & bandwidth	
Cons.	High profile, Complex structure, Diode power consumption	

Wide-Angle Antennas

Dielectric resonator (DR) based structure

③ Z. -L. Su, K. W. Leung and K. Lu, "A Shaped-Beam Antenna for Wide-Angle Scanning Phased Array," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 9, pp. 7659-7669, Sept. 2022.



(a)

(b)

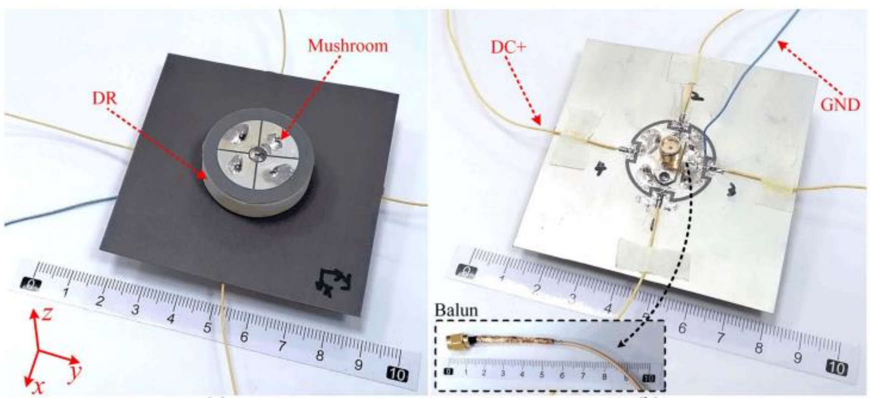
Operation Freq. : 10.5 GHz

Performance	Total Antenna Size ($\lambda_0{}^3$)	1.1 x 4.3 x 0.4
	Array size	1 x 9
	Peak Gain (dBi)	14.1
	Main lobe angle (deg)	±72 (H-p.)
	Impedance Bandwidth (%)	5.2
	Isolation (dB)	-19
Pros.	Wide 1-D beam scanning	
Cons.	High profile, Complex structure, High SLL	

Wide-Angle Antennas

Dielectric resonator (DR) based structure

④ Z. Wang, S. Zhao and Y. Dong, "Miniaturized, Vertically Polarized, Pattern Reconfigurable Dielectric Resonator Antenna and Its Phased Array for Wide-Angle Beam Steering," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 10, pp. 9233-9246, Oct. 2022.



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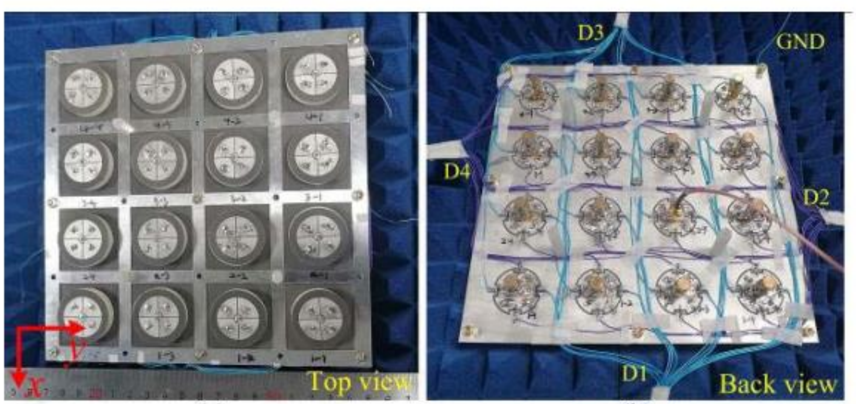


(a) (b)

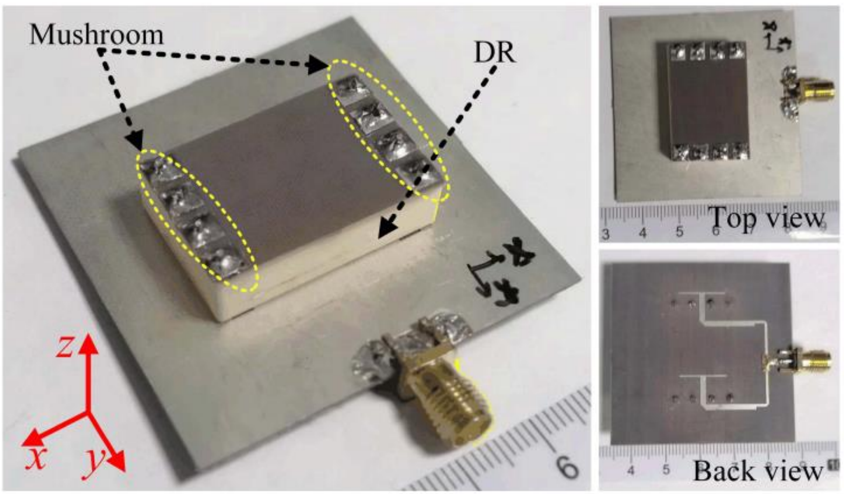
Operation Freq. : 3.5 GHz

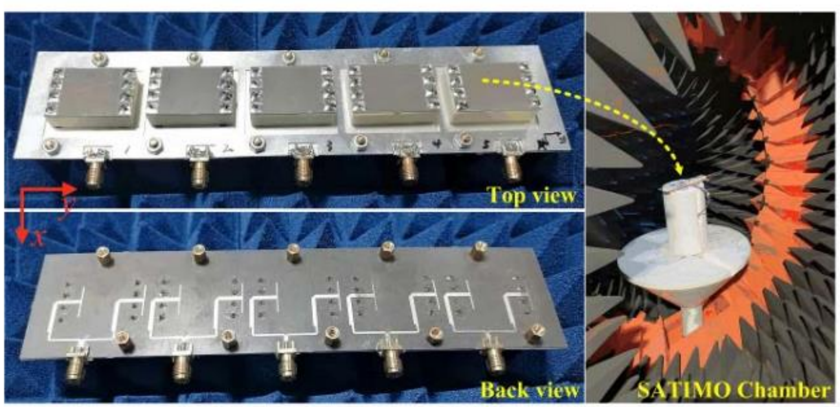
Performance	Total Antenna Size (λ_0^3)	1.87 x 1.87 x 0.09
	Array size	4 x 4
	Peak Gain (dBi)	14.8
	Main lobe angle (deg)	±60 (E-p.), ±60 (H-p.)
	Impedance Bandwidth (%)	10
	Isolation (dB)	-15
Pros.	Wide 2-D beam scanning	
Cons.	High profile, Complex structure, additional power consumption	

Wide-Angle Antennas

Dielectric resonator (DR) based structure

⑤ Z. Wang, S. Zhao and Y. Dong, "Metamaterial-Based Wide-Beam Dielectric Resonator Antenna for Broadband Wide-Angle Beam-Scanning Phased Array Applications," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 10, pp. 9061-9072, Oct. 2022.





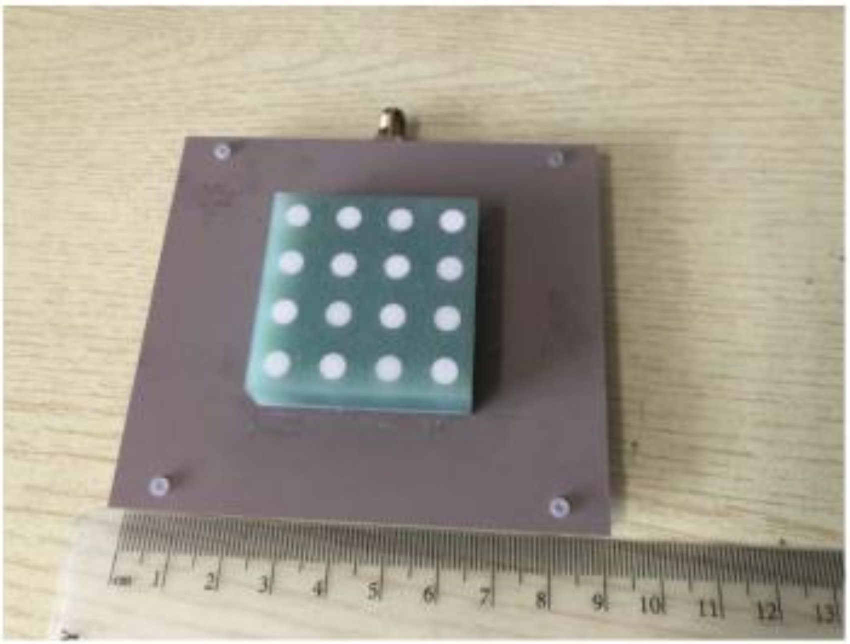
Operation Freq. : 3.5 GHz

Performance	Total Antenna Size (λ_0^3)	0.49 x 2.13 x 0.09
	Array size	1 x 5
	Peak Gain (dBi)	9
	Main lobe angle (deg)	±60 (E-p.)
	Impedance Bandwidth (%)	14.1
	Isolation (dB)	-10
Pros.	Wide 1-D beam scanning	
Cons.	High profile, Complex structure	

Wide-Angle Antennas

Dielectric resonator (DR) based structure

⑥ Z. -K. Chen, L. Zhang, Z. Weng and R. -Y. Li, "Wideband Wide-Beam Hybrid Dielectric Resonator Antenna Using Uniaxial Material," *IEEE Antennas and Wireless Propagation Letters*, vol. 22, no. 1, pp. 124-128, Jan. 2023.



Operation Freq. : 3.5 GHz

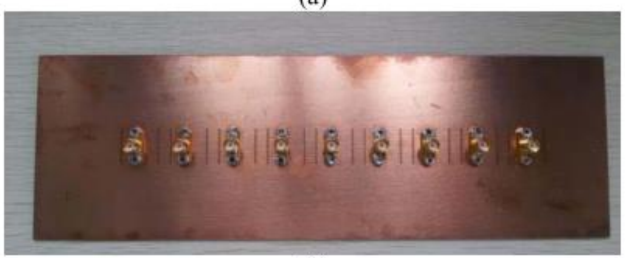
Performance	Total antenna size (λ_0^3)	1.1 x 1.1 x 0.15
	Peak gain (dBi)	0.3
	3dB beamwidth (deg)	250, 162
	Impedance bandwidth (%)	35.7
	Radiation efficiency (%)	80
Pros.	Wide beamwidth & bandwidth	
Cons.	High profile, Array not suitable, Low gain	

Wide-Angle Antennas

Magnetic dipole or magneto-electric dipole based structure

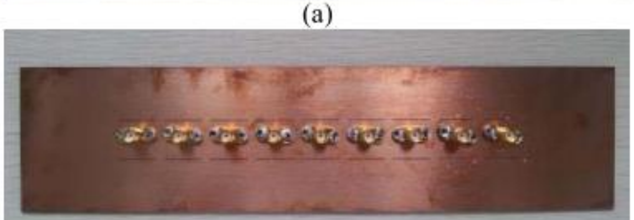
① C. -M. Liu, S. -Q. Xiao, H. -L. Tu and Z. Ding, "Wide-Angle Scanning Low Profile Phased Array Antenna Based on a Novel Magnetic Dipole," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 3, pp. 1151-1162, March 2017.

(a)



(b)

(a)



(b)

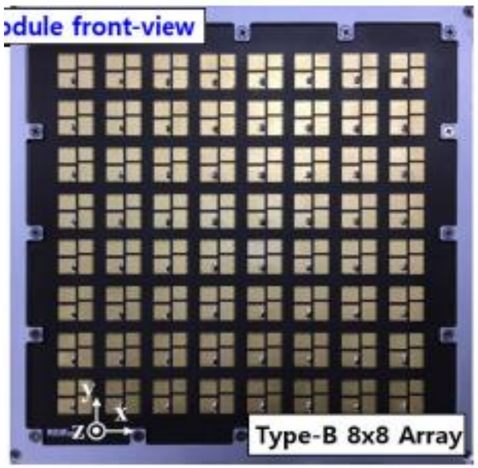
Operation Freq. : (5.8GHz)

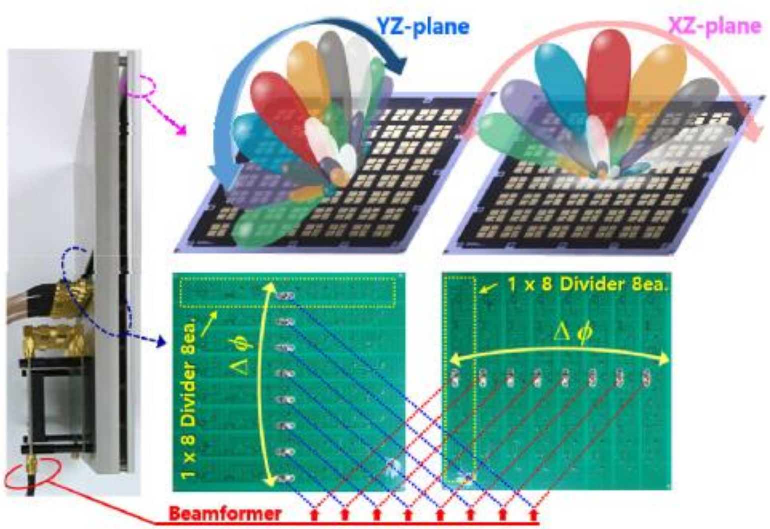
Performance	Total antenna size (λ_0^3)	1.5 x 4.8 x 0.02
	Array size	1 x 9
	Peak gain (dBi)	6.3
	3dB beam scanning (deg)	152, 128
	Impedance bandwidth (%)	4.4
Pros.	Planar type, Wide beam scanning	
Cons.	High resolution of via process, Narrow bandwidth	

Wide-Angle Antennas

Magnetic dipole or magneto-electric dipole based structure

② Y. -B. Kim, S. Lim and H. L. Lee, "Electrically Conformal Antenna Array With Planar Multipole Structure for 2-D Wide Angle Beam Steering," *IEEE Access*, vol. 8, pp. 157261-157269, 2020.





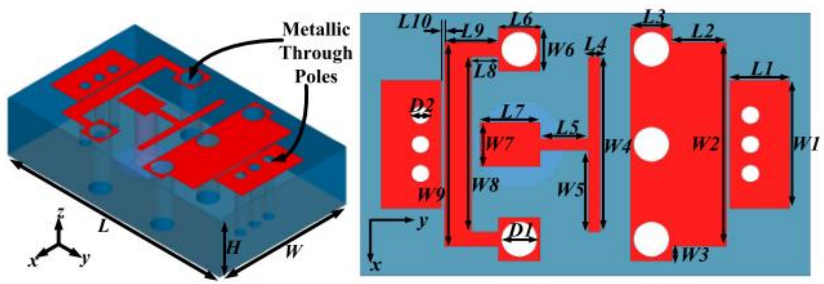
Operation Freq. : 5.9 GHz

Performance	Total antenna size (λ_0^3)	4.25 x 4.25 x 0.02
	Array size	8 x 8
	Peak gain (dBi)	21
	3dB Beam scanning (deg)	154, 149
	Impedance bandwidth (%)	11.7
	Radiation efficiency (%)	85
Pros.	Planar type, Wide beam scanning& bandwidth	
Cons.	High resolution of via process	

Wide-Angle Antennas

Magnetic dipole or magneto-electric dipole based structure

③ H. Yang, X. Cao, J. Gao, H. Yang and T. Li, "A Wide-Beam Antenna for Wide-Angle Scanning Linear Phased Arrays," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 12, pp. 2122-2126, Dec. 2020.



