Fraunhofer IIS

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Antennenentwicklung für EASYPILOT2.0

HFS_PN-140392
Edition 01
Revision 07

Inhalt: Simulationsergebnisse und Messungen an der EasyPilot UWB Antenne

Erstellt von:

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2 Publisher

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3 References

The following documents were used to create this document:

RD1	Specification „EasyPILOT 2.0 localisiation System“ V1.0	Jungheinrich
RD2	WiSmIt Plattform v4.3	Fraunhofer IIS
RD3	Evaluierung EasyPILOT 2.0	Fraunhofer IIS
RD4	Spezifikation_EasyPILOT_Komponenten_v5	Fraunhofer IIS
RD5	Kommunikationsprotokoll EasyPILOT V1.5	Jungheinrich

3.1 Scope of the System

The "EasyPILOT 2.0" system consists of four vehicle nodes and a mobile control panel. Figure 1 shows the positions of the four vehicle nodes, each of which is to be equipped with a UWB receiver antenna. Node A is also equipped with an external NFC radio module (ACD).

The UWB antenna for the person component is not considered in this document because it was not developed by IIS.

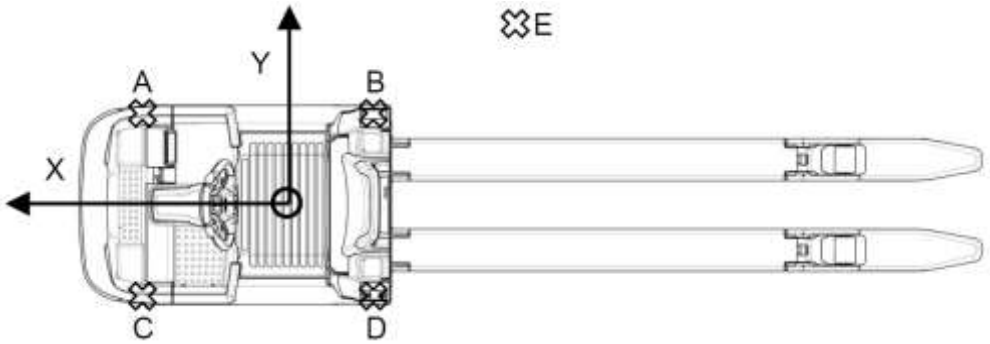


Figure 1: Antenna position „EasyPILOT 2.0“

A-D: Vehicle Components for Distance Measurement

A: Assembly Variant „Master“

B,C,D: Assembly Variant „Slave“

E: Person Component (Control Panel)

3.2 Specifications

The antenna is a small wideband dipole having a frequency range between 3.7 – 6.8 GHz. The antenna has 100 ohms differential line feed.

The antenna has vertical polarization.

The dimensions of the antenna are demonstrated in the figure.

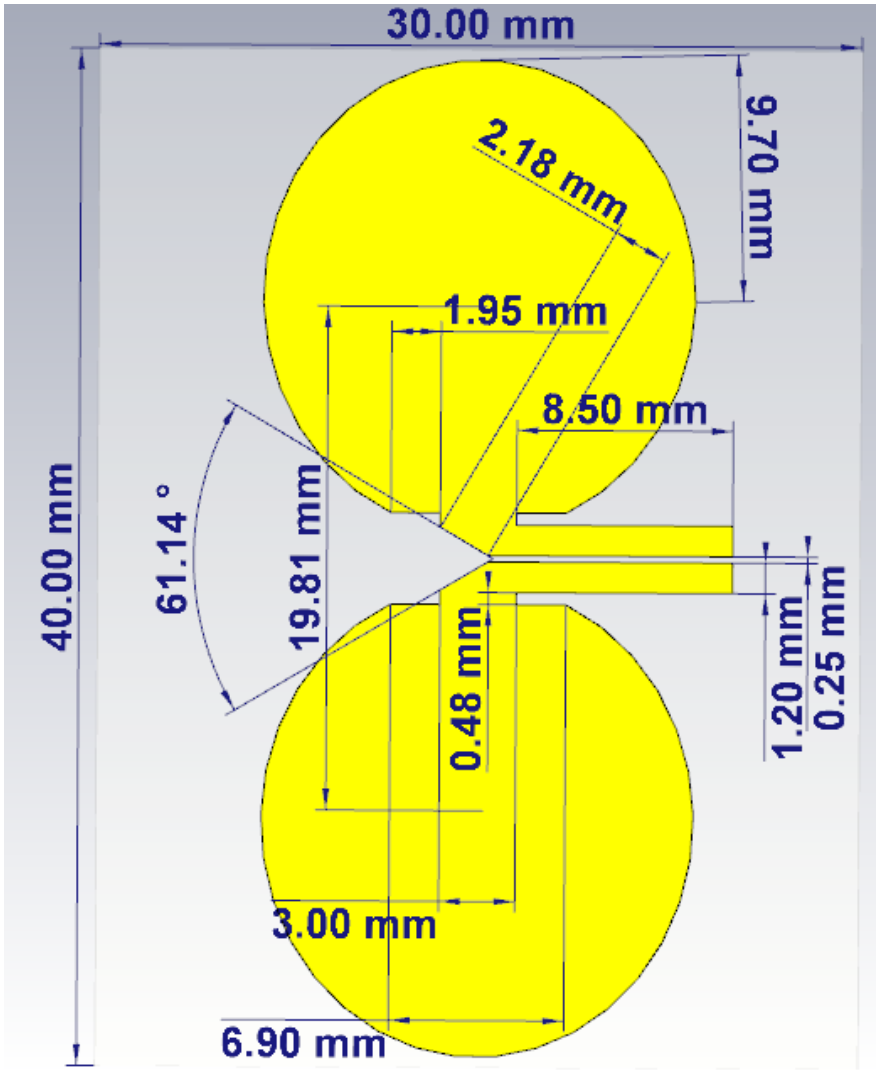
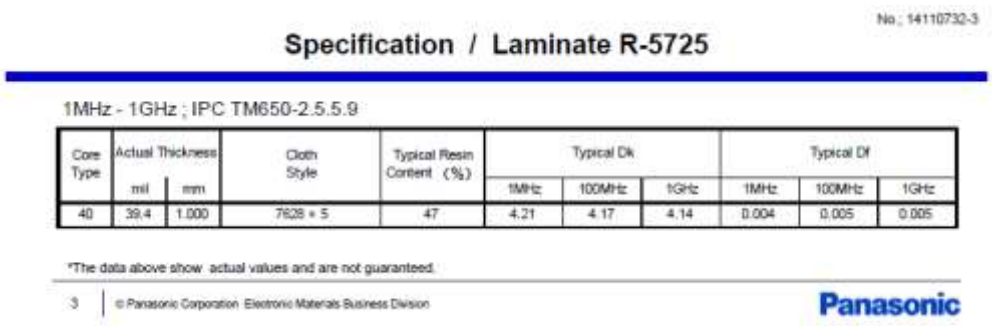


Figure 2: Dimensions of the antenna

The substrate is 1mm thick MEGTRON-4, for which the properties can be demonstrated below.



No.; 14110732-3

Specification / Laminate R-5725

1MHz - 1GHz ; IPC TM650-2.5.5.9

Core Type	Actual Thickness		Cloth Style	Typical Resin Content (%)	Typical Dk			Typical Df		
	mil	mm			1MHz	100MHz	1GHz	1MHz	100MHz	1GHz
40	39.4	1.000	7628 × 5	47	4.21	4.17	4.14	0.004	0.005	0.005

*The data above show actual values and are not guaranteed.

3 | © Panasonic Corporation Electronic Materials Business Division

Panasonic

Figure 3: MEGTRON-4 material properties

A chip balun with model reference of HHM1595A1 is attached at the input of antenna's transmission lines, which transforms the antenna to a single ended 50 ohms feed design. The balun has a specified frequency range of 3-8GHz.

Figure 4: The antenna with chip balun circuitry

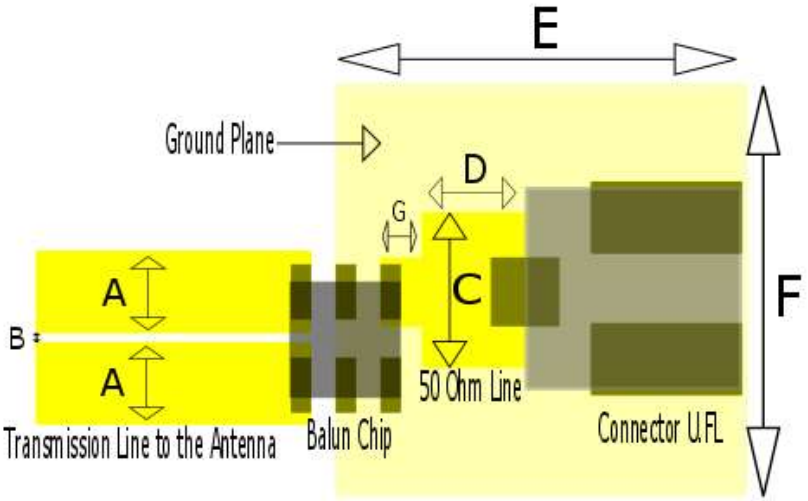


Figure 5: Precise layout of the balun and transmission line connections. A: 1.2mm, B: 0.25mm, C: 2.02 mm, D: 50 ohm line, E: 6mm, F: 6mm, G: 0.5mm

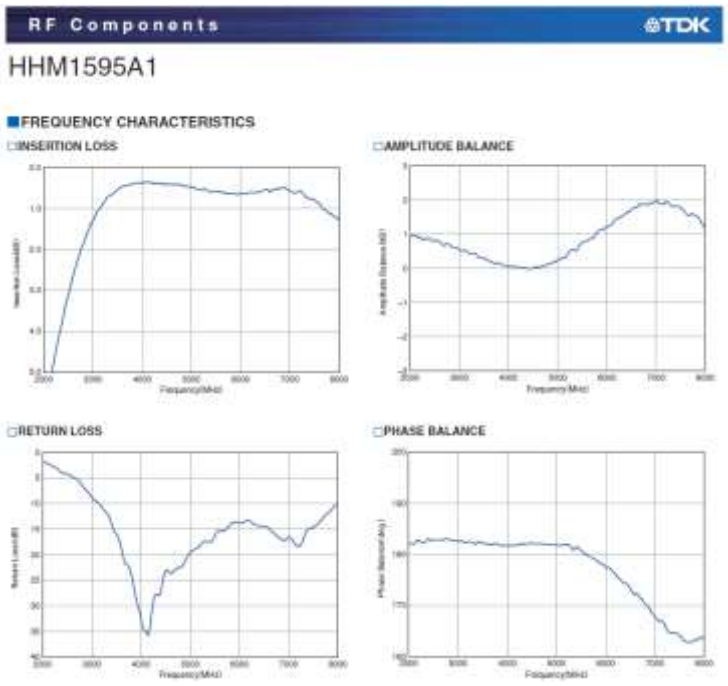


Figure 6: Properties of the chip balun

3.3 Simulation

3.3.1 Bare antenna simulations

The realized gain values for the frequencies 3.5, 5 and 6 GHz are demonstrated respectively, for the case where the antenna element is alone.

Bare antenna realized gain pattern at the frequency 3.5 GHz is demonstrated.

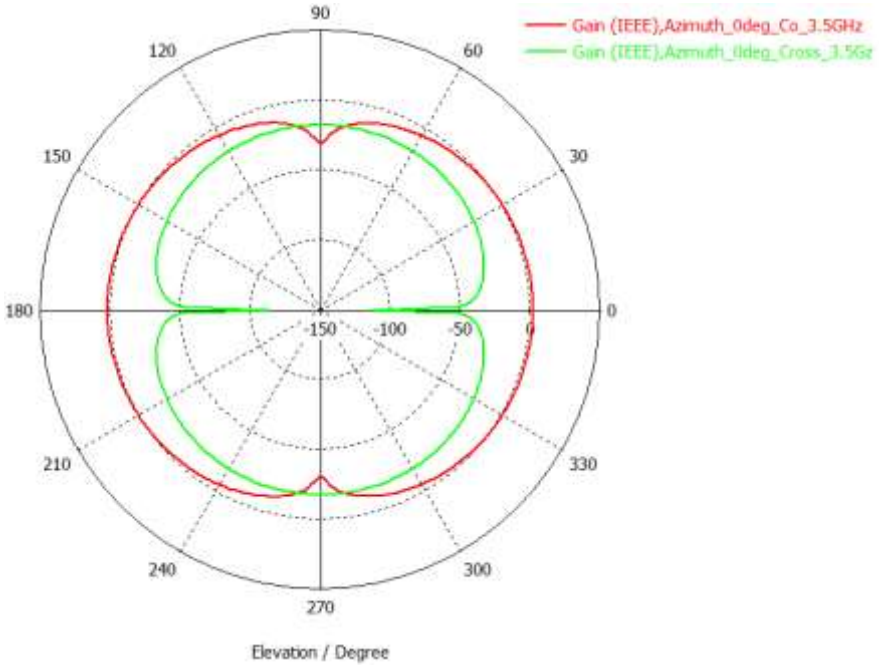


Figure 7: Simulation result of the bare antenna at constant azimuth, co and cross polarizations at 3.5 GHz.

