BGT60ATR24C ES shield characterization

XENSIV™ 60 GHz radar system platform

Board version V2.0

About this document

Scope and purpose

This application note describes the performance characterization and measurement results of the BGT60ATR24C [1] engineering samples-based shield (SHIELD_60ATR24ES_01) [2], part of Infineon's XENSIV™ 60 GHz radar system platform. The shield provides the supporting circuitry to the on-board BGT60ATR24C monolithic microwave integrated circuit (MMIC) Infineon's 60 GHz radar chipset. The MMIC is designed to work with external antennas. Additionally, the shield offers a digital interface for configuration and transfer of the acquired radar data to a microcontroller board, e.g., Radar Baseboard MCU7 [3].

Intended audience

The intended audience for this document are design engineers, technicians, and developers of electronic systems, working with Infineon's XENSIV™ 60 GHz radar sensors, especially in automotive scenarios called in-cabin sensing (ICMS). Among the many applications it can be used for are – rear occupancy alert (ROA) and – left behind child (LBC) systems.

Note: *The MMIC-related parameters mentioned in this document are based on engineering samples (ES). This is an important consideration when interpreting the results and measurements presented in the document.*

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1 Introduction

1.1 Device overview and orientation

The BGT60ATR24C ES shield is the demo platform for Infineon's 60 GHz radar sensor. This application note focuses on the performance characterization measurements of the radar sensor board.

Figure 1 shows the orientation of the external transmit and receive antennas on the BGT60ATR24C ES shield. The distance between the adjacent Rx antennas is half-wavelength, which corresponds to 0.25 cm. For Tx antennas, the offset is again half-wavelength for both directions.

The RF shield has a minimized form factor of 16 x 26 mm with external antennas, and the chipset size is 6 x 6 mm.

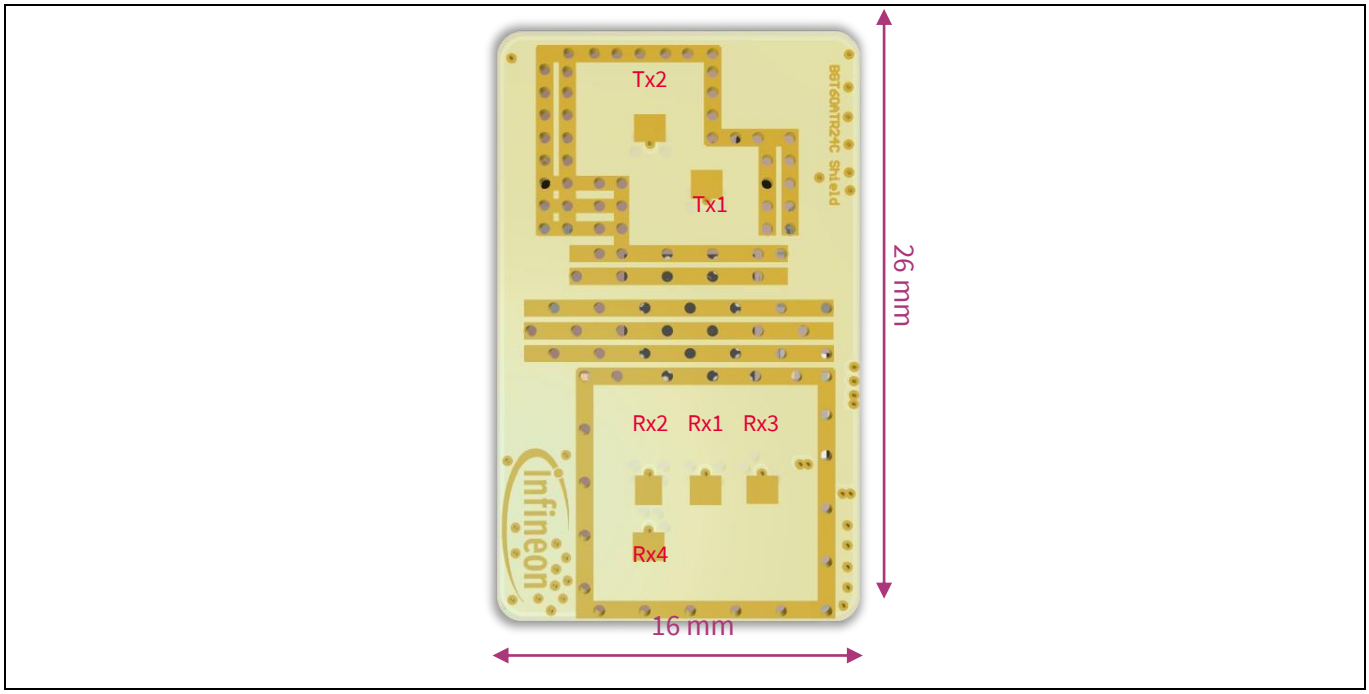

Figure 1 Antenna orientation and size of the BGT60ATR24C ES shield

1.2 Virtual antenna array

With two Tx and four Rx channels, the BGT60ATR24C ES shield can be used in multiple-input and multiple-output (MIMO) mode. With these antennas, a virtual antenna array that consists of eight elements can be achieved, as illustrated in Figure 2.

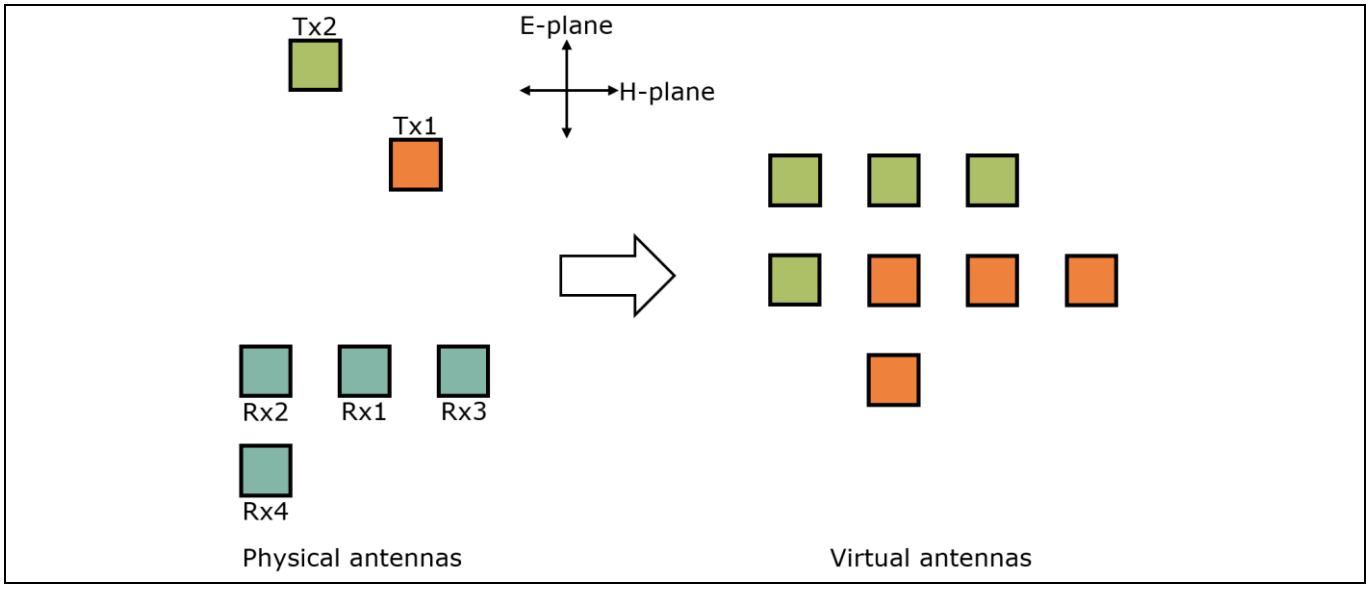

Figure 2 Orientation of the physical antennas and corresponding virtual antenna array

2 Measurement setup and characterization algorithm

2.1 Anechoic antenna chamber

The characterization measurements are taken in the anechoic antenna chamber shown in Figure 3. A corner reflector is used in front of the radar as a stable target.

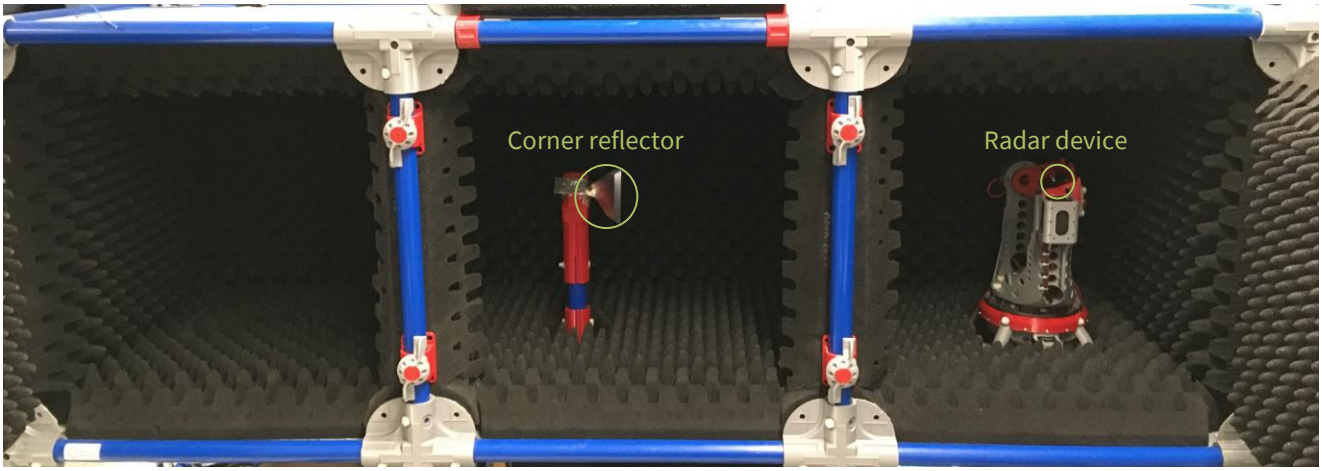

Figure 3 Anechoic antenna chamber used for the measurements

The antenna positioner (gimbal) in Figure 4 is used for horizontal and vertical axis rotations of antennas. The measurements are taken for each vertical position by scanning all horizontal angles at that angle.

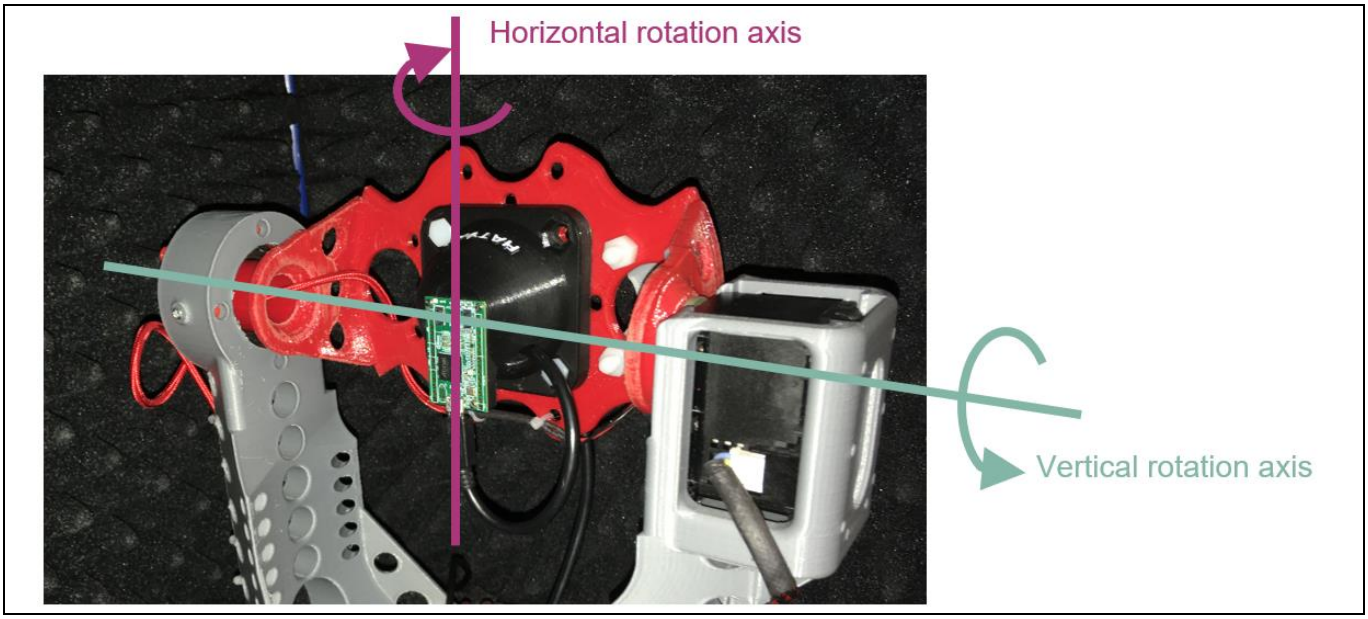

Figure 4 Antenna positioner (gimbal) for horizontal and vertical rotation of antennas

2.2 Measurement parameters and settings

Table 1 Measurement parameters and settings

Parameter	Value
Horizontal measurement angles	–50 degrees to +50 degrees with 5-degree steps
Vertical measurement angles	–50 degrees to +50 degrees with 5-degree steps
Total measured angles	441
Distance to corner reflector	1.4 m
Tx output power setting	31
Measured frequency bands	58 to 62 GHz 58 to 61 GHz 58.5 to 61.5 GHz 59 to 62 GHz
Number of Rx antennas	4
Number of Tx antennas	2
Number of samples per chirp	128
Number of chirps per frame	32
Number of frames	10
HP_GAIN	1
HP_CUTOFF	3
VGA_GAIN	3

2.3 Characterization algorithm

In order to reconstruct the amplitude and angle information from the measurements, the characterization algorithm in Figure 5 is used. The algorithm is repeated for each measured angle to obtain amplitude and angle characteristics for the measurement span.

The amplitudes are illustrated with heatmaps for each virtual antenna element, as in the upper-right plots of Figure 5. For angle estimation, all virtual antennas are used for the digital beamforming algorithm. The azimuth and elevation angles are reconstructed separately and illustrated with 3D and 2D plots, as in the lower-right plots of Figure 5.

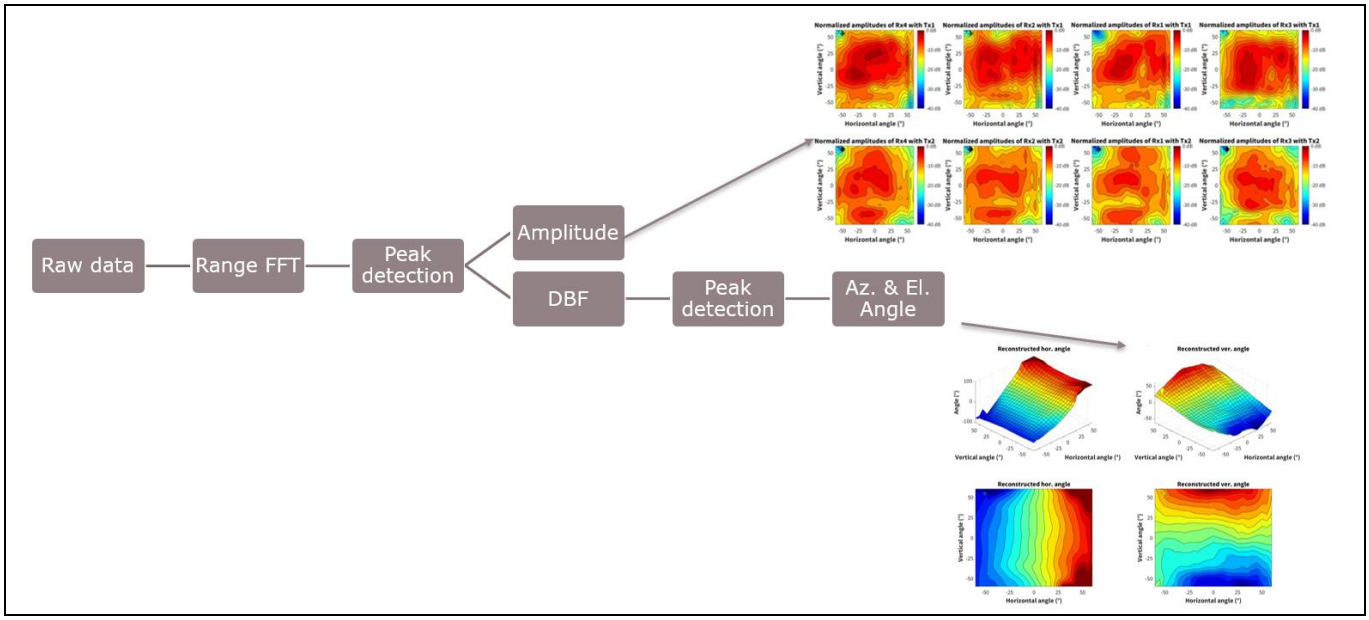

Figure 5 Characterization algorithm for amplitude and angle reconstruction

3 Amplitude characterization

This section of the document presents a detailed overview of the amplitudes over measurement angles for different frequency bands, boards, and antennas.

3.1 Amplitude characteristics over boards

In this section, characteristics are compared for different boards for each frequency band. For each amplitude characteristic, the corresponding signal-to-antenna chamber noise ratio (SACNR) is also plotted.