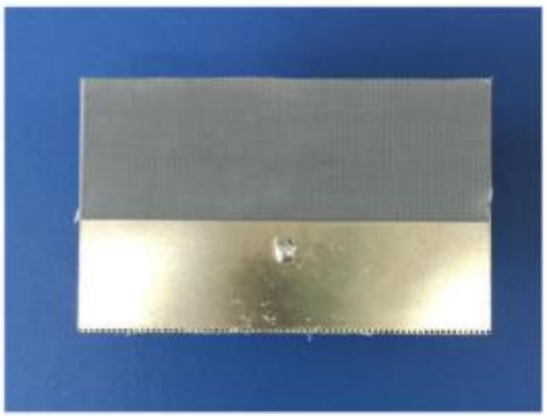
Operation Freq. : 10 GHz

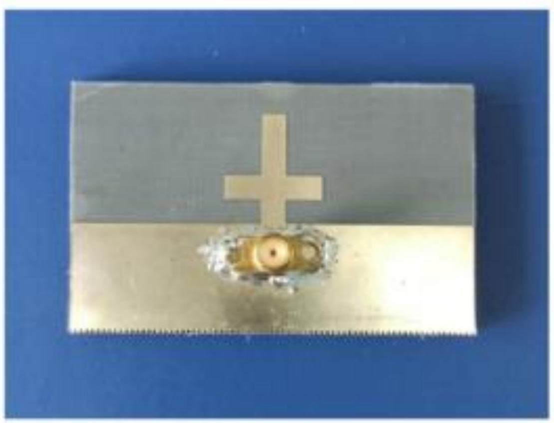
Performance	Total antenna size (λ_0^3)	0.7 x 6 x 0.12
	Array size	1 x 12
	Peak gain (dBi)	21
	3dB Beam scanning (deg)	180, 140
	Impedance bandwidth (%)	9.34
Pros.	Planar type, Wide beam scanning	
Cons	High resolution of via process, difficult to expand to 2-D array	

Wide-Angle Antennas

Magnetic dipole or magneto-electric dipole based structure

④ W. -H. Zhang, Q. Xue, S. Liao, W. Che and W. Yang, "Low-Profile Compact Microstrip Magnetic Dipole Antenna With Large Beamwidth and Broad Bandwidth for Vehicular Applications," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 6, pp. 5445-5456, June 2021.





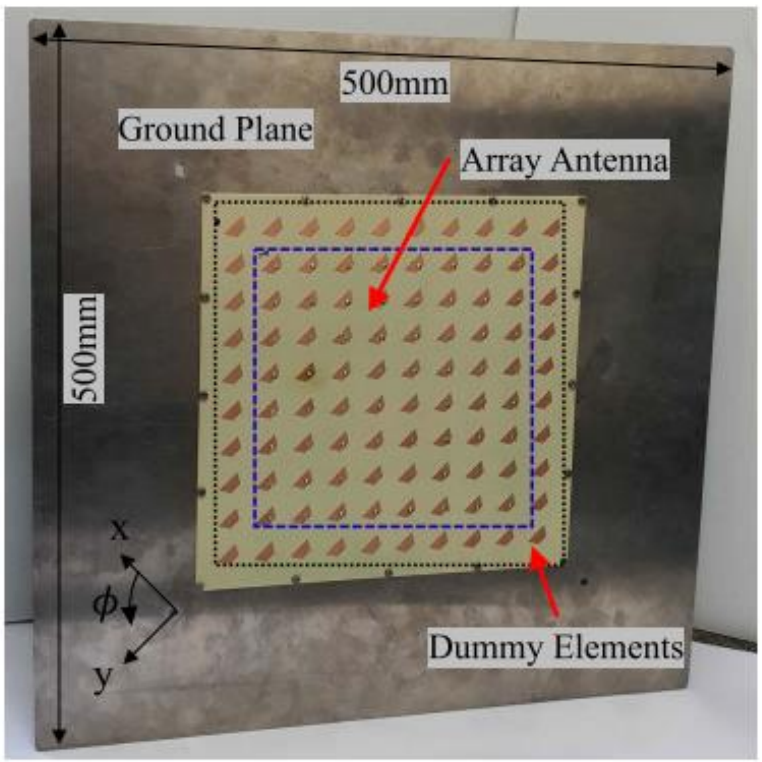
Operation Freq. 2.45 GHz

Performance	Total Antenna Size (λ_0^3)	0.65 x 0.45 x 0.02
	Peak Gain (dBi)	3.63
	3dB Beamwidth (deg)	99, 180
	Impedance Bandwidth (%)	14.9
	Radiation Efficiency (%)	88
Pros.	Planar type, 1-D Wide Beamwidth, Compact size	
Cons.	High resolution of via process, not suitable for array implementation	

Wide-Angle Antennas

Magnetic dipole or magneto-electric dipole based structure

⑤ H. Cho, H. -W. Jo, J. -W. Kim, K. -S. Kim, J. -I. Oh and J. -W. Yu, "Shorted Trapezoidal SIW Antenna With Quasi-Hemispherical Pattern for 2D Wide Scanning Planar Phased Array Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 8, pp. 7211-7216, Aug. 2022.



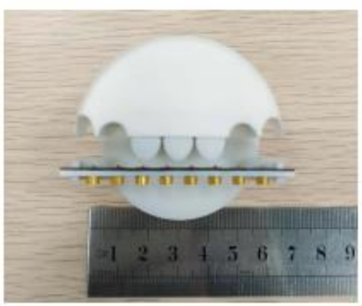
Operation Freq. : 5.8 GHz

Performance	**Total antenna size (λ_0^3)**	**9.6 x 9.6 x 0.03**
	Array size	**8 x 8**
	Peak gain (dBi)	**21.4**
	3dB Beam scanning (deg)	**143, 168**
	Impedance bandwidth (%)	**1.3**
Pros.	**Planar type, Wide beam scanning**	
Cons.	**High resolution of via process, Large size, Narrow BW**	

Wide-Angle Antennas

Lens based antenna

① K. Liu, S. Yang, S. -W. Qu, C. Chen and Y. Chen, "Phased Hemispherical Lens Antenna for 1-D Wide-Angle Beam Scanning," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 12, pp. 7617-7621, Dec. 2019.



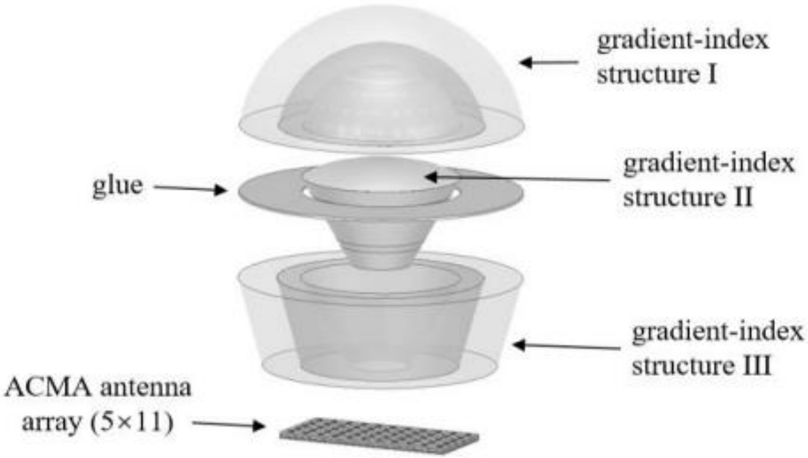
Operation Freq. : 27.3 GHz

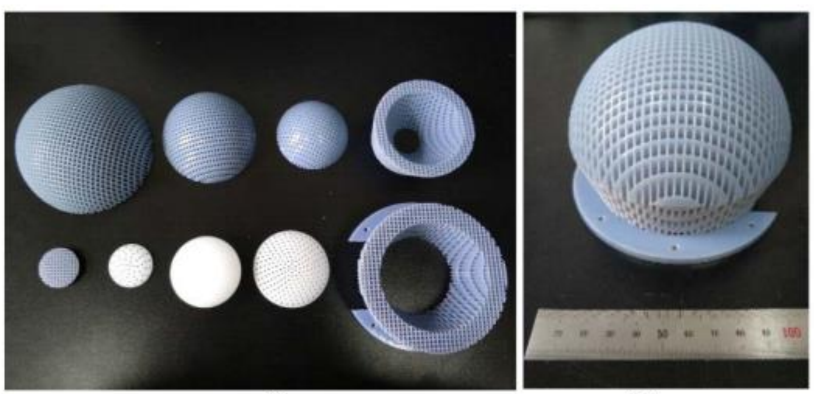
Performance	**Array size**	**1 x 8**
	Peak Gain (dBi)	**19**
	Main lobe angle (deg)	**±60 (H-p.)**
	Impedance Bandwidth (%)	**3.57**
	Beamforming components	**Feeding network**
Pros.	**1-D beam scanning**	
Cons.	**High profile, Narrow bandwidth, Additional feeding**	

Wide-Angle Antennas

Lens based antenna

② Z. Qu, S. -W. Qu, Z. Zhang, S. Yang and C. H. Chan, "Wide-Angle Scanning Lens Fed by Small-Scale Antenna Array for 5G in Millimeter-Wave Band," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 5, pp. 3635-3643, May 2020.





(a) (b)

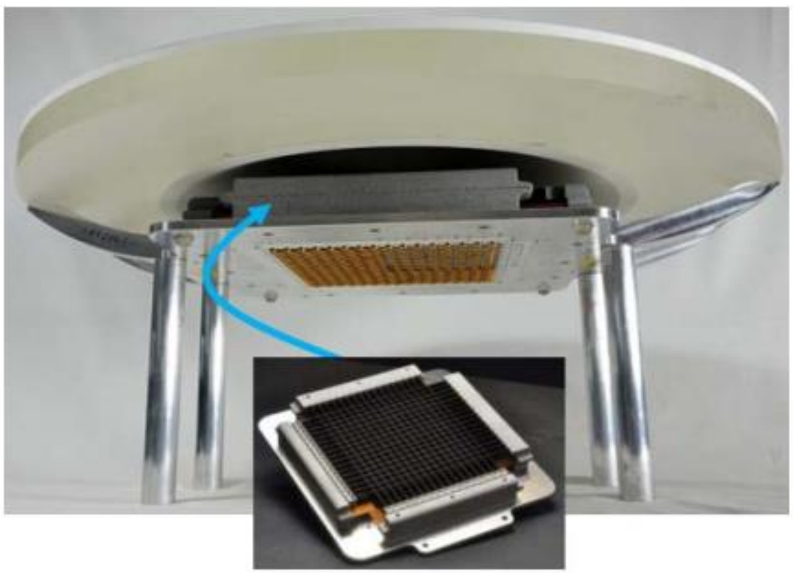
Operation Freq. : 28GHz

Performance	**Array size**	**6 x 5**
	Peak Gain (dBi)	**21.2**
	Main lobe angle (deg)	**±58 (H-p.)**
	Impedance Bandwidth (%)	**7.14**
	Beamforming components	**Feeding network**
Pros.	**1-D Wide beam scanning**	
Cons.	**High profile, Complex structure, multi-step integration**	

Wide-Angle Antennas

Lens based antenna

③ E. Gandini *et al.*, "A Dielectric Dome Antenna With Reduced Profile and Wide Scanning Capability," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 2, pp. 747-759, Feb. 2021.



Illuminating array [15]

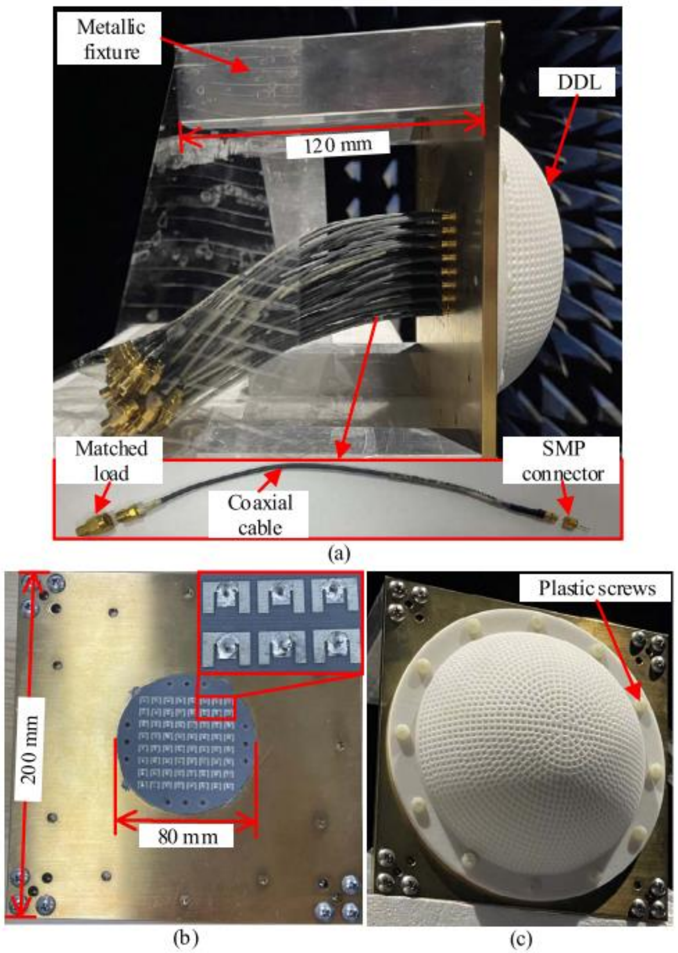
Operation Freq. : 13 GHz

Performance	**Array size**	**16 x 16**
	Peak Gain (dBi)	**24**
	Main lobe angle (deg)	**+70 (H-p.)**
	Impedance Bandwidth (%)	**15**
	Beamforming components	**Feeding network**
Pros.	**1-D Wide beam scanning**	
Cons.	**High profile, Additional feeding, 1-D extension**	

Wide-Angle Antennas

Lens based antenna

④ L. Xiao, S. -W. Qu and S. Yang, "3-D Printed Dielectric Dome Array Antenna With ±80° Beam Steering Coverage," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 11, pp. 10494-10503, Nov. 2022.



