WHITEPAPER

6G MASSIVE MIMO

Beam steering *for initial access using Antenna Arrays at 28 GHz.*

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1. Introduction:

5G deployments are taking place rapidly and 6G technologies are emerging. One of the common technologies carried over from 5G to 6G is Massive MIMO, which will be especially useful in the FR-2 band utilizing LOS or near LOS propagation paths. Synchronizing Signal Blocks (SSB) are needed to enable the beam management procedures. Beam management is a set of Layer 1 (PHY) and Layer 2 (MAC) procedures to establish and retain an optimal beam pair for good connectivity. A beam pair consists of a transmit beam and a corresponding receive beam in one link direction. Before a UE can communicate with the network, it must perform cell search and selection procedures and obtain initial cell synchronization and system information. The first step in that process is acquiring frame synchronization, discovering the cell identity, and decoding the MIB and SIB1. Higher operating frequencies in the FR-2 band enable directional communication with a larger number of antennas and provide an additional gain due to beamforming, compensating for the propagation loss at higher frequencies. However, directional links would need precise alignment of beams at the gNodeB (gNB) and UE. This introduces the need for efficient management of beams where UE and gNB regularly identify the optimal beams to work at any given time. 3GPP has defined a set of beam management procedures that are applicable for both idle and connected modes of operation:

- **Idle mode:** This occurs when the UE does not have an active data transmission. The idle mode procedure is used when UE is trying to connect to a network for the first time while switching on or re-initiating the connection after waking up. Beam management in idle mode will help in establishing a directional initial access.

- **Connected mode:** This occurs when the active data exchange is taking place between the UE and gNB while the UE is moving within the cell. In this mode, there is a high chance of the signal deteriorating rapidly due to the propagation characteristics, so managing the beam in real-time will help in maintaining a healthy link.

2. Scope of this paper

The objective of this technical report is to present the results of MATLAB-based analysis & simulations on SSB beam management procedures for SSB generation, beam sweeping, beam measurement, and beam determination. Before that, the important aspect of array antennas is presented as an essential technology that is a highlight and indispensable feature of Massive MIMO. The Sub-arrays are designed using two types of basic antenna elements: (1) the 3GPP TS 38.901 Antenna Model and (2) the practical and efficient Microstrip Patch Antenna. Both these Antenna Elements are analyzed for visualizations of spatial radiation patterns and RF performance parameters and radiation characteristics like beamwidth and directivity. The same elements are then combined in sub-arrays (Antenna Panels) and visualizations of spatial radiation patterns and RF performance parameters are presented for the sub-array (panel). The sub-array-based panel antenna is a fundamental unit used for individual beams in beamforming and it also provides two transmission layers (one layer per beam, one beam per polarization).

With an Antenna Array of a panel, beam steering is demonstrated for various tilt angles in azimuth and elevation planes. Once the panel antenna is available, SS Burst analysis on beam sweeping, measurement, and determination procedures are carried out. A CDL (spatially aware) channel is used, which utilizes the TX and RX side Antenna Array parameters. All analysis and visualizations are performed using MATLAB 5G, Phased Array System, and Antenna Toolboxes.

3. Antenna element & array design 28 GHz (FR-2 band)

The 28 GHz band is potentially an instrumental frequency band for the service providers and many deployments are planned. It corresponds to the n257 and n261 bands in FR-2.

Antenna sub-arrays (panels) are made up of elements arranged in a lattice. Sub-arrays are in turn stacked up in two directions to form arrays. The arrangement of elements on the surface can be random, circular, or rectangular. The elements can be placed on a uniform or curved (conformal) plane. The far-field radiation pattern or sub-arrays and arrays are due to the contribution of amplitudes & phases of each element interfering in the spatial domain. Some rules from antenna theory are followed while placing the elements on a plane, like the distance between elements and the boresight direction of radiation of the elements. 5G and 6G Antenna elements can have one or two polarizations. The established technology uses 2 polarizations at +/- 45 degrees tilts to the horizontal axis. Each polarization has its own radiation pattern and field distributions the two polarizations do not interfere with each other. This useful property has been exploited to double the number of transmission layers - thus offering higher throughput and/or concurrent users connected. Figure 3.1 highlights the antenna model described in 3GPP TS 38.901.

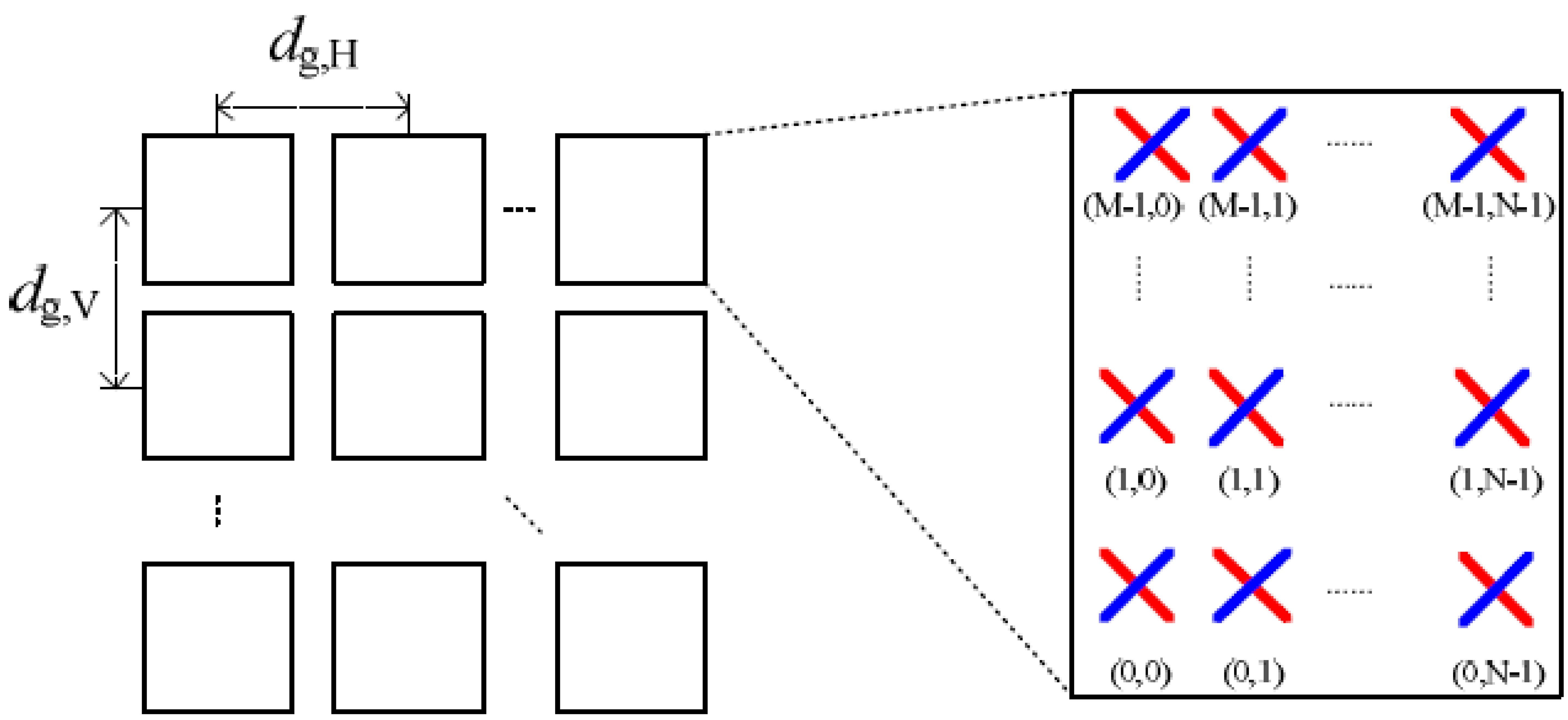

Fig. 3.1: Array, Panels & Elements (from 3GPP TS 38.901)

In this analysis, we have two different types of antenna elements with two polarizations each are considered using the MATLAB Toolboxes - 5G toolbox, Antenna toolbox, and Phased Array System toolbox, as a result, the plots are presented.

The two antenna elements analyzed are (1) Microstrip Patch - a very efficient and popular element for array applications and (2) A generalized antenna element model specified by the 3GPP TS 38.901 standard.

A. Using antenna element model specified by 3GPP 38.901 standard

A 5G Antenna Element is described in the 3GPP TR 38.901 specification. The element specifications are given in Table 3.11 below. The analyzed array parameters are given in Table 3.12 below. These elements are analyzed and results/visualizations are presented in this section.

S.No.	Antenna Parameter	Value
1	Element Object	phased.NRAntennaElement
2	Frequency Range	27.5 - 28.5 GHz
3	Polarization Angle	+/- 45 deg
4	Polarization Model	2
5	Beamwidth (Azimuth)	65 deg
6	Beamwidth (Elevation)	55 deg
7	Side Lobe Level (Azimuth)	30 deg
8	Side Lobe Level (Elevation)	30 deg
9	Max. Gain	8 dB

Table 3.11: 6G Antenna Element Parameters with a 3GPP TS 38.901 element

S.No.	Array Parameter	Value
1	Element Object	phased.NRAntennaElement
2	Frequency Range	27.5 - 28.5 GHz
3	Sub-Array Size (Panel)	8 x 16
4	Directivity (TX sub-array)	26.5 dBi
5	Beamwidth (Azimuth) (TX)	6.8 deg
6	Beamwidth (Elevation) (TX)	12 deg
7	Amplitude Taper (TX)	TaylorWin, Chebyshev
8	Directivity (RX sub-array)	13.38 dBi
9	Beamwidth (Azimuth) (RX)	43.2 deg
10	Beamwidth (Elevation) (RX)	39.9 deg
11	Amplitude Taper (RX)	None
12	Beam steering Tilt [Az, El] (TX)	[30, 45] deg
13	TX Sub-array Width (mm)	89.08
14	TX Sub-array Height (mm)	44.54