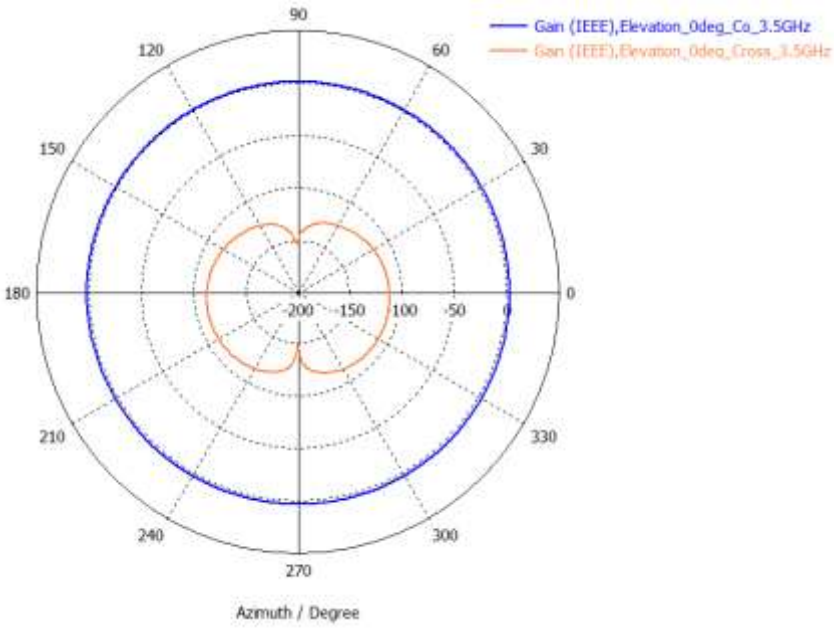


Figure 8: Simulation result of the bare antenna at constant elevation, co and cross polarizations at 3.5 GHz.

Bare antenna realized gain pattern at the frequency 5 GHz is demonstrated.

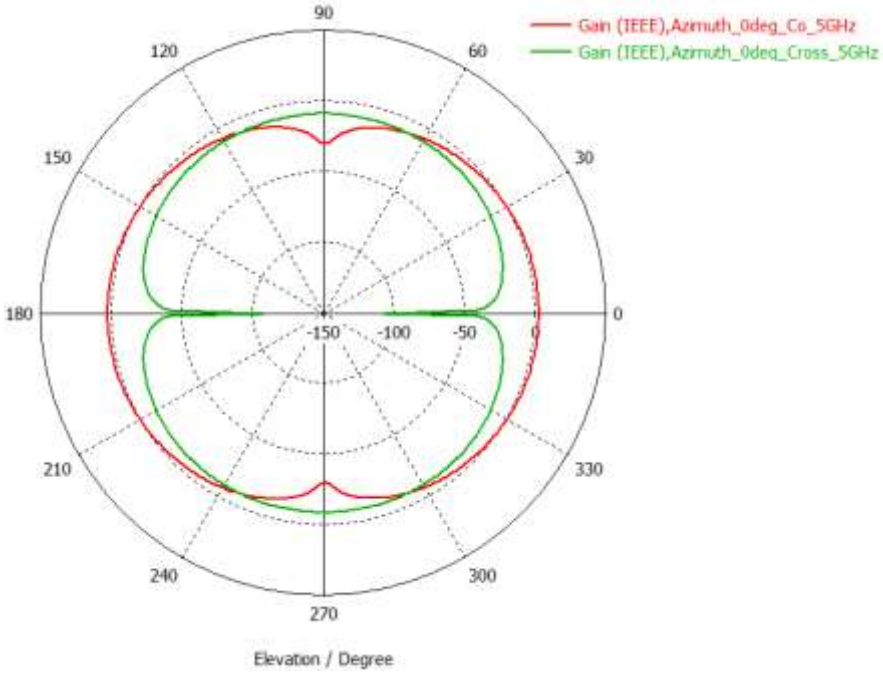


Figure 9: Simulation result of the bare antenna at constant azimuth, co and cross polarizations at 5 GHz.

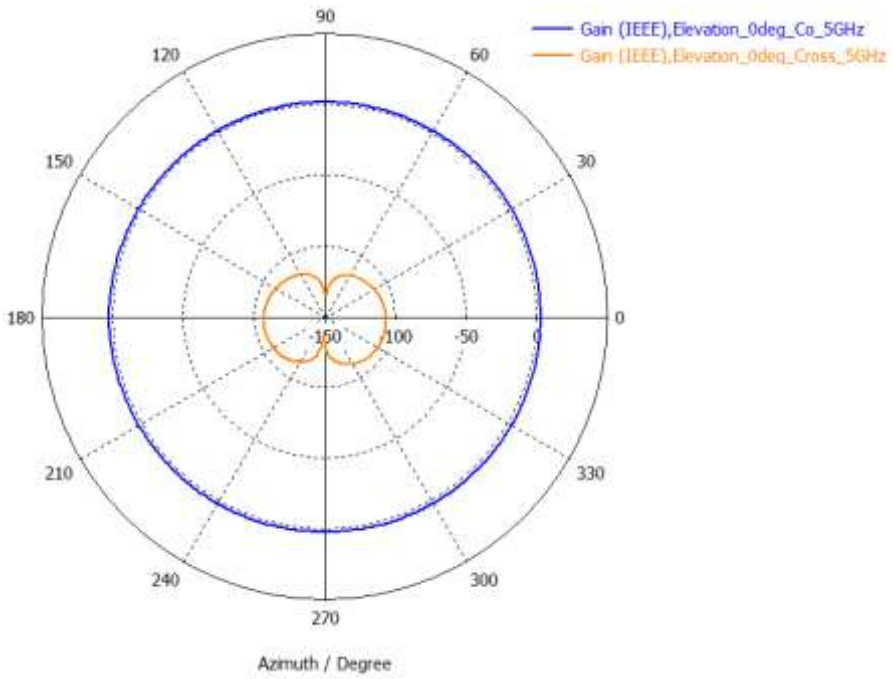


Figure 10: Simulation result of the bare antenna at constant elevation, co and cross polarizations at 5 GHz.

Bare antenna realized gain pattern at the frequency 6 GHz is demonstrated.

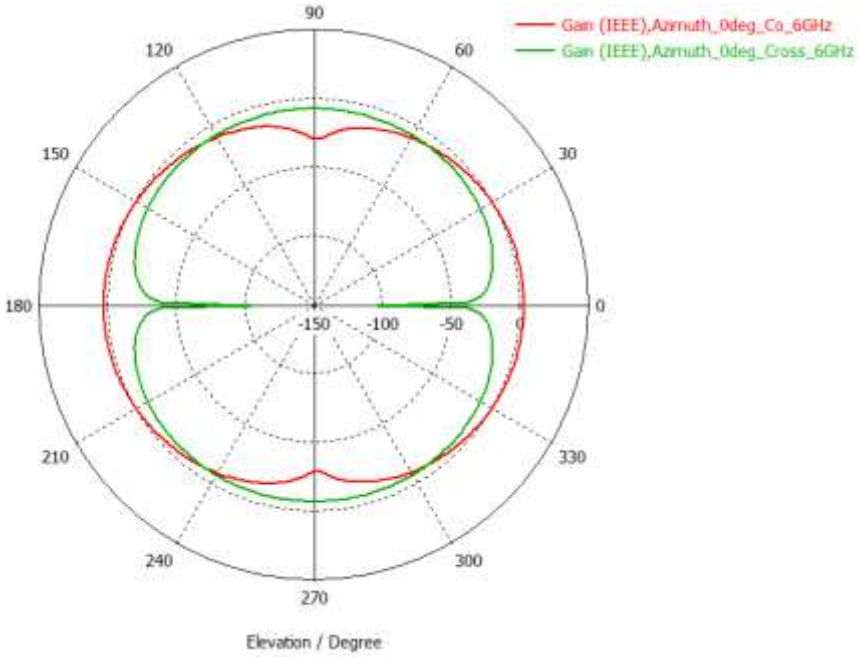


Figure 11: Simulation result of the bare antenna at constant azimuth, co and cross polarizations at 6 GHz.

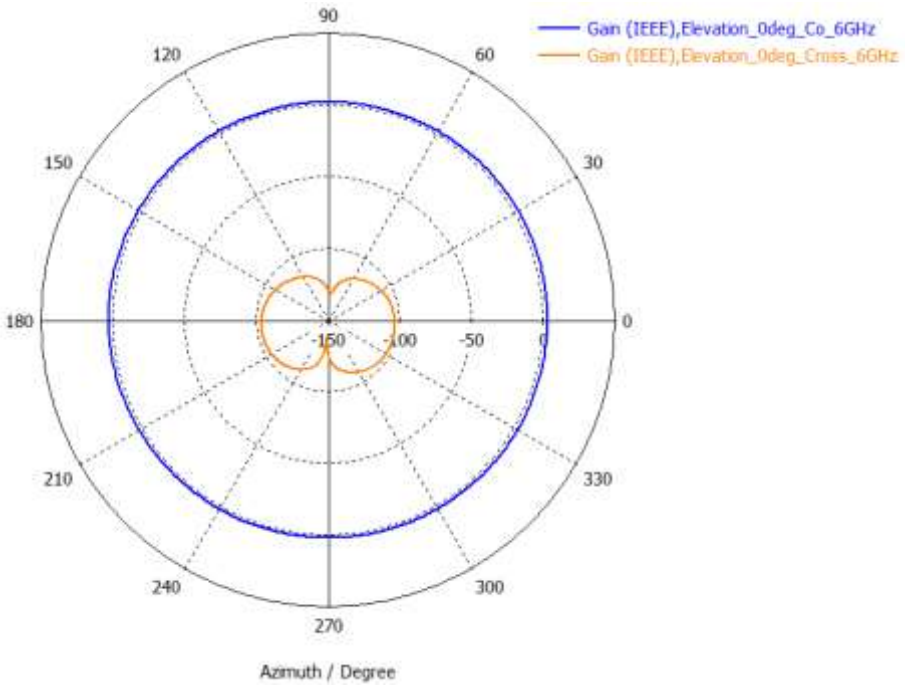


Figure 12: Simulation result of the bare antenna at constant elevation, co and cross polarizations at 6 GHz.

3.3.2 Back side antenna simulations

The simulation model for the back side of the vehicle is demonstrated.

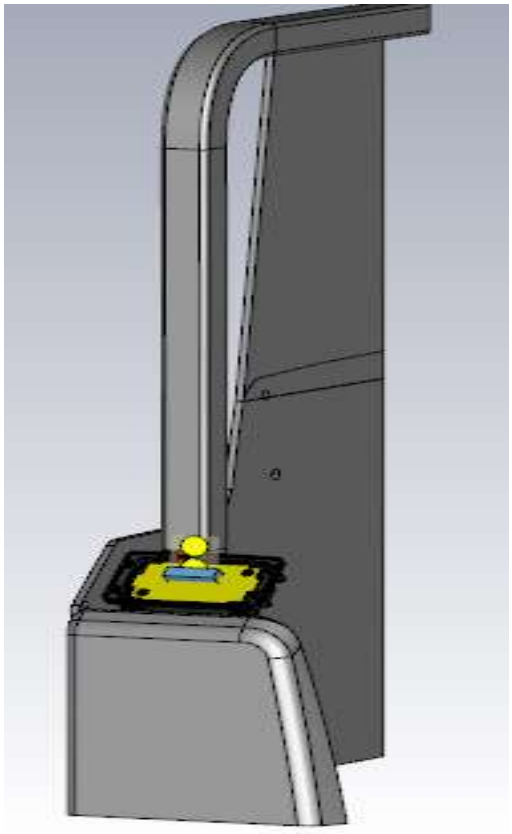


Figure 13: Simulation model for the back right antenna including the nearby elements of the vehicle.

The S-Parameter (S11) of the antenna taken from back side simulation is demonstrated.

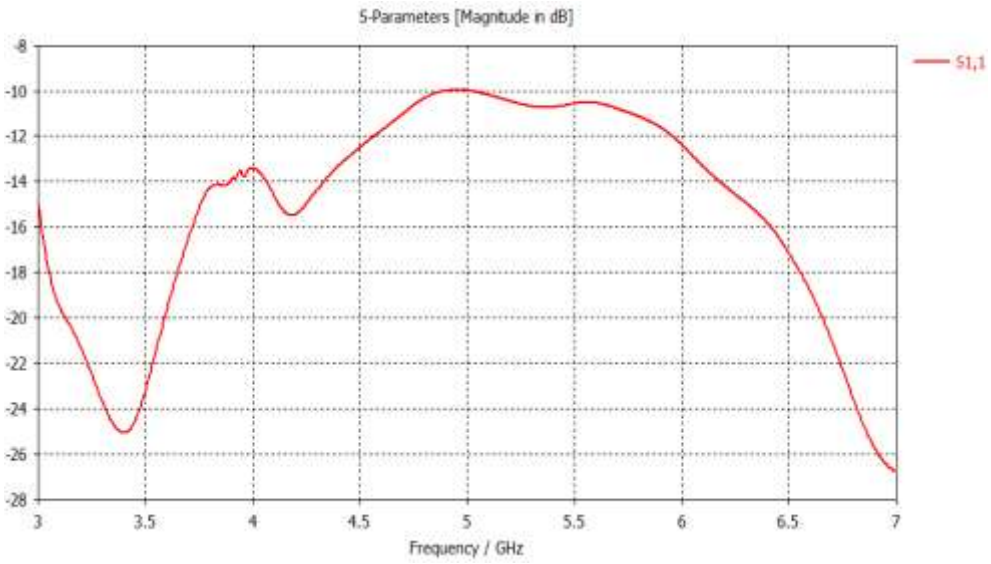


Figure 14: Simulated S-parameter of the back side antenna (S11).

The realized gain values for the frequencies 3.5, 5 and 6 GHz are considered for this report.

Back side antenna realized gain pattern at the frequency 3.5 GHz is demonstrated.