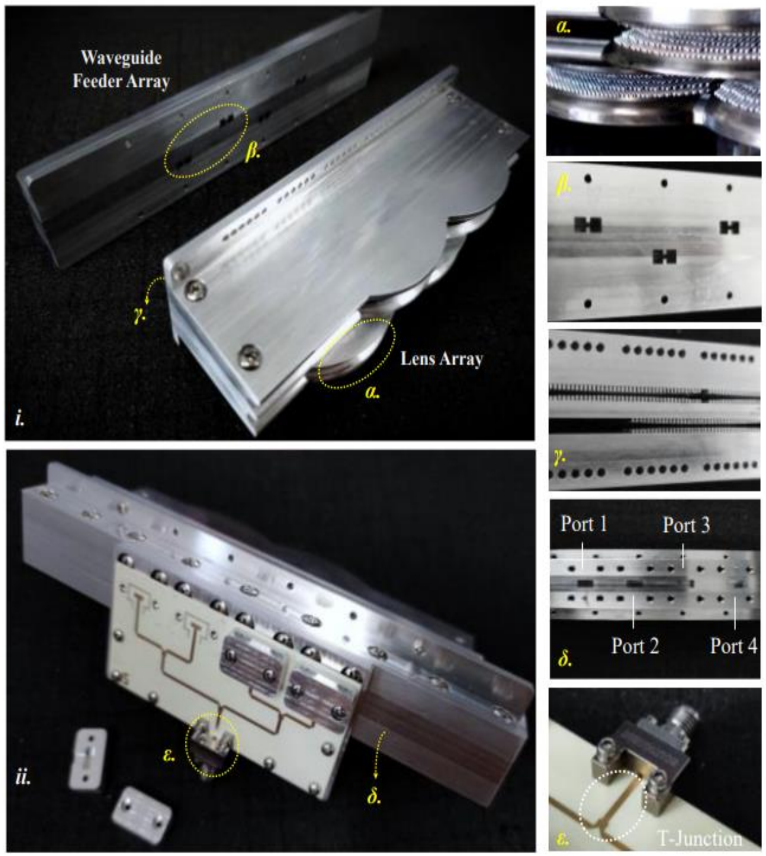
Operation Freq. : 20 GHz

Performance	Array size	8 x 8
	Peak Gain (dBi)	19
	Main lobe angle (deg)	+80 (E-p.), +80 (H-p.)
	Impedance Bandwidth (%)	16
	Beamforming components	Feeding network
Pros.	2-D Wide beam scanning	
Cons.	High profile, Integration with IC not proven	

Wide-Angle Antennas

Lens based antenna

⑤ B. Nie *et al*., "Fully Metallic Gradient Index Lens Array Antenna for Wide-Angle Scanning Phased Array," *IEEE Transactions on Antennas and Propagation*, doi: 10.1109/TAP.2023.3296198.



Operation Freq. :28GHz

Performance	Array size	1 x 4
	Peak Gain (dBi)	20.3
	Main lobe angle (deg)	+65 (H-p.)
	Impedance Bandwidth (%)	14.2
	Beamforming components	Feeding network
Pros.	1-D Wide beam scanning	
Cons.	High profile, Additional feeding, 1-dimensional extension	

Contents

1 Fundamentals of Phased Array Antenna

2 Recent Works on Wide-Angle Antennas

3 Wide-Angle Scanning Phased Array Antennas

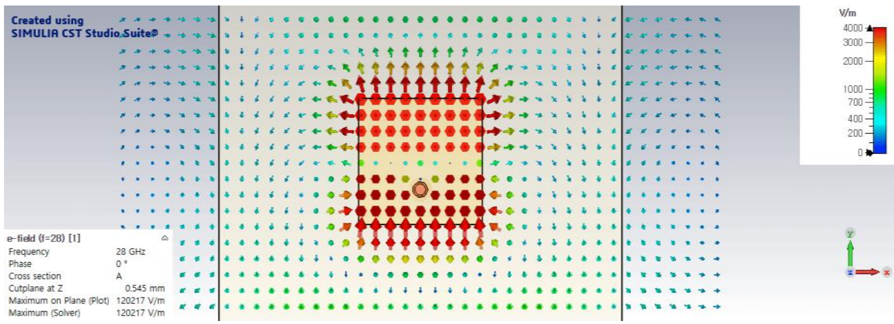
1) Multipole based antenna

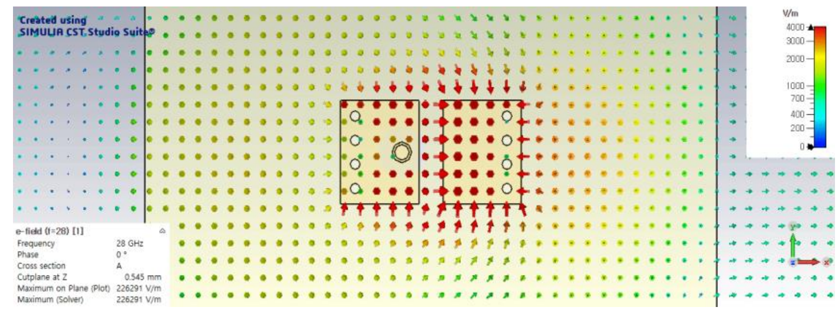
2) Dielectric grid layer based antenna

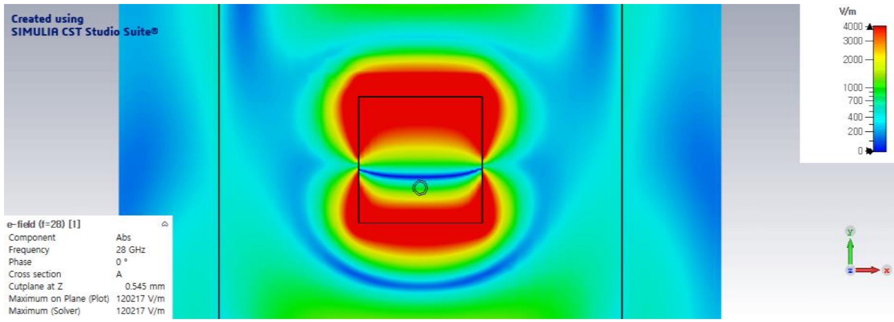
4 Conclusion

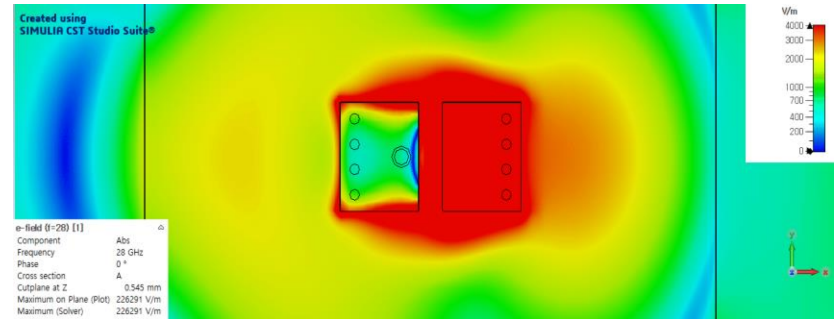
Wide-Angle Scanning Phased Array Antennas

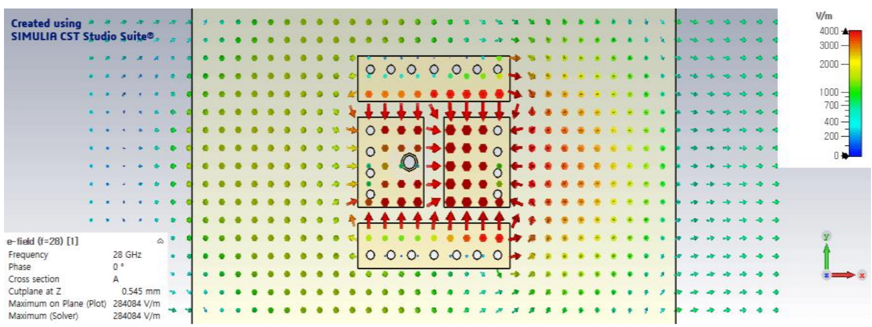
Single element multipole antenna fundamentals

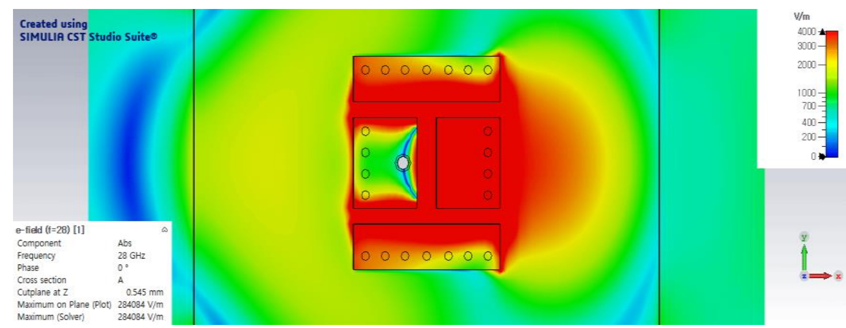






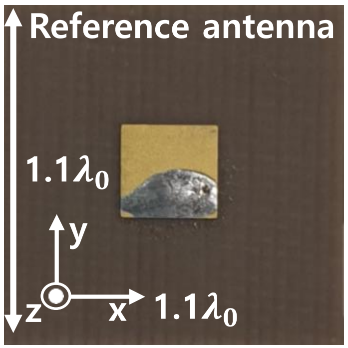


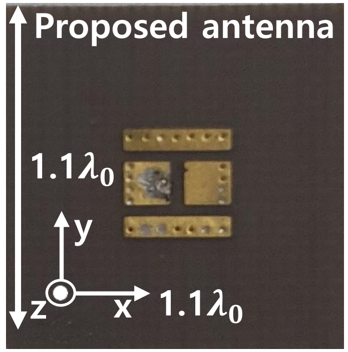


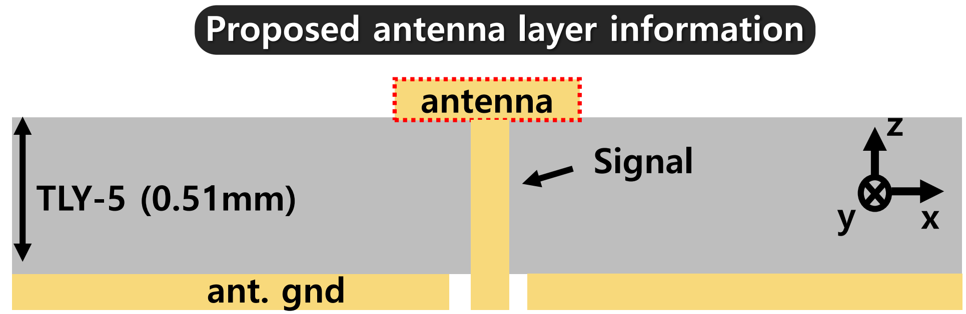


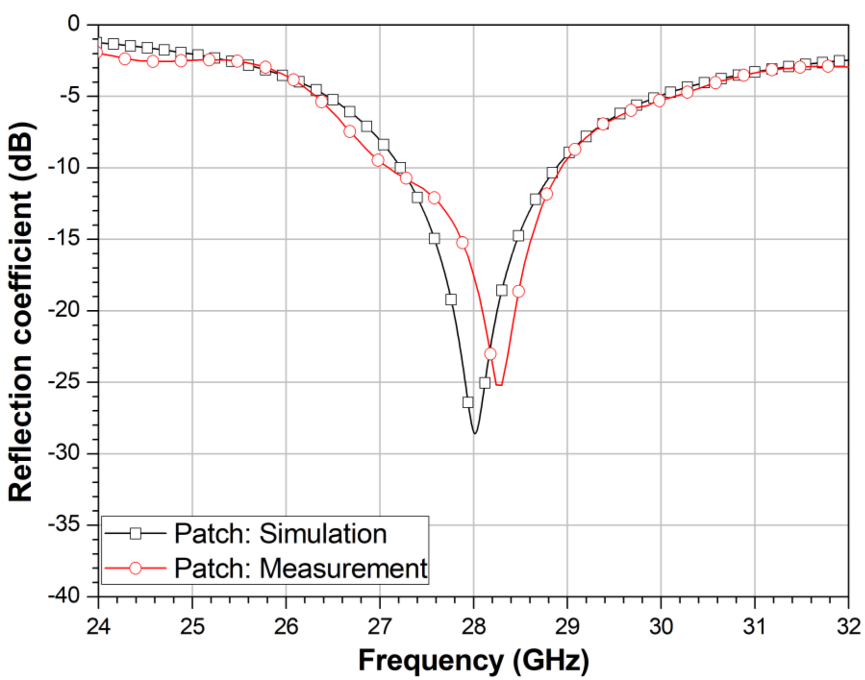
Wide-Angle Scanning Phased Array Antennas

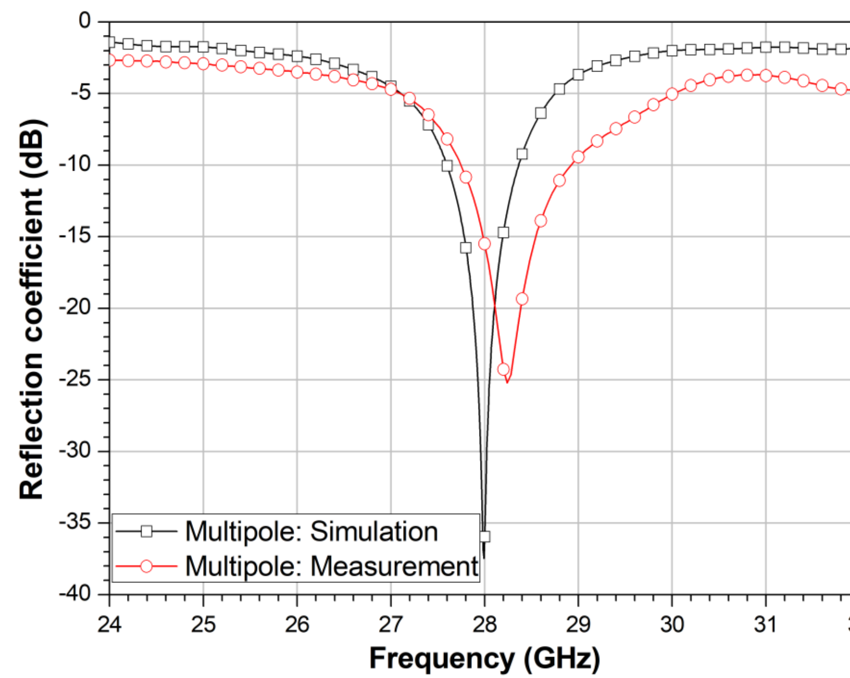
Single element multipole antenna bandwidth