3.1.1 58 to 61 GHz

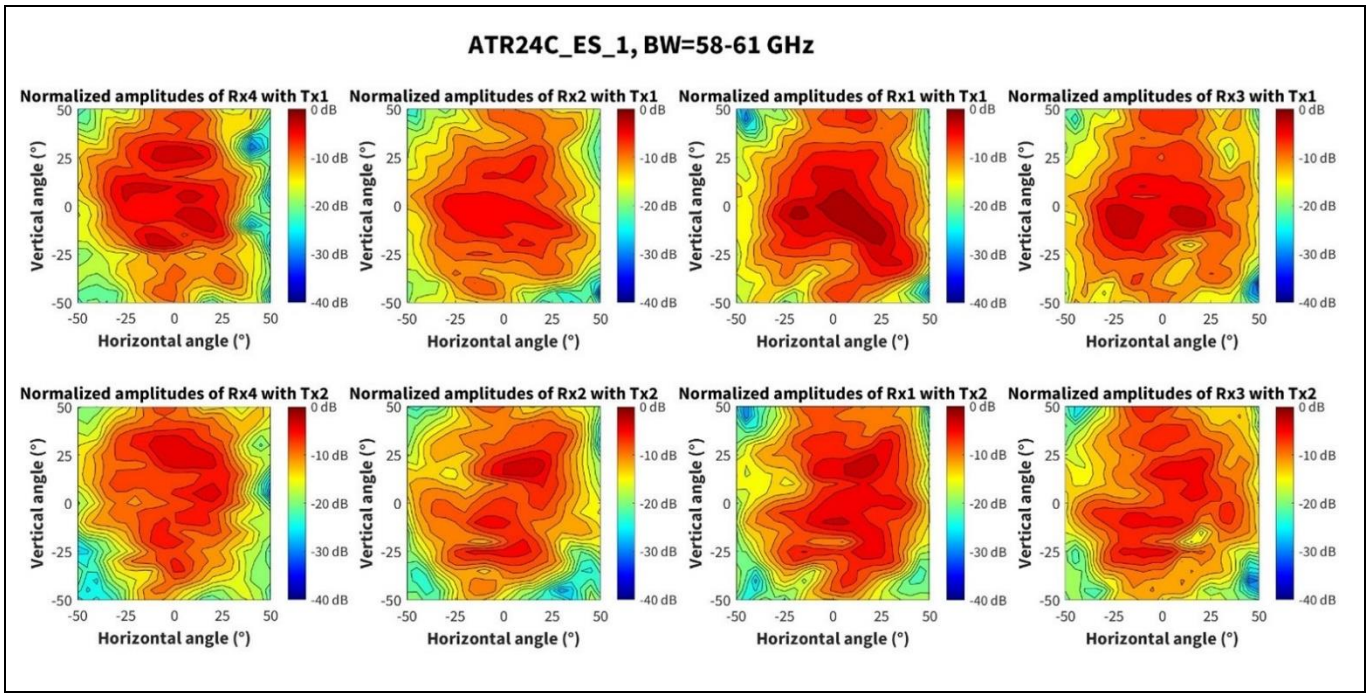

Figure 6 Amplitude characteristics of all virtual antennas for 58 to 61 GHz band

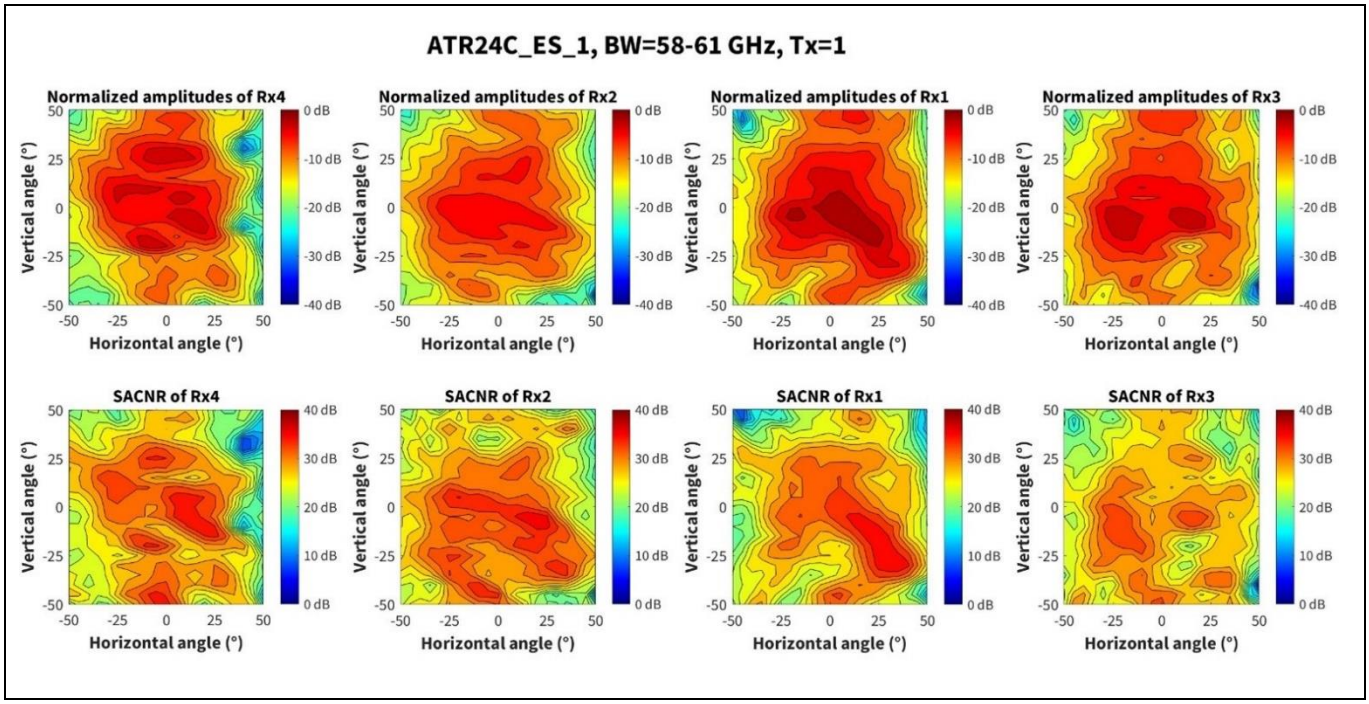

Figure 7 Amplitude and SACNR characteristics with Tx1 channel for 58 to 61 GHz band

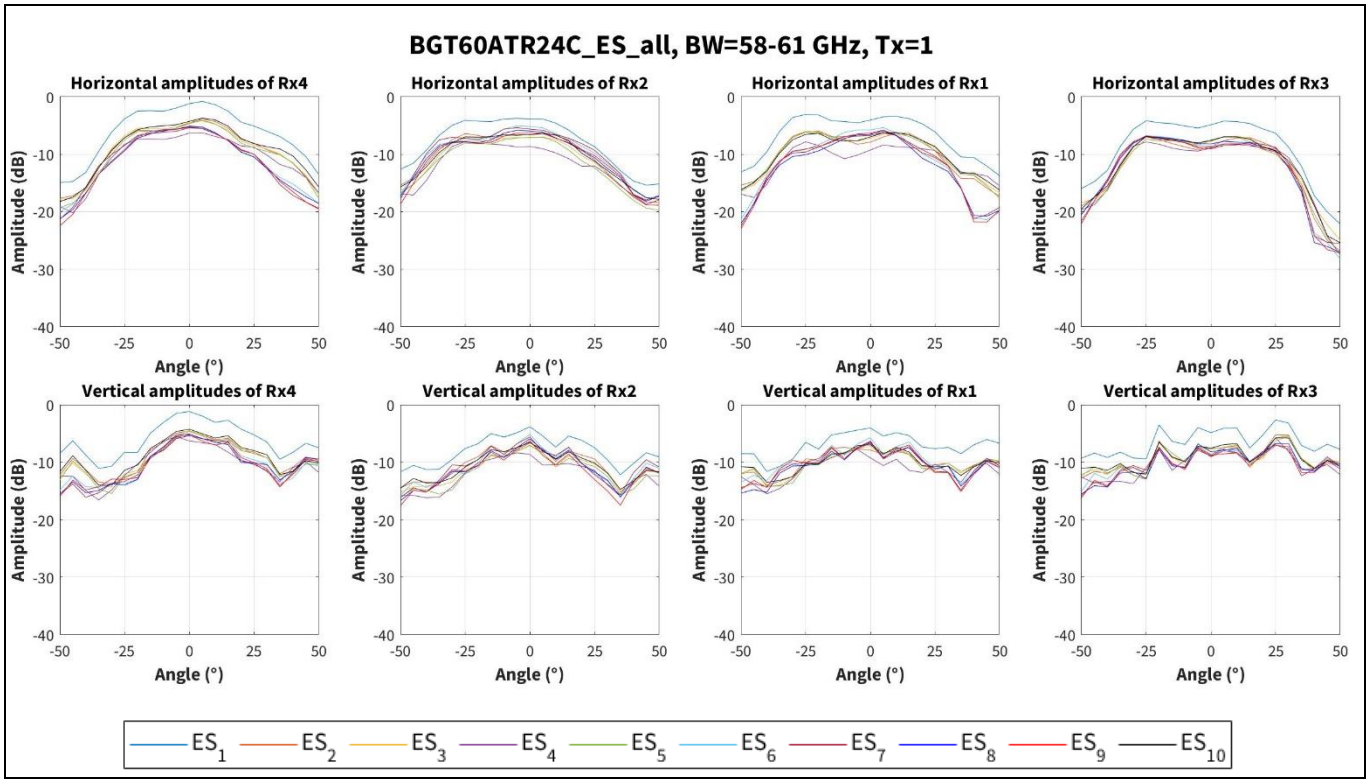

Figure 8 Amplitude characteristics on horizontal and vertical cross-sections with Tx1 channel for 58 to 61 GHz band for 10 boards

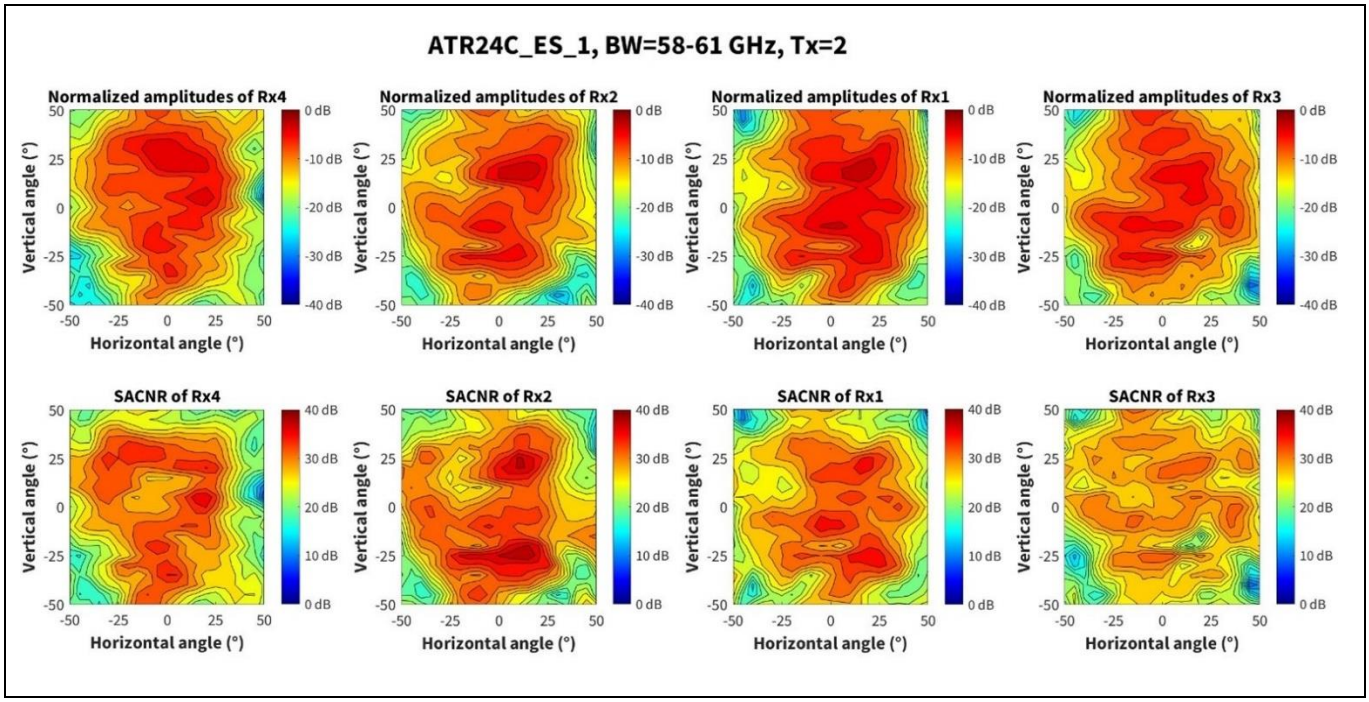

Figure 9 Amplitude and SACNR characteristics with Tx2 channel for 58 to 61 GHz band

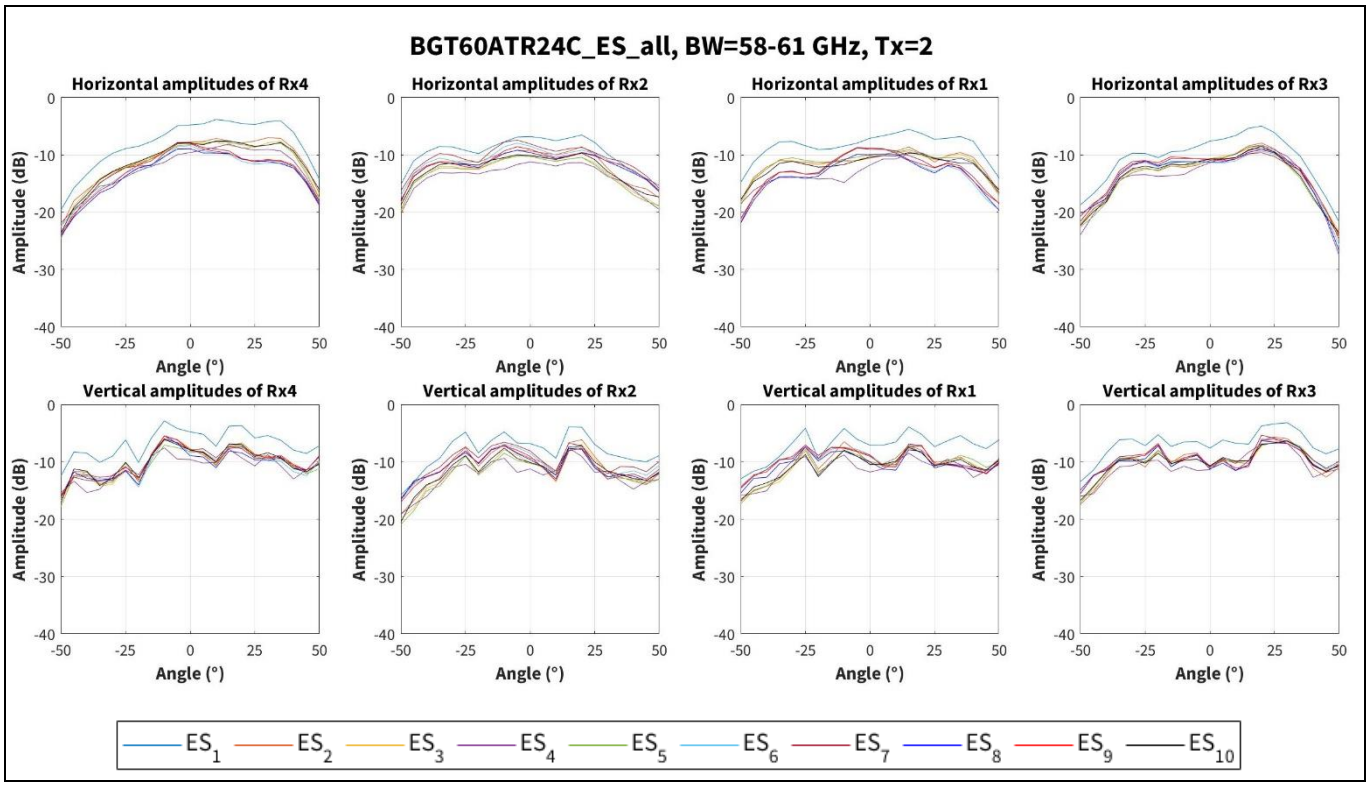

Figure 10 Amplitude characteristics on horizontal and vertical cross-section with Tx2 channel for 58 to 61 GHz band for 10 boards

3.1.2 58.5 to 61.5 GHz

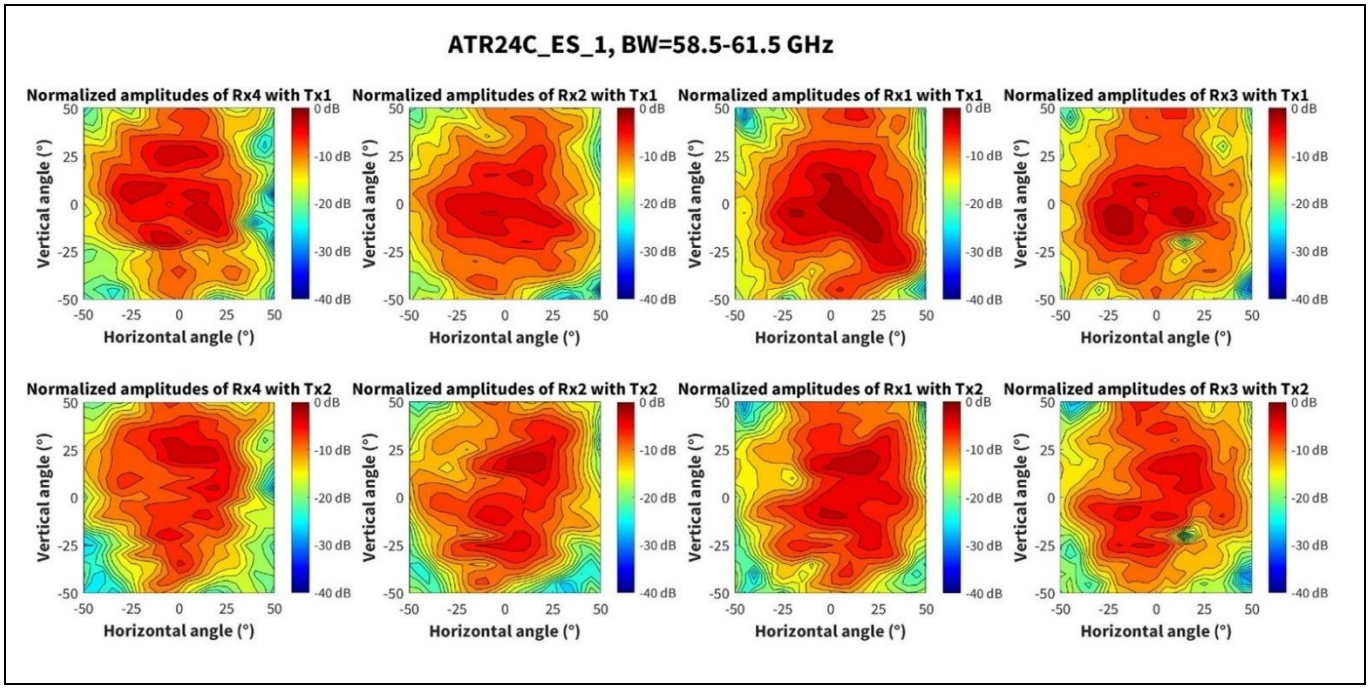

Figure 11 Amplitude characteristics of all virtual antennas for 58.5 to 61.5 GHz band