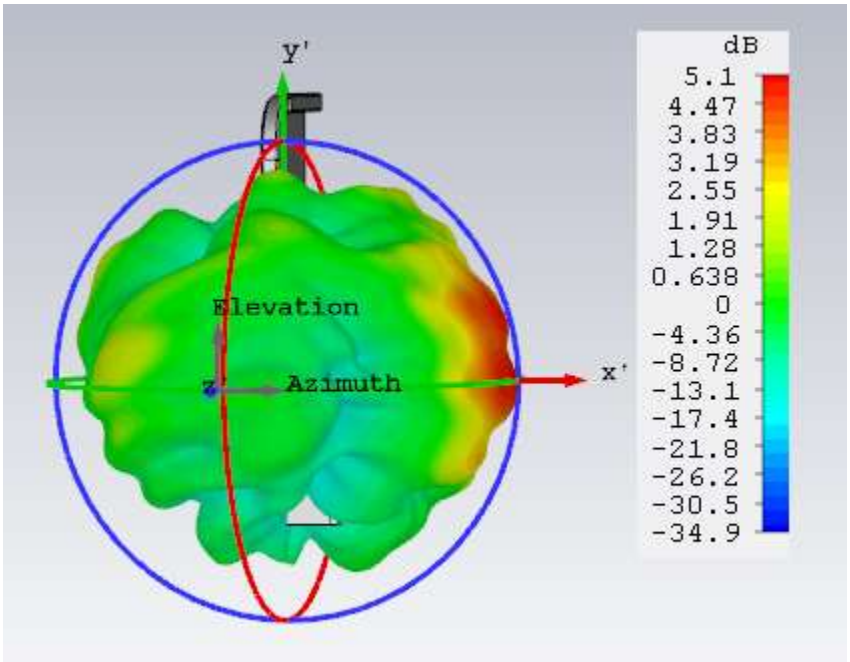


Figure 15: 3D Co-polarization simulated realized gain at 3.5 GHz of the back side antenna, together with the vehicle parts.

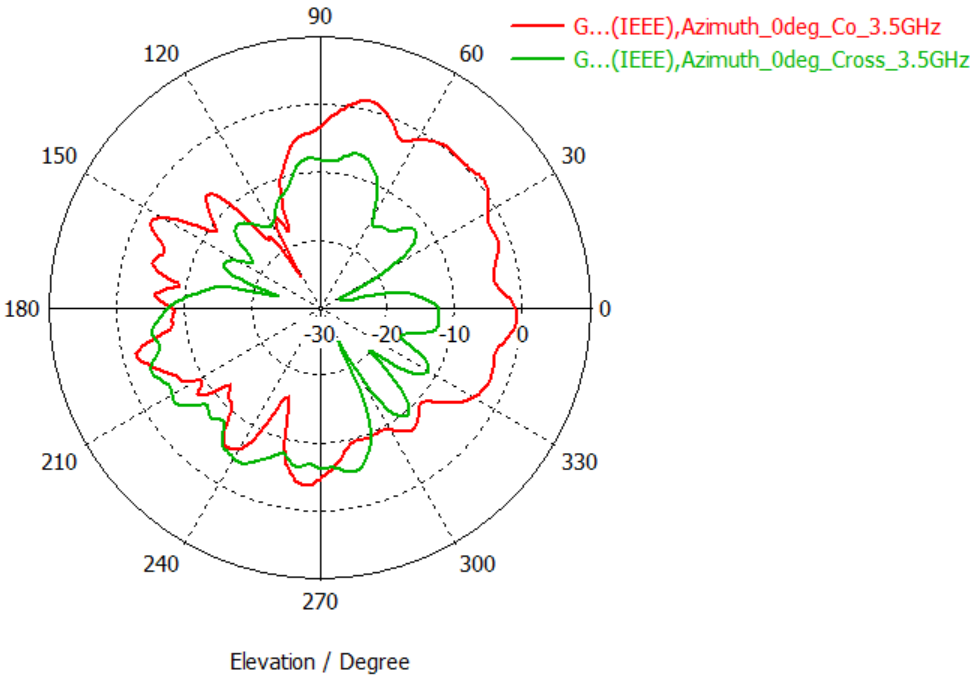


Figure 16: Simulation result of the backside antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 3.5 GHz.

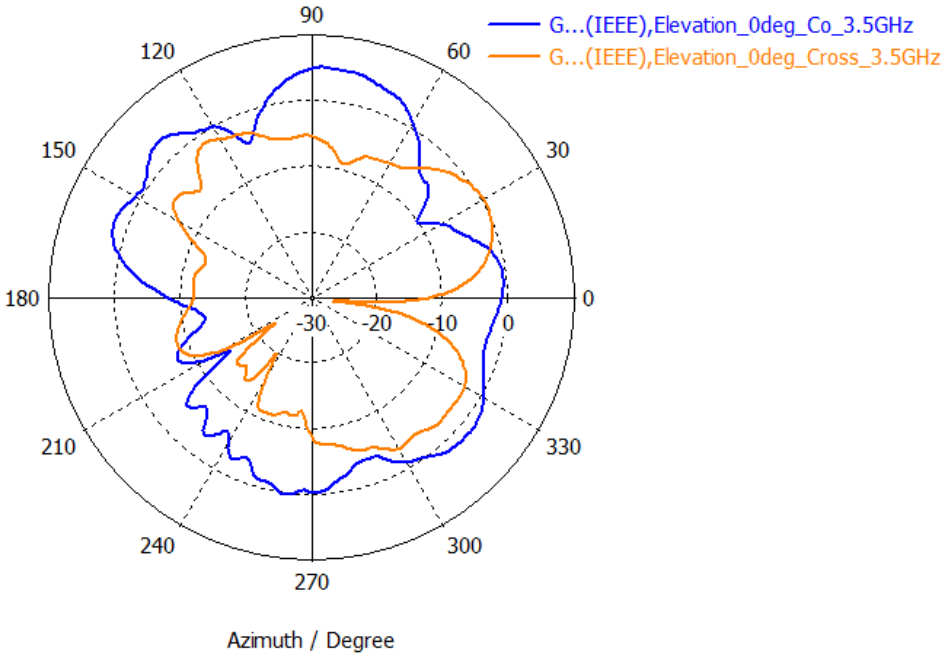


Figure 17: Simulation result of the backside antenna together with the vehicle parts at constant elevation, co and cross polarizations at 3.5 GHz.

Back side antenna realized gain pattern at the frequency 5 GHz is demonstrated.

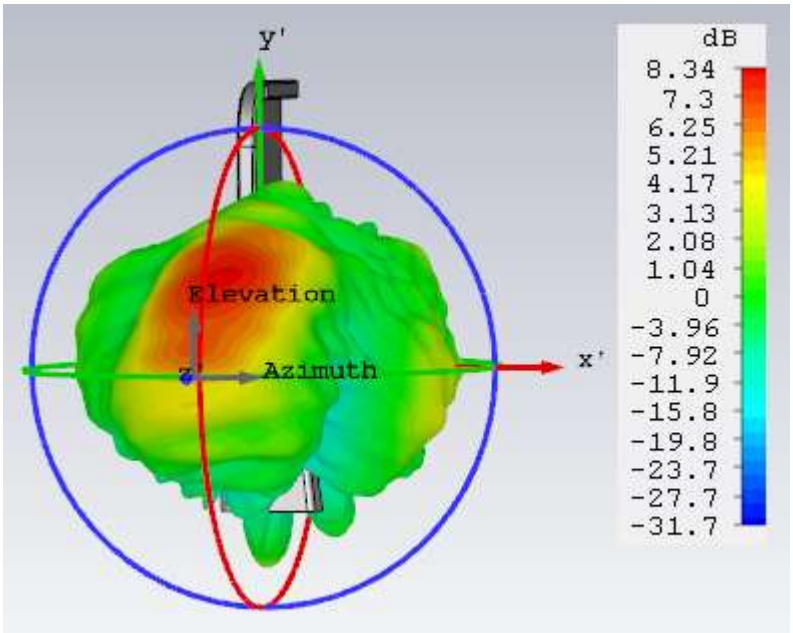


Figure 18: 3D Co-polarization simulated realized gain at 5 GHz of the back side antenna, together with the vehicle parts.

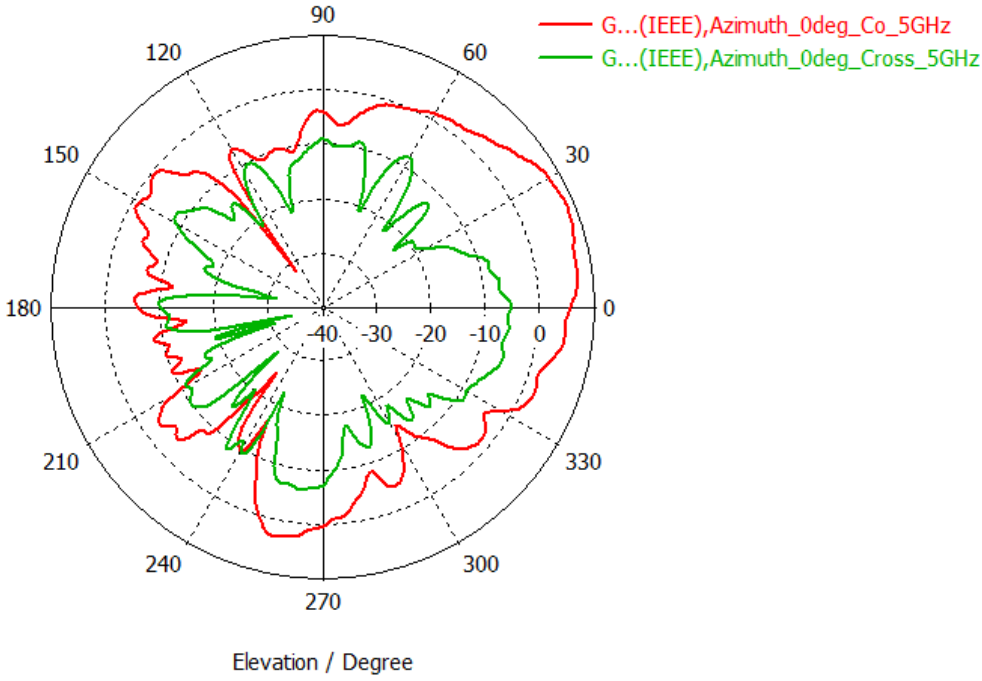


Figure 19: Simulation result of the backside antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 5 GHz.

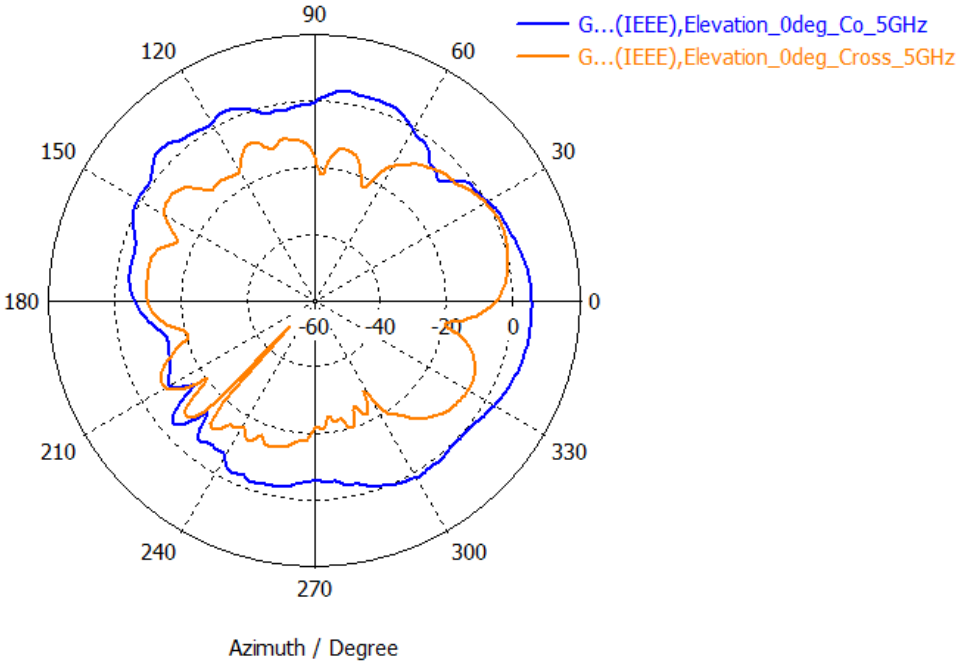


Figure 20: Simulation result of the backside antenna together with the vehicle parts at constant elevation, co and cross polarizations at 5 GHz.

Back side antenna realized gain pattern at the frequency 6 GHz is demonstrated.

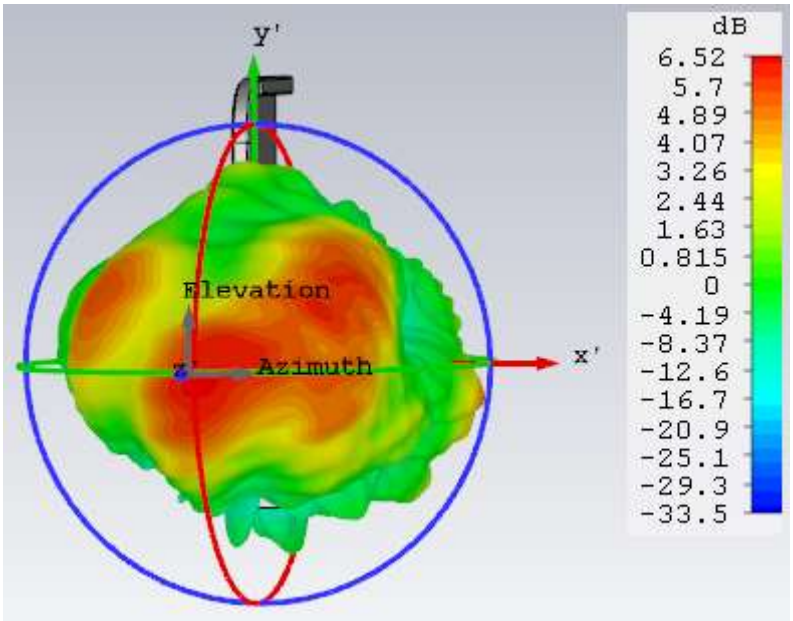


Figure 21: 3D Co-polarization simulated realized gain at 6 GHz of the back side antenna, together with the vehicle parts.