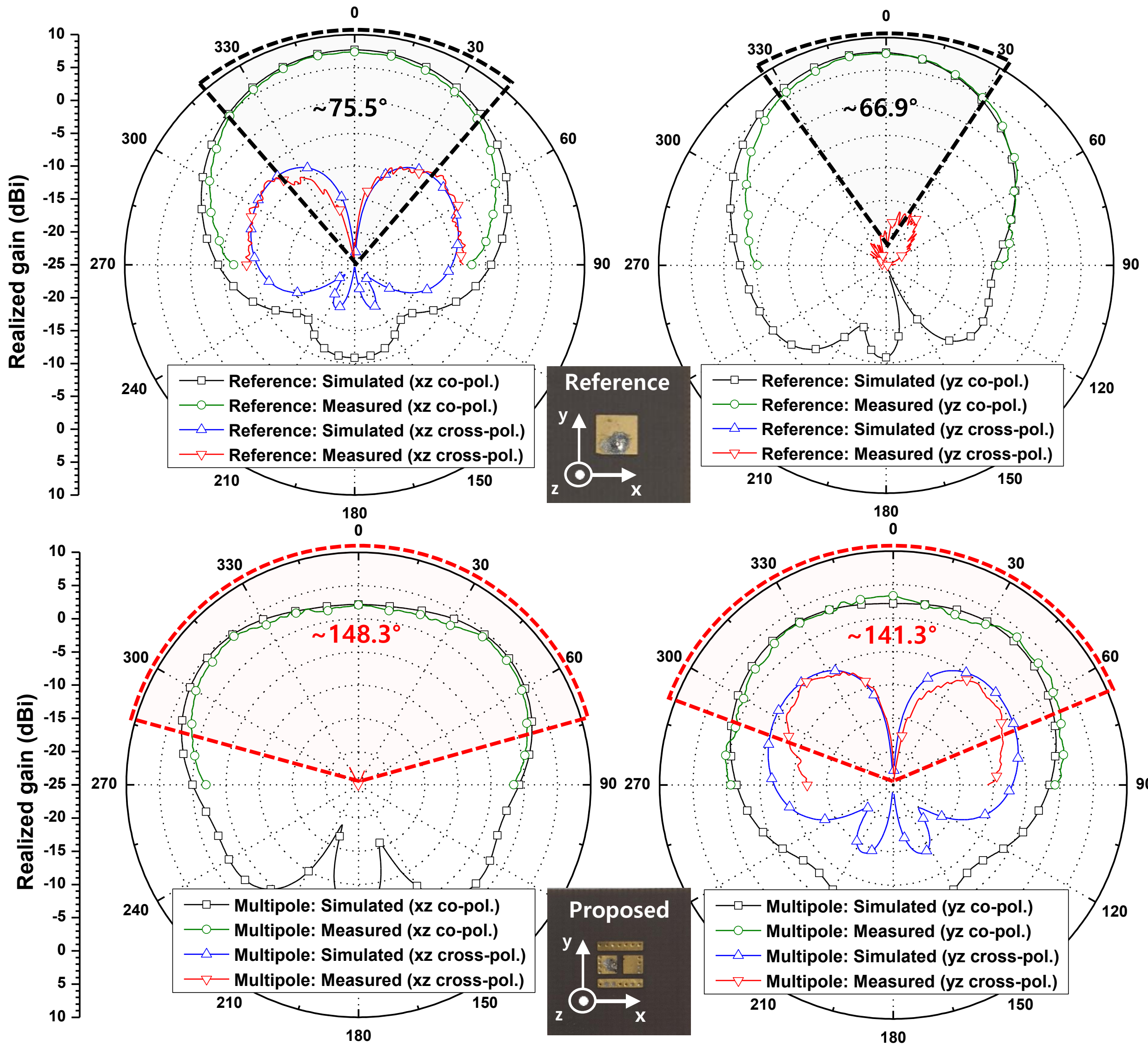






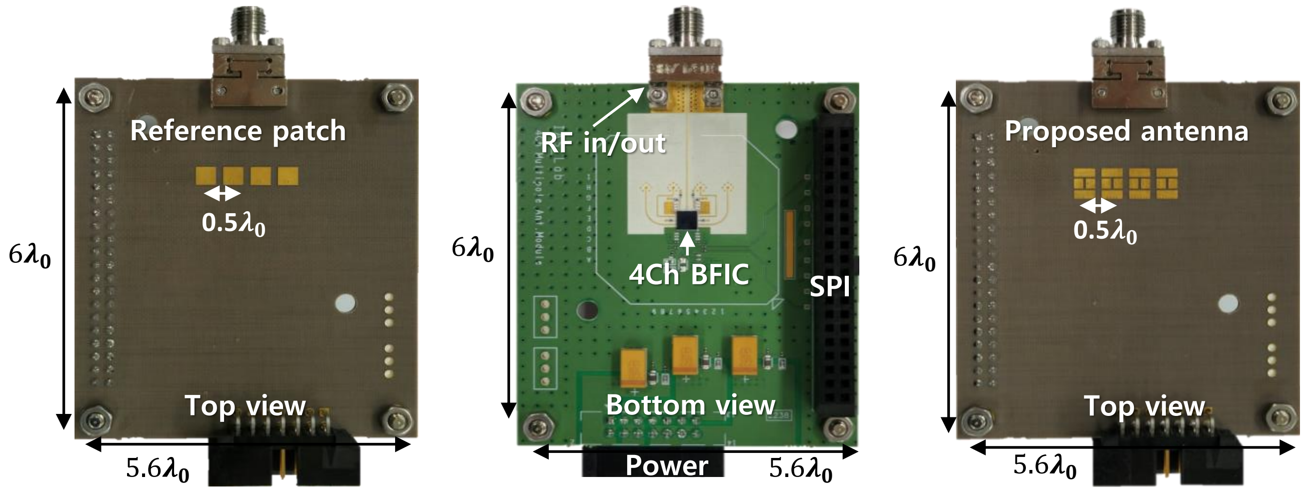
Wide-Angle Scanning Phased Array Antennas

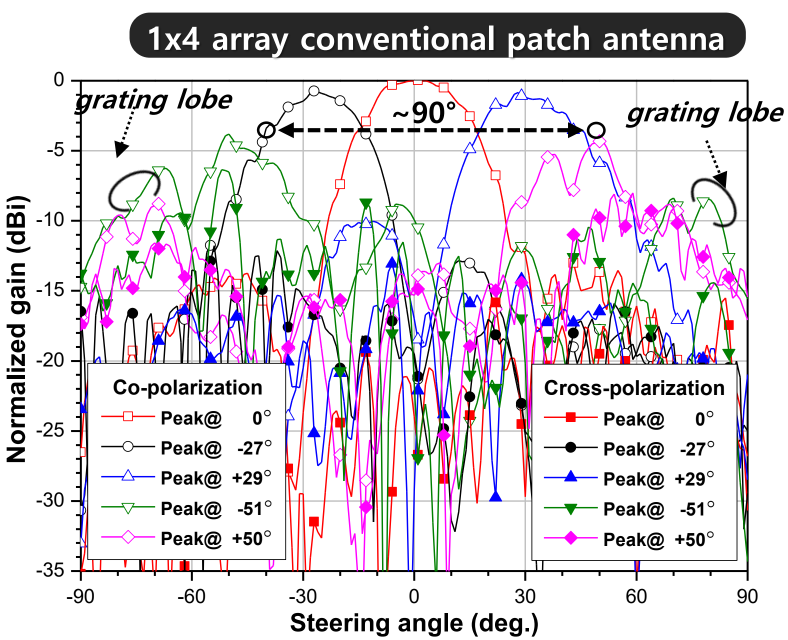
Single element multipole antenna radiation patterns

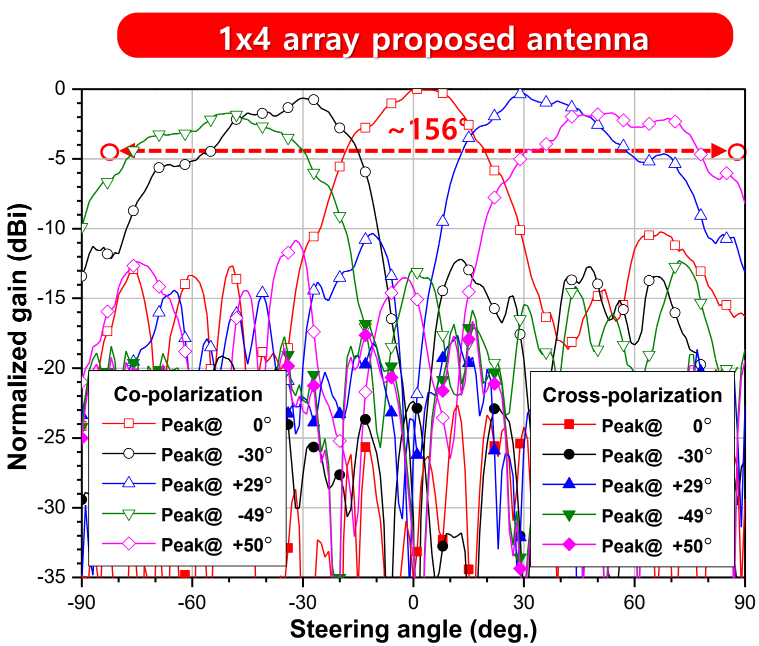


Wide-Angle Scanning Phased Array Antennas

1 x 4 Multipole-based PAA scanning performance

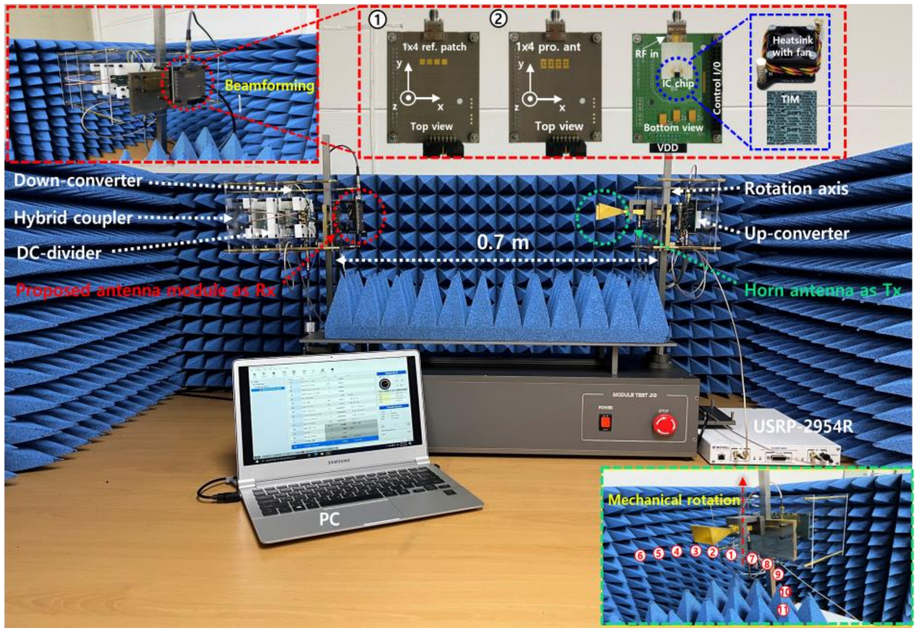


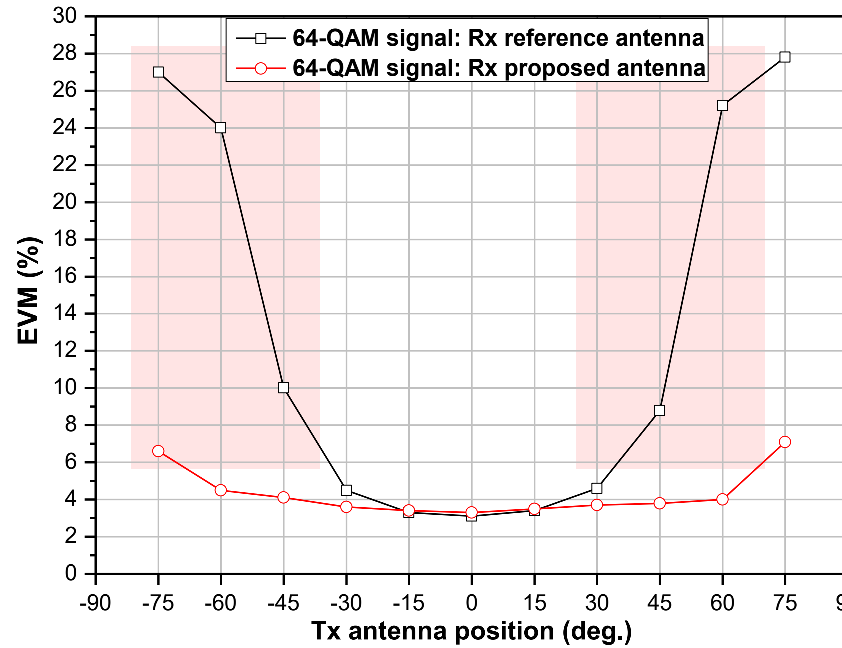




Wide-Angle Scanning Phased Array Antennas

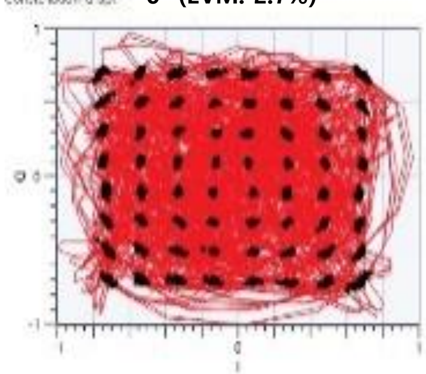
1 x 4 Multipole-based PAA scanning performance (64-QAM)



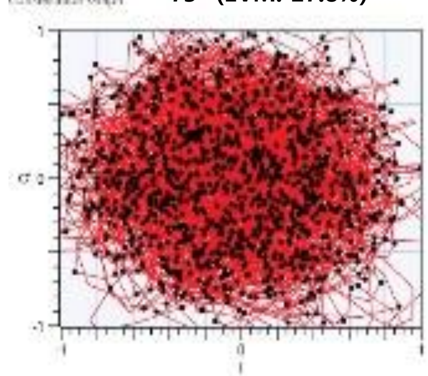


Reference antenna

0° (EVM: 2.7%)

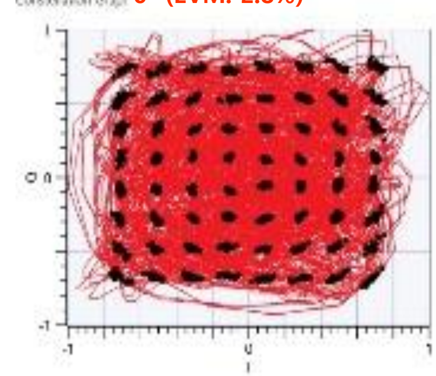


-75° (EVM: 27.8%)