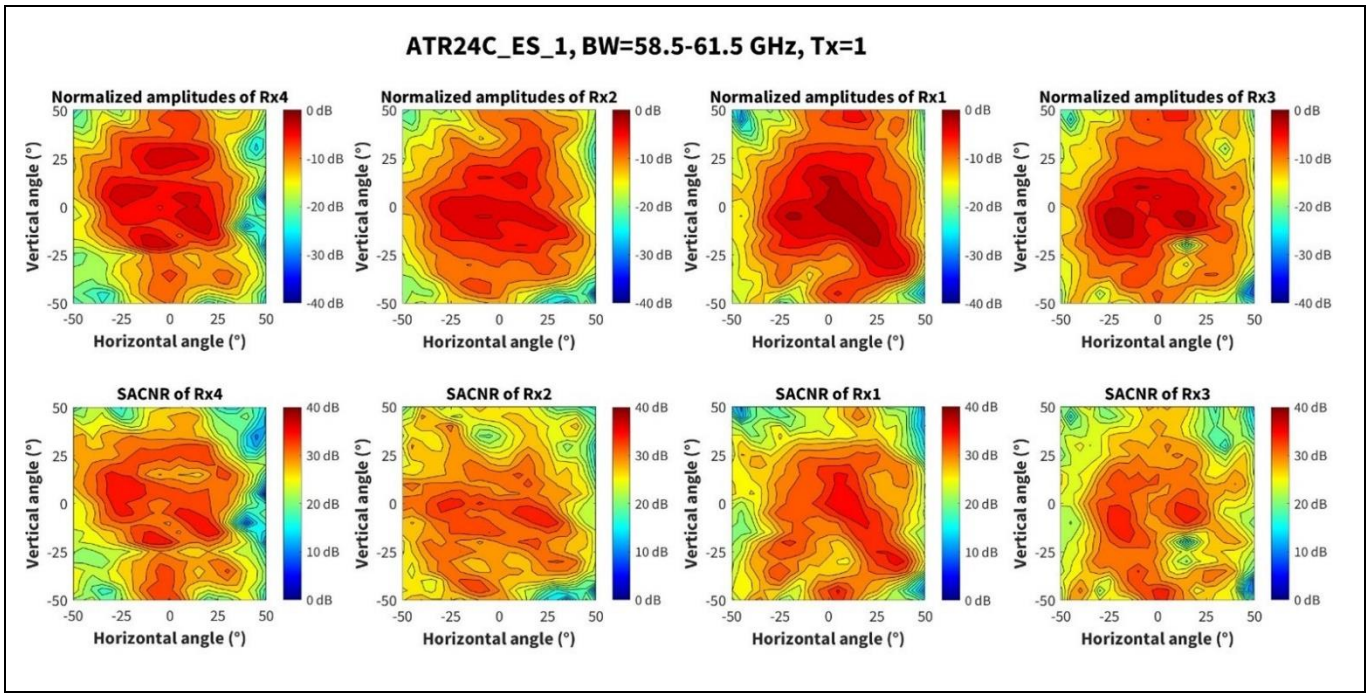

Figure 12 Amplitude and SACNR characteristics with Tx1 channel for 58.5 to 61.5 GHz band

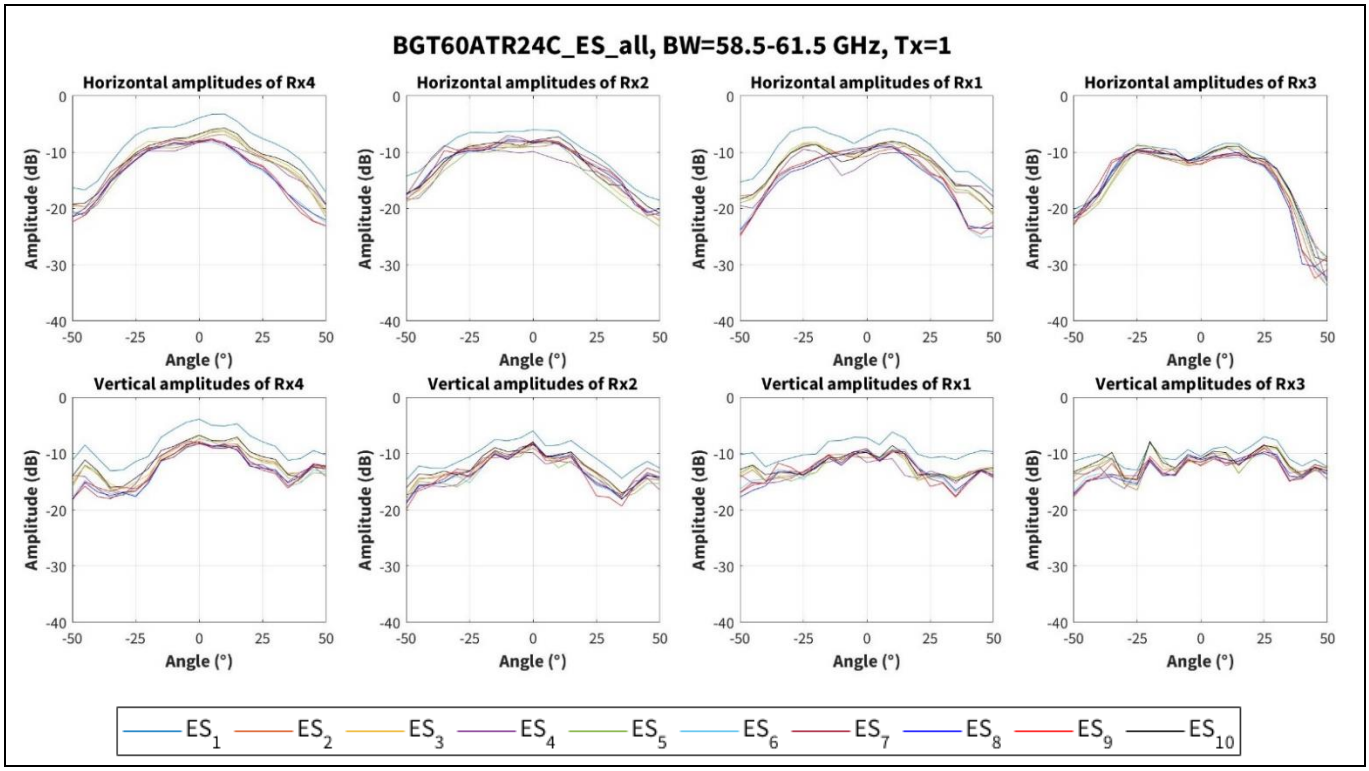

Figure 13 Amplitude characteristics on horizontal and vertical cross-sections with Tx1 channel for 58.5 to 61.5 GHz band for 10 boards

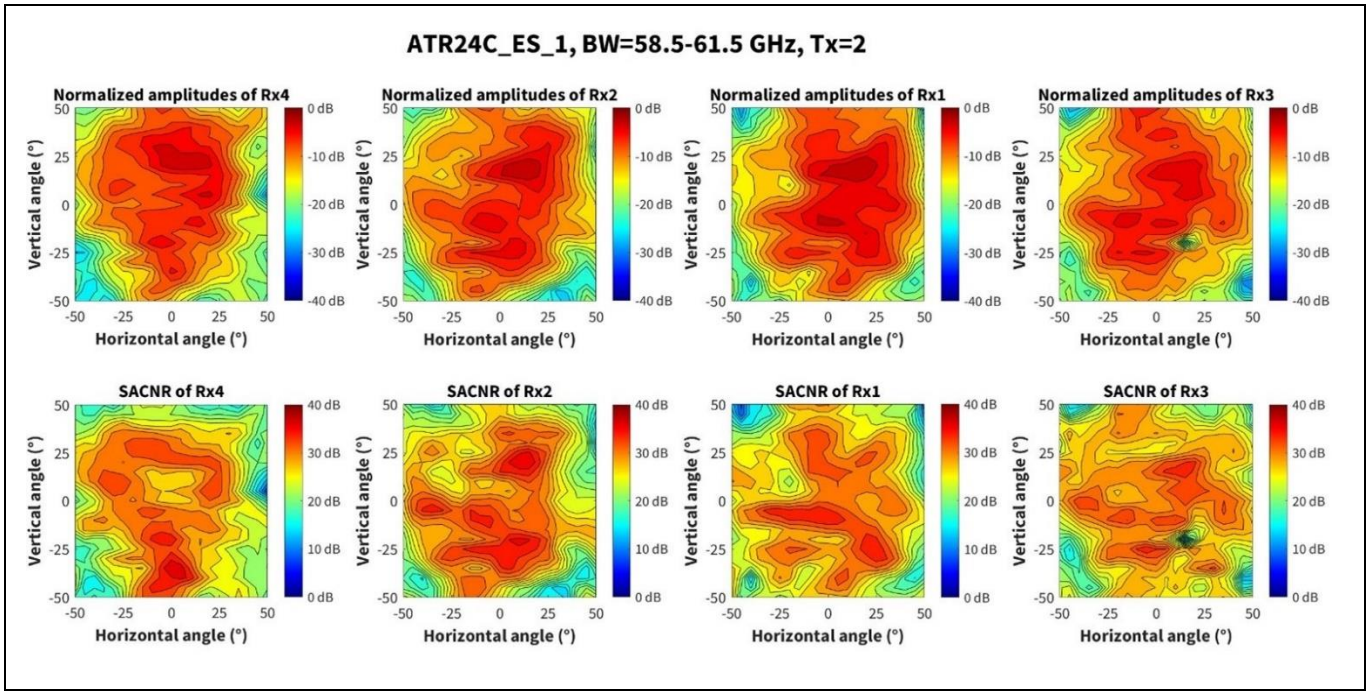

Figure 14 Amplitude and SACNR characteristics with Tx2 channel for 58.5 to 61.5 GHz band

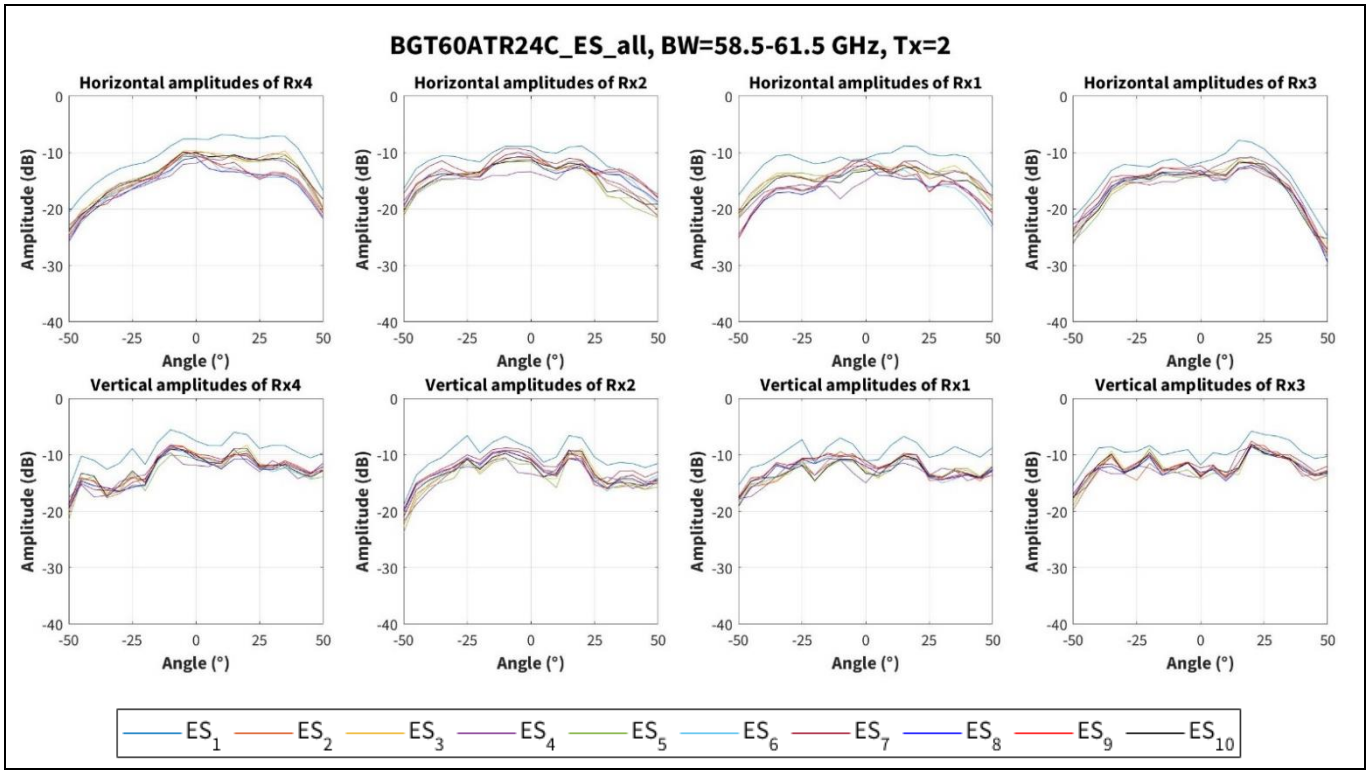

Figure 15 Amplitude characteristics on horizontal and vertical cross-sections with Tx2 channel for 58.5 to 61.5 GHz band for 10 boards

3.1.3 59 to 62 GHz

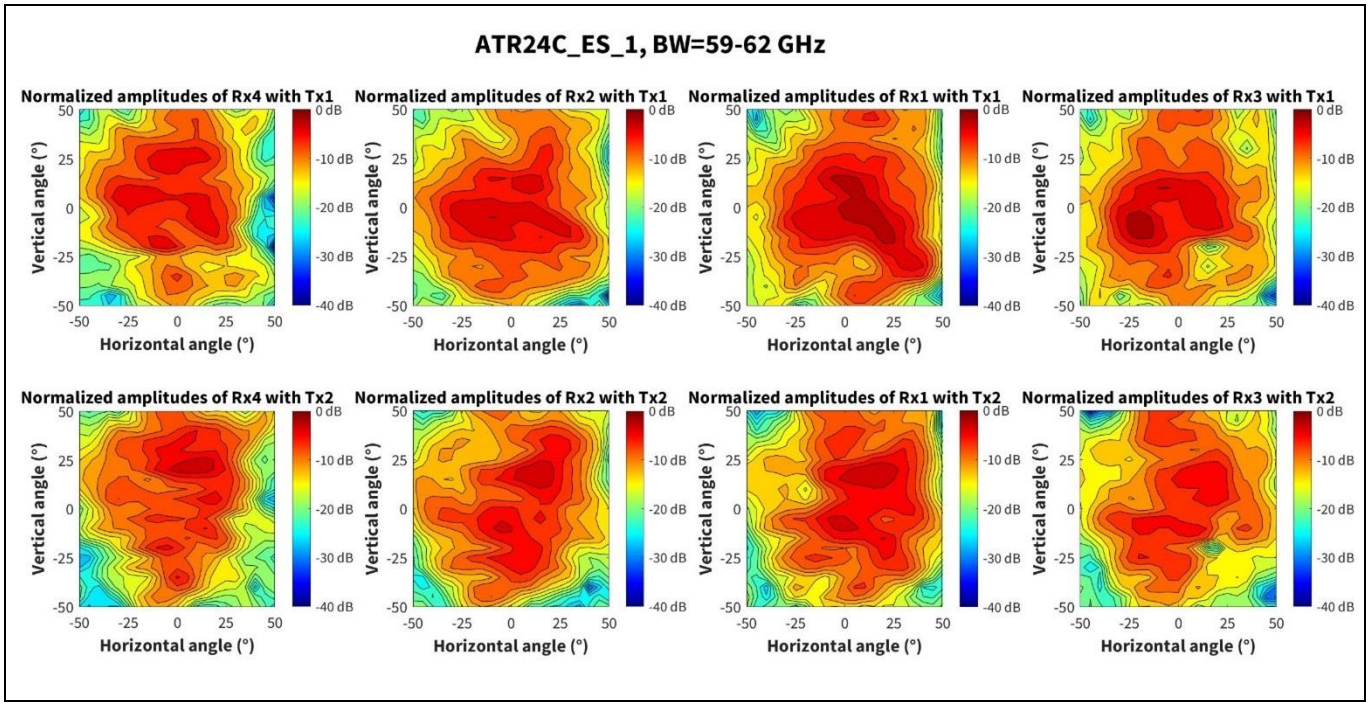

Figure 16 Amplitude characteristics of all virtual antennas for 59 to 62 GHz band