Table 3.12: 6G Antenna Array Parameters with a 3GPP TS 38.901 element

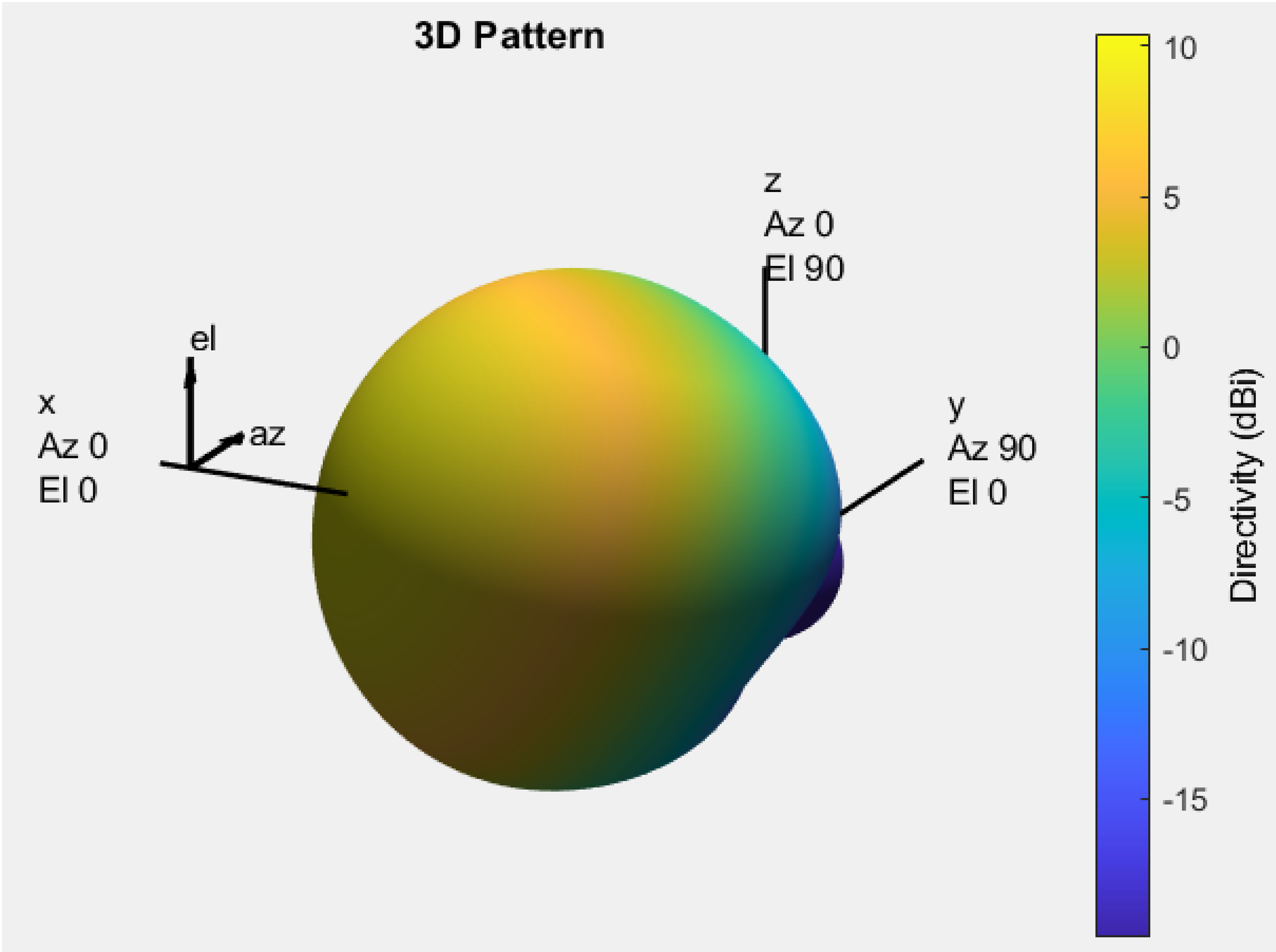

Fig. 3.11: 3D Radiation Pattern of the 3GPP TS 38.901 element

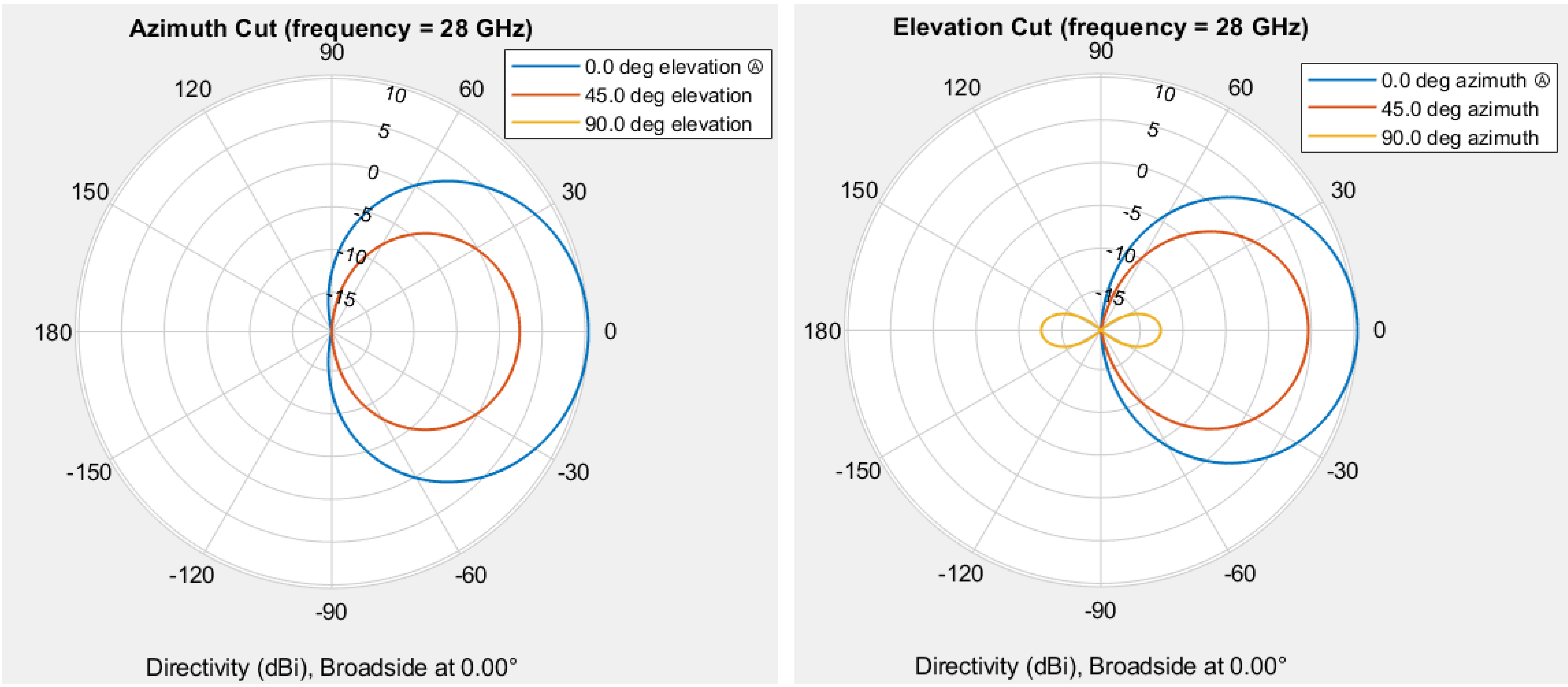

Fig. 3.12: Radiation Pattern along Azimuth and Elevation Cuts of the 3GPP TS 38.901 element

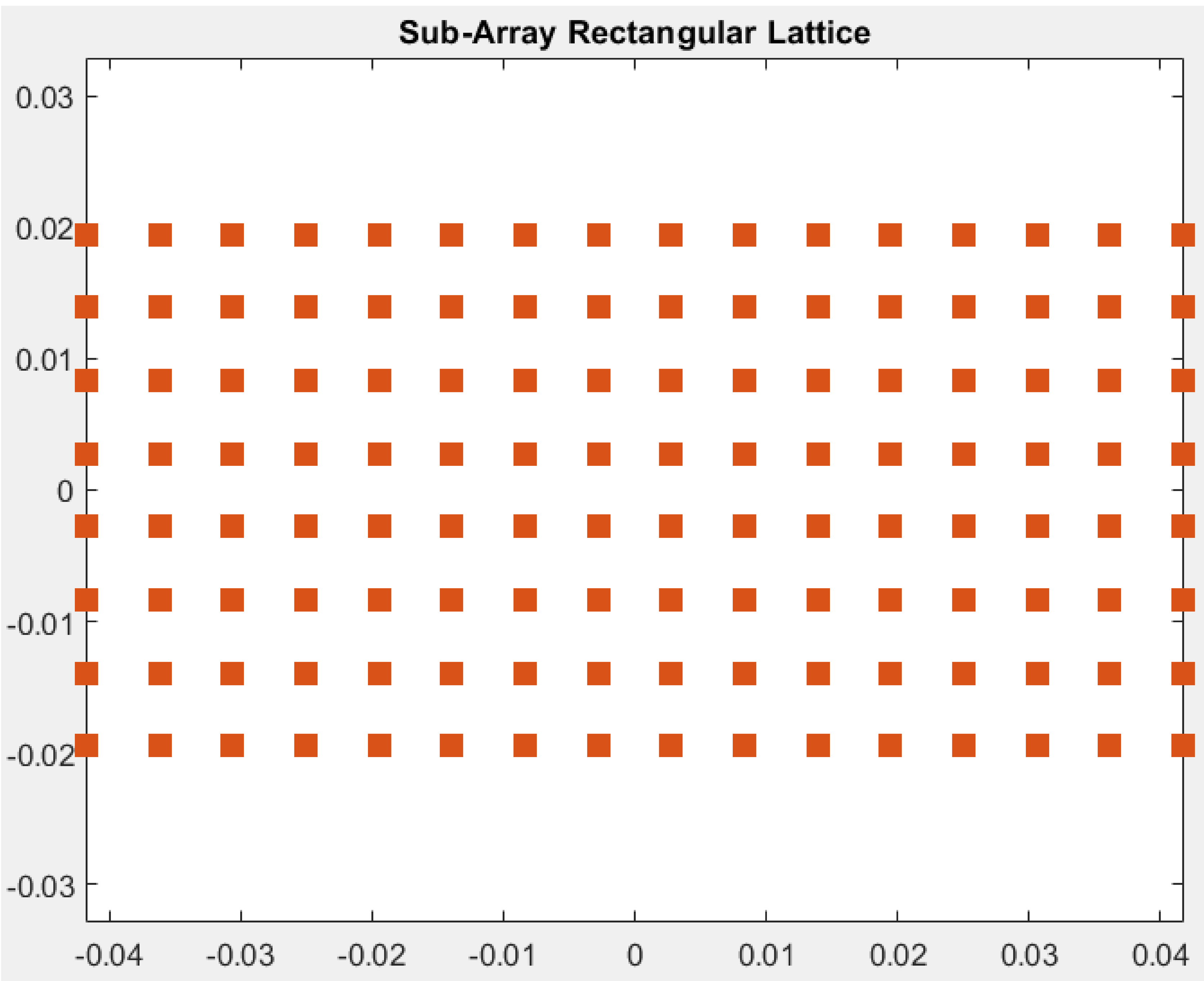

Fig. 3.13: Planar Layout of the Sub-Array (Panel) consisting of elements (8 x 16 array)