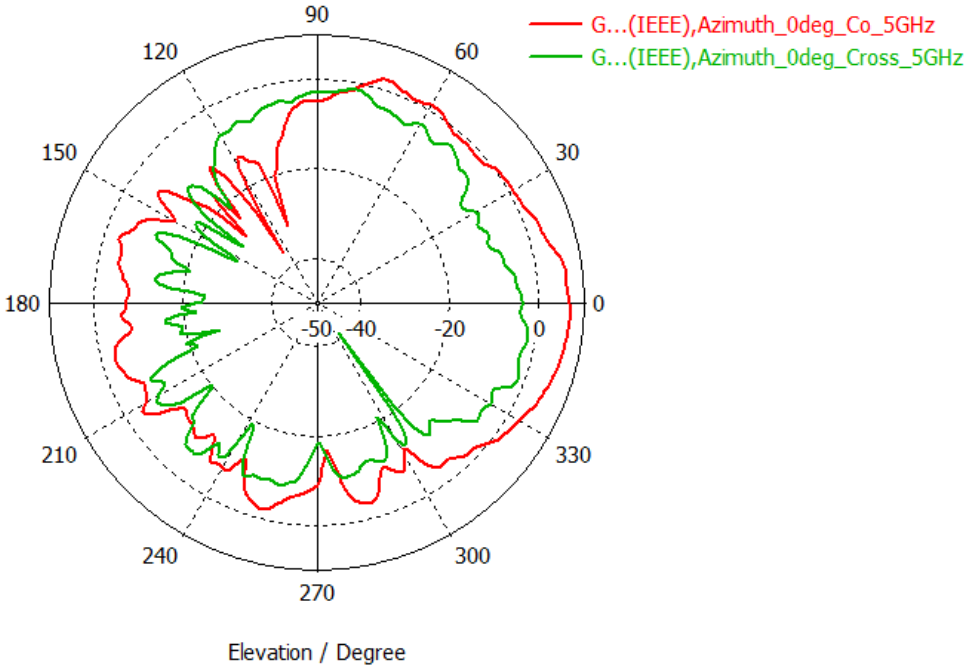


Figure 22: Simulation result of the backside antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 6 GHz.

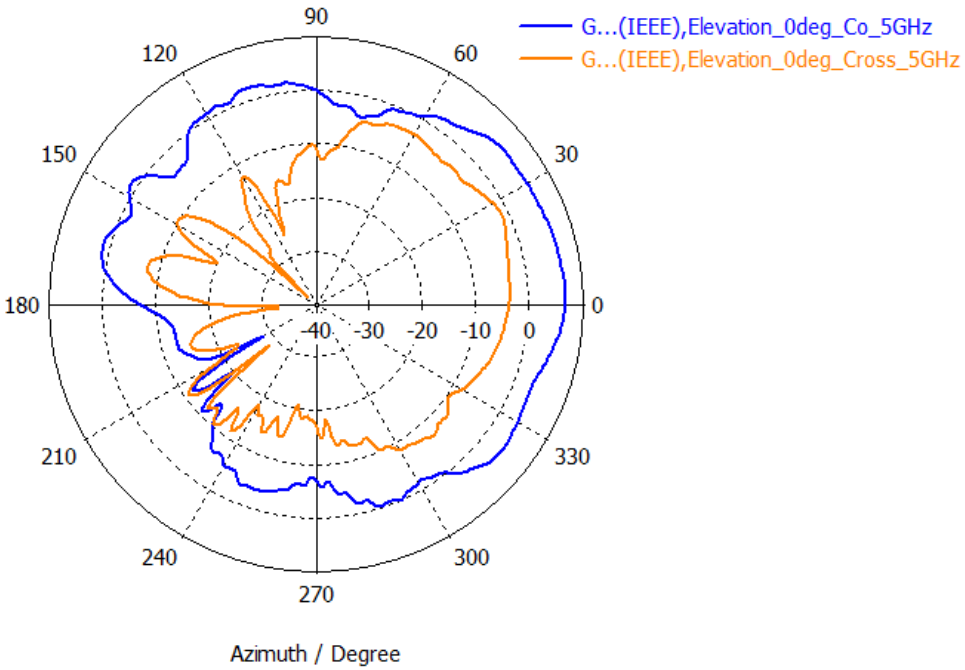


Figure 23: Simulation result of the backside antenna together with the vehicle parts at constant elevation, co and cross polarizations at 6 GHz.

3.3.3 Front side antenna simulations

The simulation model for the front side of the vehicle is demonstrated.

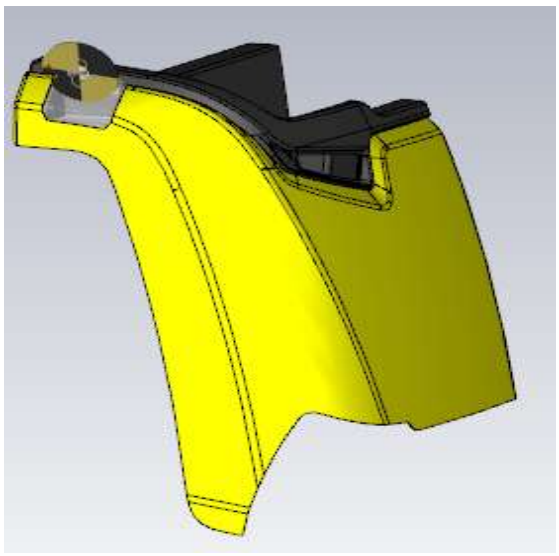


Figure 24: Simulation model for the front right antenna including the nearby elements of the vehicle.

The S-Parameter (S11) of the antenna taken from front side simulation is demonstrated.

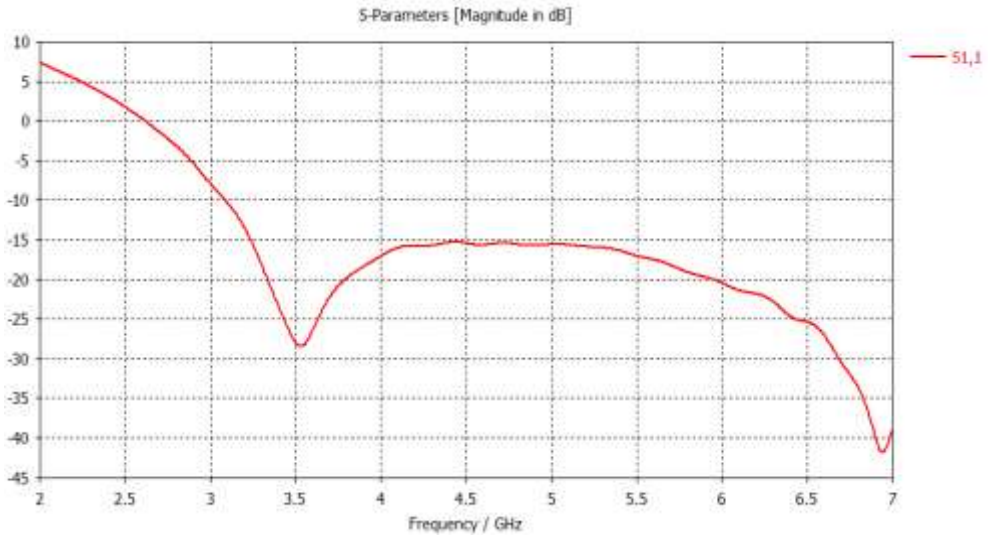


Figure 25: Simulated S-parameter of the front side antenna (S11).

The realized gain values for the frequencies 3.5, 5 and 6 GHz are considered for this report.

Front side antenna realized gain pattern at the frequency 3.5 GHz is demonstrated.

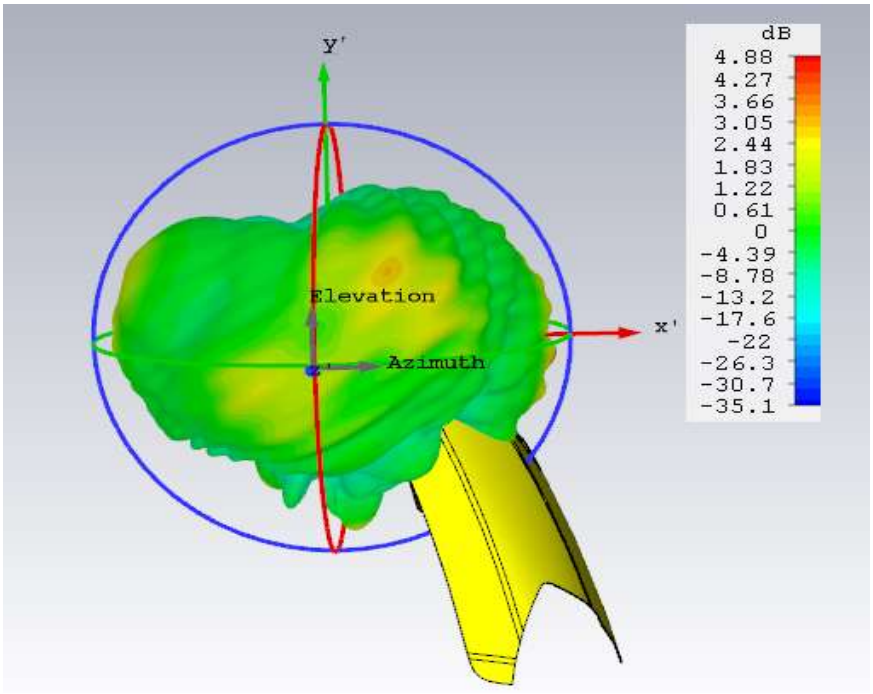


Figure 26: 3D Co-polarization simulated realized gain at 3.5 GHz of the front side antenna, together with the vehicle parts.

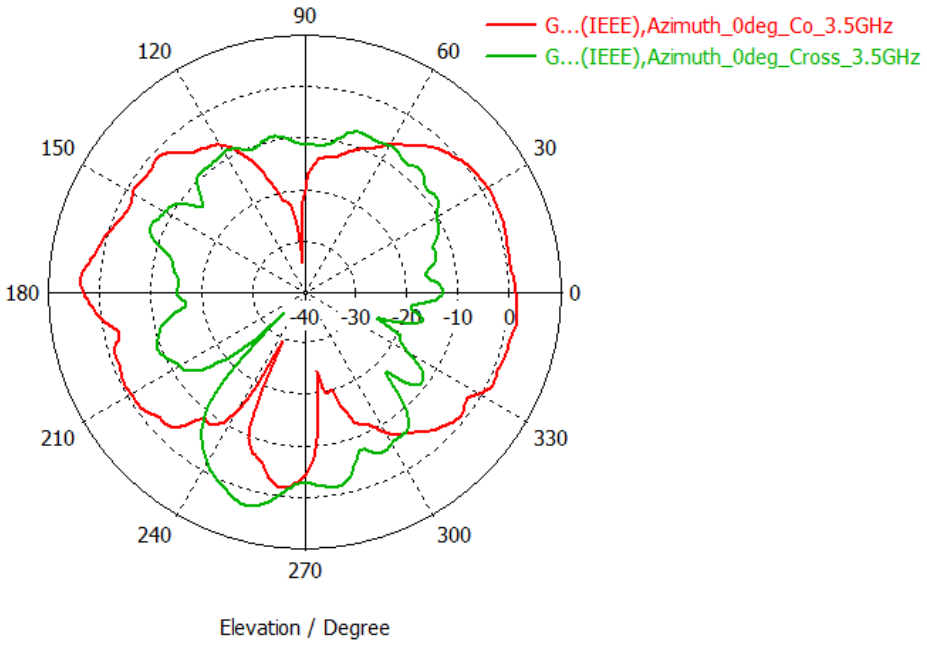


Figure 27: Simulation result of the front side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 3.5 GHz.

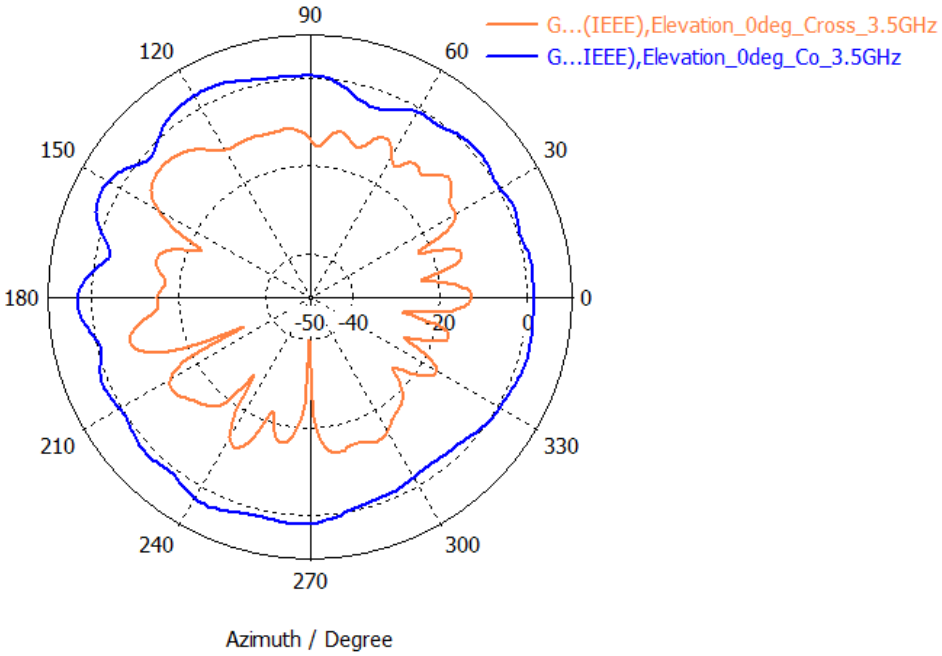


Figure 28: Simulation result of the front side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 3.5 GHz.