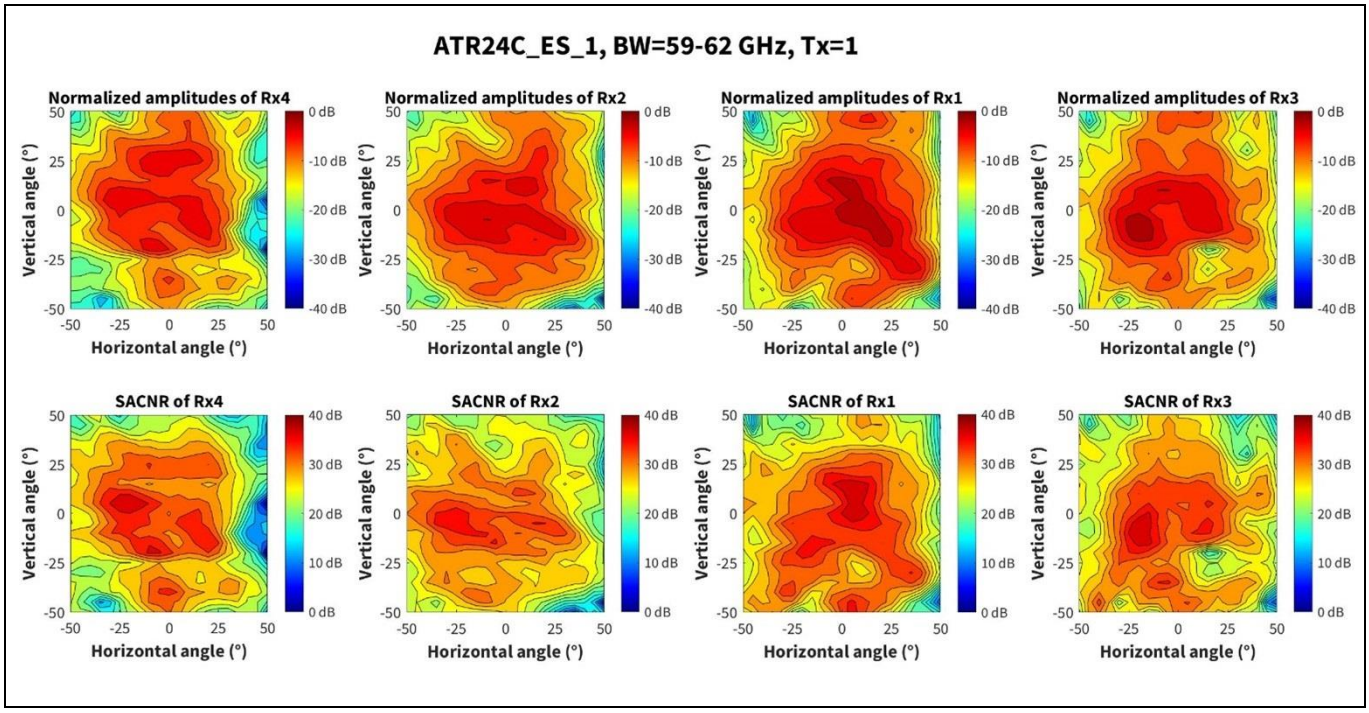

Figure 17 Amplitude and SACNR characteristics with Tx1 channel for 59 to 62 GHz band

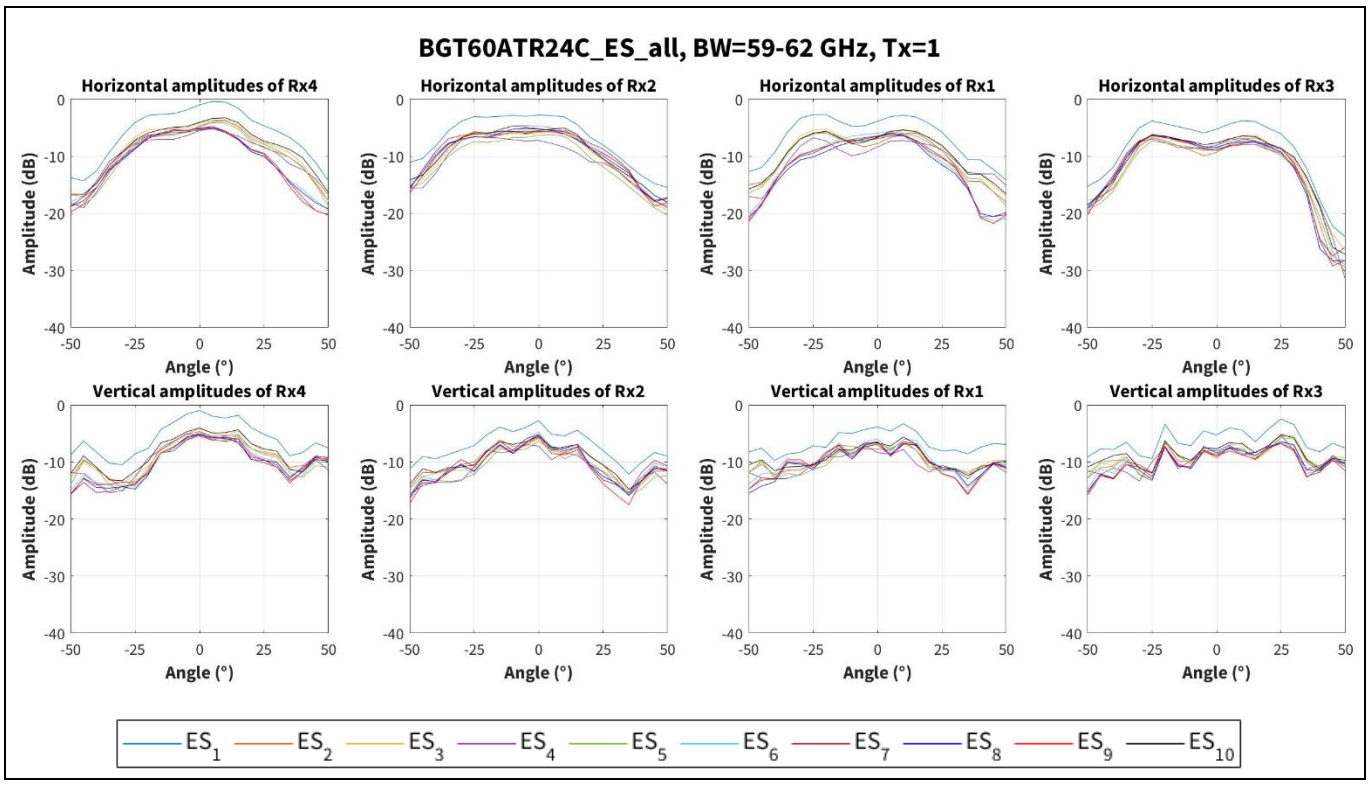

Figure 18 Amplitude characteristics on horizontal and vertical cross-sections with Tx1 channel for 59 to 62 GHz band for 10 boards

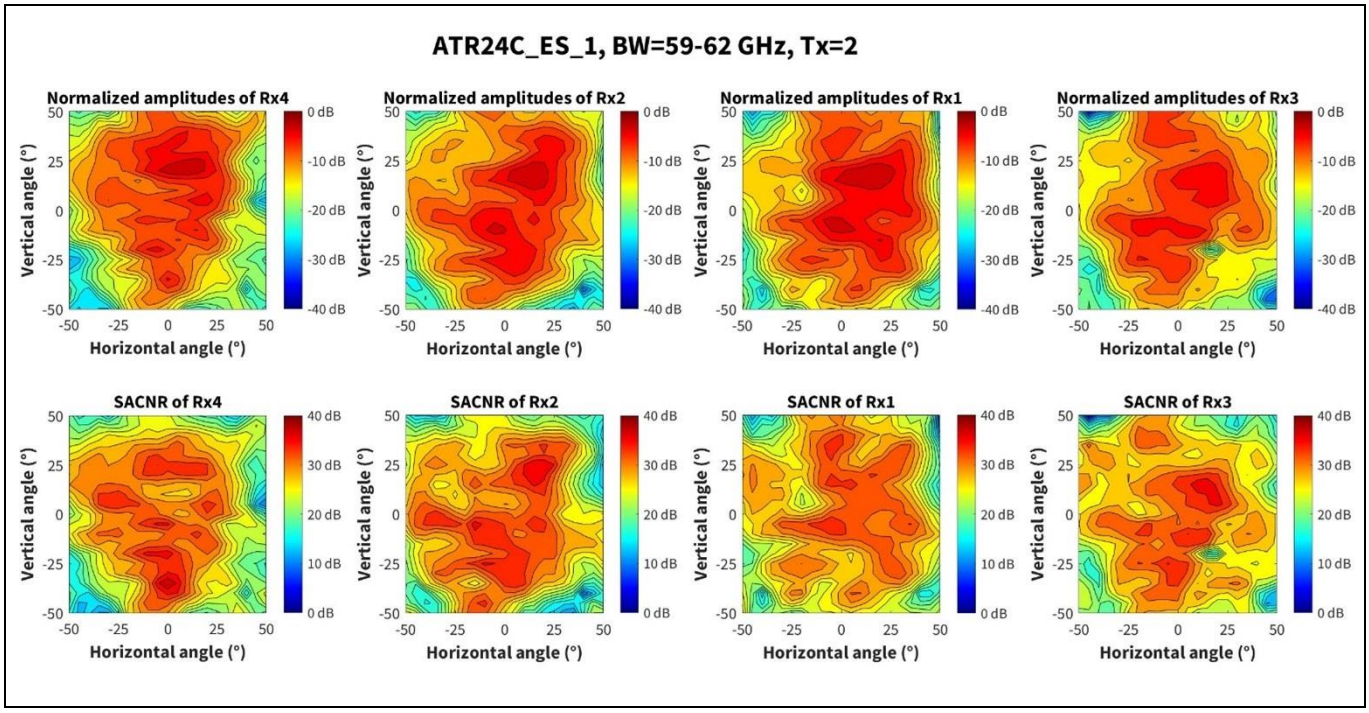

Figure 19 Amplitude and SACNR characteristics with Tx2 channel for 59 to 62 GHz band

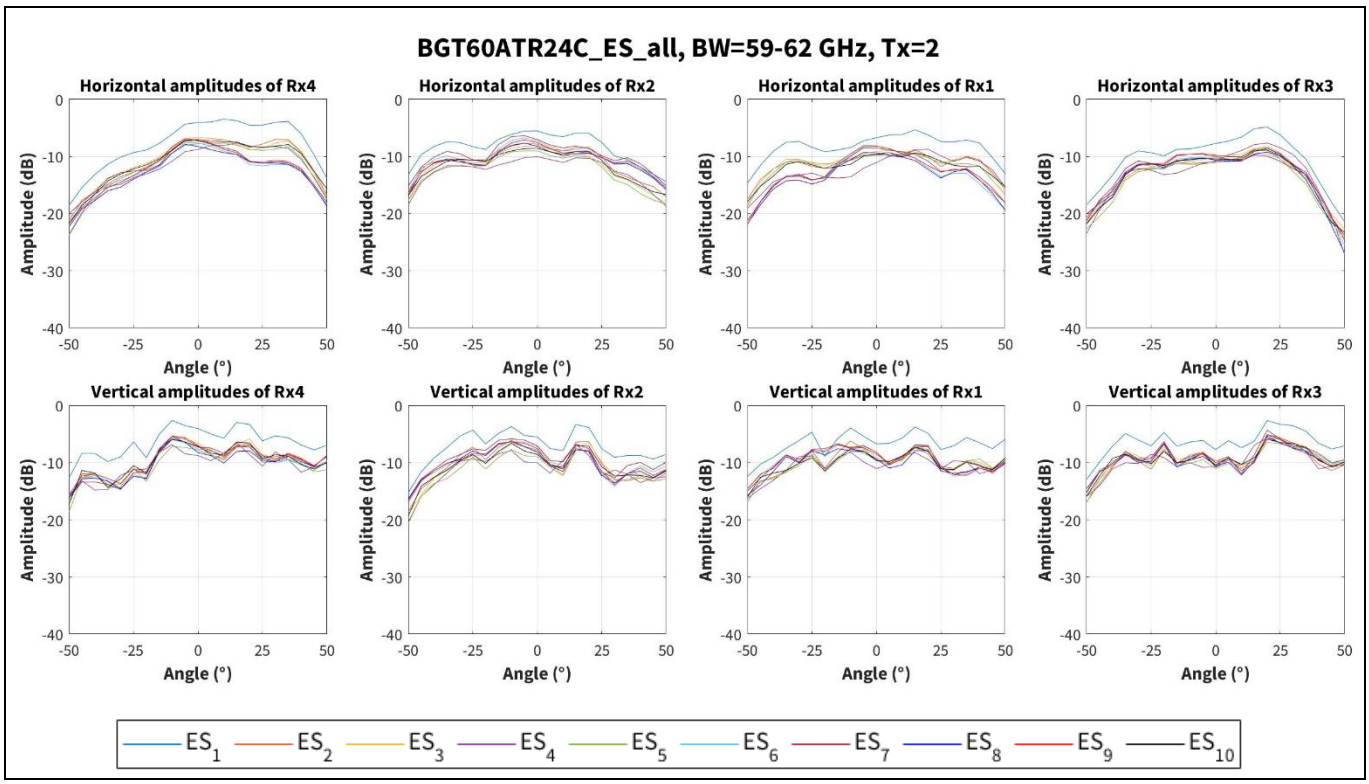

Figure 20 Amplitude characteristics on horizontal and vertical cross-sections with Tx2 channel for 59 to 62 GHz band for 10 boards

3.1.4 58 to 62 GHz

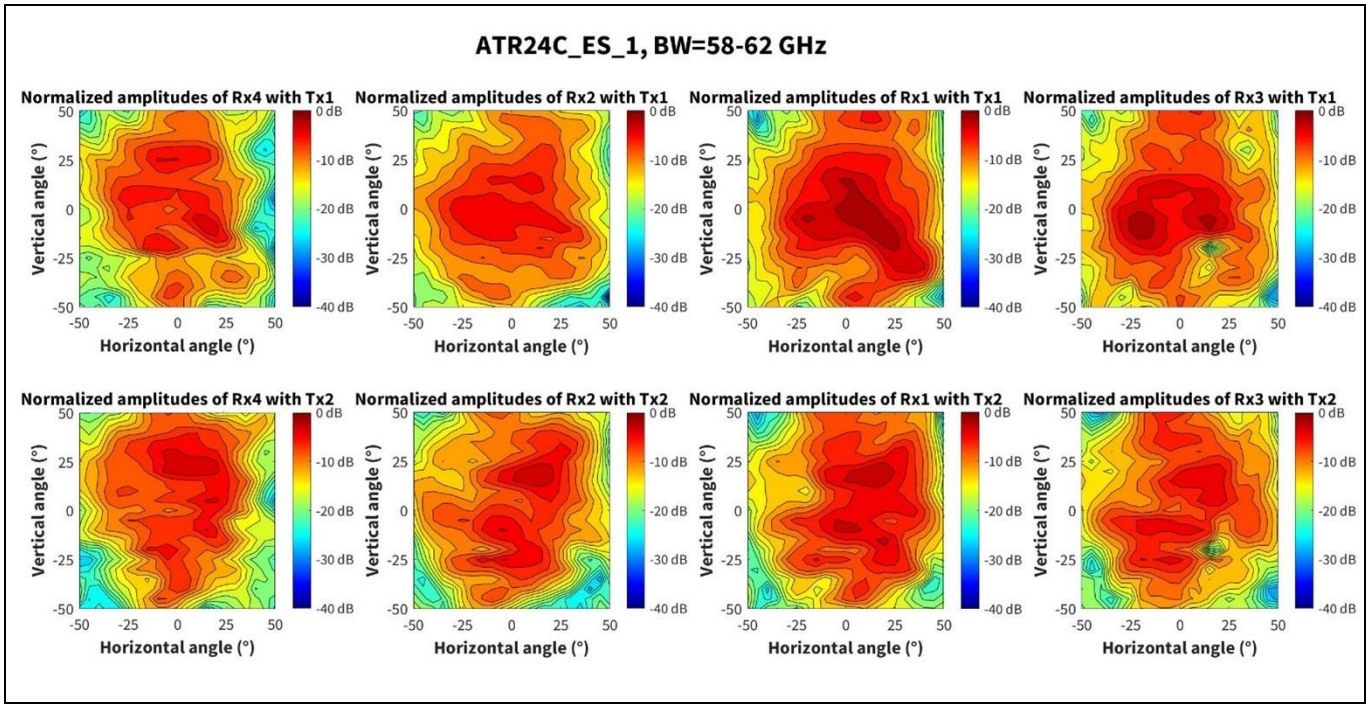

Figure 21 Amplitude characteristics of all virtual antennas for 58 to 62 GHz band