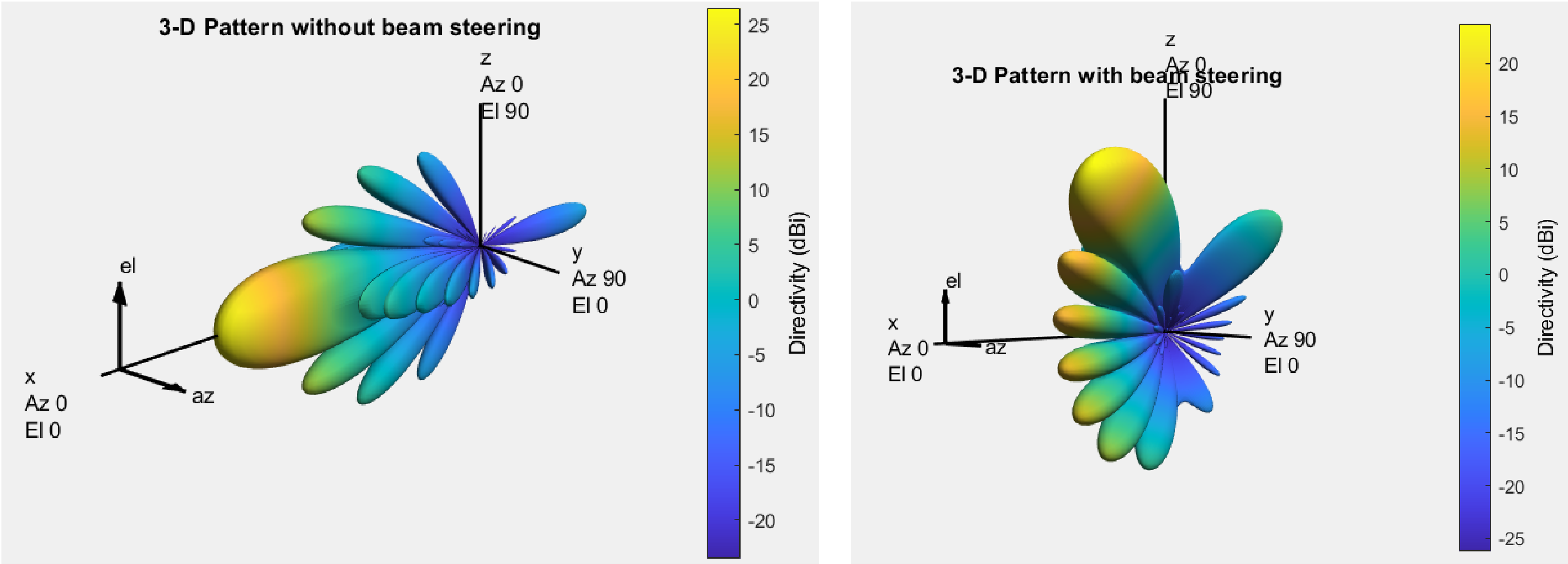

Fig. 3.14: 3D Sub-Array Radiation Pattern without and with Beam Steering

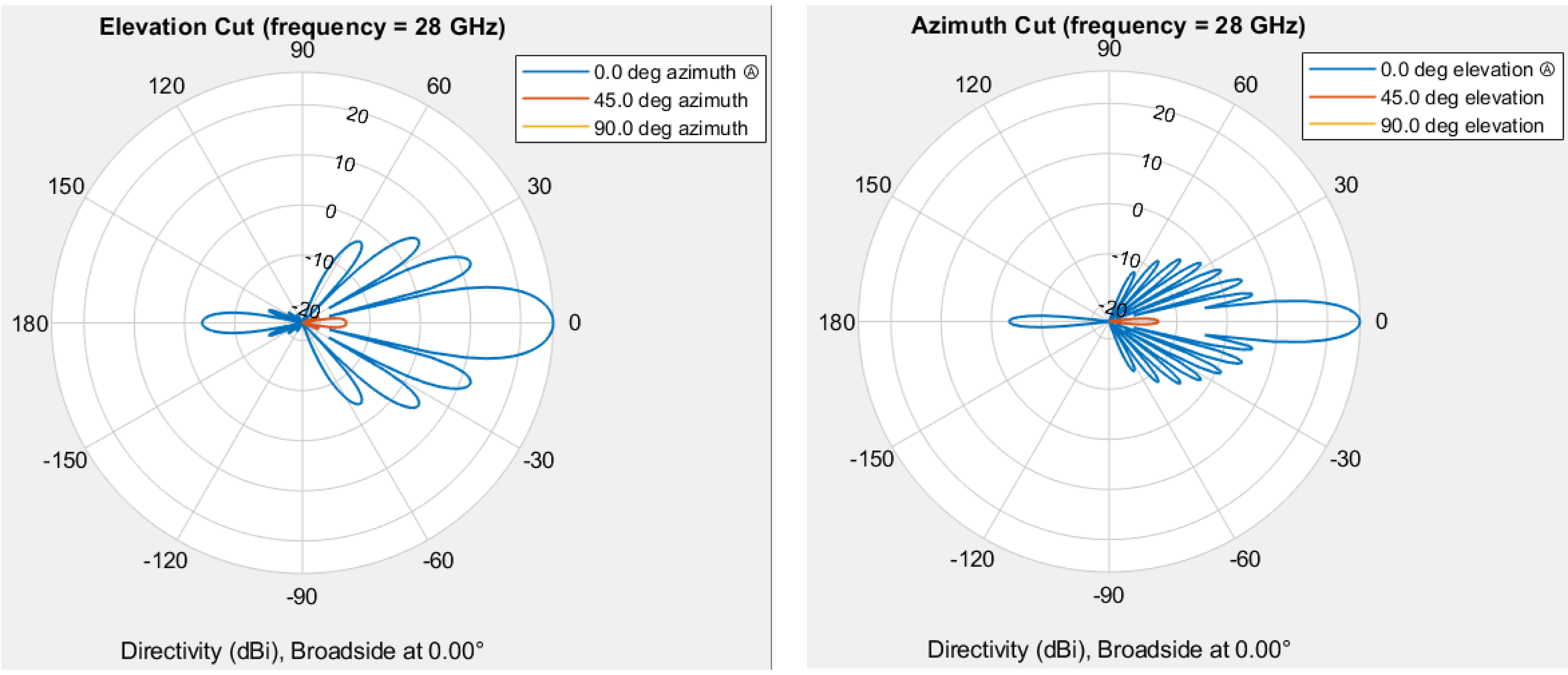

Fig. 3.15: Sub-Array Radiation Pattern along Azimuth/Elevation Cuts without Beam Steering

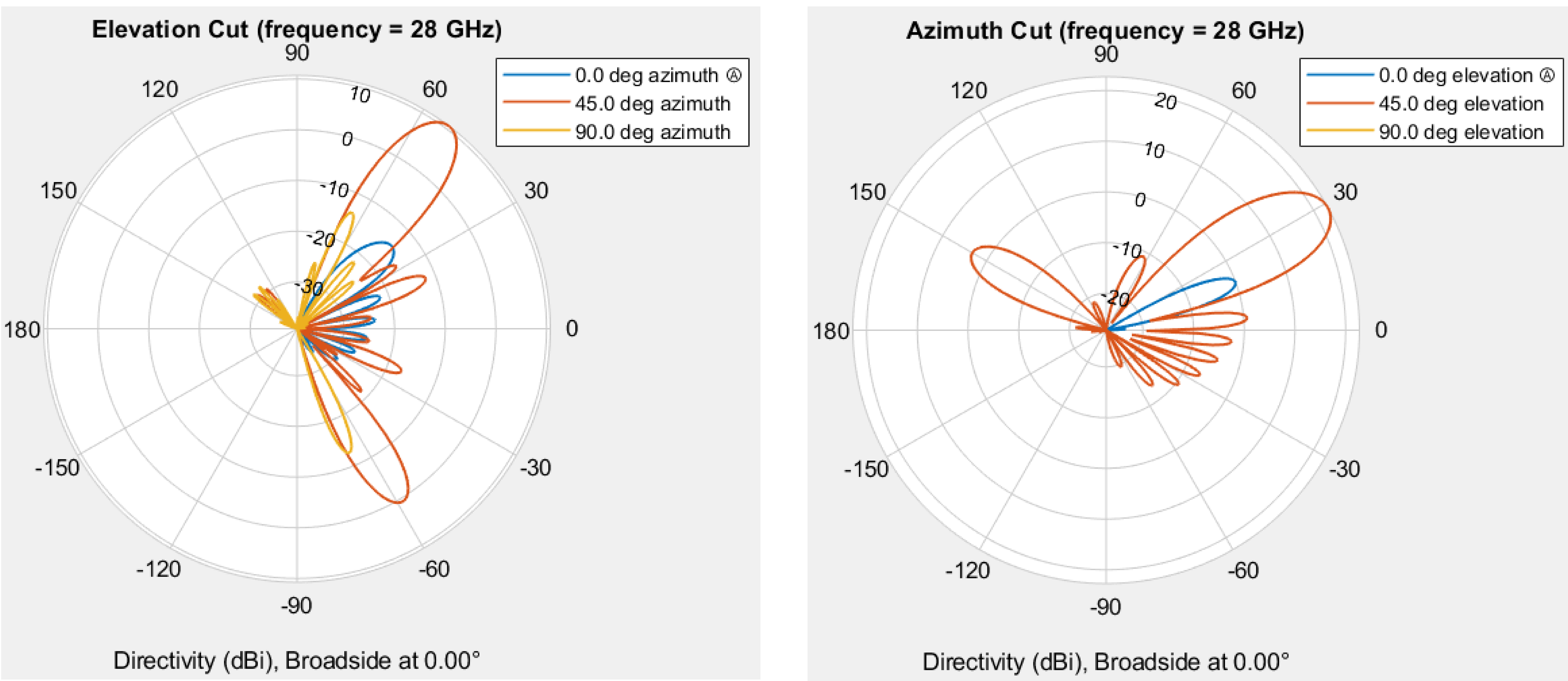

Fig. 3.16: Sub-Array Radiation Pattern along Azimuth/Elevation Cuts with Beam Steering

B. Using a designed microstrip patch element

A very common Microstrip Patch Antenna Element is analyzed and the results/visualizations are presented in this section.