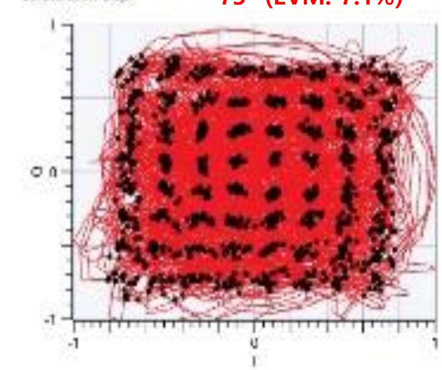


Proposed antenna

0° (EVM: 2.8%)

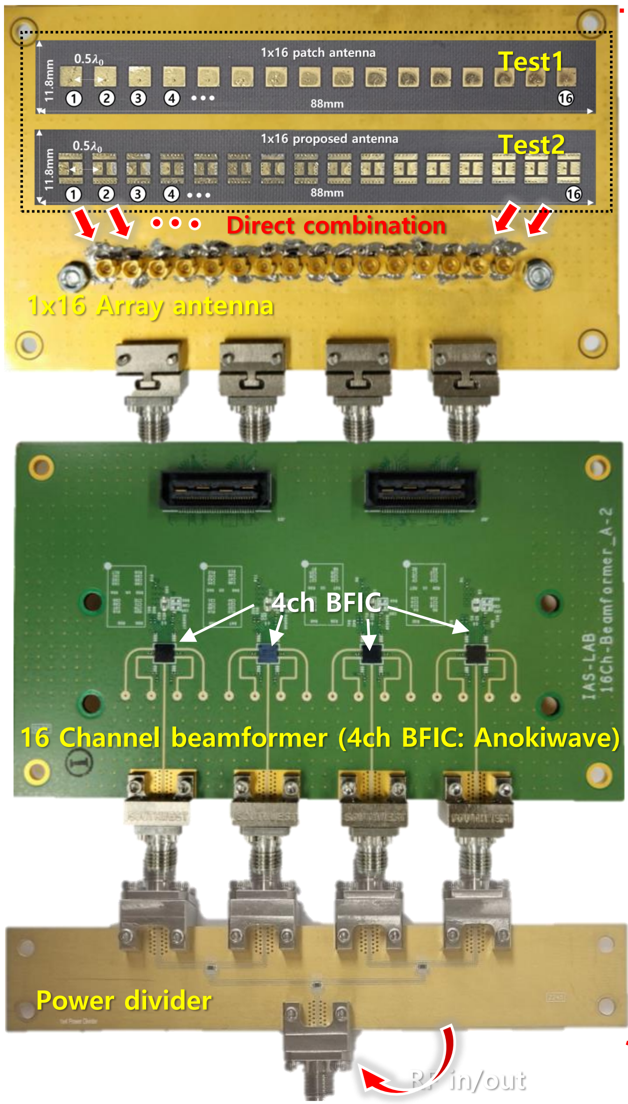


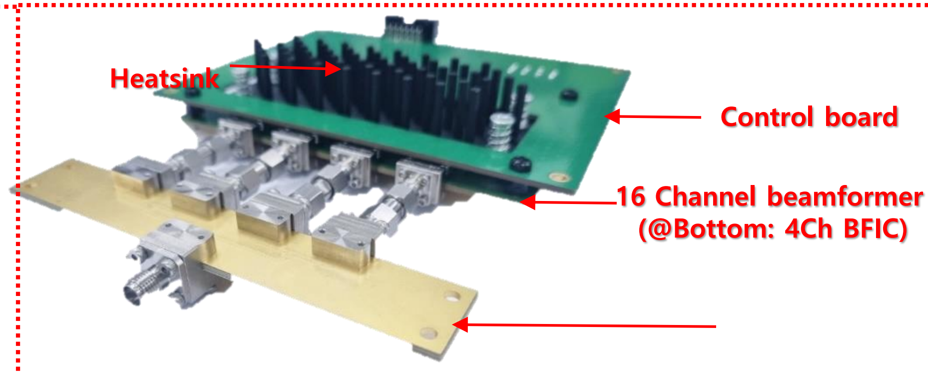
-75° (EVM: 7.1%)

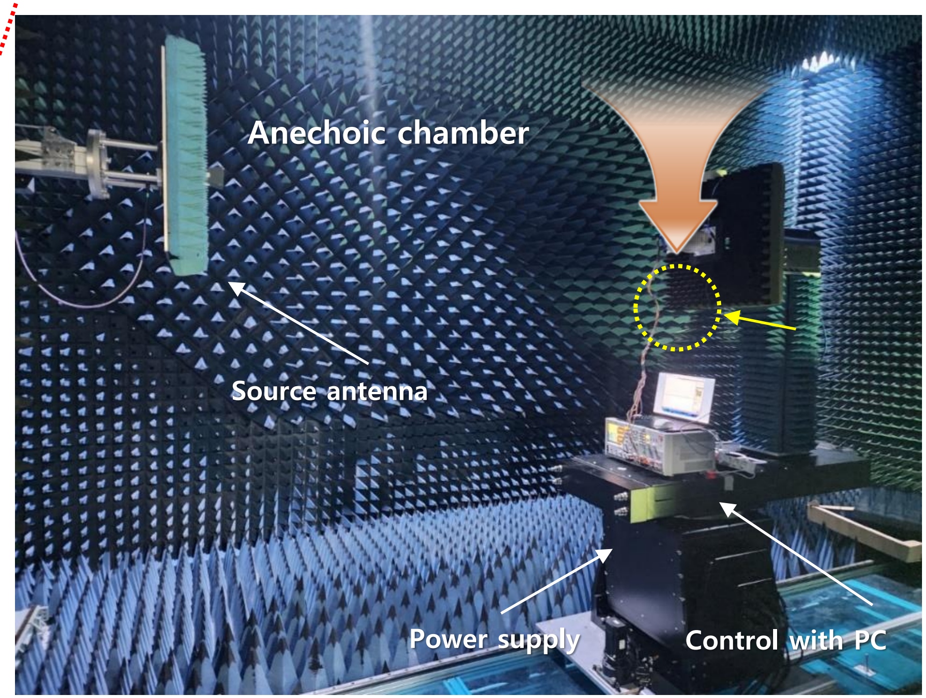


Wide-Angle Scanning Phased Array Antennas

1 x 16 PAA Implementation

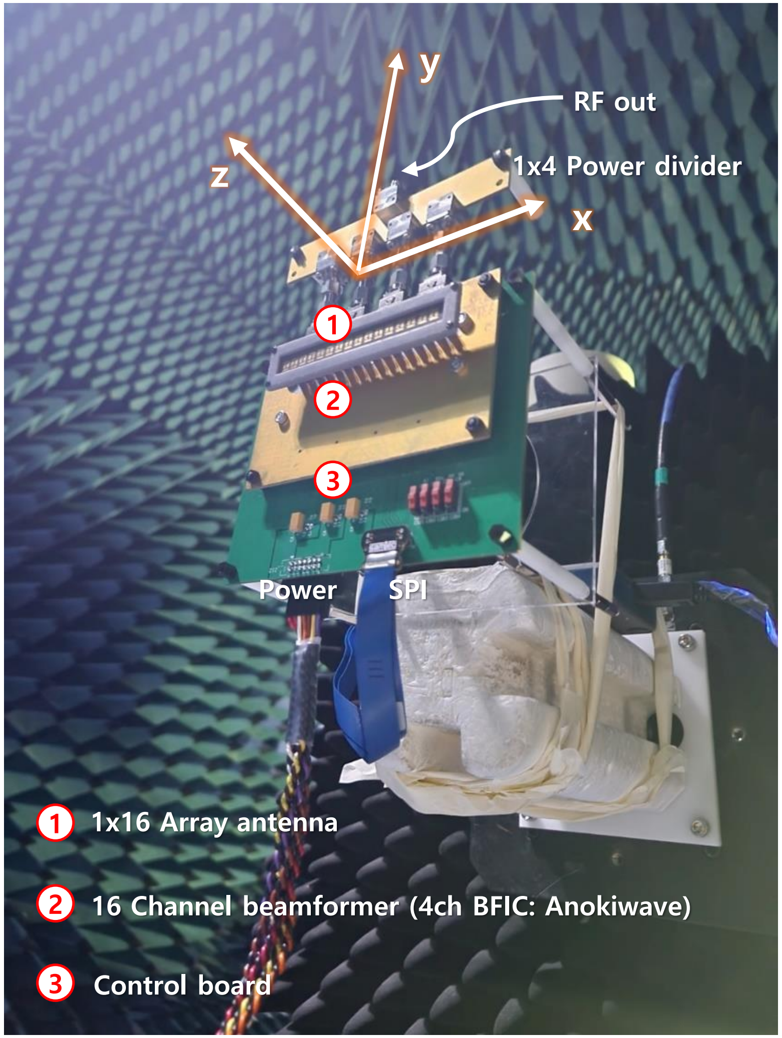


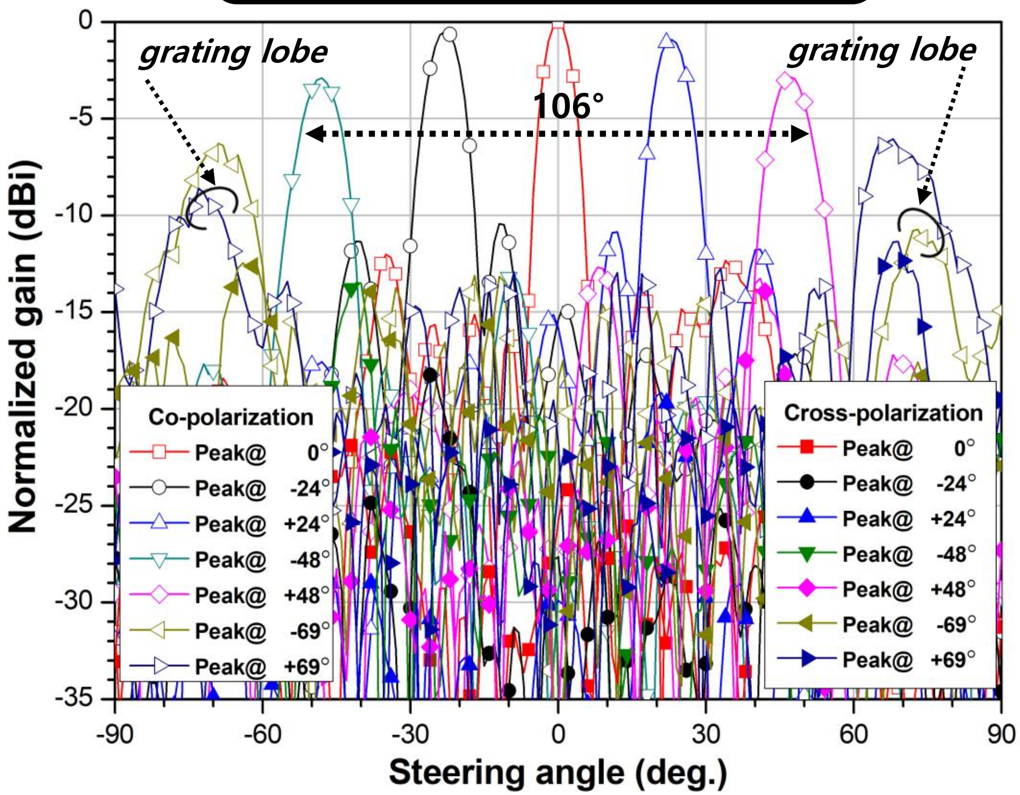




Wide-Angle Scanning Phased Array Antennas

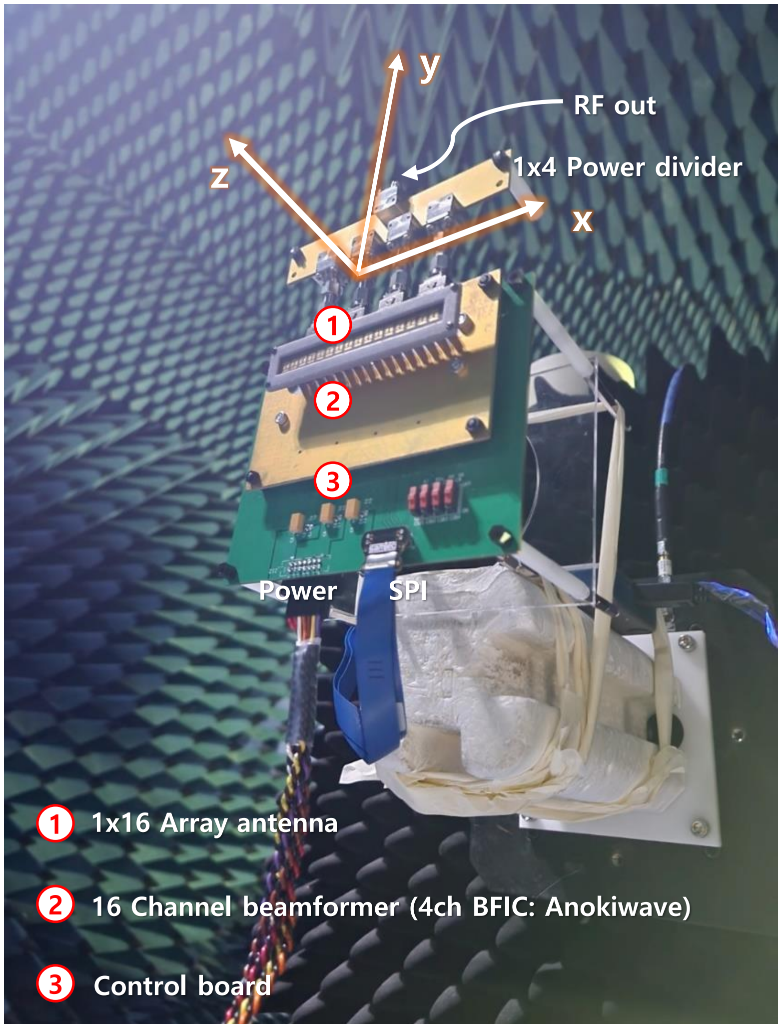
1 x 16 Conventional patch-based PAA scanning performance