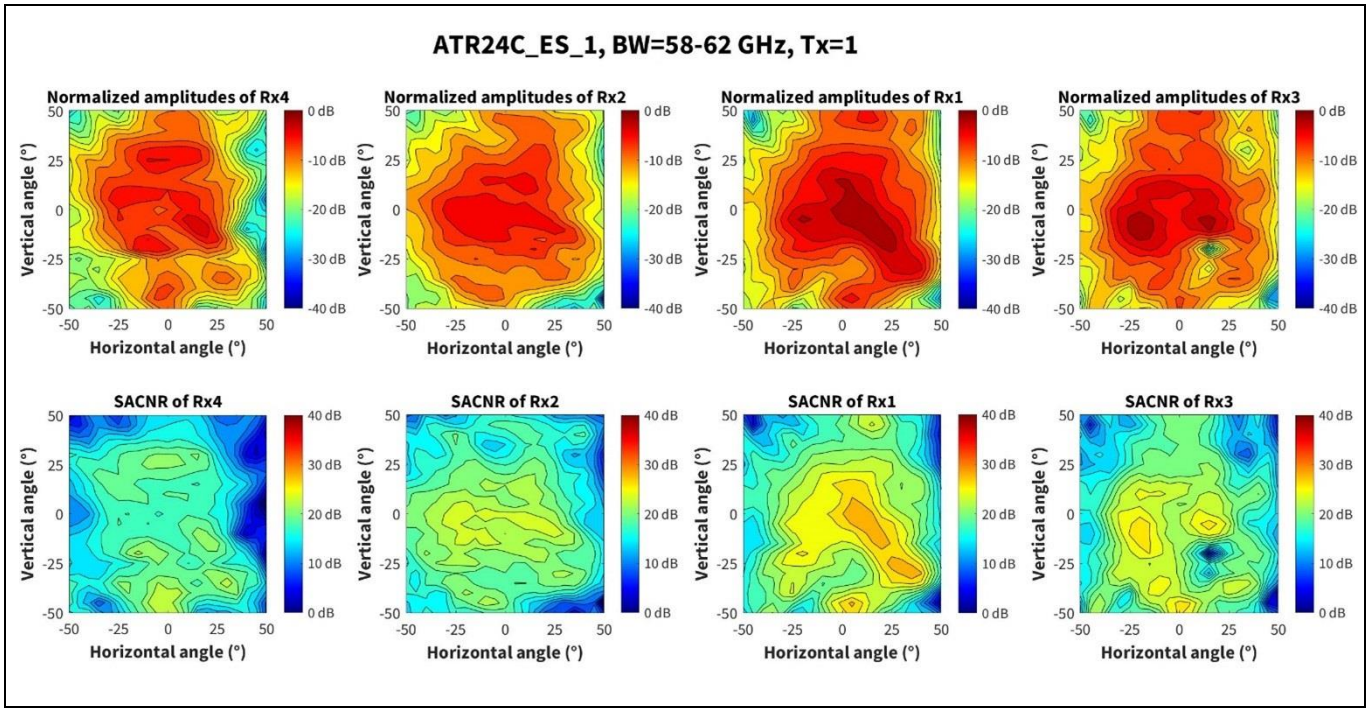

Figure 22 Amplitude and SACNR characteristics with Tx1 channel for 58 to 62 GHz band

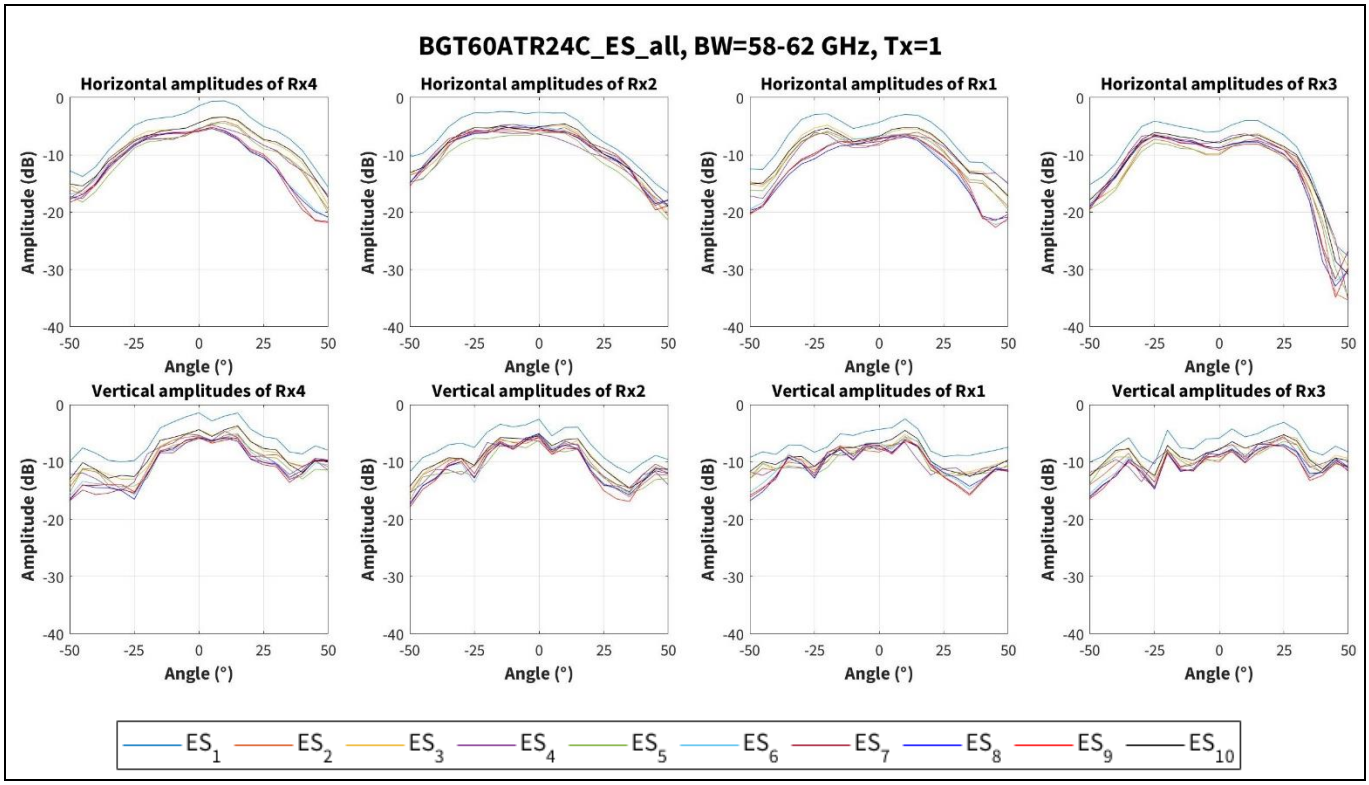

Figure 23 Amplitude characteristics on horizontal and vertical cross-sections with Tx1 channel for 58 to 62 GHz band for 10 boards

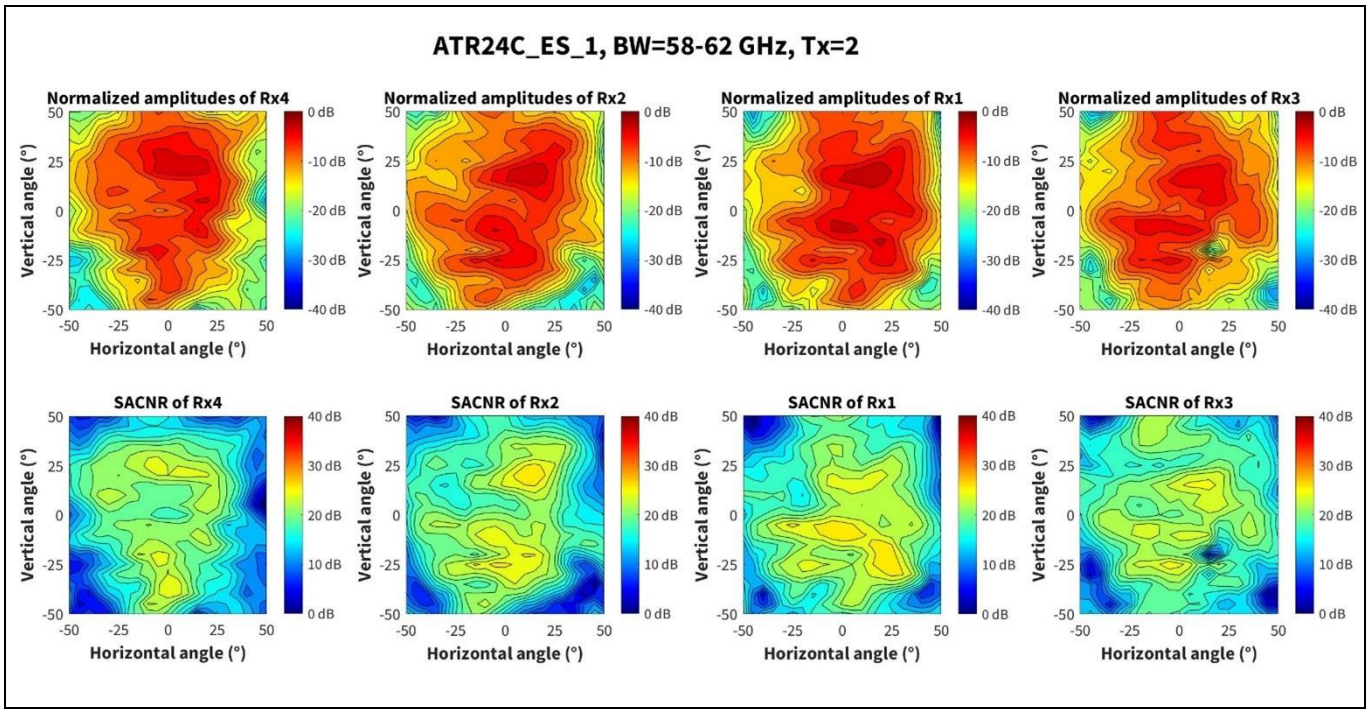

Figure 24 Amplitude and SACNR characteristics with Tx2 channel for 58 to 62 GHz band

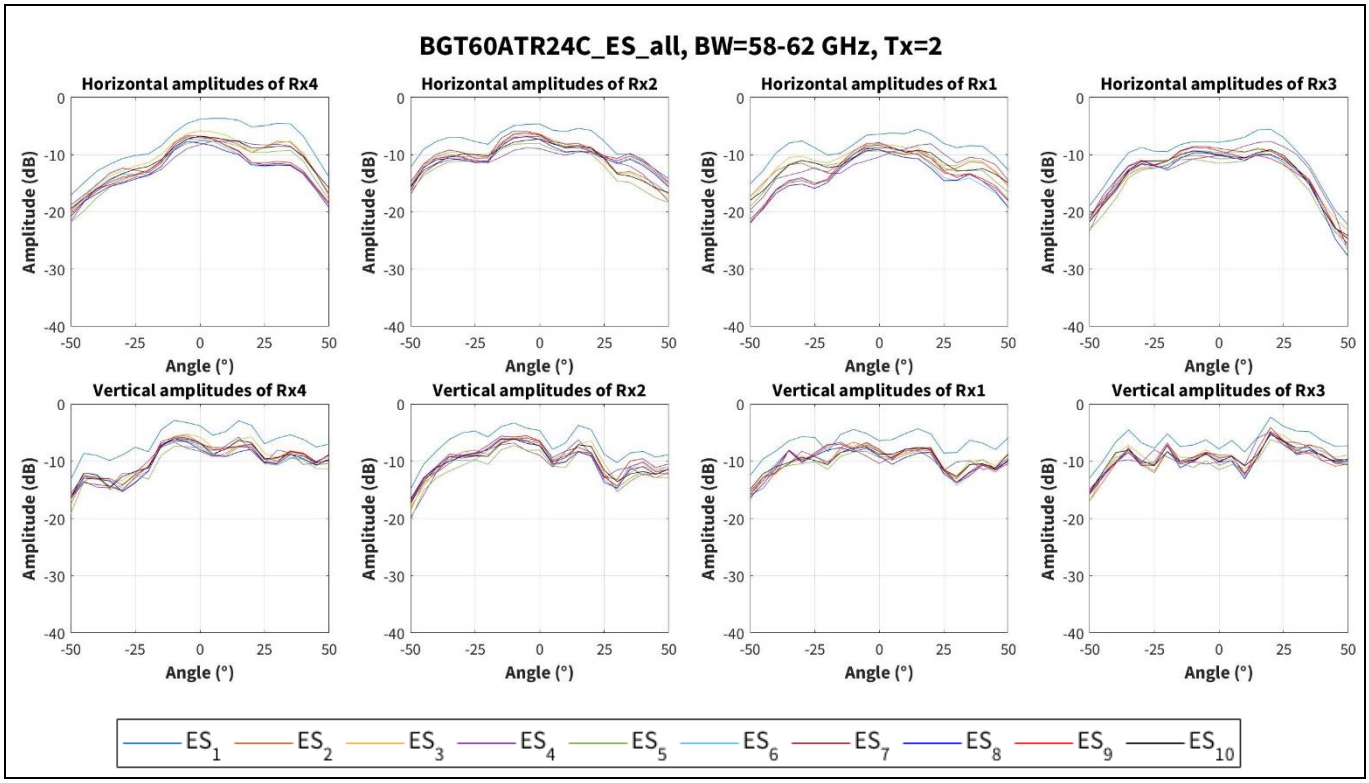

Figure 25 Amplitude characteristics on horizontal and vertical cross-sections with Tx2 channel for 58 to 62 GHz band for 10 boards

3.2 Amplitude characteristics over frequency

Figure 26 through to Figure 29 show amplitude characteristics over different frequency bands with the results of 10 different boards. Each plot compares the results of horizontal and vertical cross-sections of both Tx antennas for each Rx antenna.

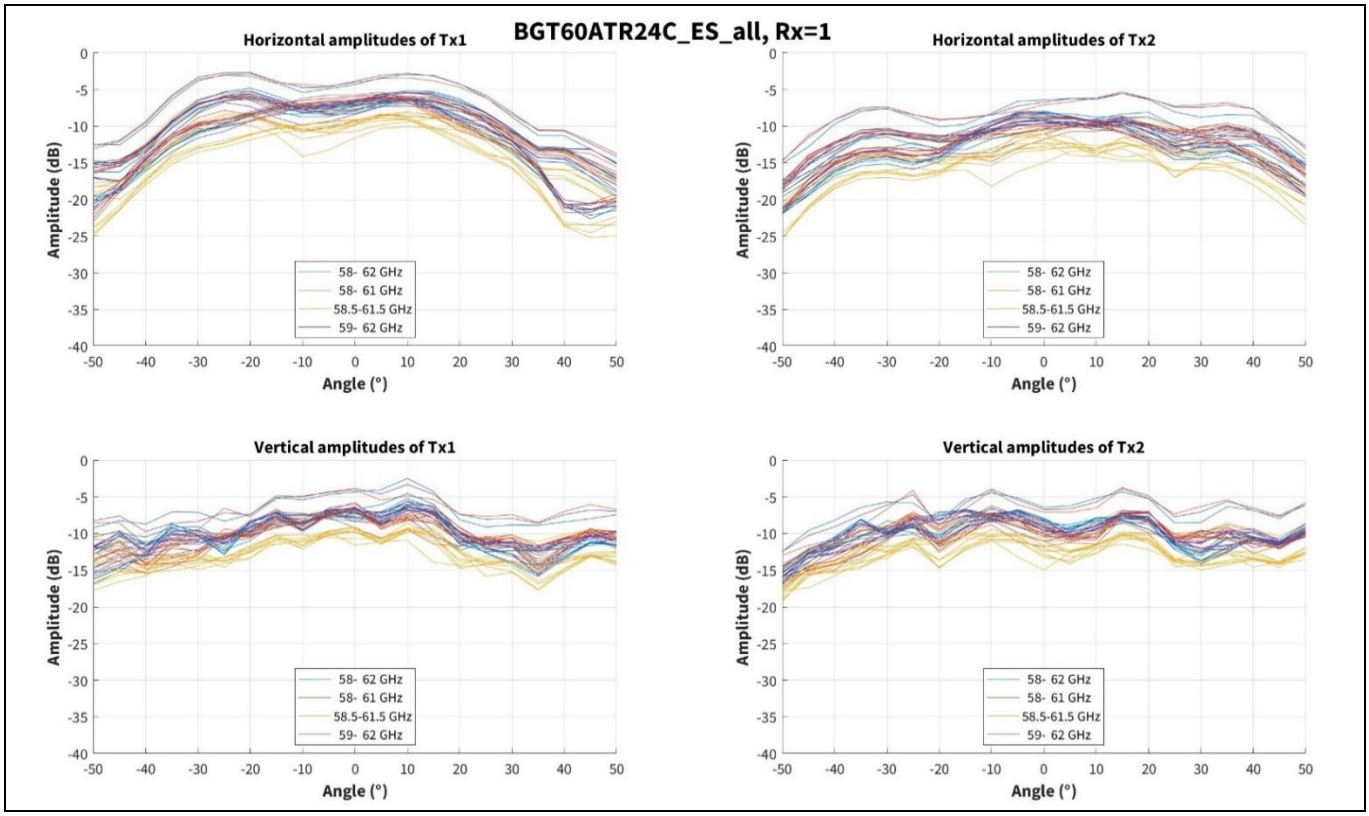

Figure 26 **Amplitude characteristics on horizontal and vertical cross-sections with Rx1 channel for all frequency bands and 10 boards**