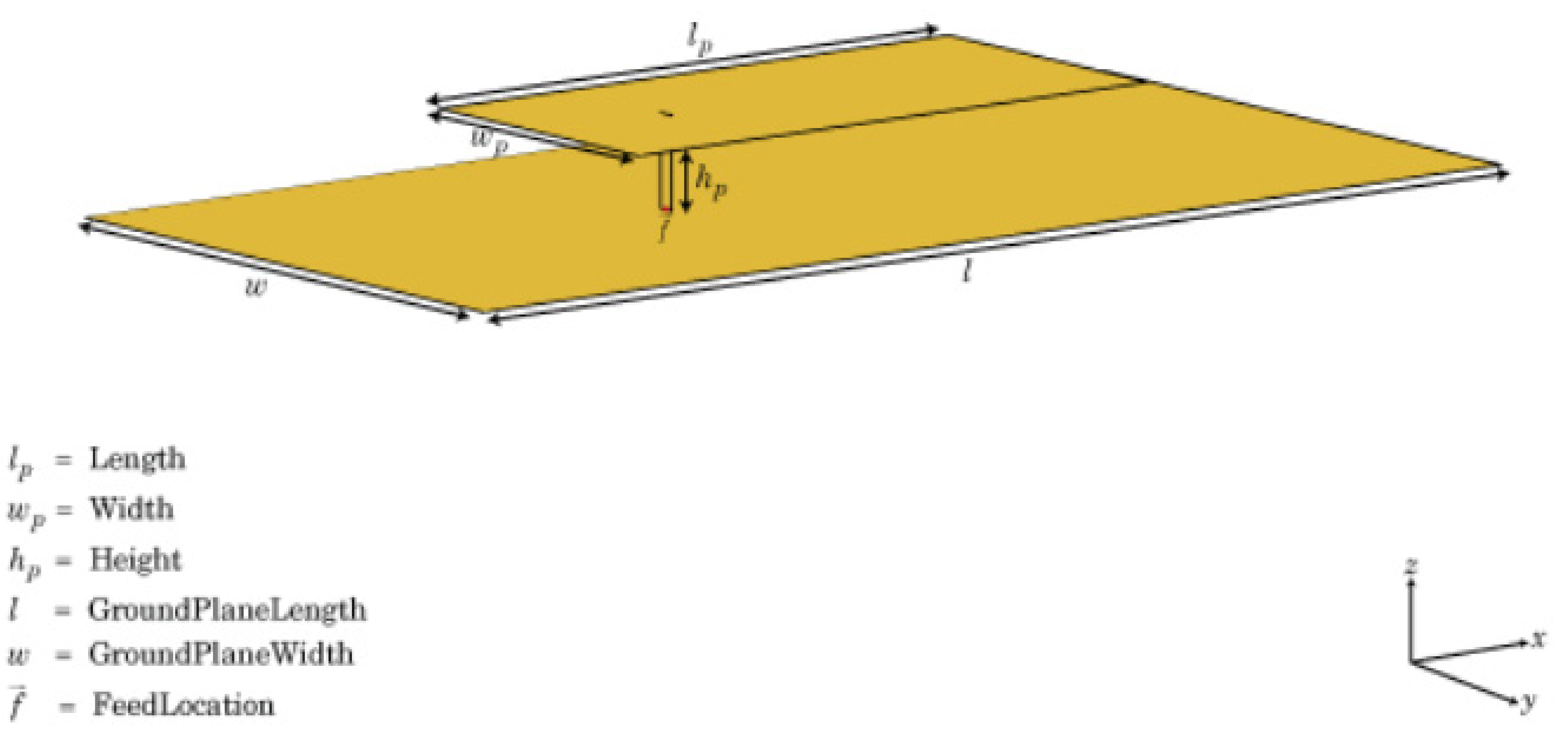

Fig. 3.2a: A General Microstrip Patch Antenna Element

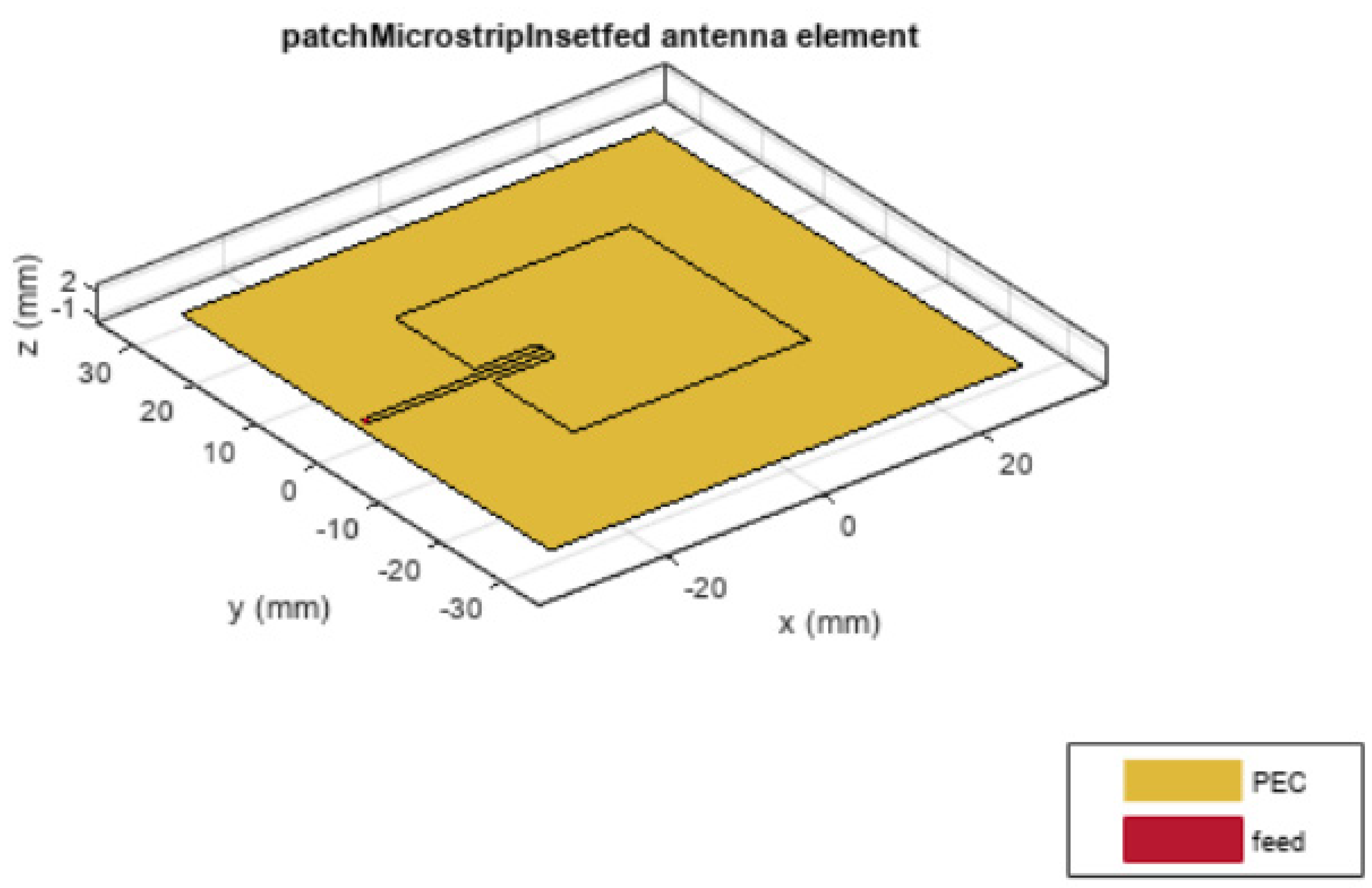

Fig. 3.b: A Microstrip Patch Antenna Element with inset feed

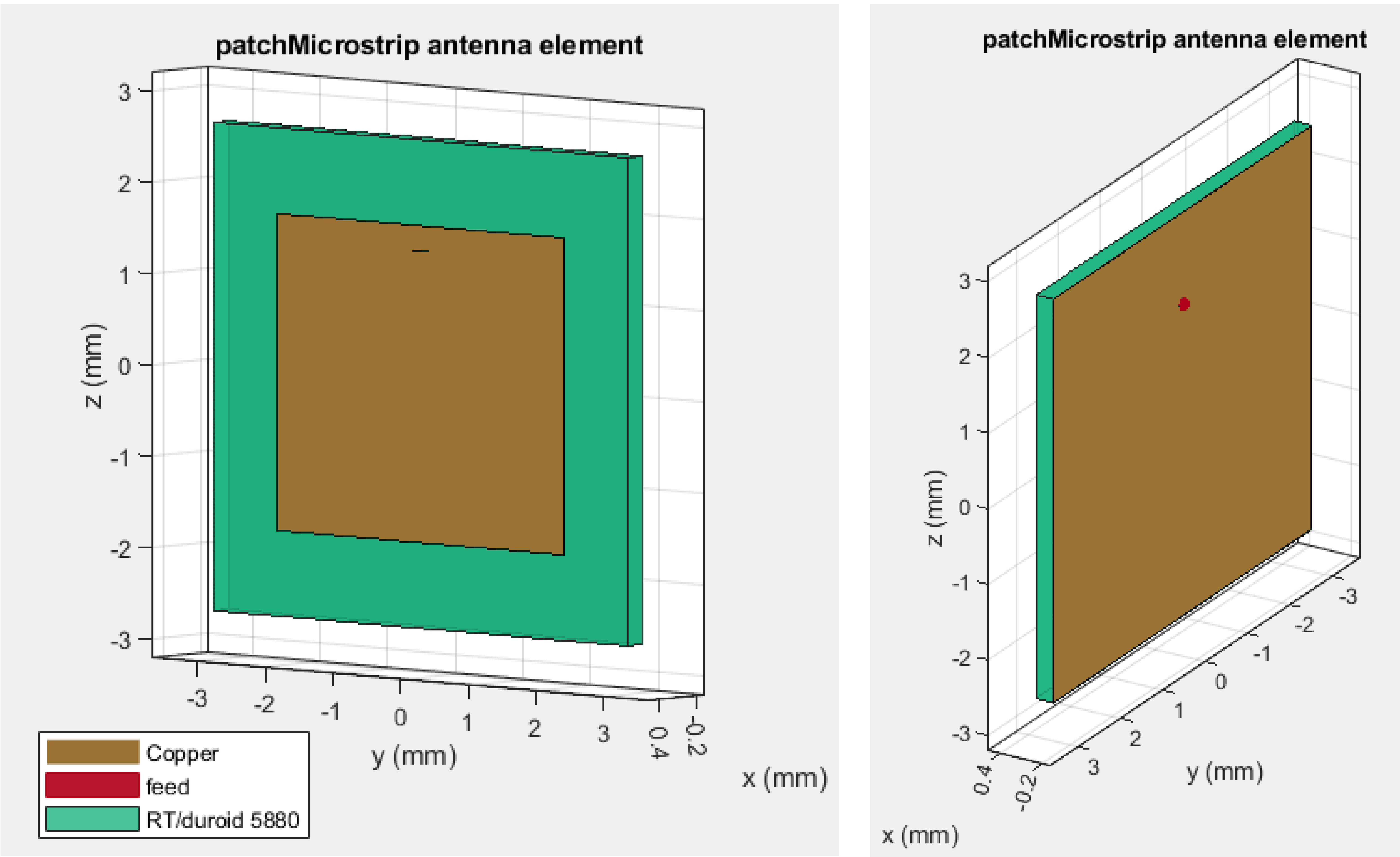

Fig. 3.2c: A Designed Microstrip Patch Element

S.No.	Antenna Parameter	Value
1	Element Object	patchMicrostrip
2	Frequency Range	27.5 - 28.5 GHz
3	Polarization Angle	+/- 45 deg
4	Beamwidth (Azimuth)	83 deg
5	Beamwidth (Elevation)	83 deg
6	Side Lobe Level (Azimuth)	< -30 dB
7	Side Lobe Level (Elevation)	< -30 dB
8	Max. Gain	7.18 dBi
9	Substrate Dielectric Name	RT/duroid 5880
10	Dielectric EpsilonR	2.2
11	Dielectric LossTangent	0.0009
12	Dielectric Thickness	0.25 mm
13	Conductor Type	Copper
14	Conductor Conductivity	5.96e7
15	Conductor Thickness	17 um (Copper peel of 1/2 Oz.)
16	Microstrip Patch Length	3.469 mm
17	Microstrip Patch Width	4.232 mm
18	Feed Offset Position	[-1.4601,0] mm
19	Ground Plane Length	5.35 mm
20	Ground Plane Width	6.12 mm