Front side antenna realized gain pattern at the frequency 5 GHz is demonstrated.

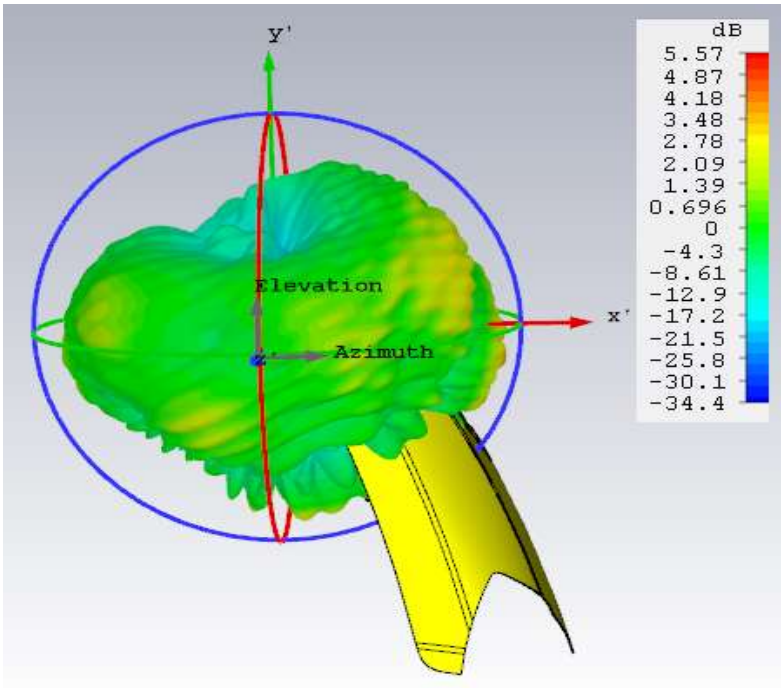


Figure 29: 3D Co-polarization simulated realized gain at 5 GHz of the front side antenna, together with the vehicle parts.

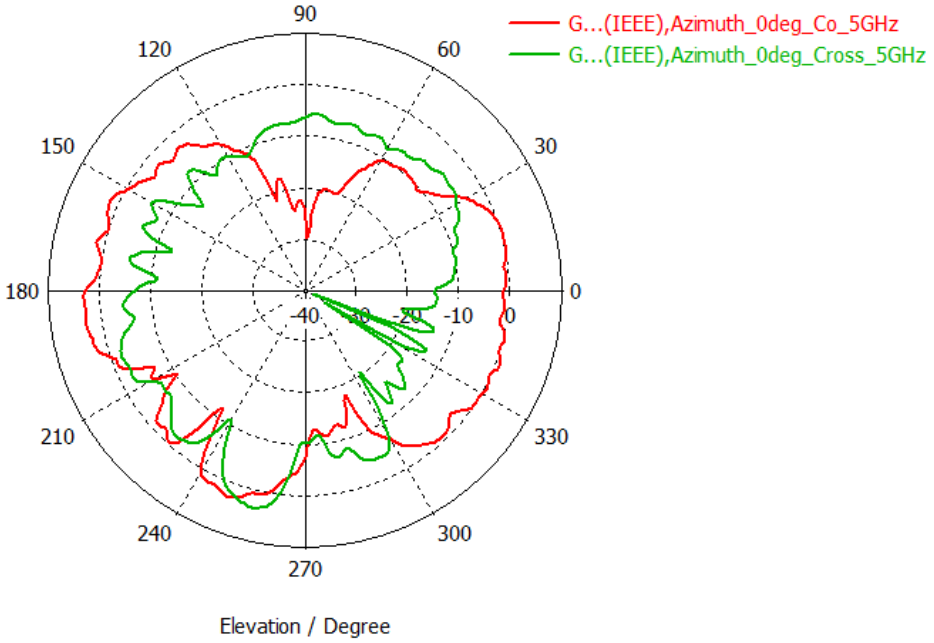


Figure 30: Simulation result of the front side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 5 GHz.

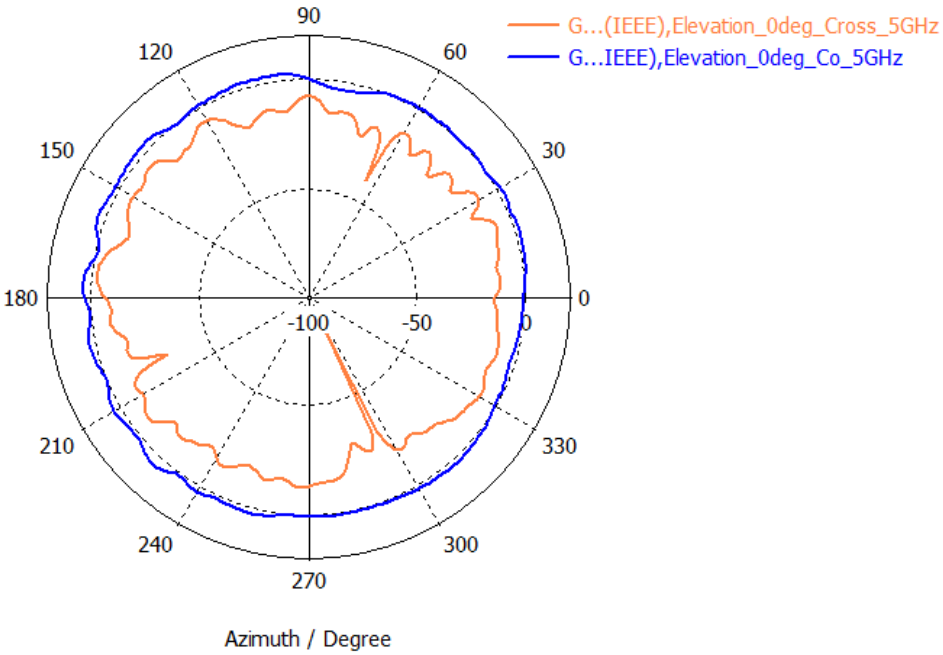


Figure 31: Simulation result of the front side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 5 GHz.

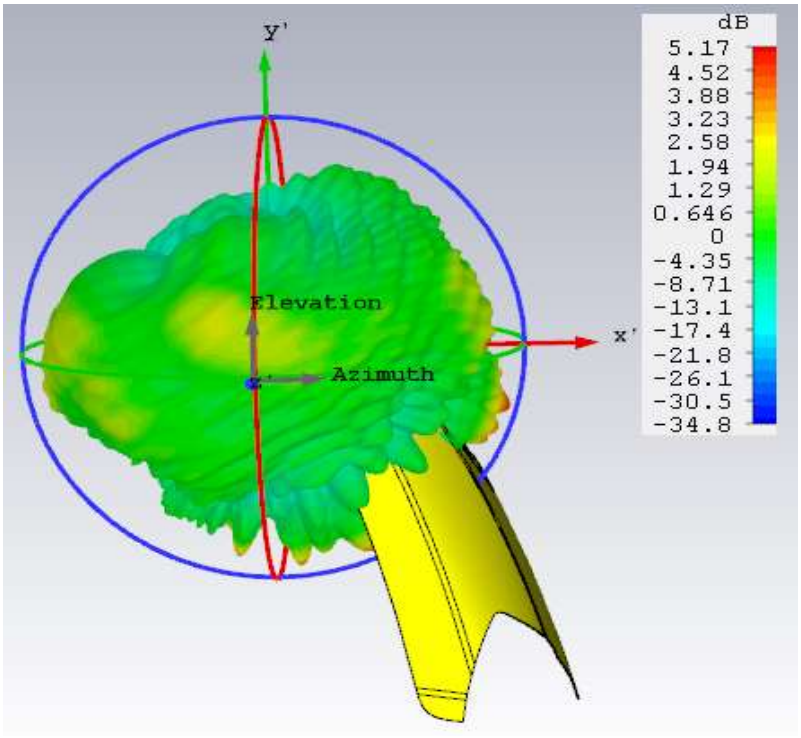


Figure 32: 3D Co-polarization simulated realized gain at 6 GHz of the front side antenna, together with the vehicle parts.

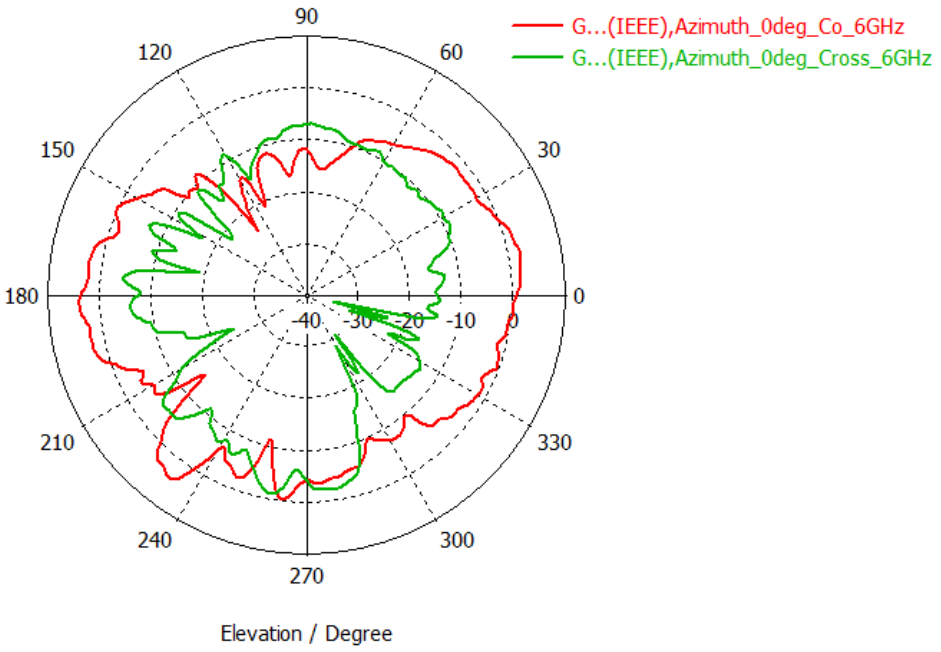


Figure 33: Simulation result of the front side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 6 GHz.

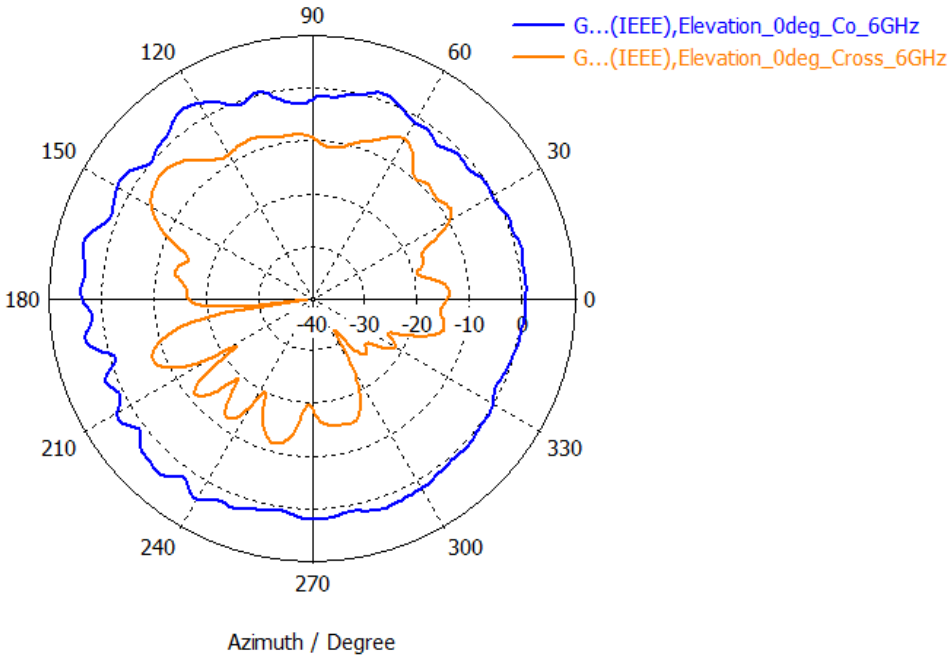


Figure 34: Simulation result of the front side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 6 GHz.