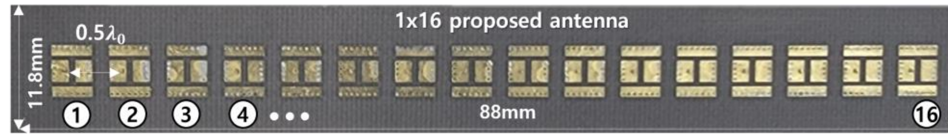


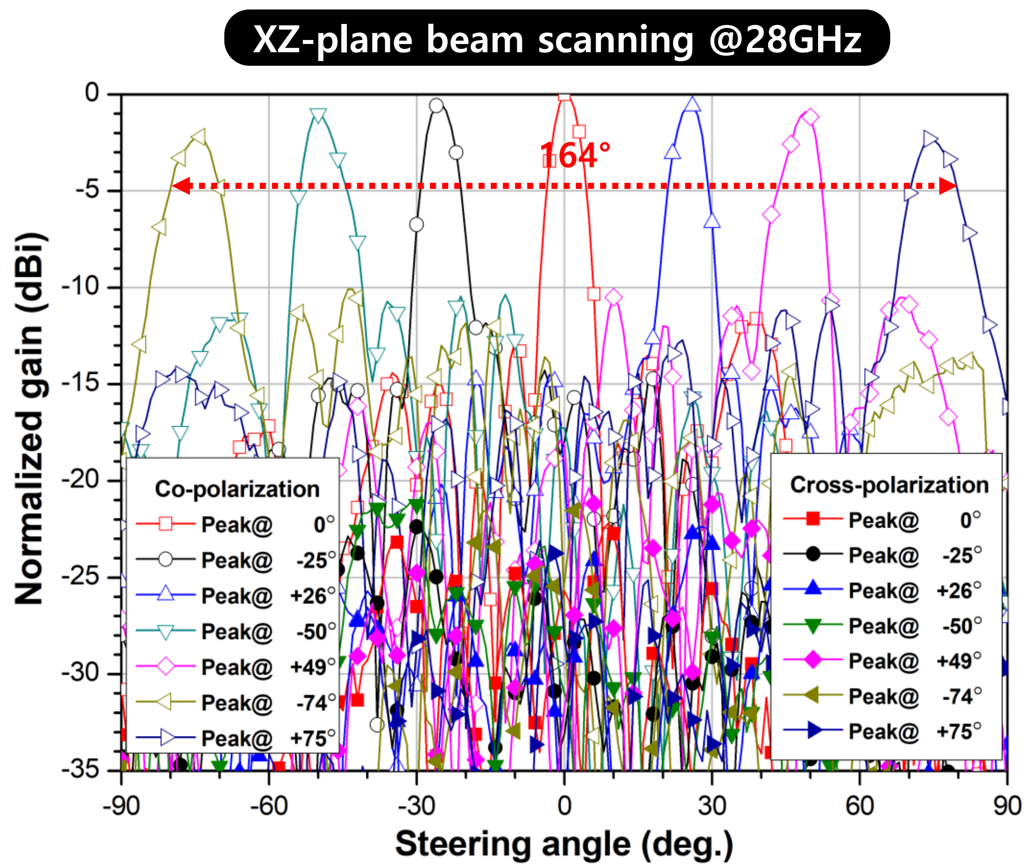


Wide-Angle Scanning Phased Array Antennas

1 x 16 Multipole-based PAA scanning performance

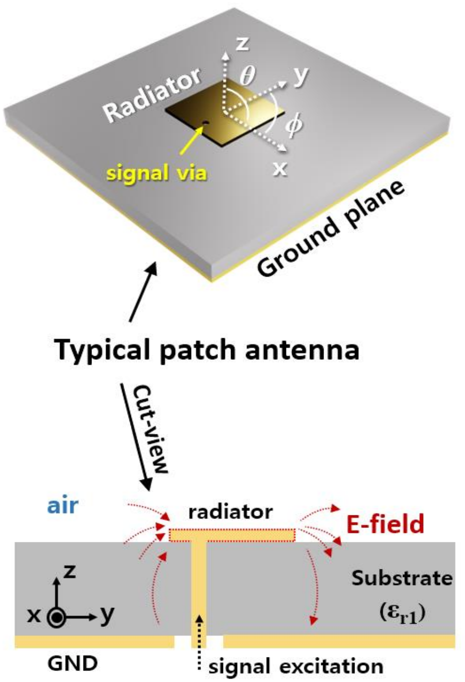


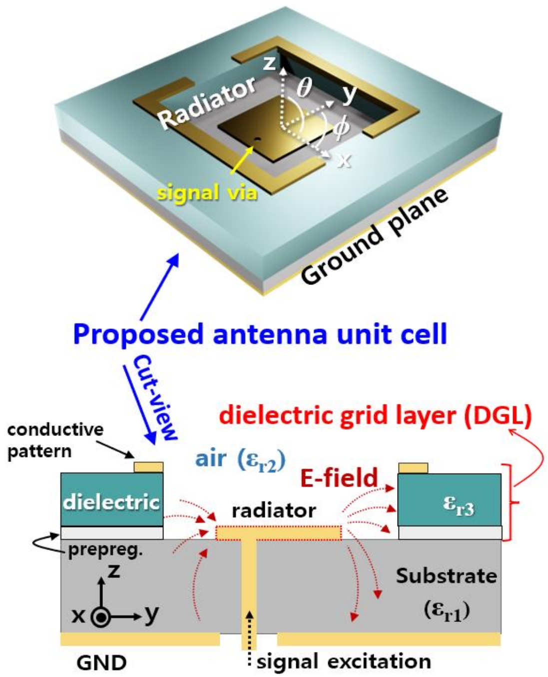


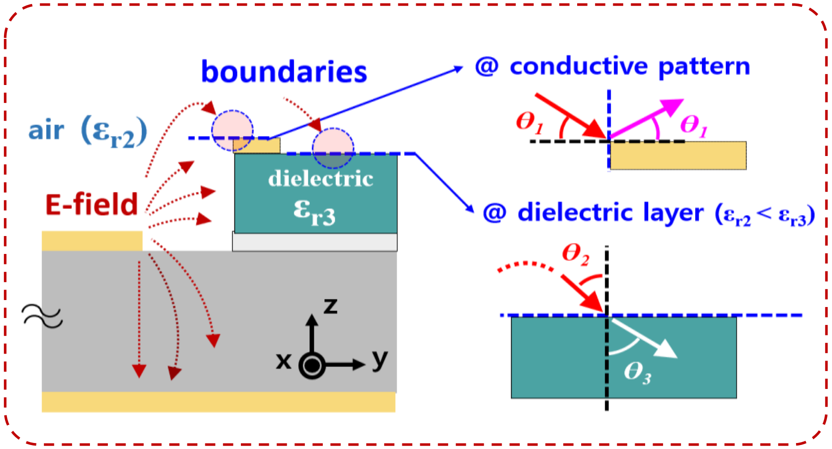


Wide-Angle Scanning Phased Array Antennas

Dielectric Grid Layer (DGL) based antenna







$$n_1 \sin\theta_i = n_2 \sin\theta_t$$

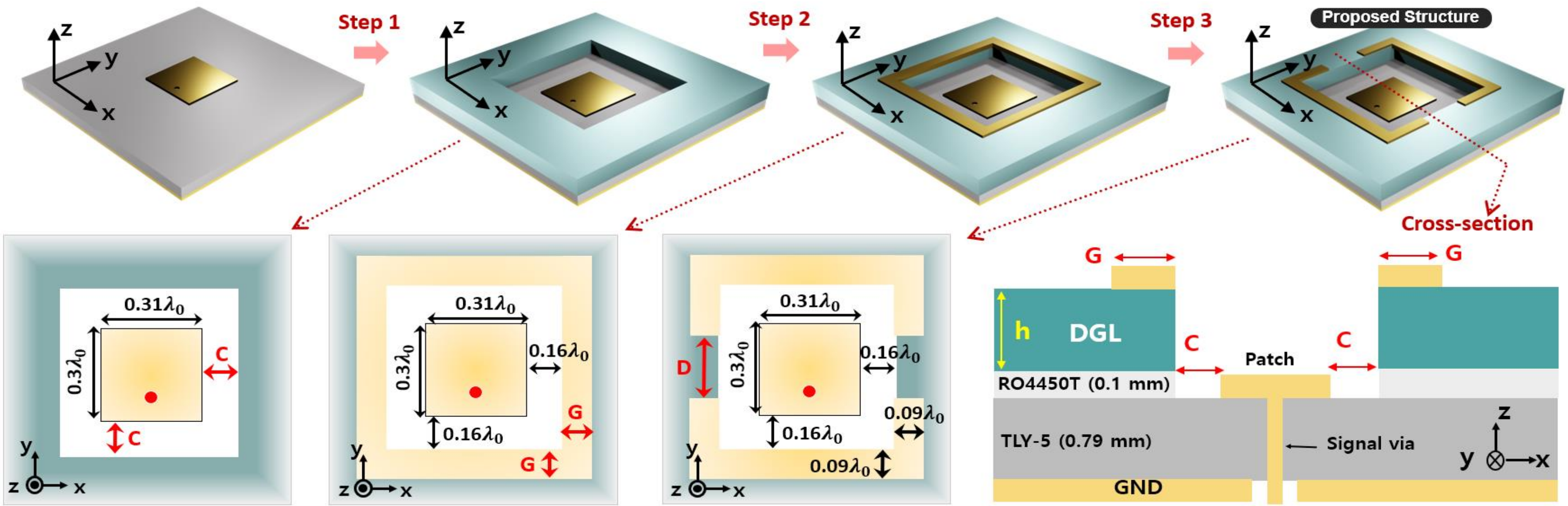
$$\sqrt{\varepsilon_{r2}}\,\sin\theta_2 = \sqrt{\varepsilon_{r3}}\,\sin\theta_3$$

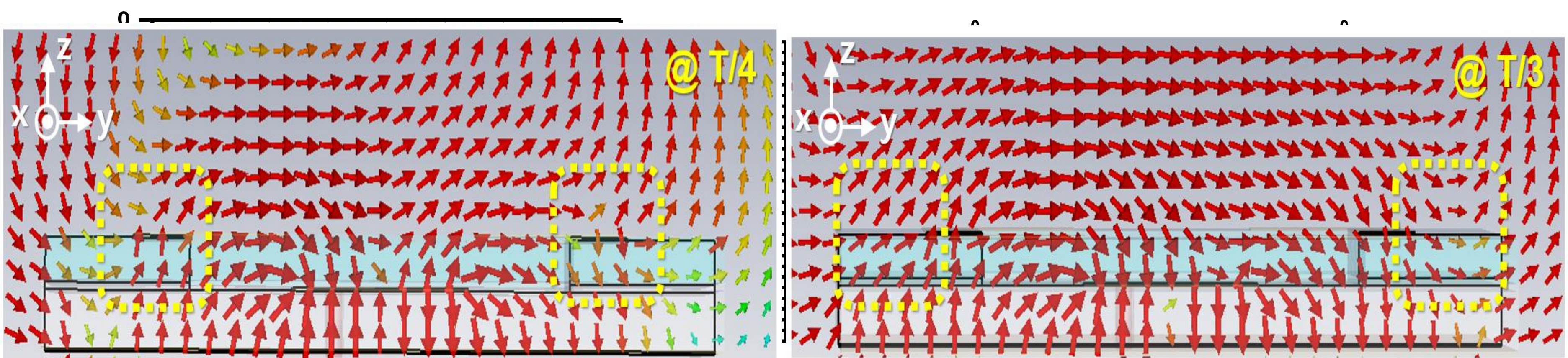
Very simple but effective!

$$\theta_3 = \sin^{-1}\left(\sqrt{\frac{\varepsilon_{r2}}{\varepsilon_{r3}}}\cdot\sin\theta_2\right) \simeq \sin^{-1}\left(\frac{\sin\theta_2}{\sqrt{\varepsilon_{r3}}}\right)$$

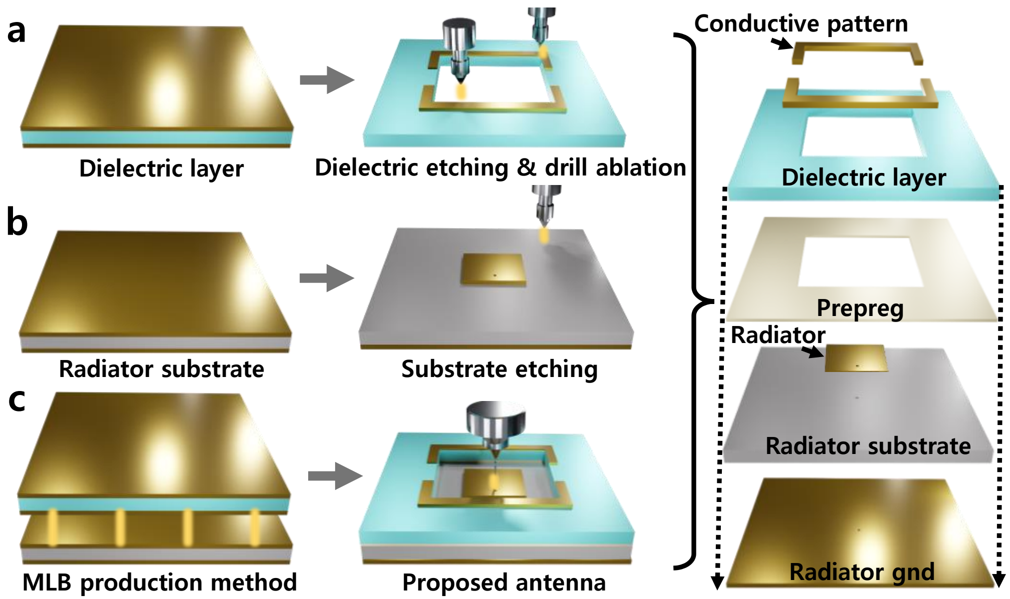
Wide-Angle Scanning Phased Array Antennas