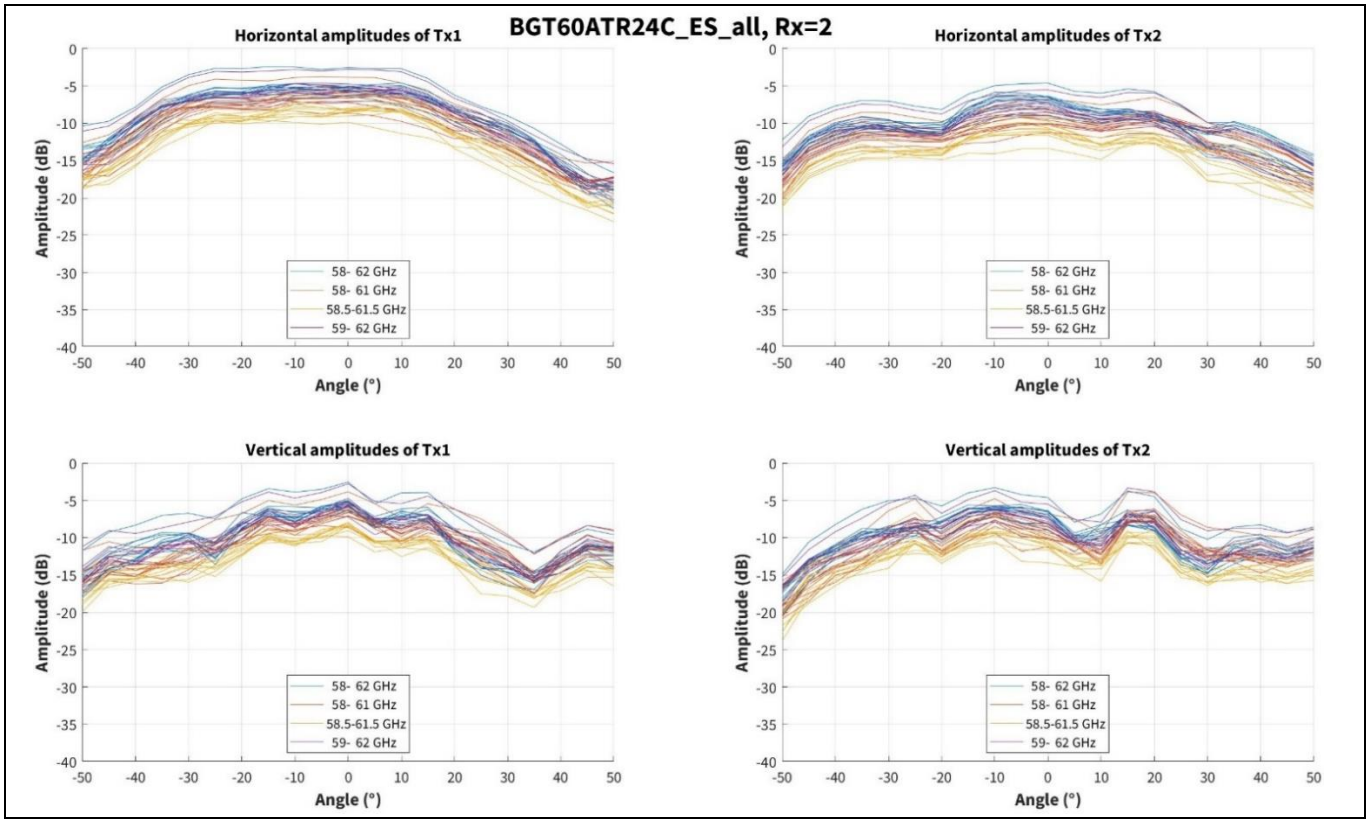

Figure 27 **Amplitude characteristics on horizontal and vertical cross-sections with Rx2 channel for all frequency bands and 10 boards**

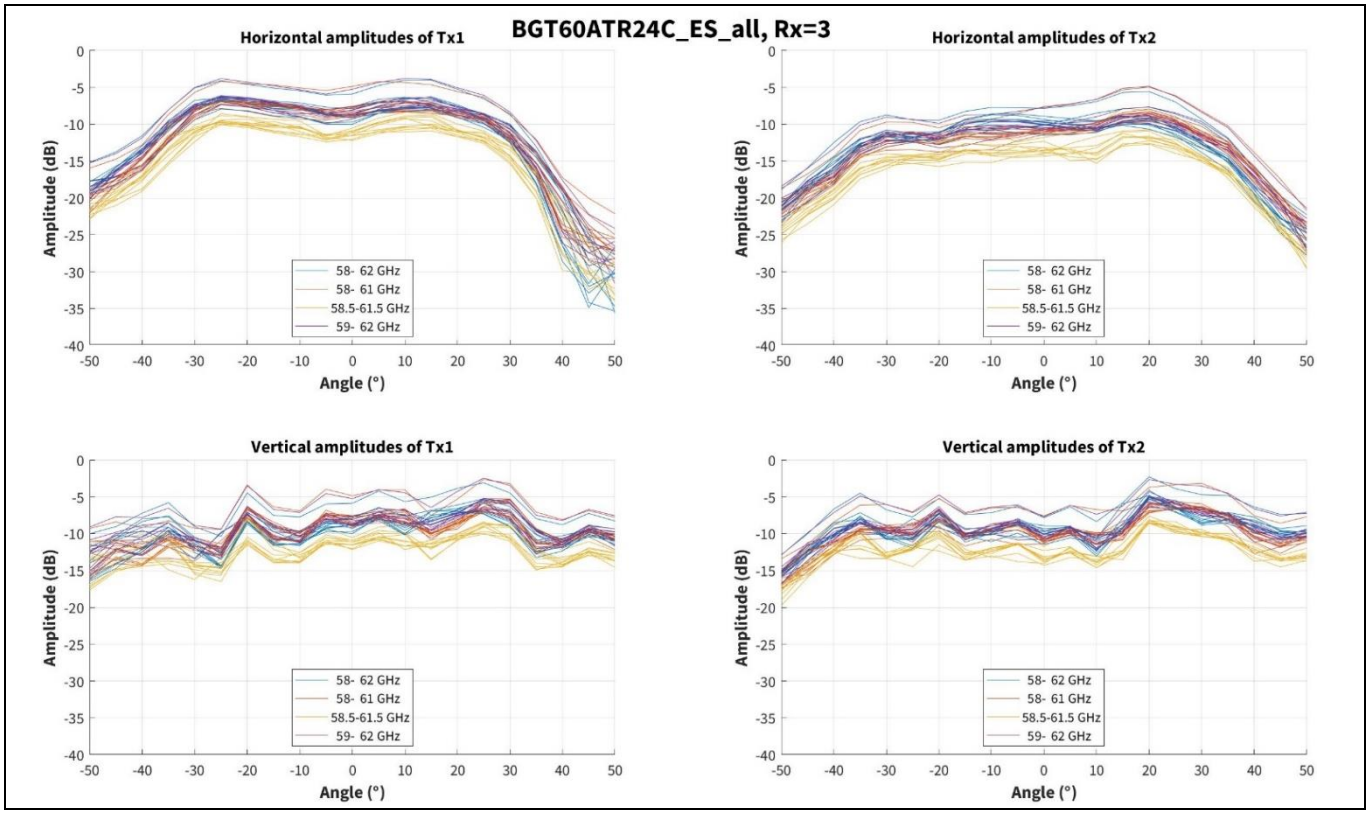

Figure 28 **Amplitude characteristics on horizontal and vertical cross-sections with Rx3 channel for all frequency bands and 10 boards**

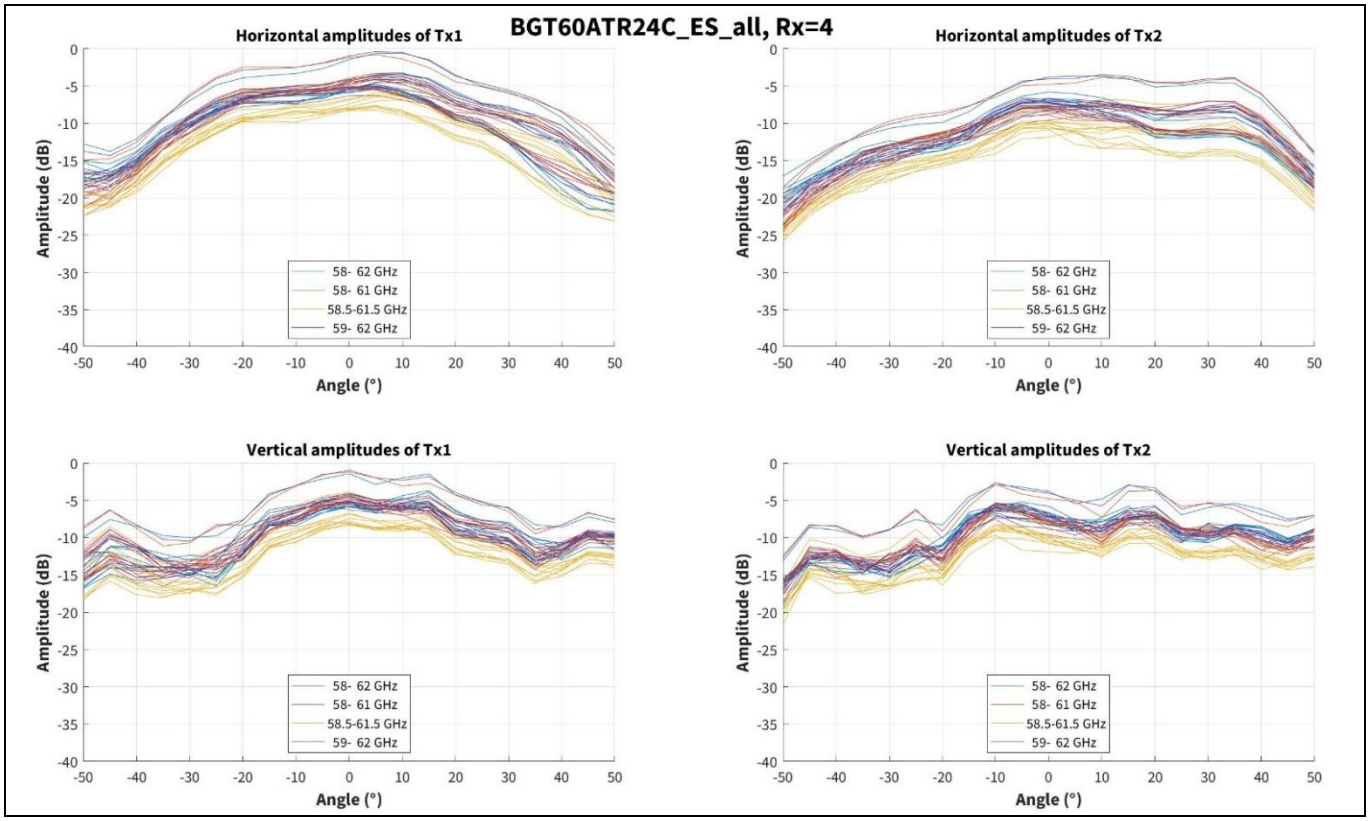

Figure 29 **Amplitude characteristics on horizontal and vertical cross-sections with Rx4 channel for all frequency bands and 10 boards**

3.3 Half-power beam width

Using the measured amplitude characteristics at the 58 to 62 GHz band, half-power beam width (HPBW) values for the E-plane (vertical) and H-plane (horizontal) are calculated as in Figure 30. The measured data for eight virtual antenna elements and 10 boards is averaged to obtain data points on horizontal and vertical planes. The beam characteristics for the E-plane and H-plane are plotted in Figure 30 by fitting curves to the averaged data points.

The resultant HPBW is 80 degrees for the H-plane and 100 degrees for the E-plane.

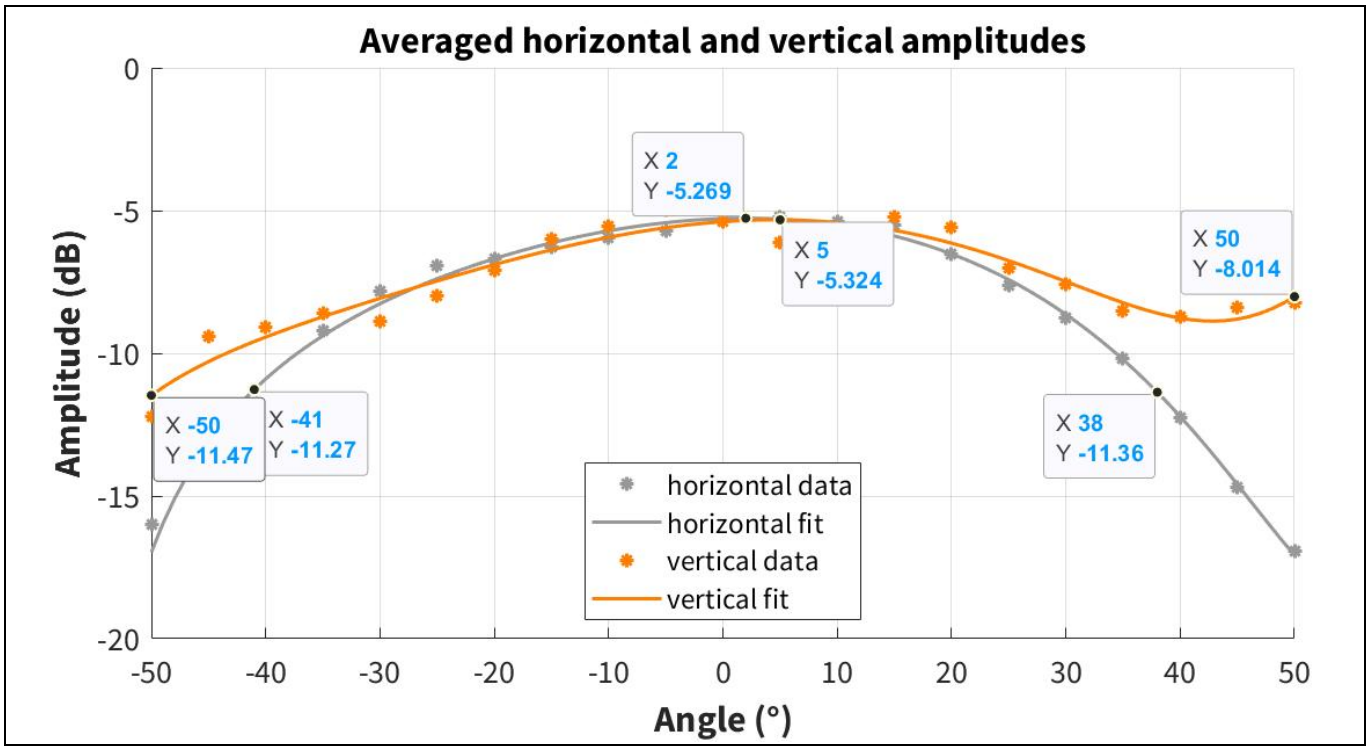

Figure 30 Averaged horizontal and vertical amplitudes and HPBW values for E-plane and H-plane

4 Angle estimation

4.1 Direction of arrival estimation

Using the phase information from the virtual antennas, the direction of arrival (DoA) of the reflection is estimated. A conventional 2D beamforming algorithm is used on a test grid of -90 degrees, to +90 degrees with 1-degree steps for azimuth and elevation angles. Figure 31 shows the angle spectrum output of the beamformer for 0-degree azimuth and 0-degree elevation angle measurements. By taking the peak of the 2D angle spectrum, both azimuth and elevation angles are estimated. This process is repeated for all measured angles.

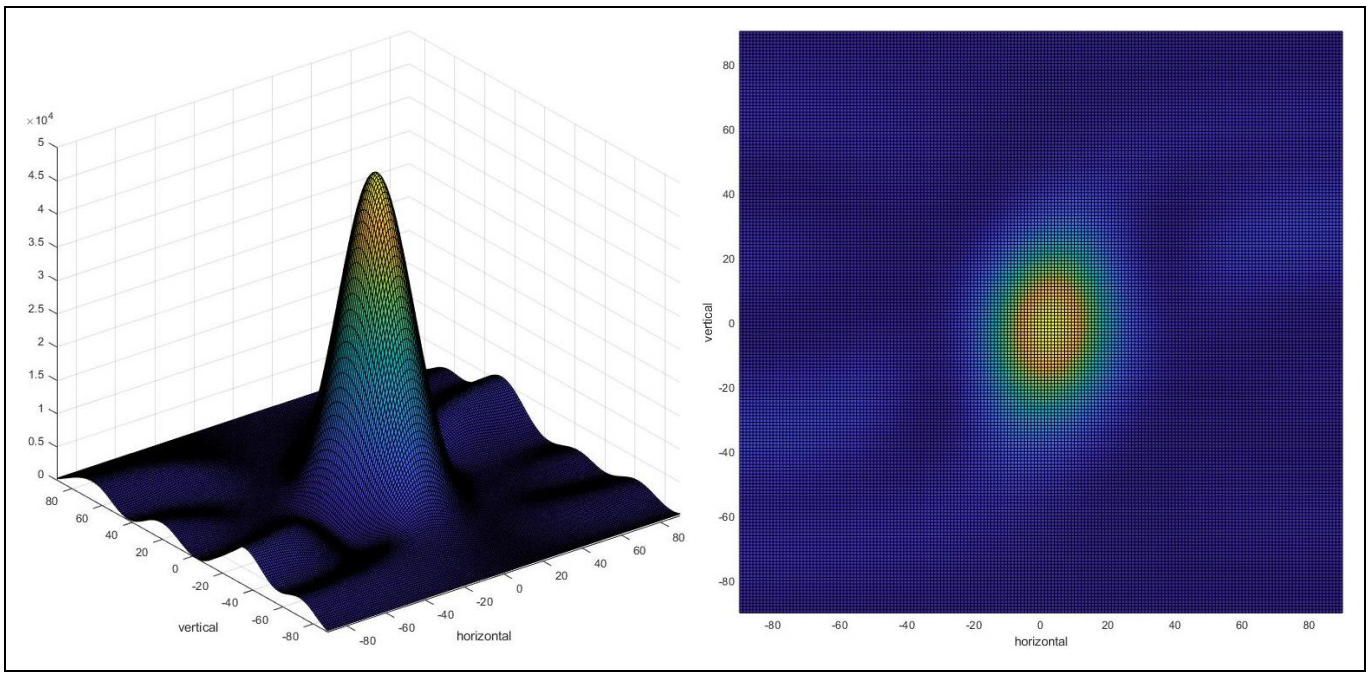

Figure 31 Angle spectrum after 2D beamforming for 0-degree azimuth and 0-degree elevation angle measurement

4.2 Reconstructed angles

This section presents the reconstructed angles for all measured angles for each frequency band, with 3D surface plots and 2D projections. Angle reconstruction errors are also plotted by subtracting calculated angles from the real measurement angles.