Table 3.21: 6G Antenna Element Parameters with a Microstrip Patch element

S.No.	Array Parameter	Value
1	Element Object	patchMicrostrip
2	Frequency Range	27.5 - 28.5 GHz
3	Array Size (Panel)	8 x 16
4	Directivity	26.26 dB
5	Beamwidth (Azimuth)	6.78 deg
6	Beamwidth (Elevation)	12.21 deg
7	Amplitude Taper	TaylorWin, Chebyshev
8	Beam steering Tilt [Az, El]	[30, 45] deg
9	Sub-array Width (mm)	89.08
10	Sub-array Height (mm)	44.54

Table 3.22: 6G Antenna Array Parameters with a Microstrip Patch Element

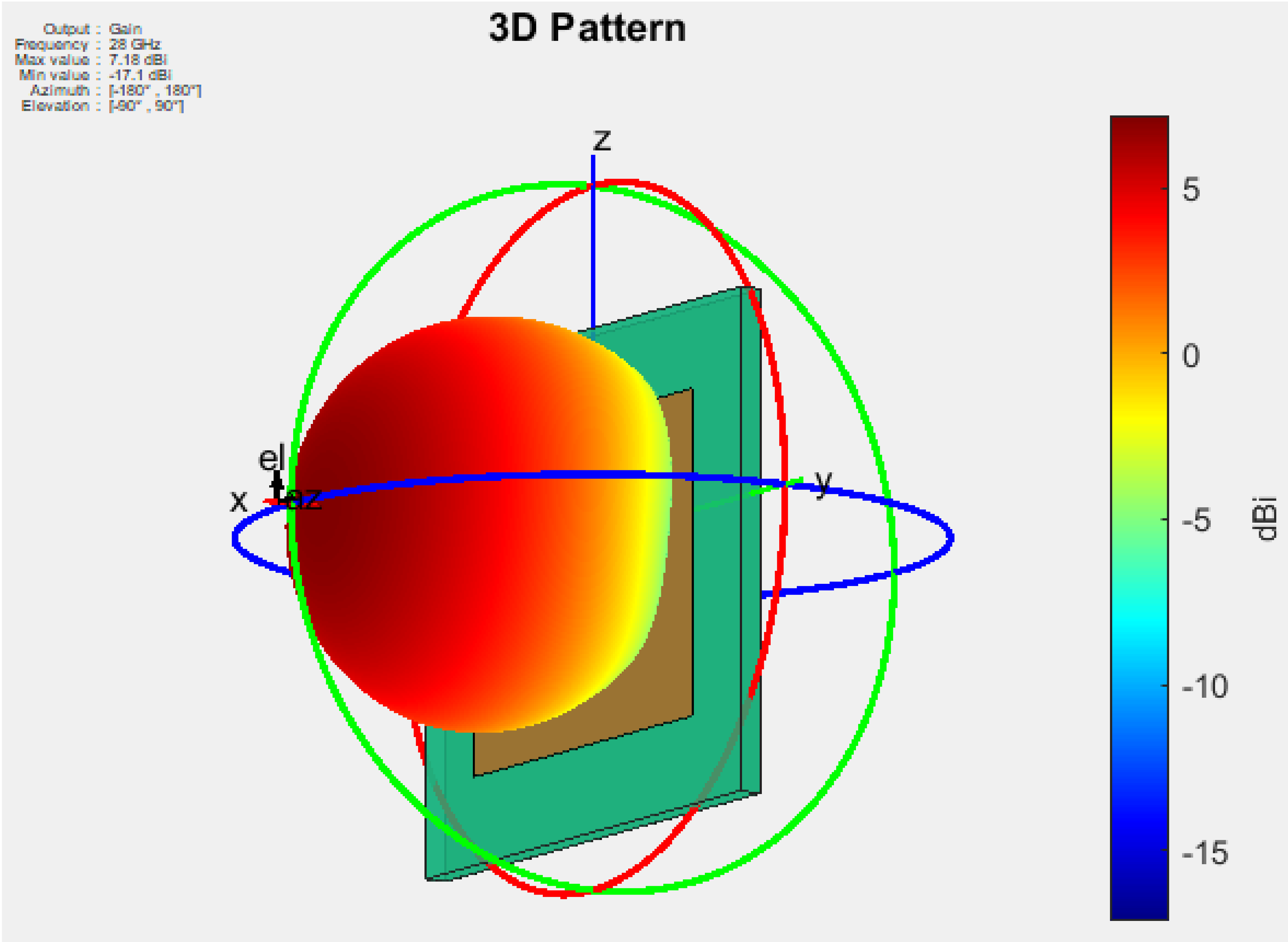

Fig. 3.21: 3D Radiation Pattern of the Microstrip Patch element

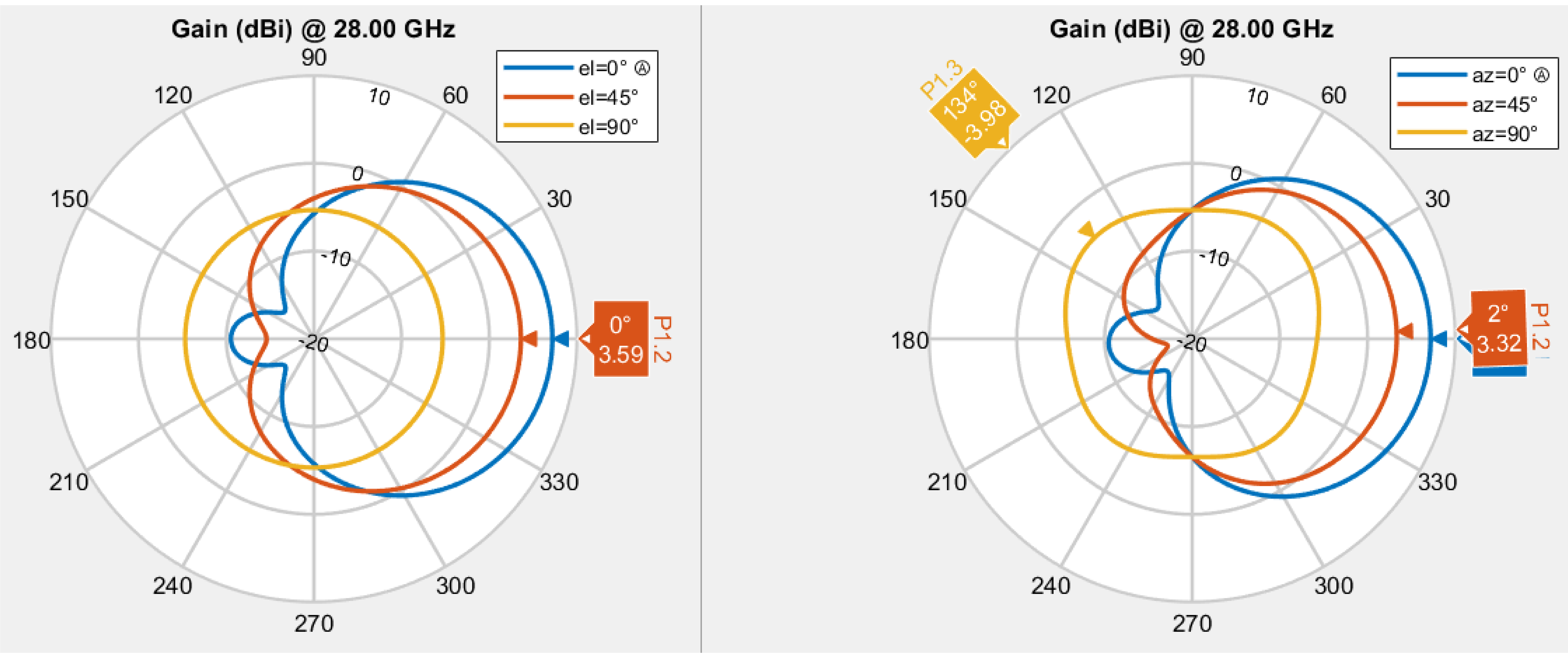

Fig. 3.22: Radiation Pattern along Azimuth and Elevation Cuts of the Microstrip Patch element