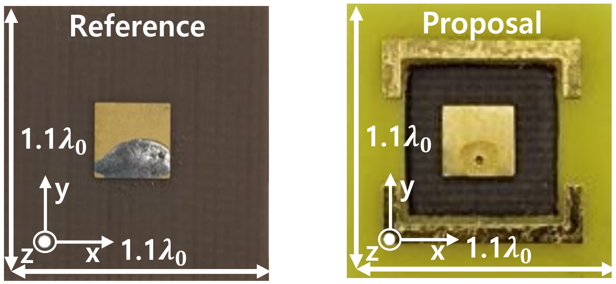
DGL-based antenna design & simulation

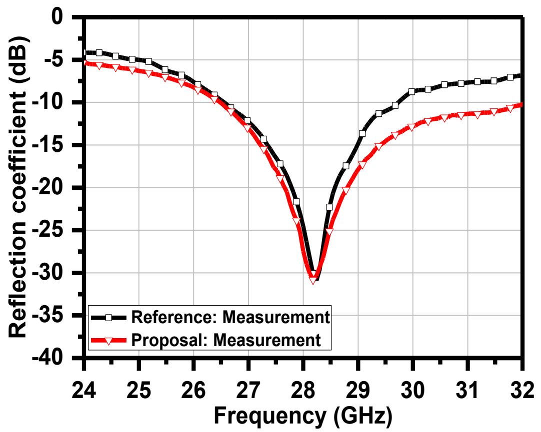


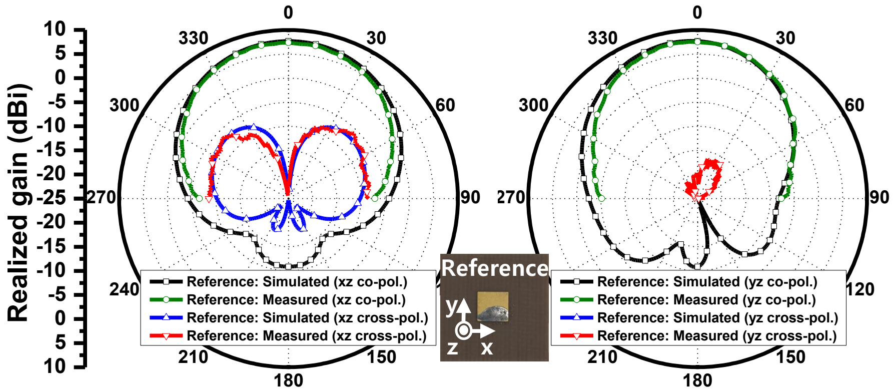


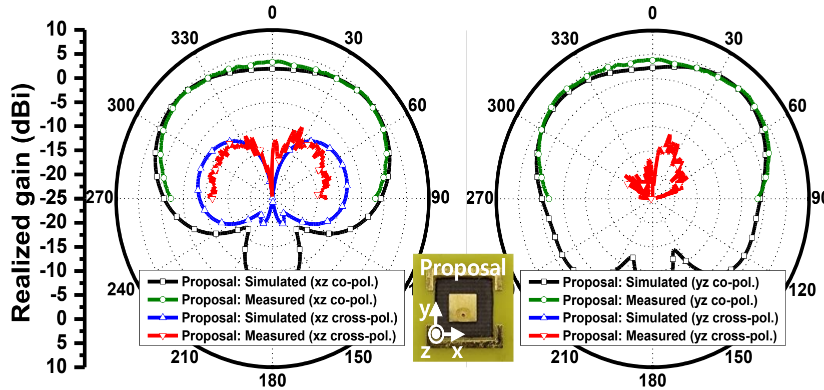
DGL-based antenna fabrication and verification





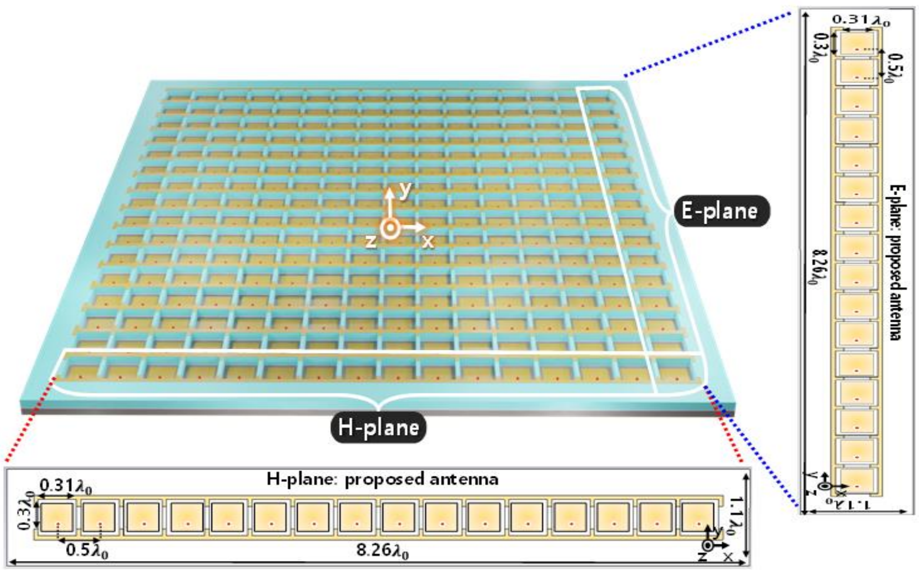


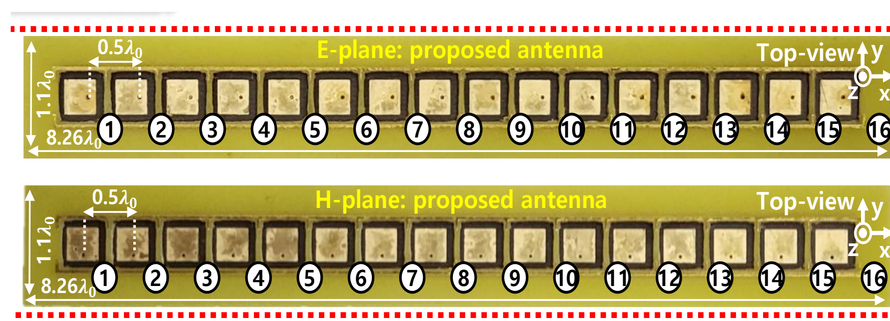


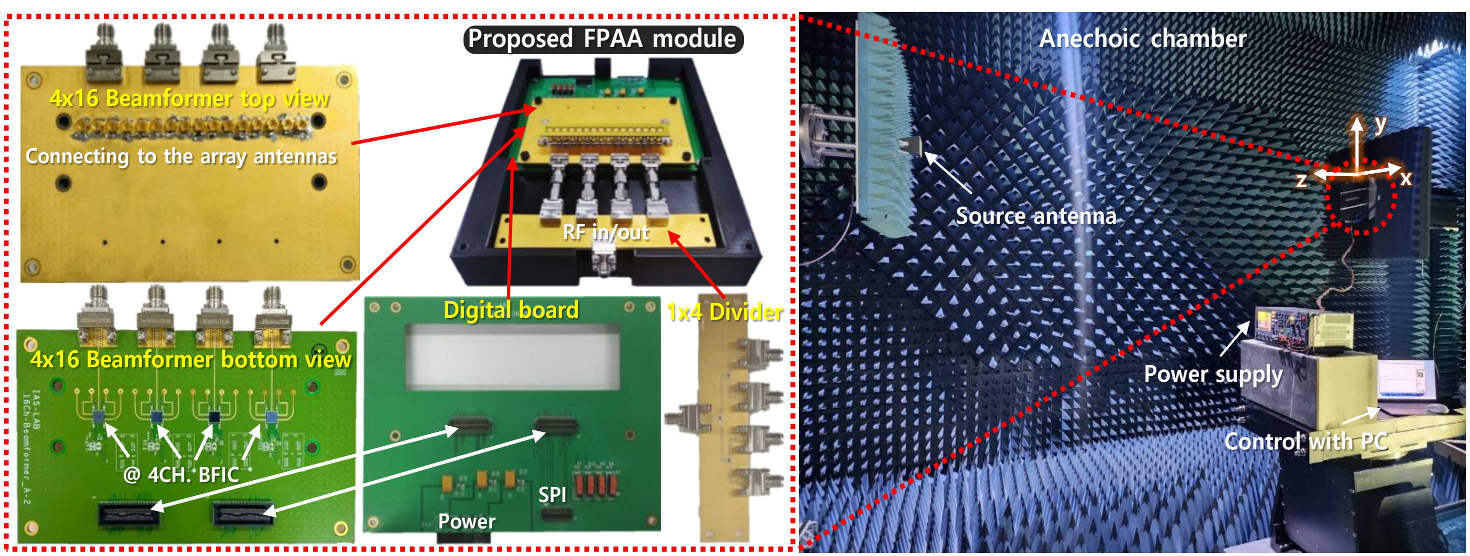


Wide-Angle Scanning Phased Array Antennas

DGL-based array antenna fabrication and measurement

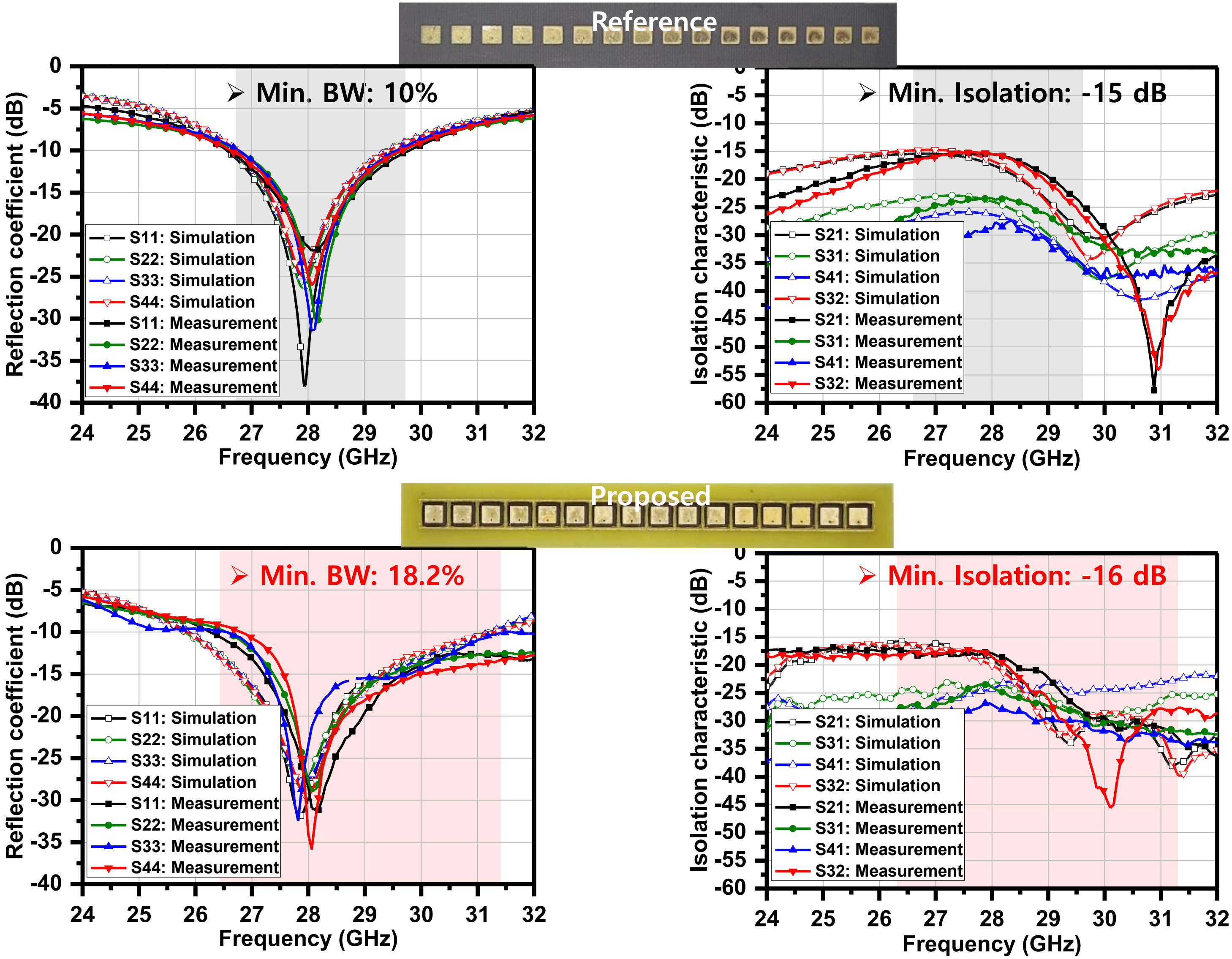






Wide-Angle Scanning Phased Array Antennas

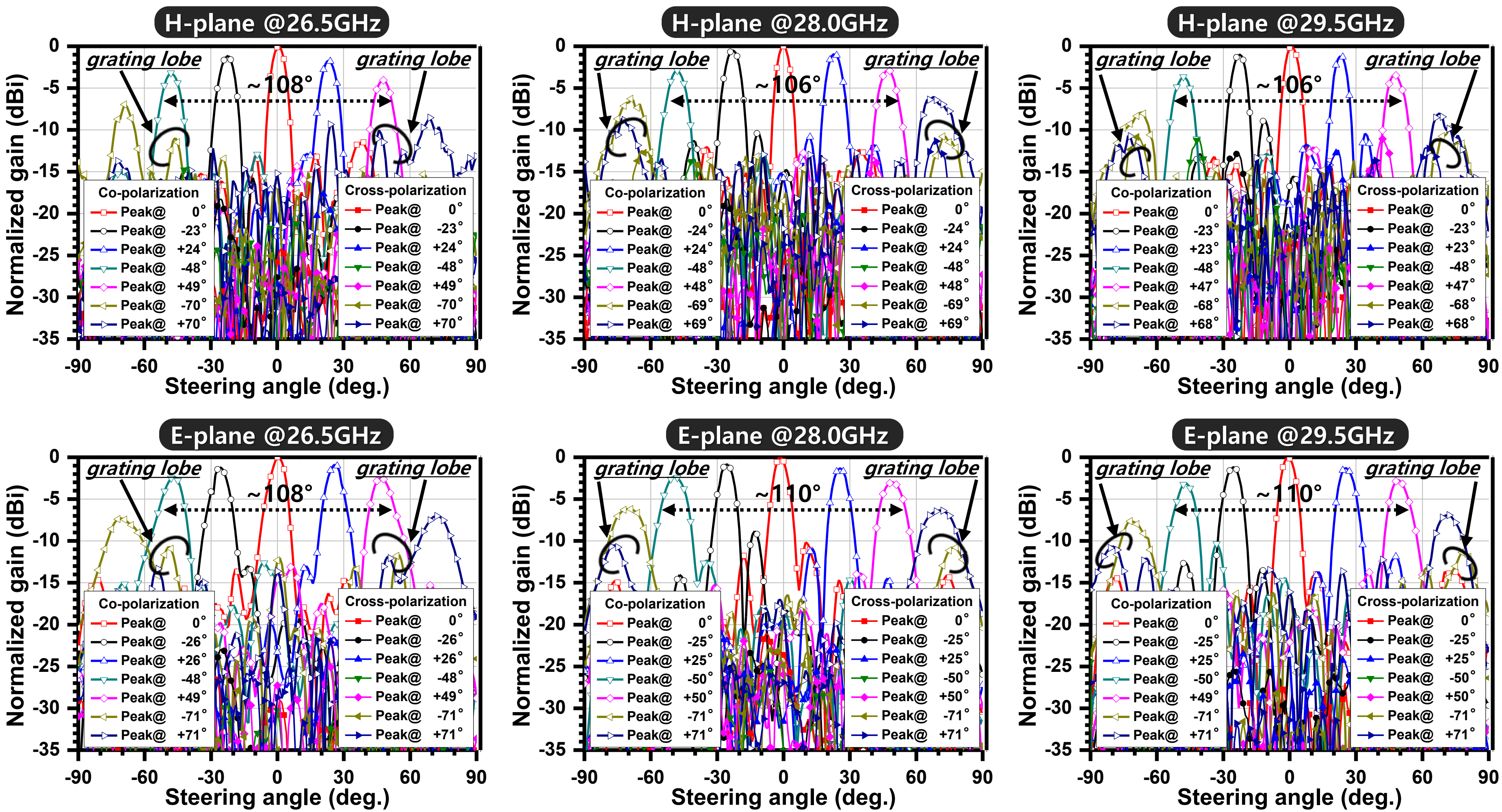
DGL-based 1x16 array impedance bandwidth in E/H planes