4.2.1 58 to 61 GHz

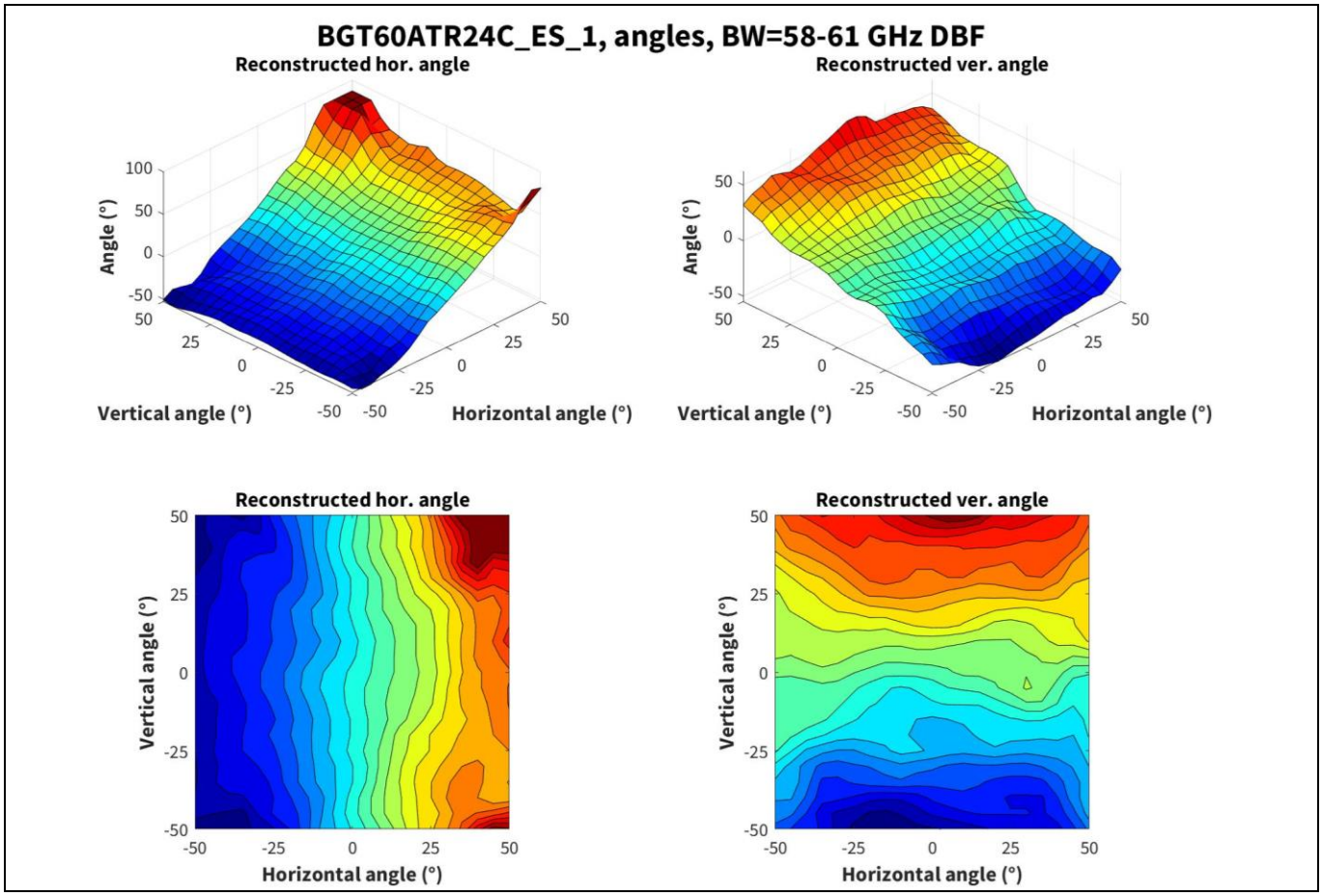

Figure 32 Reconstructed horizontal and vertical angles for 58 to 61 GHz measurements

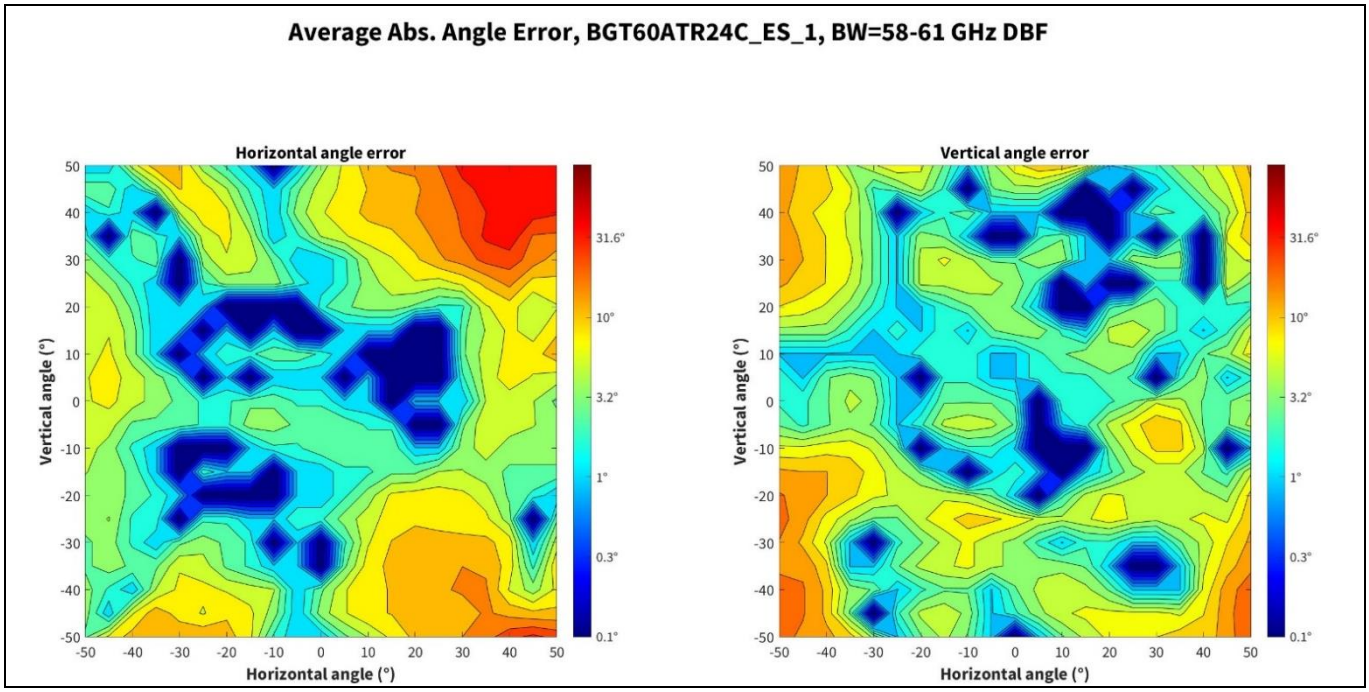

Figure 33 Angle reconstruction errors for 58 to 61 GHz measurements

4.2.2 58.5 to 61.5 GHz

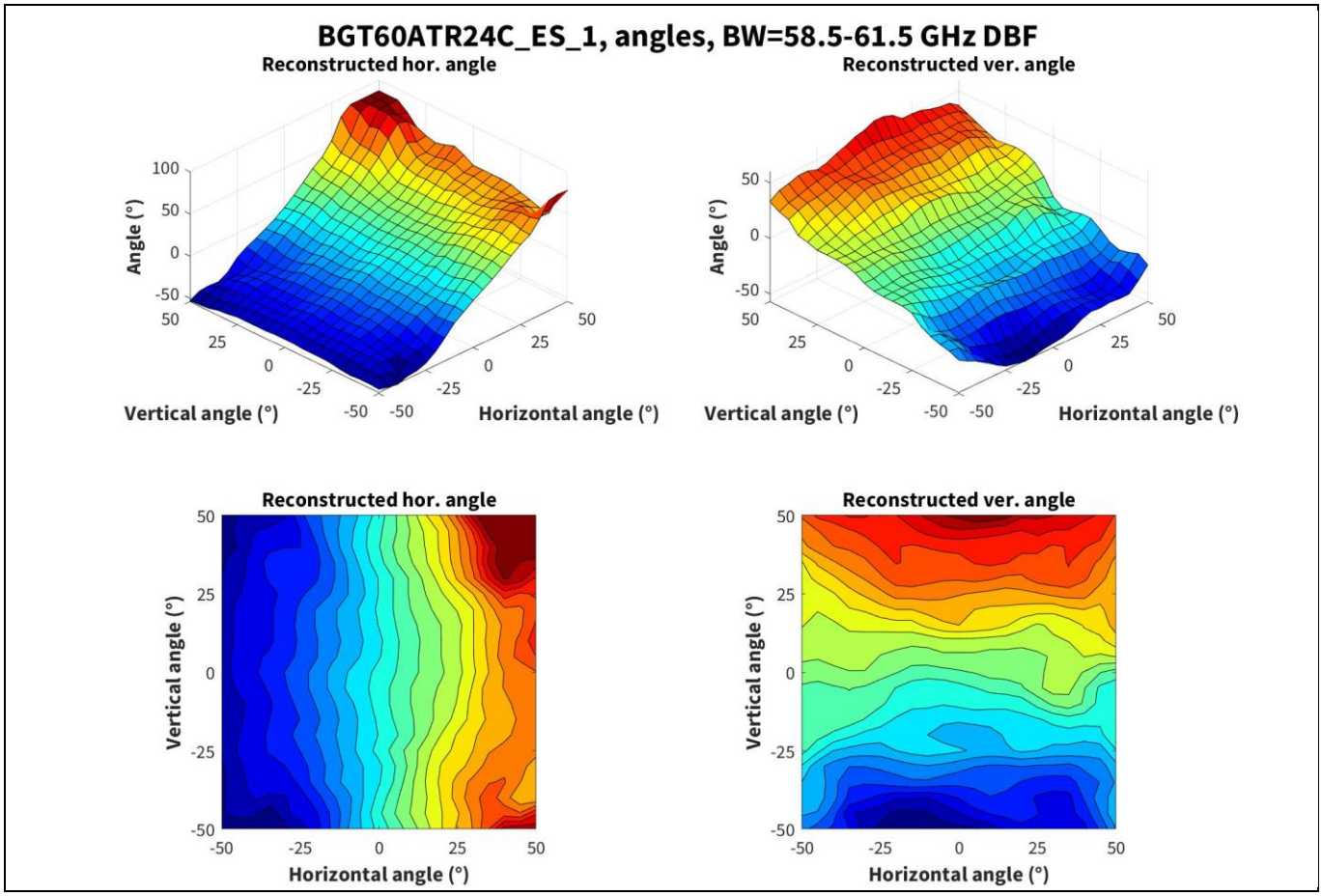

Figure 34 Reconstructed horizontal and vertical angles for 58.5 to 61.5 GHz measurements

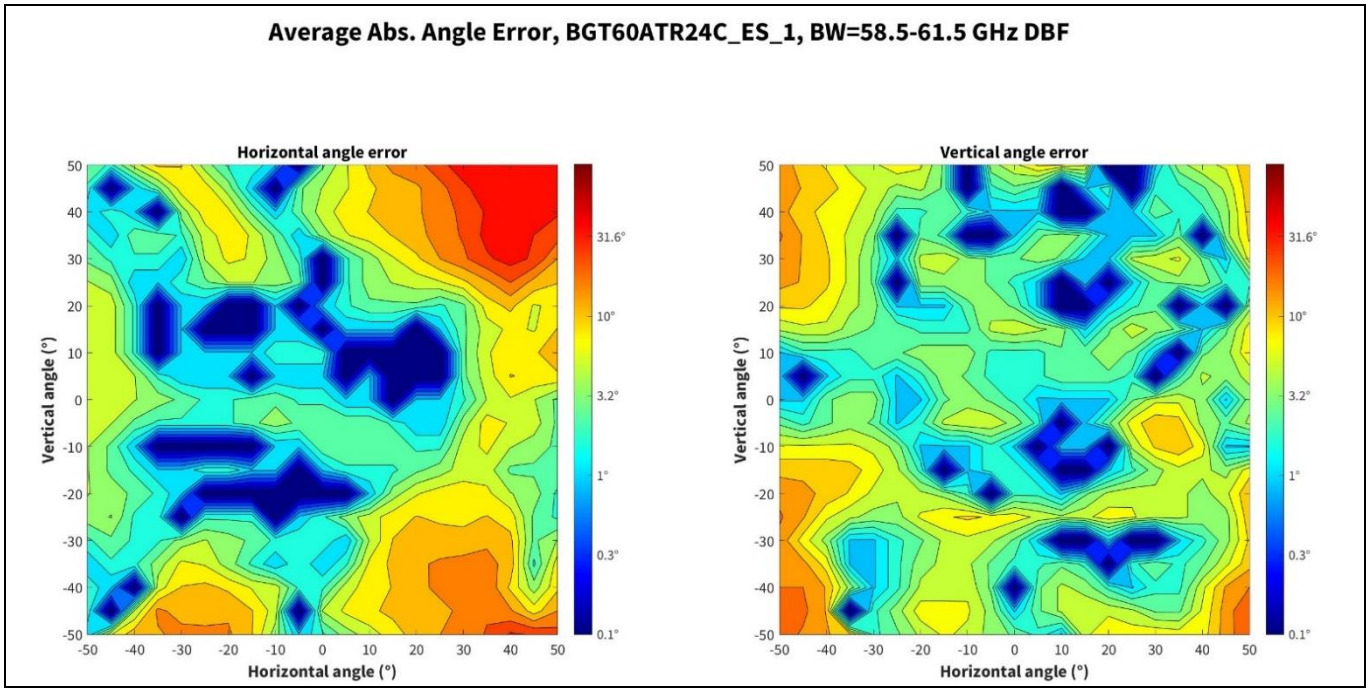

Figure 35 Angle reconstruction errors for 58.5 to 61.5 GHz measurements

4.2.3 59 to 62 GHz

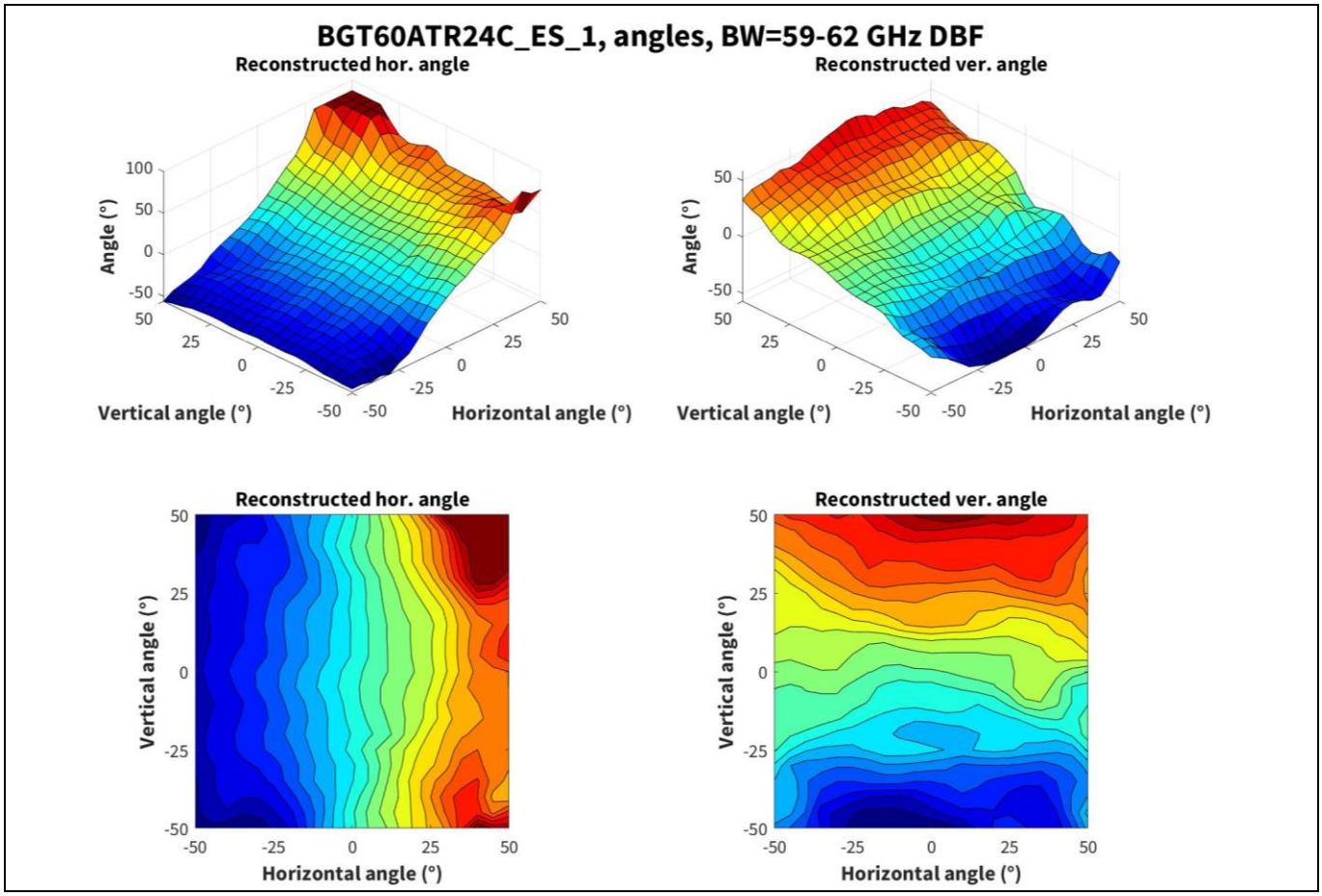

Figure 36 Reconstructed horizontal and vertical angles for 59 to 62 GHz measurements