3.4 Measurement Results

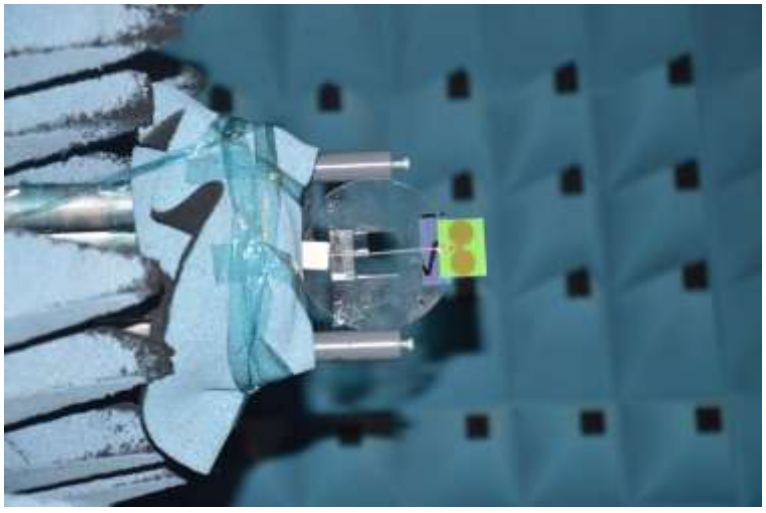


Figure 3-35 UWB Antenna without vehicle components

Figure 3-36 UWB Antenna with vehicle parts in position B (back)

Figure 3-37 UWB Antenna with vehicle parts in position A (front)

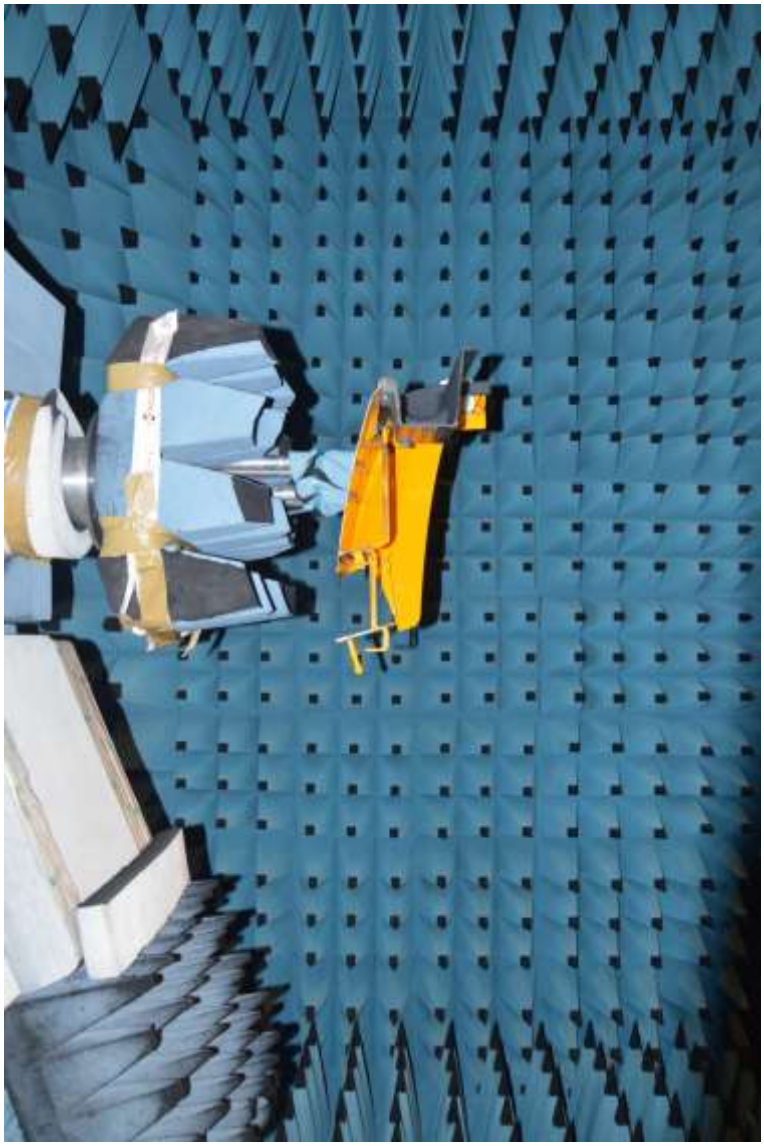


Figure 3-38 UWB Antenna with vehicle parts in position A (front)

3.4.1 Antenna Gain

File	NF_DRWG_UWB-Proto-A1_01.NSI				NF_DRWG_UWB-Proto-WagenteileVR_07.NSI				NF_DRWG_UWB-Proto-WagenteileHR_06.NSI			
Frequency	**MaxFF_Glc**	**Directivity**	**Gain [dBi]** cable loss compensated	**Efficiency**	**MaxFF_Glc**	**Directivity**	**Gain [dBi]** cable loss compensated	**Efficiency**	**MaxFF_Glc**	**Directivity**	**Gain [dBi]** cable loss compensated	**Efficiency**
3.0	2.58	4.96	**0.96**	40%	4.12	5.90	**2.50**	46%	7.46	8.82	**5.83**	50%
3.1	2.19	5.05	**1.50**	44%	3.69	6.06	**3.01**	50%	5.62	7.57	**4.93**	54%
3.2	1.93	5.09	**1.93**	48%	3.44	6.14	**3.43**	54%	4.75	6.95	**4.74**	60%
3.3	1.12	4.95	**1.69**	47%	3.07	6.46	**3.64**	52%	3.81	6.95	**4.38**	55%
3.4	1.52	5.22	**2.15**	49%	3.90	7.04	**4.53**	56%	2.21	5.79	**2.84**	51%
3.5	1.42	5.40	**2.78**	55%	3.38	6.73	**4.73**	63%	2.32	6.00	**3.67**	59%
3.6	1.09	5.47	**2.92**	56%	2.96	6.79	**4.78**	63%	2.68	6.68	**4.51**	61%
3.7	0.50	5.58	**3.04**	56%	2.42	6.89	**4.96**	64%	2.12	6.76	**4.66**	62%
3.8	-1.07	5.66	**2.89**	53%	0.80	6.83	**4.76**	62%	0.32	6.49	**4.28**	60%
3.9	-1.70	5.72	**2.79**	51%	-0.28	6.51	**4.21**	59%	0.11	6.83	**4.60**	60%
4.0	-1.62	5.76	**2.83**	51%	-0.36	6.50	**4.09**	57%	0.33	7.19	**4.79**	58%
4.1	-0.94	5.97	**2.89**	49%	0.16	6.62	**3.99**	55%	0.83	7.45	**4.66**	53%
4.2	-0.63	5.90	**3.00**	51%	0.24	6.35	**3.88**	57%	1.52	7.79	**5.15**	54%
4.3	-0.64	5.95	**2.65**	47%	-0.30	5.82	**2.99**	52%	1.62	7.90	**4.91**	50%
4.4	-1.16	6.06	**2.34**	43%	-0.93	5.85	**2.57**	47%	0.74	8.16	**4.25**	41%
4.5	-1.54	6.05	**2.75**	47%	-1.44	5.73	**2.85**	51%	1.20	9.07	**5.49**	44%
4.6	-1.55	5.88	**2.63**	47%	-1.16	5.89	**3.02**	52%	1.43	8.77	**5.61**	48%
4.7	-1.12	5.79	**2.86**	51%	-0.20	6.48	**3.78**	54%	0.25	7.03	**4.23**	52%
4.8	-1.39	5.72	**3.13**	55%	-0.53	6.31	**3.99**	59%	0.06	6.92	**4.58**	58%
4.9	-2.43	5.70	**2.32**	46%	-1.13	6.64	**3.62**	50%	-0.51	7.65	**4.24**	46%
5.0	-2.48	5.65	**2.04**	44%	-0.89	7.00	**3.63**	46%	-1.10	7.16	**3.42**	42%
5.1	-2.80	5.57	**2.38**	48%	-1.08	7.12	**4.10**	50%	-0.64	7.49	**4.53**	51%
5.2	-2.80	5.58	**3.08**	56%	-1.01	7.22	**4.87**	58%	-0.21	7.64	**5.66**	63%
5.3	-2.73	5.56	**2.97**	55%	-0.76	7.21	**4.94**	59%	0.57	8.43	**6.27**	61%
5.4	-3.95	5.62	**2.44**	48%	-2.32	7.04	**4.07**	50%	-1.58	7.84	**4.81**	50%
5.5	-4.47	5.78	**1.84**	40%	-2.98	7.16	**3.34**	41%	-2.48	7.28	**3.83**	45%
5.6	-3.64	5.75	**1.80**	40%	-1.99	7.32	**3.44**	41%	-1.37	7.21	**4.07**	48%
5.7	-3.46	5.59	**2.33**	47%	-1.67	7.20	**4.11**	49%	-0.93	7.38	**4.86**	56%
5.8	-4.08	5.55	**2.36**	48%	-2.14	7.11	**4.30**	52%	-1.36	7.54	**5.07**	57%
5.9	-4.96	5.55	**1.66**	41%	-3.11	7.12	**3.52**	44%	-2.14	7.77	**4.48**	47%
6.0	-5.87	5.64	**1.64**	40%	-4.23	7.08	**3.28**	42%	-3.25	7.86	**4.25**	44%
6.1	-6.24	5.49	**1.84**	43%	-4.61	6.91	**3.47**	45%	-3.73	7.51	**4.35**	48%
6.2	-5.28	5.57	**2.32**	47%	-3.95	6.59	**3.64**	51%	-2.69	7.35	**4.90**	57%
6.3	-4.97	5.76	**2.72**	50%	-4.01	6.41	**3.68**	53%	-2.74	7.08	**4.95**	61%
6.4	-5.21	5.88	**2.81**	49%	-4.08	6.70	**3.95**	53%	-3.41	7.04	**4.61**	57%
6.5	-5.11	6.03	**2.59**	45%	-3.59	7.16	**4.11**	50%	-3.06	7.14	**4.64**	56%
6.6	-5.82	5.93	**2.53**	46%	-4.10	7.18	**4.25**	51%	-3.46	7.02	**4.88**	61%
6.7	-6.36	5.89	**2.86**	50%	-4.50	7.28	**4.71**	55%	-4.22	6.91	**4.99**	64%
6.8	-6.08	6.26	**3.38**	51%	-5.07	6.83	**4.39**	57%	-4.70	6.87	**4.75**	61%
6.9	-5.59	6.60	**3.52**	49%	-4.98	6.85	**4.13**	53%	-4.90	6.83	**4.21**	55%
7.0	-5.41	6.70	**3.62**	49%	-4.10	7.59	**4.92**	54%	-4.73	6.88	**4.29**	55%

Table 3-1: Measured antenna gain and efficiency of the UWB antenna [left side, the UWB antenna without antenna housing, in the middle the UWB antenna with car parts in the position A, right side, the UWB antenna with car parts in the position B].

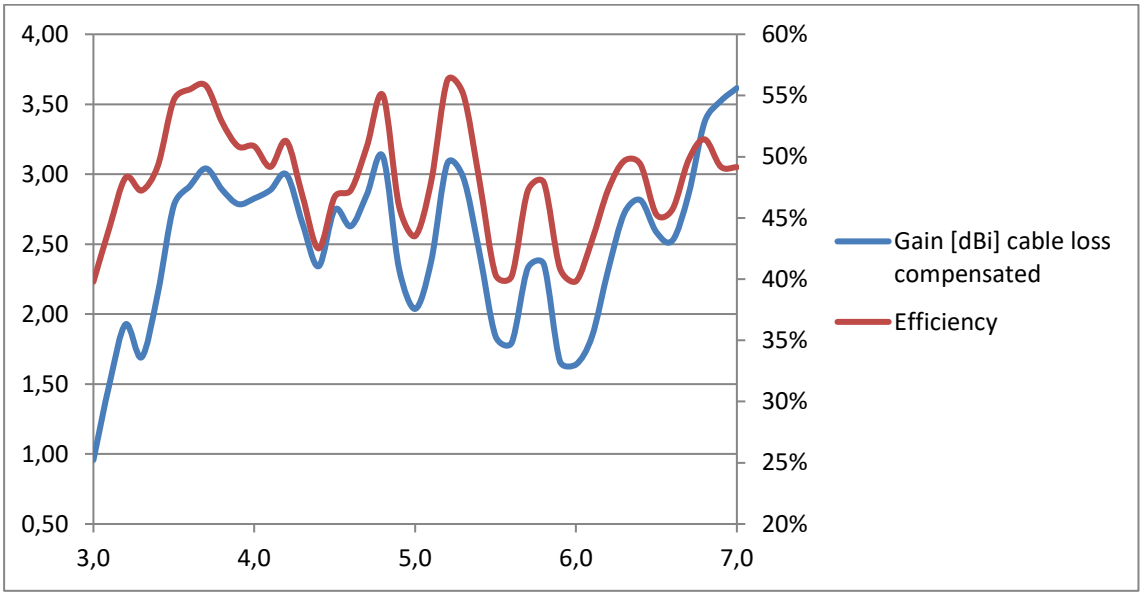


Figure 3-39: Antenna gain in dBi and efficiency for the UWB antennas without additional components.

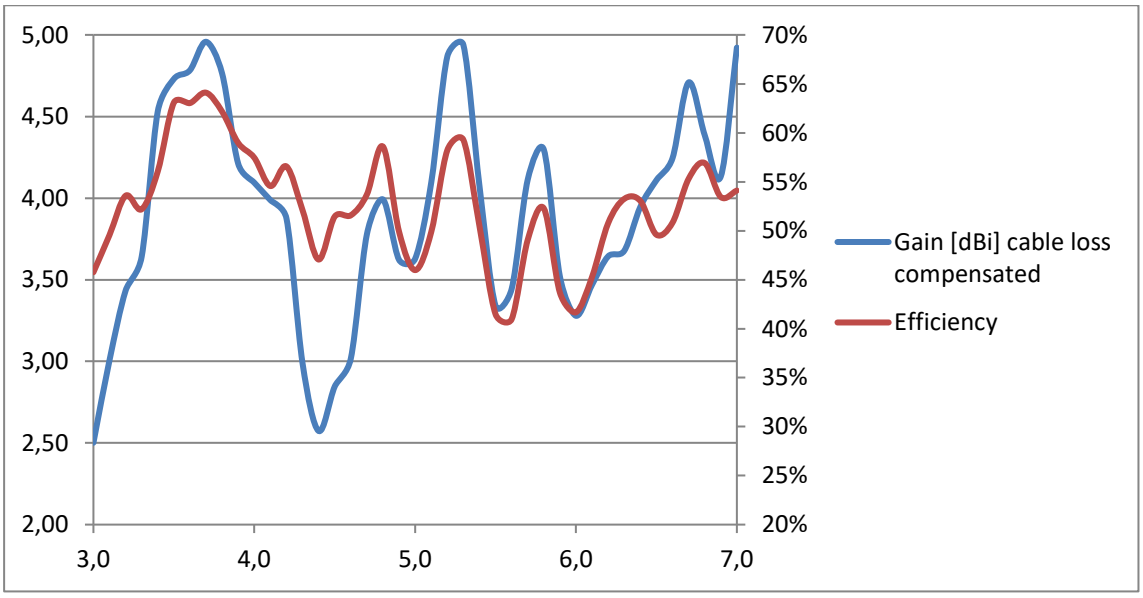


Figure 3-40: Antenna gain in dBi and efficiency for the UWB antennas with vehicle parts in position A.