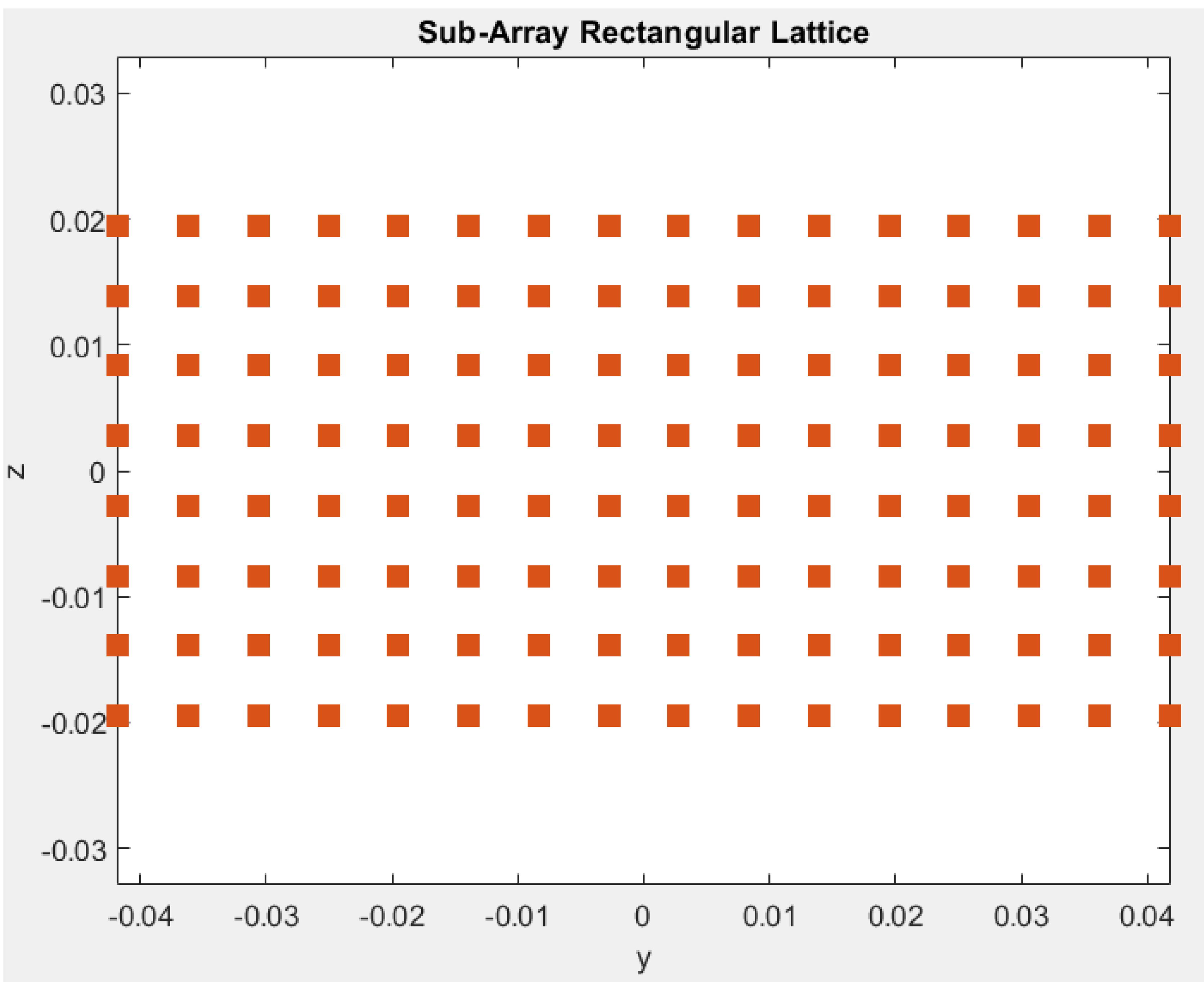

Fig. 3.23: Planar Layout of the Sub-Array (Panel) consisting of elements (8 x 16 array)

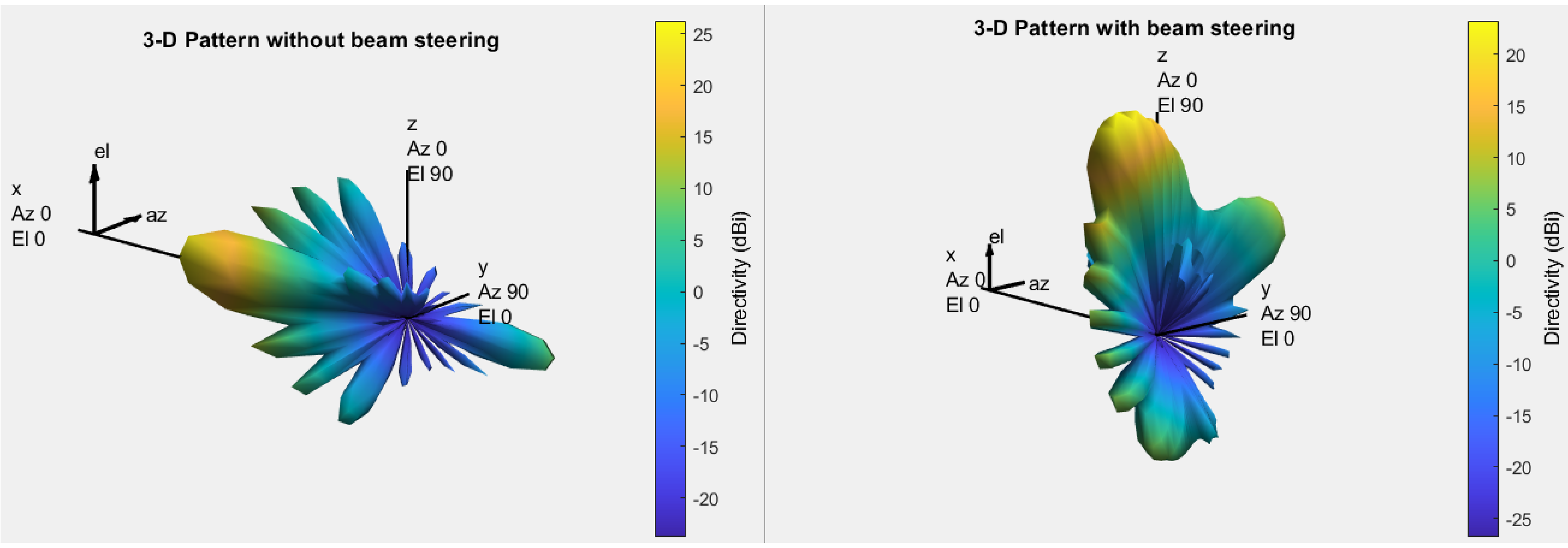

Fig. 3.24: 3D Sub-Array Radiation Pattern without and with Beam Steering

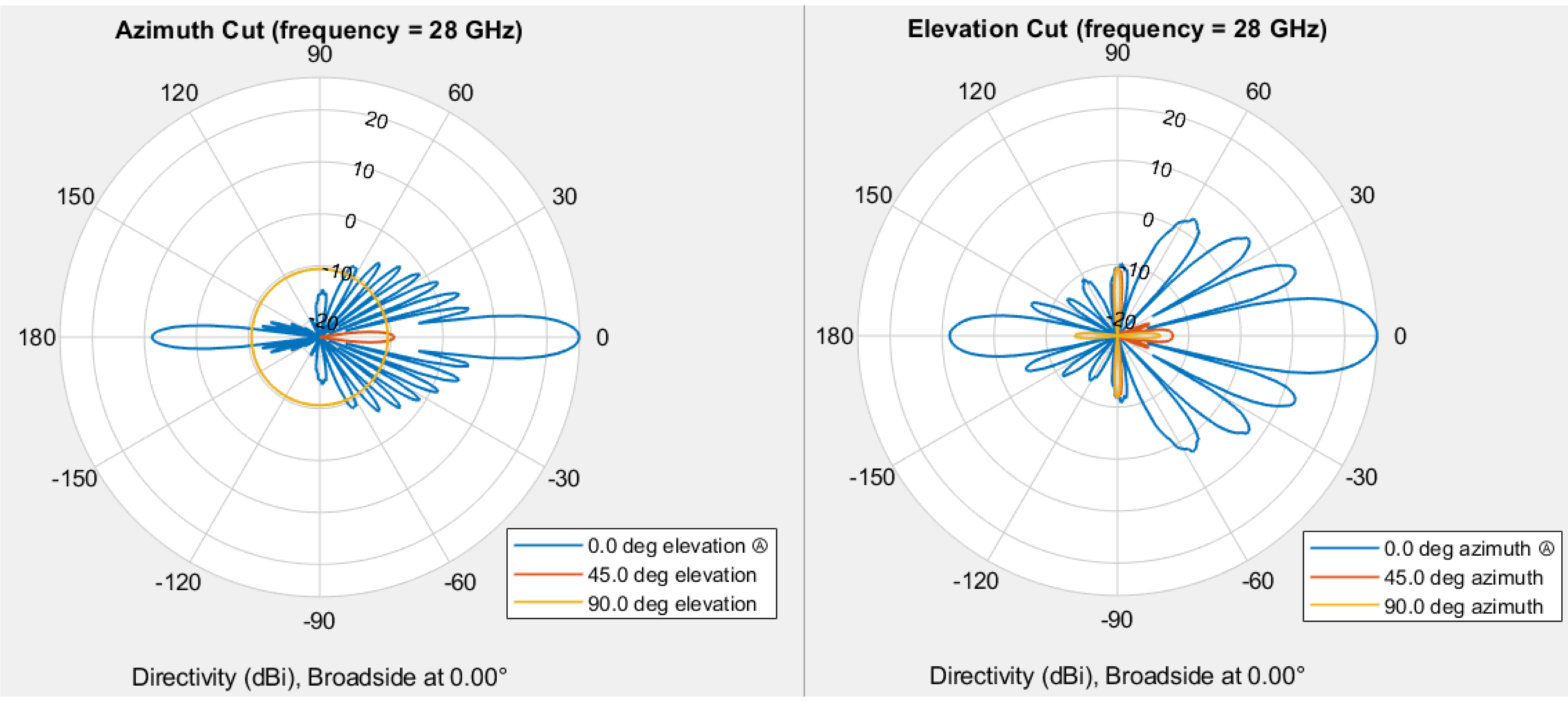

Fig. 3.25: Sub-Array Radiation Pattern along Azimuth/Elevation Cuts without Beam Steering