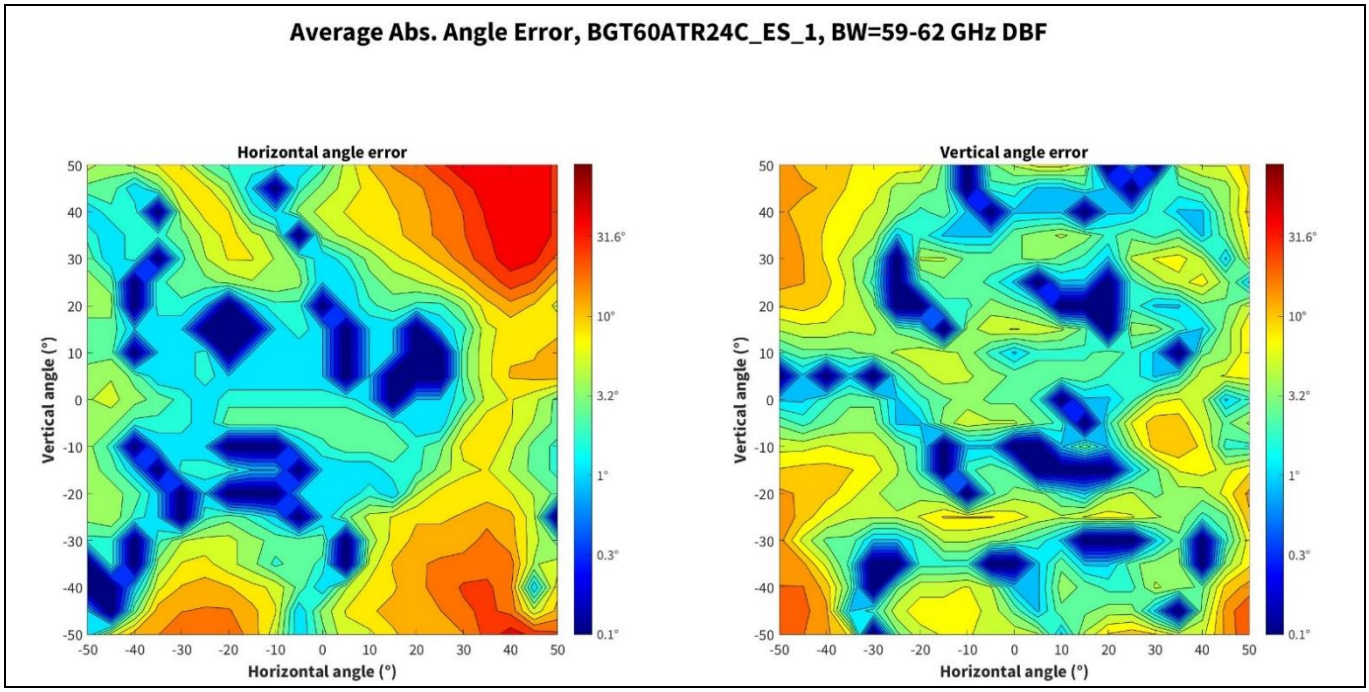

Figure 37 Angle reconstruction errors for 59 to 62 GHz measurements

4.2.4 58 to 62 GHz

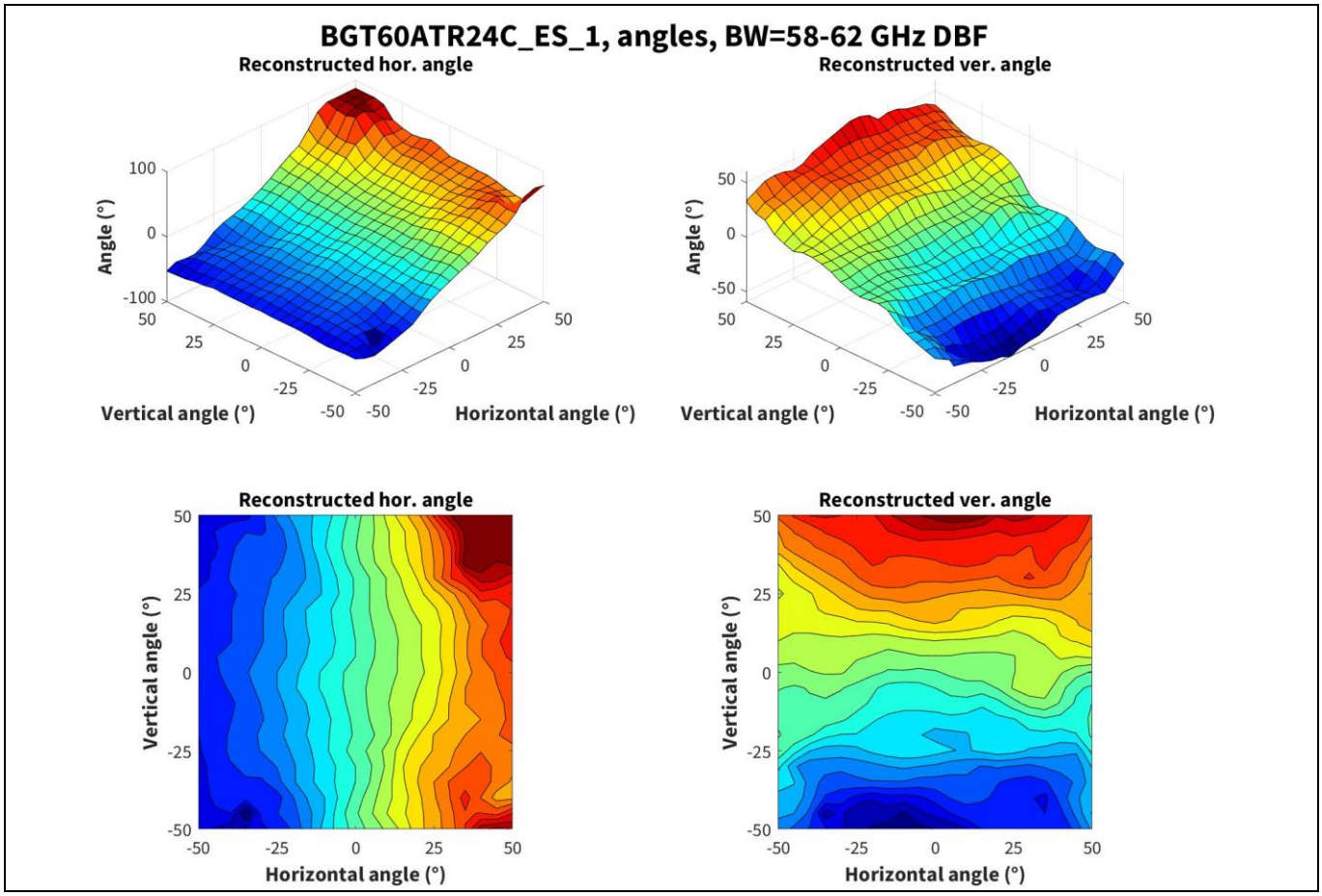

Figure 38 Reconstructed horizontal and vertical angles for 58 to 62 GHz measurements

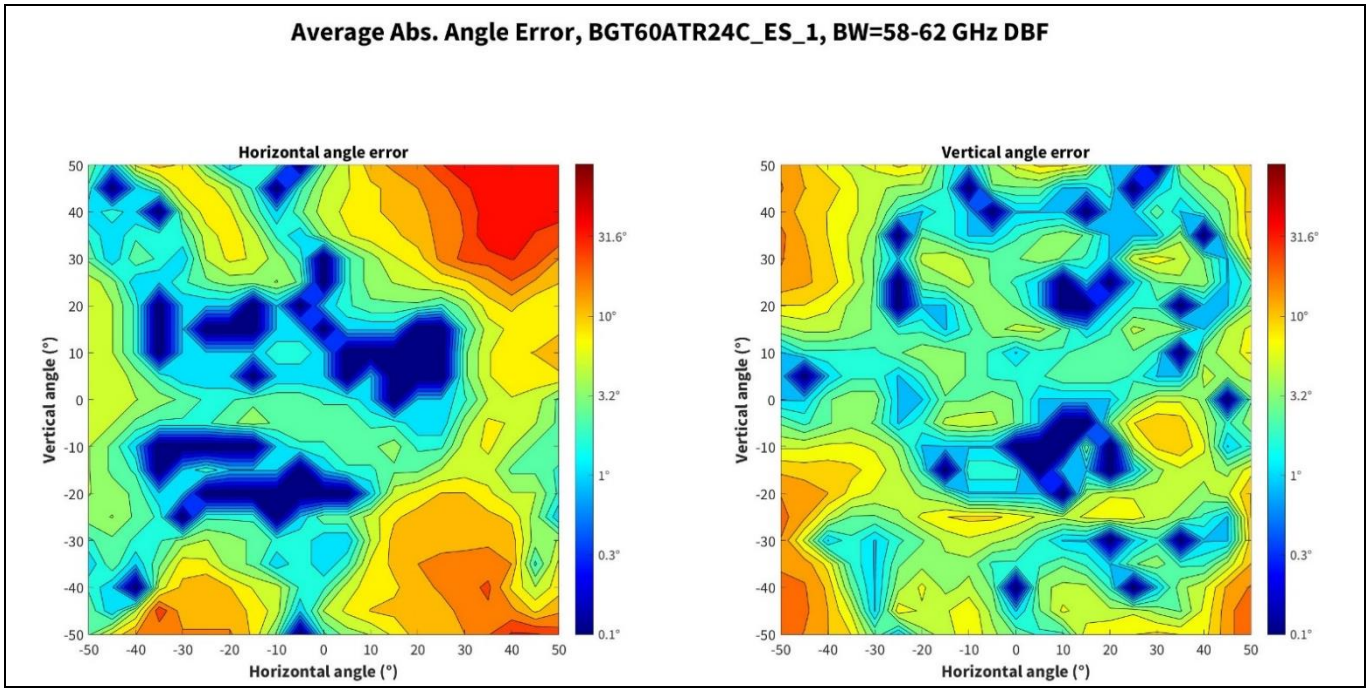

Figure 39 Angle reconstruction errors for 58 to 62 GHz measurements

4.3 Statistical analysis

This section presents a statistical analysis of angle reconstruction errors for different frequency bands and boards. From Table 2 to Table 7, they show the mean of angle errors and the standard deviation of the errors in a certain angle span.

4.3.1 Angle span: ±30 degrees horizontal/vertical

Table 2 Mean angle errors of all frequencies and boards for angle span of ±30 degrees horizontal/vertical

Mean error	ES_1		ES_2		ES_3		ES_4		ES_5		ES_6		ES_7		ES_8		ES_9		ES_10	
Bandwidth	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)
58 to 62 GHz	2.94	3.01	3.00	3.64	3.00	5.10	2.84	3.34	2.98	4.01	2.34	3.08	2.60	2.85	2.44	3.01	2.57	3.17	3.46	3.41
58 to 61 GHz	2.72	3.09	2.79	3.34	2.64	4.46	2.57	3.04	2.56	3.51	2.20	2.86	2.40	2.77	2.32	2.79	2.38	2.95	2.93	3.10
58.5 to 61.5 GHz	2.79	3.04	2.90	3.70	2.88	4.95	2.79	3.20	2.80	3.86	2.35	3.24	2.54	2.94	2.43	3.08	2.42	3.14	3.23	3.20
59 to 62 GHz	2.85	3.05	3.07	4.09	3.07	5.43	2.92	3.39	2.96	4.20	2.47	3.74	2.88	3.38	2.62	3.54	2.57	3.41	3.57	3.30

Table 3 Standard deviation of angle errors of all frequencies and boards for angle span of ±30 degrees horizontal/vertical

Std. dev.	ES_1		ES_2		ES_3		ES_4		ES_5		ES_6		ES_7		ES_8		ES_9		ES_10	
Bandwidth	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)
58 to 62 GHz	3.81	2.39	3.56	2.25	3.20	3.04	3.00	2.06	3.37	2.50	2.50	2.15	2.35	2.01	2.43	2.07	2.32	2.05	2.75	2.06
58 to 61 GHz	3.20	2.40	3.07	2.18	2.69	2.79	2.83	2.02	2.86	2.28	2.43	1.96	2.29	1.99	2.36	1.92	2.09	1.96	2.35	1.95
58.5 to 61.5 GHz	3.37	2.31	3.15	2.36	2.91	3.01	2.98	2.07	3.06	2.44	2.49	2.31	2.37	2.16	2.45	2.14	2.28	2.10	2.46	1.95
59 to 62 GHz	3.32	2.45	3.17	2.62	3.13	3.17	2.99	2.30	3.22	2.56	2.52	2.53	2.41	2.32	2.55	2.48	2.37	2.37	2.58	2.05

4.3.2 Angle span: ±40 degrees horizontal/vertical

Table 4 Mean angle errors of all frequencies and boards for angle span of ±40 degrees horizontal/vertical

Mean error	ES_1		ES_2		ES_3		ES_4		ES_5		ES_6		ES_7		ES_8		ES_9		ES_10	
Bandwidth	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)
58 to 62 GHz	5.45	3.30	5.42	4.07	5.38	5.55	4.80	3.60	5.53	4.38	4.54	3.63	4.52	3.38	4.40	3.61	4.32	3.65	5.37	3.62
58 to 61 GHz	4.94	3.34	4.86	3.73	4.49	4.79	4.34	3.39	4.63	3.78	4.06	3.30	3.97	3.27	3.83	3.30	3.83	3.45	4.47	3.39
58.5 to 61.5 GHz	5.32	3.35	5.36	4.08	5.15	5.30	4.80	3.50	5.34	4.20	4.44	3.60	4.30	3.32	4.30	3.55	4.15	3.48	5.16	3.42
59 to 62 GHz	5.67	3.41	5.88	4.47	5.83	5.85	5.20	3.72	6.11	4.63	4.83	4.03	4.85	3.73	4.76	3.95	4.54	3.75	5.78	3.61

Table 5 Standard deviation of angle errors of all frequencies and boards for angle span of ±40 degrees horizontal/vertical

Std. dev.	ES_1		ES_2		ES_3		ES_4		ES_5		ES_6		ES_7		ES_8		ES_9		ES_10	
Bandwidth	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)
58 to 62 GHz	7.61	2.66	7.19	3.00	7.25	3.67	5.42	2.68	7.35	3.09	6.02	3.04	5.35	2.90	5.38	2.96	5.07	2.92	5.91	2.66
58 to 61 GHz	6.60	2.70	5.90	2.79	5.39	3.35	5.04	2.59	5.70	2.76	5.02	2.61	4.51	2.67	4.39	2.63	4.18	2.68	4.87	2.39
58.5 to 61.5 GHz	7.28	2.63	6.95	3.00	6.51	3.54	5.48	2.60	6.93	3.09	5.53	2.92	4.84	2.83	5.01	2.86	4.71	2.79	5.64	2.52
59 to 62 GHz	7.86	2.77	8.05	3.27	7.82	3.76	5.88	2.87	8.59	3.31	6.21	3.27	5.26	3.09	5.54	3.19	5.22	3.05	6.36	2.56

4.3.3 Angle span: ±50 degrees horizontal/vertical

Table 6 Mean angle errors of all frequencies and boards for angle span of ±50 degrees horizontal/vertical

Mean error	ES_1		ES_2		ES_3		ES_4		ES_5		ES_6		ES_7		ES_8		ES_9		ES_10	
Bandwidth	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)
58 to 62 GHz	7.46	4.83	7.39	5.52	7.32	6.68	6.91	5.02	7.51	5.68	6.42	5.17	6.11	5.09	6.02	5.17	5.70	5.19	6.95	4.95
58 to 61 GHz	6.83	4.86	6.71	5.22	6.32	6.05	6.27	4.83	6.54	5.16	6.00	5.00	5.57	5.08	5.37	4.99	5.27	5.14	6.02	4.75
58.5 to 61.5 GHz	7.33	4.83	7.40	5.56	7.10	6.48	6.88	4.93	7.31	5.54	6.43	5.14	6.02	5.05	5.98	5.11	5.68	5.06	6.77	4.77
59 to 62 GHz	7.80	4.88	8.18	5.92	7.98	7.01	7.45	5.10	8.31	5.95	6.93	5.44	6.69	5.29	6.66	5.39	6.21	5.20	7.62	4.93

Table 7 Standard deviation of angle errors of all frequencies and boards for angle span of ±50 degrees horizontal/vertical

Std. dev.	ES_1		ES_2		ES_3		ES_4		ES_5		ES_6		ES_7		ES_8		ES_9		ES_10	
Bandwidth	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)	H (°)	V (°)
58 to 62 GHz	9.82	4.69	9.54	4.70	9.73	5.02	8.83	4.42	9.63	4.59	8.65	4.96	7.74	5.15	7.49	4.93	7.04	5.05	8.40	4.47
58 to 61 GHz	8.81	4.67	8.18	4.51	8.00	4.66	7.86	4.24	8.11	4.28	7.85	5.01	6.88	5.18	6.55	4.98	6.20	5.19	7.40	4.26
58.5 to 61.5 GHz	9.57	4.60	9.56	4.69	9.16	4.92	8.58	4.31	9.22	4.54	8.74	4.93	7.66	5.14	7.48	4.87	7.18	4.98	8.27	4.38
59 to 62 GHz	10.43	4.71	10.97	4.96	10.66	5.19	9.28	4.59	10.86	4.82	9.39	5.17	8.23	5.36	8.39	5.06	7.94	5.16	9.17	4.52

5 Summary and remarks

- Measurements are taken at ±50 degrees due to the limitations in the measurement chamber.
- HPBW is calculated as 80 degrees for the horizontal plane (H-plane) and 100 degrees for the vertical plane (E-plane).
- Angles are reconstructed by a conventional 2D beamforming algorithm.
- Errors for reconstructed angles are stable for different boards and frequency bands.
- For ±50 degrees horizontal or vertical span, the absolute average angle error is about 7 degrees for horizontal angles and 5 degrees for vertical angles.

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Revision history

Document revision	Date	Description of changes
1.00	2021-09-17	Initial version
1.10	2022-08-26	Updated figures
1.20	2023-06-06	Miscellaneous document cleanup updates
1.30	2025-04-15	Updated document ID Editorial changes

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Edition 2025-04-15

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference

AN131711

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