Wide-Angle Scanning Phased Array Antennas

DGL-based 1x16 array scanning performance in E/H planes (1)

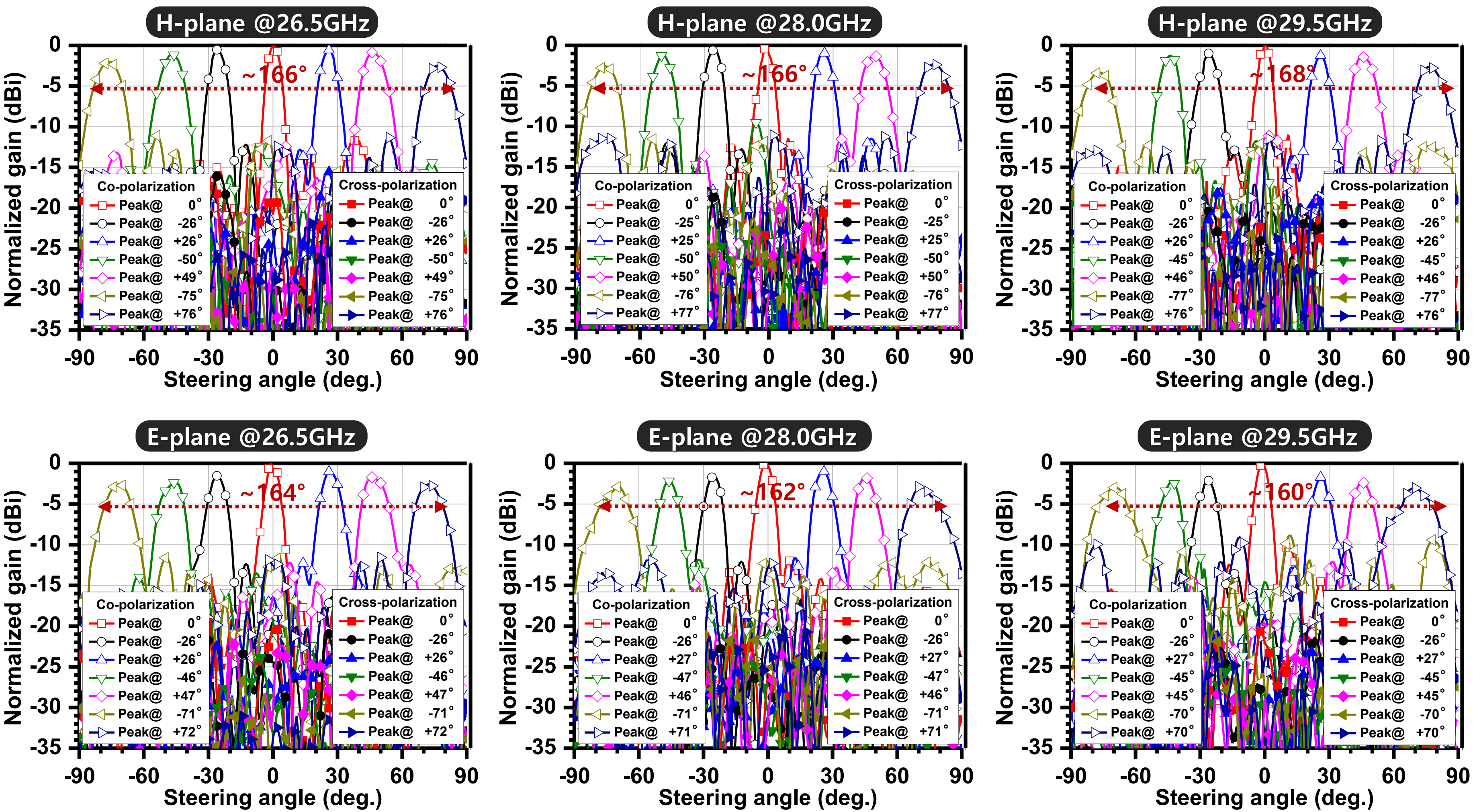
- Patch-based array



Wide-Angle Scanning Phased Array Antennas

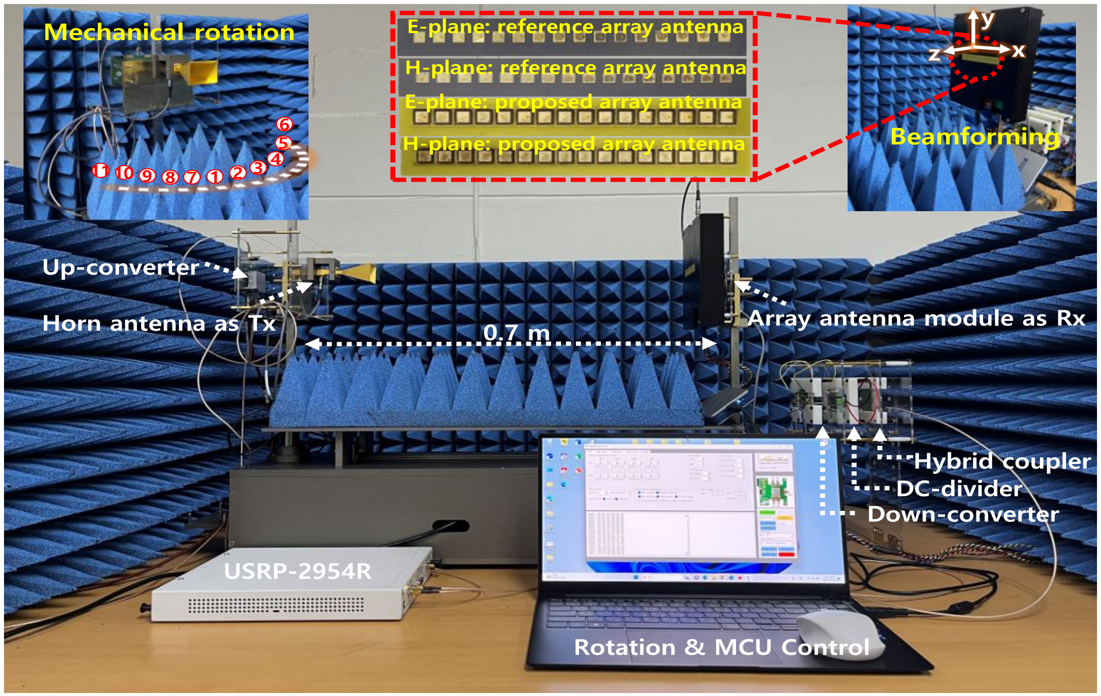
DGL-based 1x16 array scanning performance in E/H planes (2)

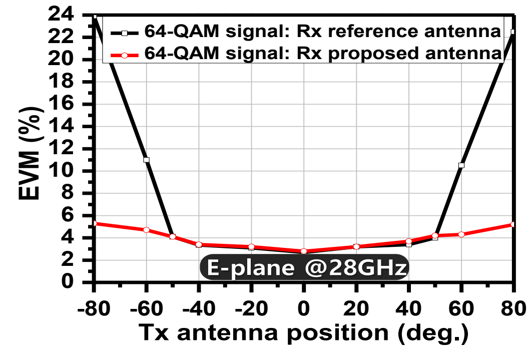
- DGL-based array

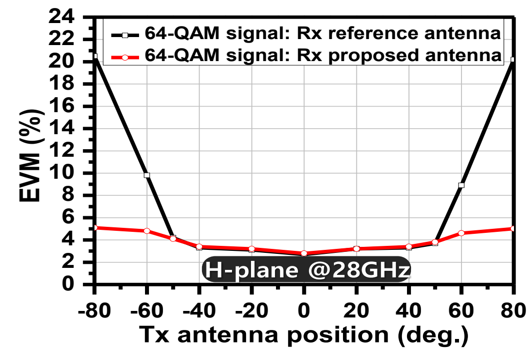


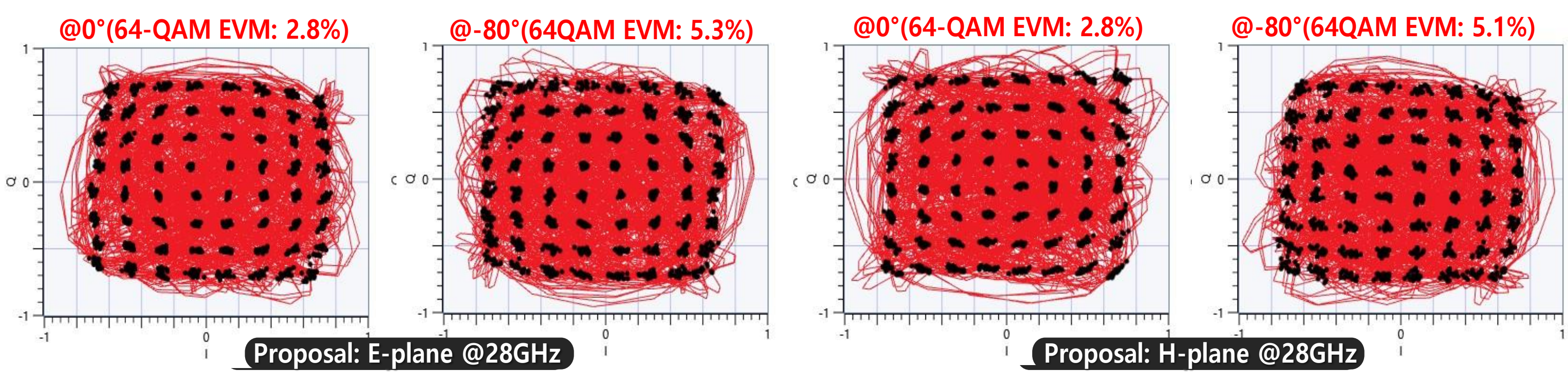
Wide-Angle Scanning Phased Array Antennas

DGL-based 1x16 array scanning performance with modulated signals









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2 Recent Works on Wide-Angle Antennas

3 Wide-Angle Scanning Phased Array Antennas

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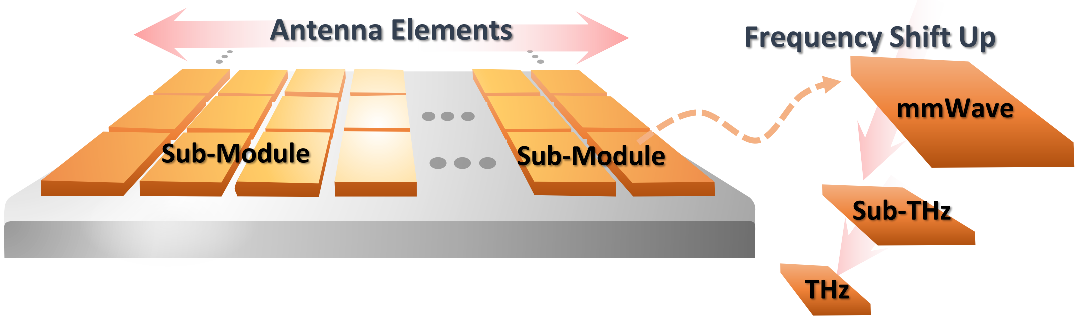
2) Dielectric grid layer based antenna

4 Conclusion

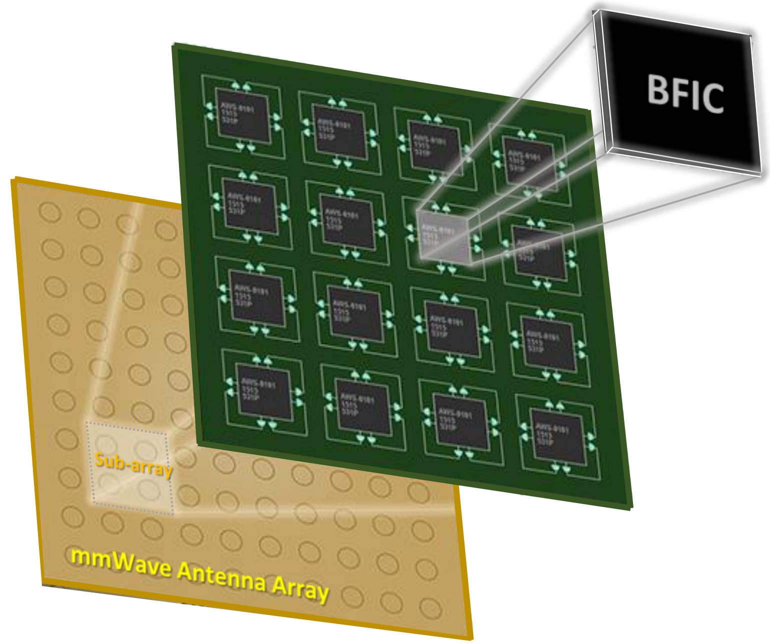
Conclusion

- **Successful adoption of mmWave/above spectrum by choosing right antenna structure**

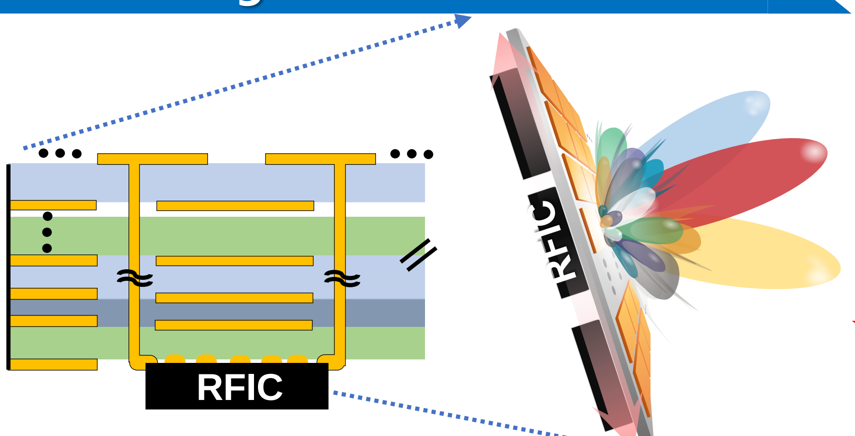
Array antennas at mmWave



- ❐ "Beamforming" as a key technology
- ❐ Antenna element "integration with driver ICs"



Active integrated antenna



- ❐ Multilayered PCB and module integration
- ❐ Planar integration (potentially for semiconductor process)
- ❐ Low-profile configuration
- ❐ Scalable configuration

★ **Integration efficiency must be considered as well as the performance!**

Thank You

Chung-Ang University
School of Electrical and Electronics Engineering
Integrated Antenna Systems

RF – mmWave - THz
IAS