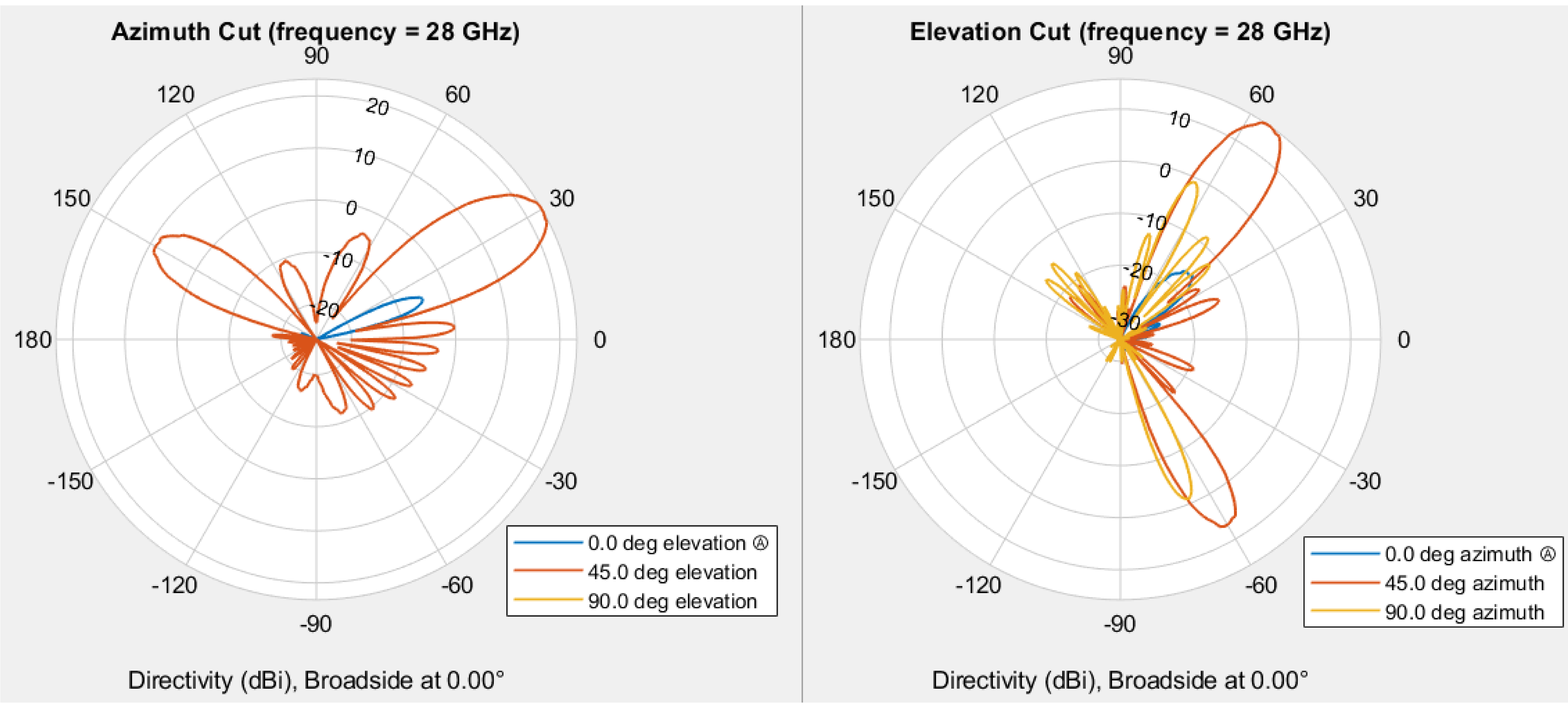

Fig. 3.26: Sub-Array Radiation Pattern along Azimuth/Elevation Cuts with Beam Steering

4. CDL (Clustered Delay Line) - A spatially aware channel

Signals get weakened & distorted in the transmission medium (channel) between TX and RX due to various factors like multipath fading, frequency-dependent delay, path loss due to beam spreading (Friis) and atmospheric absorption, etc. The channel can be predicted and quantified using various established channel models like the TDL (tapered delay line), CDL (clustered delay line), Scattering MIMO Channel, etc. A CDL channel model configures and fits the MIMO scenario very well, and it also has been used in this analysis (CDL-D). It is highly configurable and suitable for the established or custom profile that can be used for a given scenario. When CDL channel filtering is enabled, an input signal passes through the channel to transform into a channel-impaired signal. The path gains the fading process and sample times of the channel snapshots, which are also obtained. In the MATLAB 5G Toolbox, this is implemented as a nrCDLChannel object. In this technical report, the CDL-D profile for a channel model has been used in the analysis. The CDL channel specified the transmit and receive antenna array configurations. Being a spatially aware channel all parameters of TX and RX end antenna array having the panels/sub-arrays are specified. Figure 4.1 shows the configuration settings nomenclature for panels and elements.

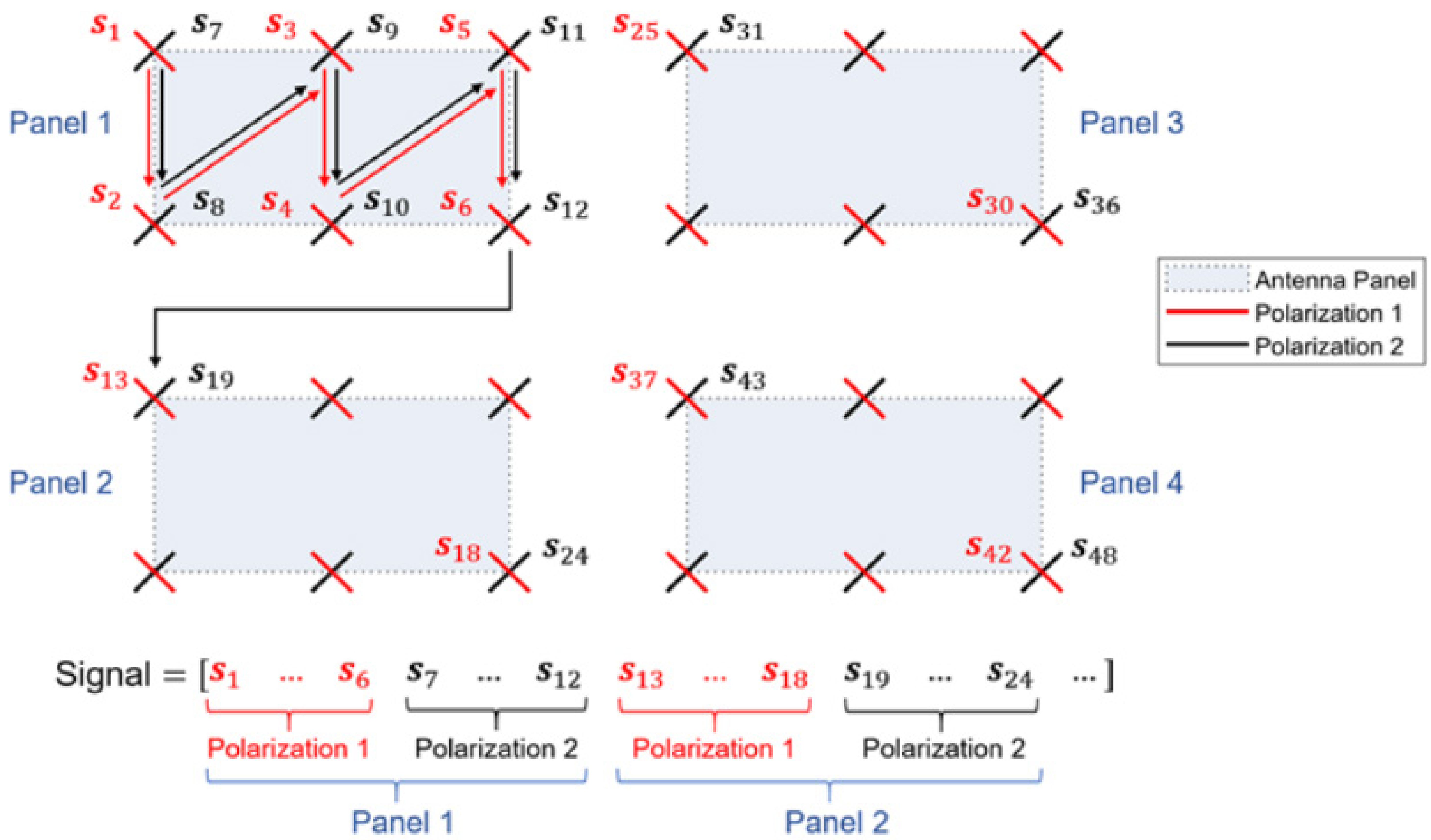

Fig. 4.1: TX/RX Antenna Array diagram.

The size of the array is specified by the vector [M N P Mg Ng] where:

M and N are the number of rows and columns of the array of each sub-array/panel. Each panel has M x N antenna elements. P is the number of polarizations used (1 or 2). Mg and Ng are the rows and columns of the overall antenna panels. The total number of panels is Mg x Ng.

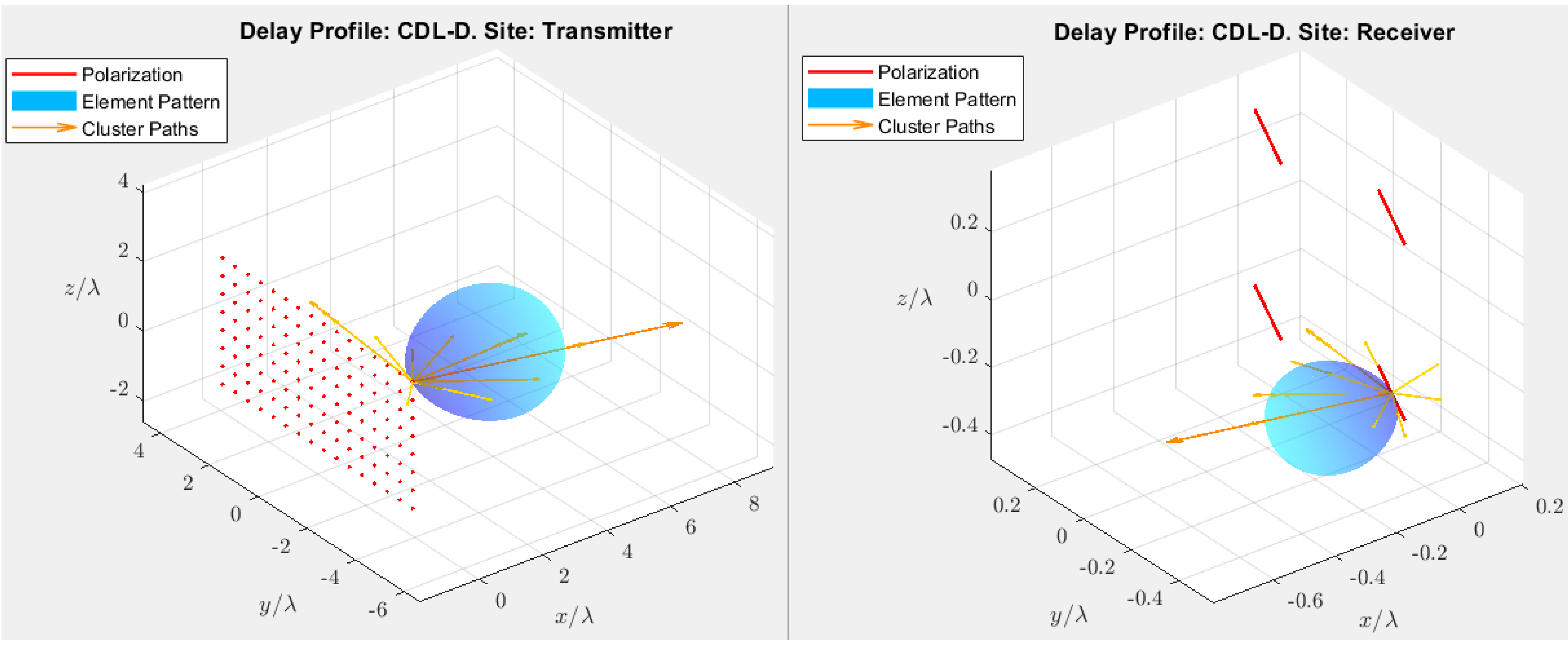

Fig. 4.2: CDL-D Channel Displayed with TX/RX array antennas, element patterns, and cluster paths.