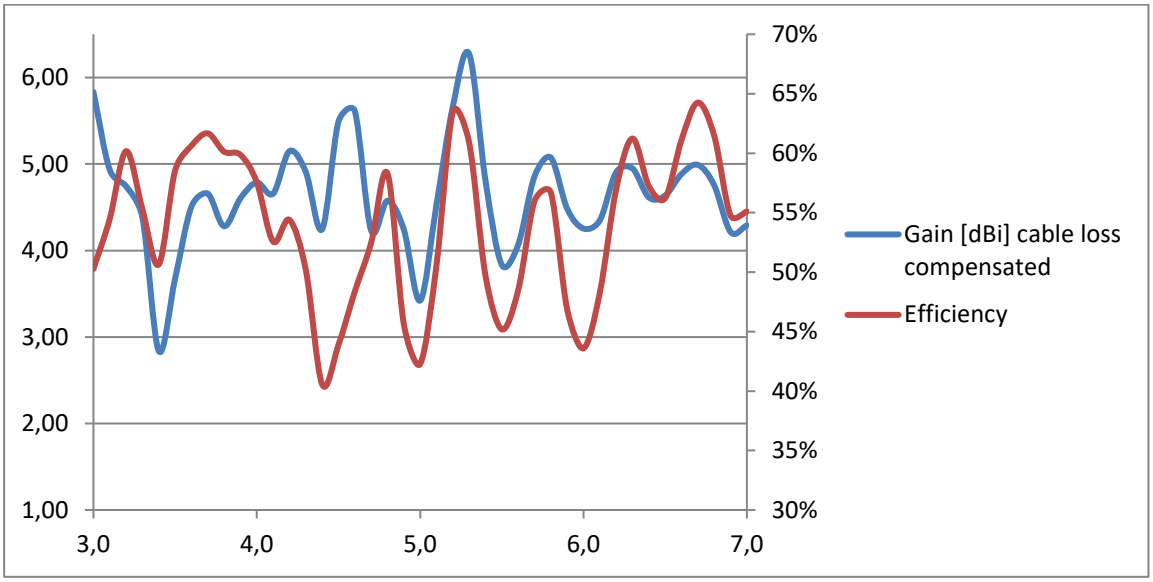


Figure 3-41: Antenna gain in dBi and efficiency for the UWB antennas with vehicle parts in position B.

3.4.2 Back side antenna with nearby vehicle components

Back side antenna measured realized gain pattern together with parts of the vehicle at the frequency 3.5 GHz is demonstrated.

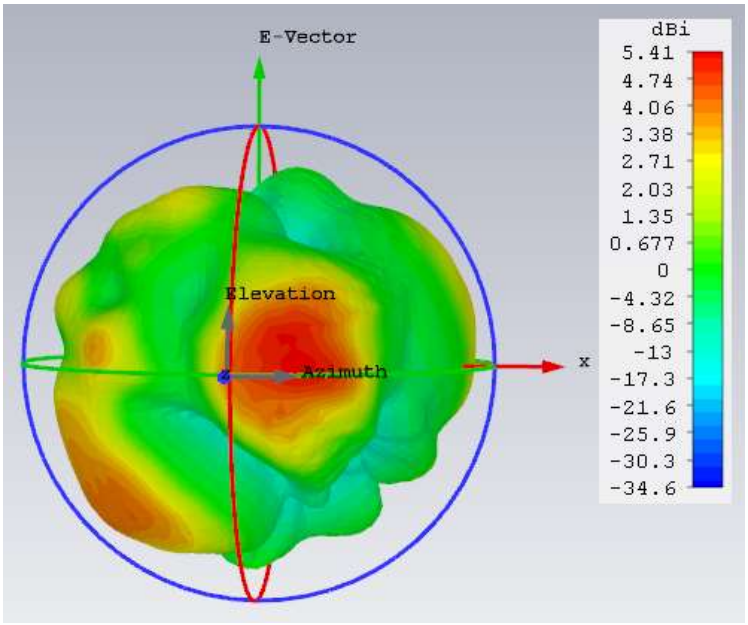


Figure 42: 3D Co-polarization measured realized gain at 3.5 GHz of the back side antenna, together with the vehicle parts.

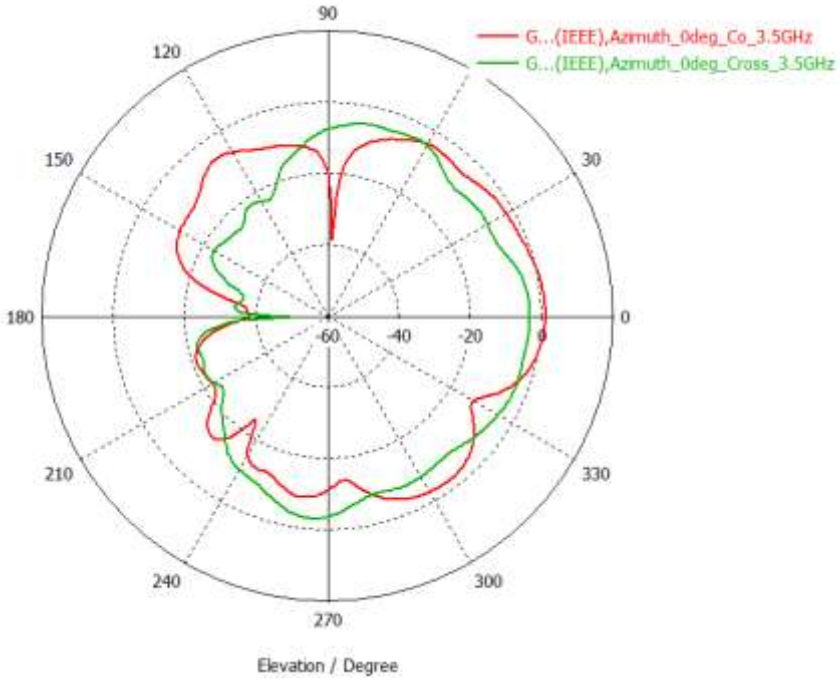


Figure 43: Measurement result of the back side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 3.5 GHz.

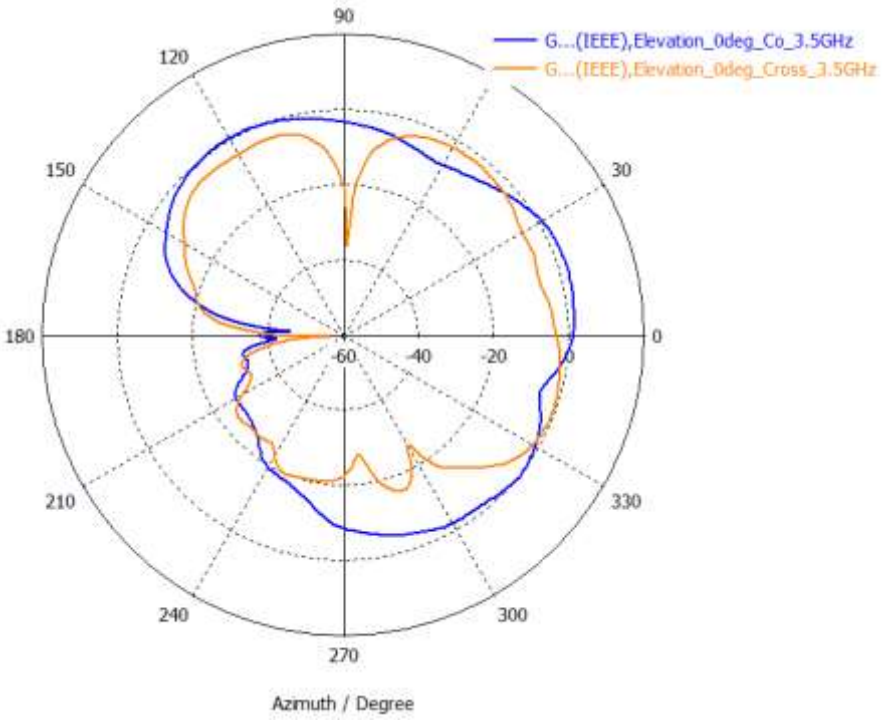


Figure 44: Measurement result of the back side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 3.5 GHz.

Back side antenna measured realized gain pattern together with parts of the vehicle at the frequency 5 GHz is demonstrated.

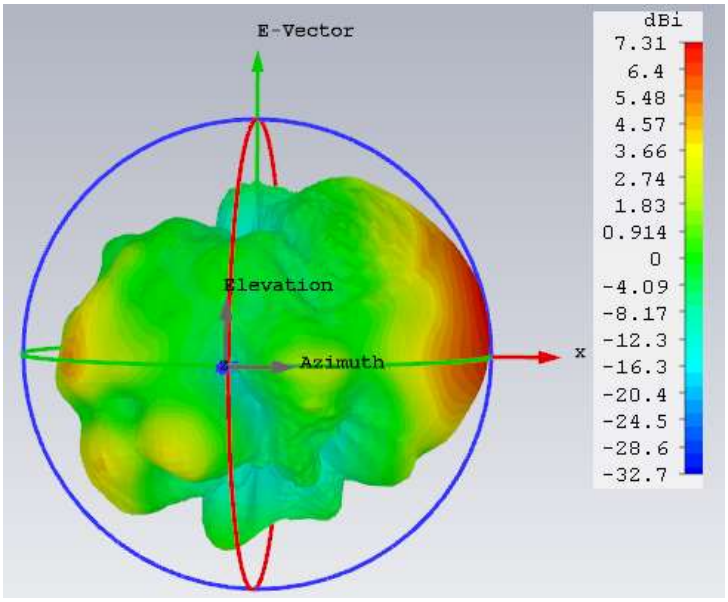


Figure 45: 3D Co-polarization measured realized gain at 5 GHz of the back side antenna, together with the vehicle parts.

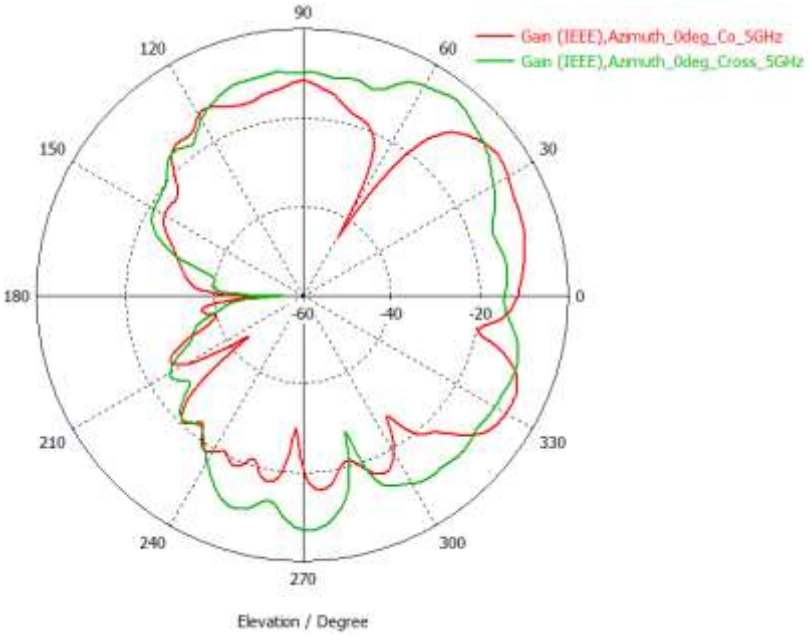


Figure 46: Measurement result of the back side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 5 GHz.

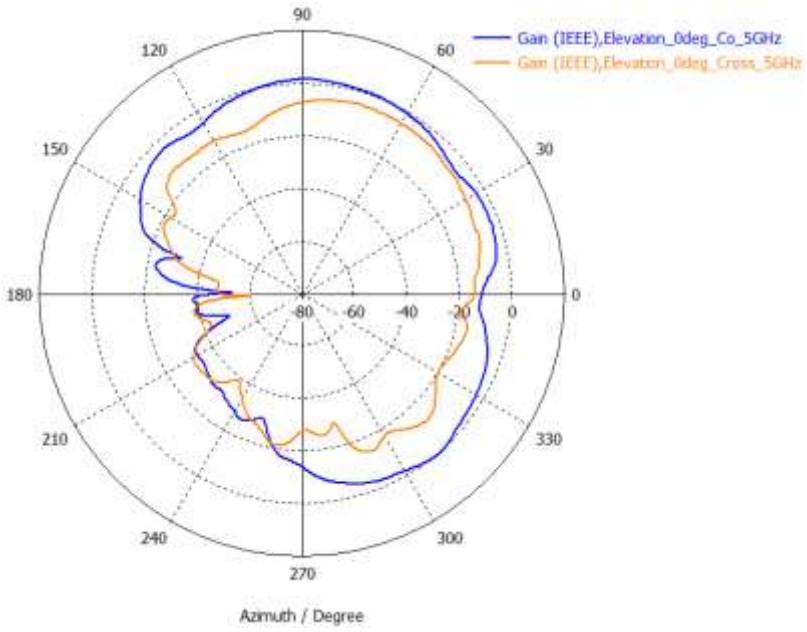


Figure 47: Measurement result of the back side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 5 GHz.

Back side antenna measured realized gain pattern together with parts of the vehicle at the frequency 6 GHz is demonstrated.