5. Downlink synchronization signal blocks (SSB) generation

The Synchronization Signal / Physical Broadcast Channel (SS/PBCH) block is specified in 3GPP TS 38.211. It has 240 subcarriers on the frequency axis and 4 OFDM symbols on the time axis containing the following channels and signals:

1. Primary synchronization signal (PSS)
2. Secondary synchronization signal (SSS)
3. Physical broadcast channel (PBCH)
4. PBCH demodulation reference signal (PBCH DM-RS)

The SS/PBCH is termed "synchronization signal block" or "SS block". Multiple SS Blocks are carried in an SS Burst. SS Block (SSB) is grouped into the first 5 ms of an SS Burst. The 5G Toolbox has been used to configure the SSB object (s) and generate SSB waveform(s). Fig. 5.1 shows the spectrogram of an SS burst waveform analyzed using the MATLAB 5G Toolbox. Table 5.1 below has the configuration parameters of the SSB object used in this analysis.

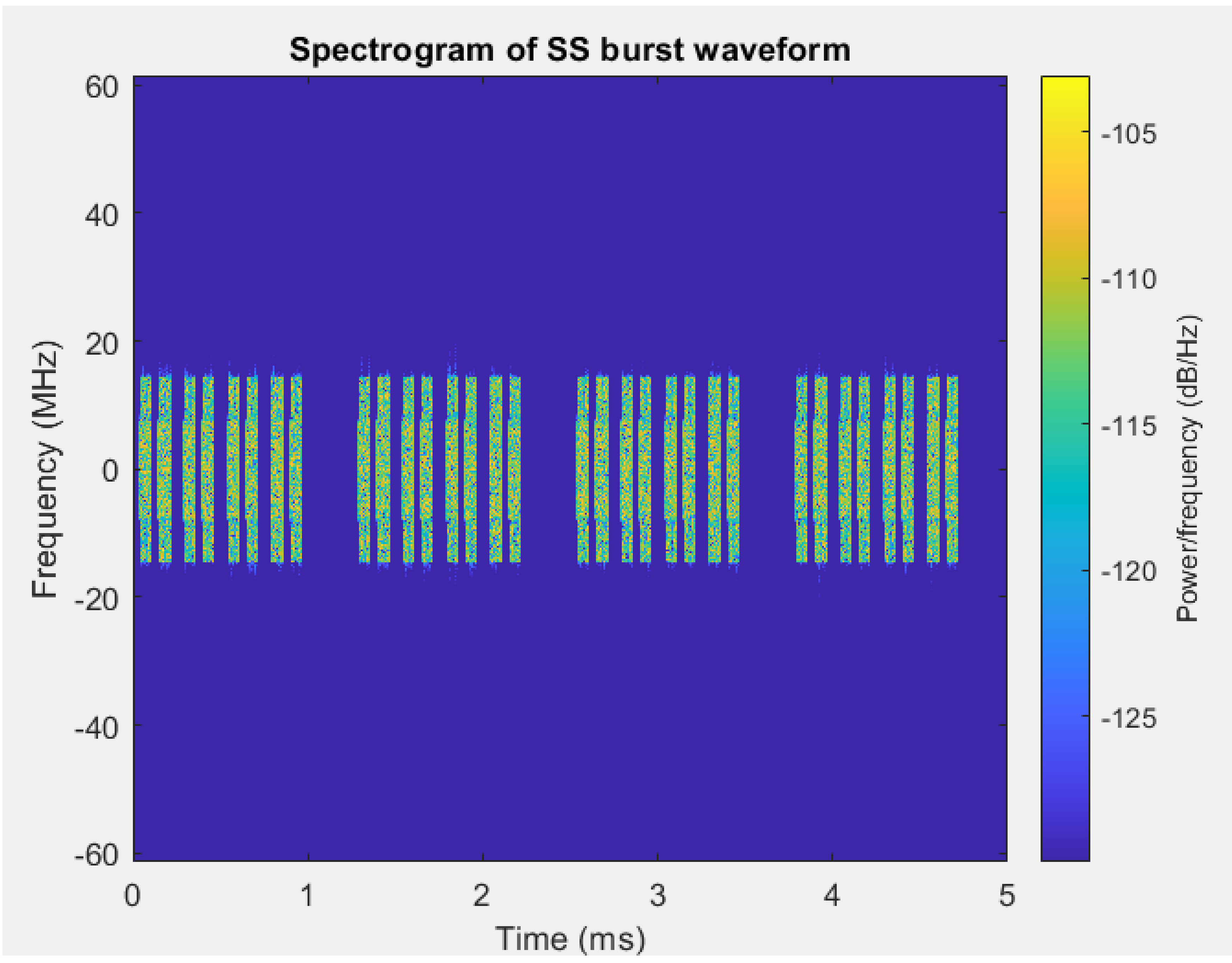

Fig. 5.1: Spectrogram of SS Burst waveform

S.No.	Parameter	Value
1	Center Frequency	28 GHz
2	Frequency Range	FR-2
3	Subcarrier Spacing Common (SCS)	120 KHz
4	Channel Bandwidth	100 MHz
5	NCellID	108
6	Power	0 dB
7	SNR	36 dB
8	Block Pattern	‘Case D’
9	Period	20 ms
10	SSB Transmitted	ones(1,64)
11	TX Array Size	8 x 16
12	RX Array Size	2 x 2
13	Number TX	128 (8x16)
14	Number RX	4 (2x2)
15	TX Position [x; y; z]	[0; 0; 0]
16	RX Position [x; y; z]	[100; 10; -20]
17	TX Azimuth Limit	[-90, 90]
18	TX Elevation Limit	[-90, 90]
19	RX Azimuth Limit	[-90, 90]
20	RX Elevation Limit	[-90, 90]
21	Elevation Sweep	1 (True)
22	RSRP Mode	‘SSSwDMRS’

Table 5.1: SSB Configuration Parameters

6. TX and RX side beam sweeping procedures

Beam management procedures are required for directional or near directional links in 5G/6G during initial access to establish a link between UE and gNB. Beam management is a set of Layer 1 (physical) and Layer 2 (medium access control) procedures to acquire and maintain a set of beam pair links (a beam used at gNB paired with a beam used at UE). Beam management procedures are applied for both downlink and uplink transmission and reception. These procedures include:

1. Beam sweeping
2. Beam measurement
3. Beam determination
4. Beam reporting, beam recovery, etc

The 3 basic performance parameters computed are defined as follows:

- RSRP per Antenna: Reference Signal Received Power per Antenna at UE
- RSSI per Antenna: Received Signal Strength Indicator per Antenna at UE
- RSRQ per Antenna: Reference Signal Received Quality per Antenna at UE

To achieve TRP beam sweeping, each of the SS blocks is beamformed in the generated burst using analog beamforming. Based on the number of SS blocks in the burst and the sweep ranges specified, both the azimuth and elevation directions are determined for the different beams. Then the individual blocks within the burst to each of these directions are beamformed. In this analysis, both transmit/receive point (TRP) beam sweeping and UE beam sweeping are to establish a beam pair link. Using MATLAB-based scripts, the analysis generates an NR synchronization signal burst, beam forms each of the SSBs within the burst to sweep over both azimuth and elevation directions, transmits this beamformed signal over a spatial scattering channel (CDL), and processes this received signal over the multiple receive-end beams.

7. Beam measurement & determination

In the analysis, reference signal received power (RSRP) measured for each of the transmit-receive beam pairs (in a dual loop - transmit beams and receive beams) is used to determine the beam pair link with the maximum RSRP. This beam pair link thus signifies the best beam pair at the transmit and receive ends for the simulated spatial scenario.

A. Beam measurement

Table 7.1 below shows the results of beam measurement while looping over transmit and receive beams with the data on performance parameters like RSRP per Antenna, RSSI per Antenna, and RSRQ per Antenna.

RX beam #	RSRP per antenna (dBm)	RSSI per antenna (dBm)	RSRQ per antenna (dB)
1 of 64	-27.65	17.46	-32.09
2 of 64	-30.52	17.74	-35.25
3 of 64	-25.98	17.79	-30.76
...	...	...	...
...	...	...	...
31 of 64	-30.63	17.61	-35.23

32 of 64	-30.63	17.61	-35.23
33 of 64	-24.03	17.97	-28.99
34 of 64	-33.12	17.66	-37.77
35 of 64	-25.17	17.76	-29.93
36 of 64	-28.00	17.57	-32.56
...	...	...	...
...	...	...	...
60 of 64	-22.49	17.87	-27.35
61 of 64	-32.90	17.62	-37.51
62 of 64	-25.47	17.97	-30.43
63 of 64	-28.29	17.87	-33.15
64 of 64	-23.33	17.89	-28.21

Table 7.1: SSB RX end Beam Sweeping and Measurement computation

B. Beam determination

Table 7.2 below shows the results of beam determination after looping over transmit and receive beams with the best data on RSRP and the associated TX and RX beam numbers. The Azimuth and Elevation angles of each beam number are shown. A dataset for another beam pair is added for comparison.

S.No.	TX Beam No.	TX Beam [Az El] (deg)	RX Beam No.	RX Beam [Az El] (deg)	RSRP (dBm)	Remarks
1	17	Azimuth: -67.5 Elevation: -22.5	28	Azimuth: 0 Elevation: 0	149.07	Best beam pair
2	49	Azimuth: -78.75 Elevation: 0	12	Azimuth: 0 Elevation: -22.5	143.74	Good pair (for comparison)

Table 7.2: Beam Determination and Best Beam Pair

8. Conclusion

This technical report presents results and visualizations for antenna elements, sub-arrays, and SSB beam sweeping computations. First, two different types of antenna elements are analyzed. One antenna element - the Microstrip Patch - is designed based on analytical calculations and using the MATLAB Antenna Toolbox solver. Next, these elements are used to design sub-arrays required for SSB beam sweeping. Beamsteering is demonstrated for given angles in azimuth and elevation plane cuts. Beamforming is used using designed antenna sub-arrays (panels) and their designed elements.

Finally, results of analysis & simulations are presented for SSB beam sweeping, measurement, and determination at the 28 GHz (FR-2) band. Results and visualizations are presented using the MATLAB toolboxes - 5G Toolbox, Phased Array System Toolbox & Antenna Toolbox.

9. References

1. MATLAB 5G Toolbox 2023b User Guide & Reference
2. MATLAB Antenna Toolbox 2023b User Guide & Reference
3. MATLAB Phased Array System Toolbox 2023b User Guide & Reference
4. NTT DOCOMO Technical Journal Vol.17, No.4, 2016
5. Ericsson White Paper, BNEW-23:004809UEN, February 2023
6. Samsung Technical White Paper, Massive MIMO for New Radio, Dec. 2020
7. Analog Dialogue 51-06, June 2017, Massive MIMO and Beamforming: The Signal Processing Behind the 5G Buzzwords
8. 3GPP Specifications 38.901 – Study on Channel Models
9. 3GPP Specifications 38.104 – Base Station Radio Transmission and Reception
10. 3GPP Specifications 38.101 – UE Radio Transmission and Reception
11. 3GPP Specifications 38.211 – Physical Channels and Modulation
12. 3GPP Specifications 38.212 – Multiplexing and Channel Coding
13. 3GPP Specifications 38.214 – Physical Layer Procedures for Data

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