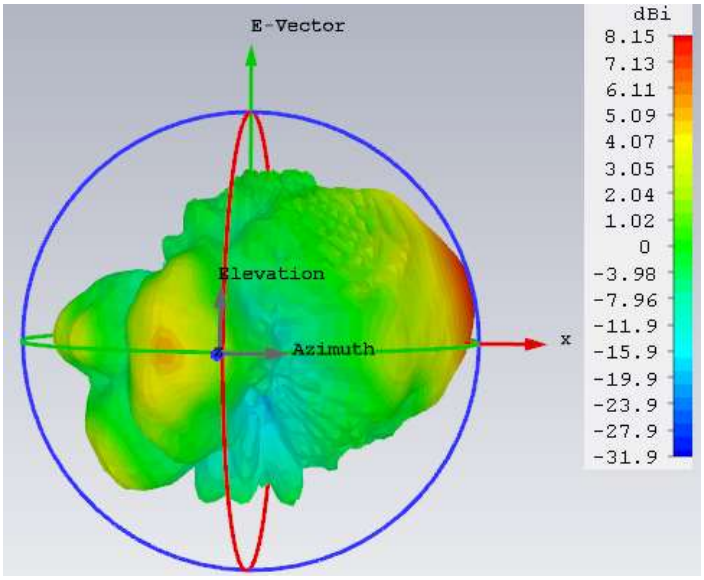


Figure 48: 3D Co-polarization measured realized gain at 6 GHz of the back side antenna, together with the vehicle parts.

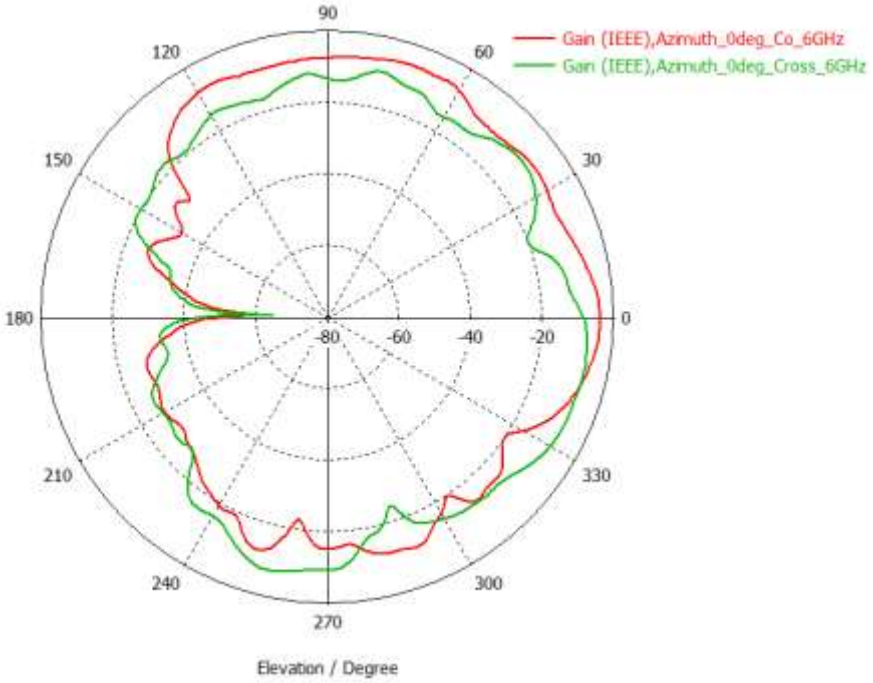


Figure 49: Measurement result of the back side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 6 GHz.

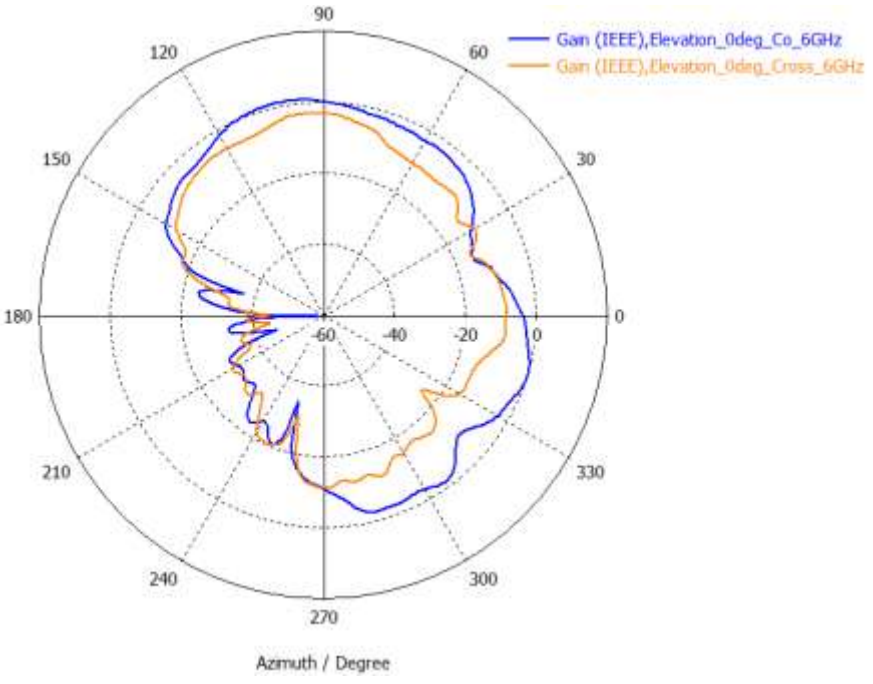


Figure 50: Measurement result of the back side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 6 GHz.

3.4.3 Front antenna with nearby vehicle components

Front side antenna measured realized gain pattern together with parts of the vehicle at the frequency 3.5 GHz is demonstrated.

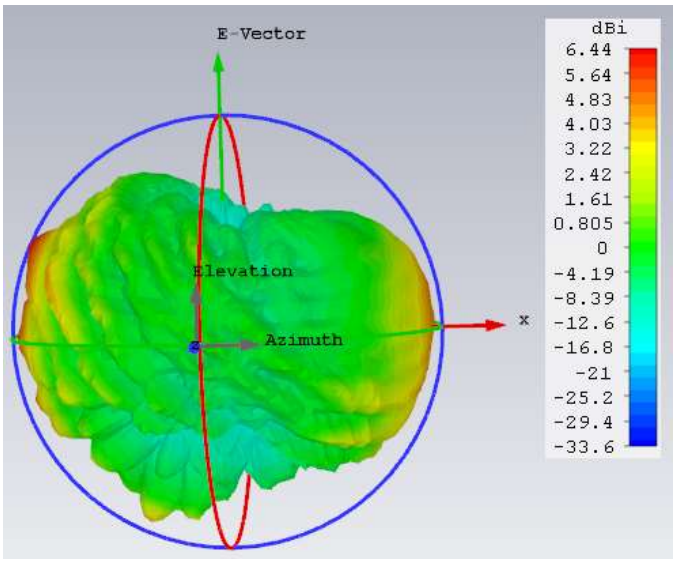


Figure 51: 3D Co-polarization measured realized gain at 3.5 GHz of the front side antenna, together with the vehicle parts.

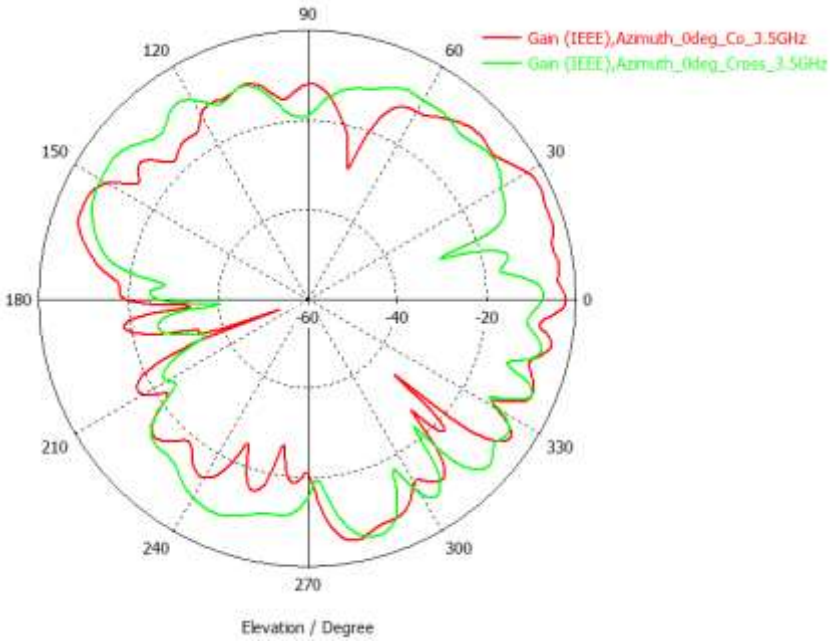


Figure 52: Measurement result of the front side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 3.5 GHz.

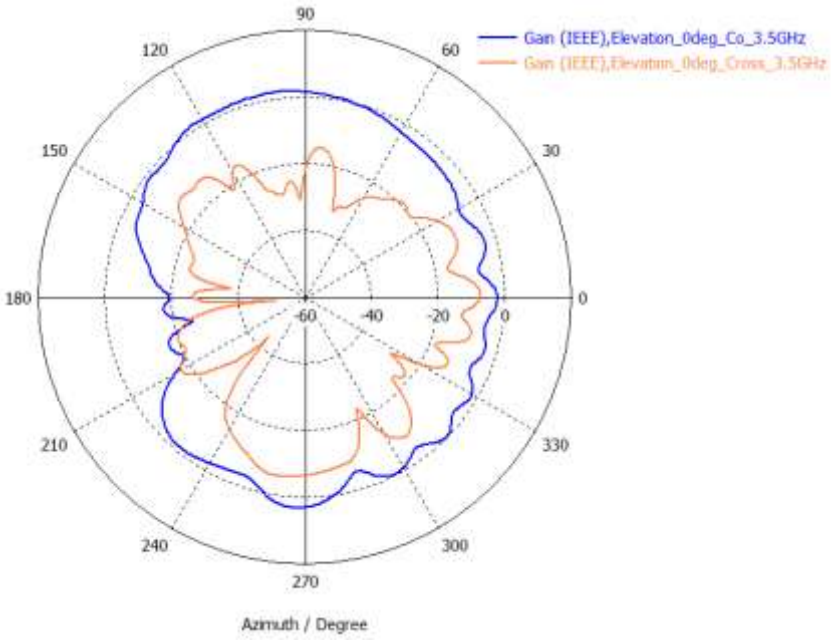


Figure 53: Measurement result of the front side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 3.5 GHz.

Front side antenna measured realized gain pattern together with parts of the vehicle at the frequency 5 GHz is demonstrated.

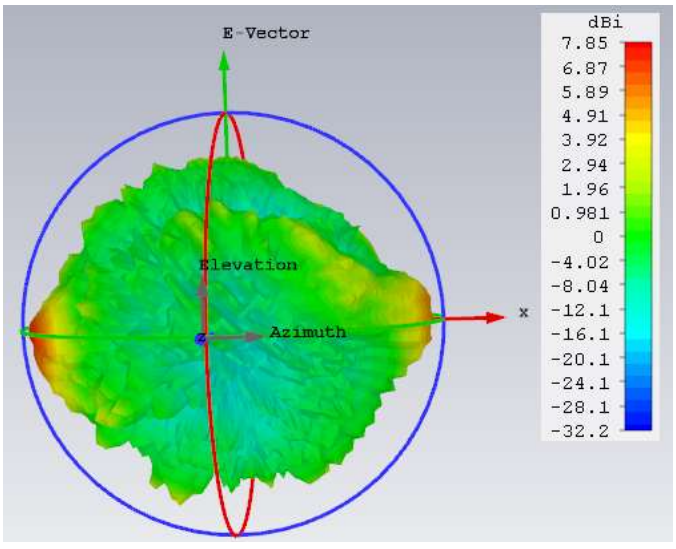


Figure 54: 3D Co-polarization measured realized gain at 5 GHz of the front side antenna, together with the vehicle parts.

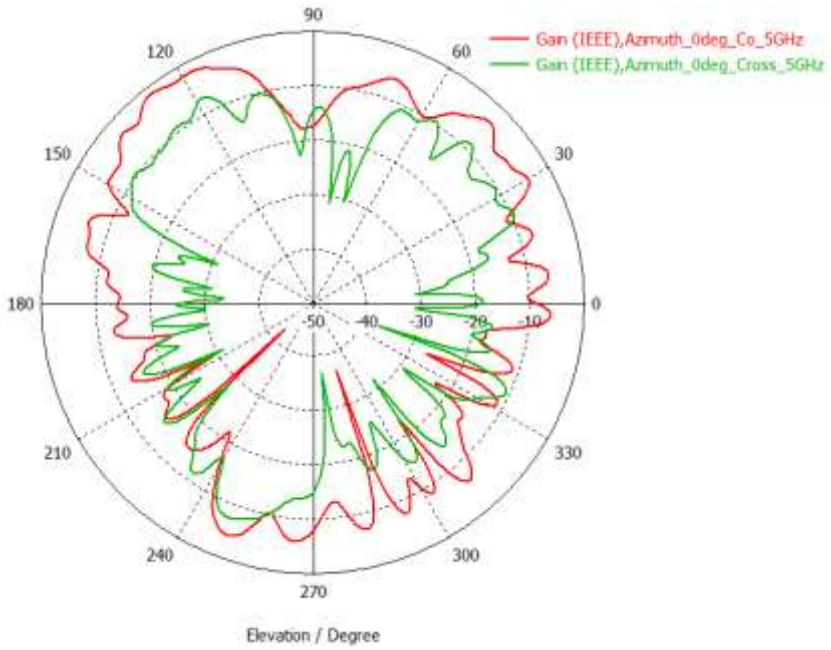


Figure 55: Measurement result of the front side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 5 GHz.

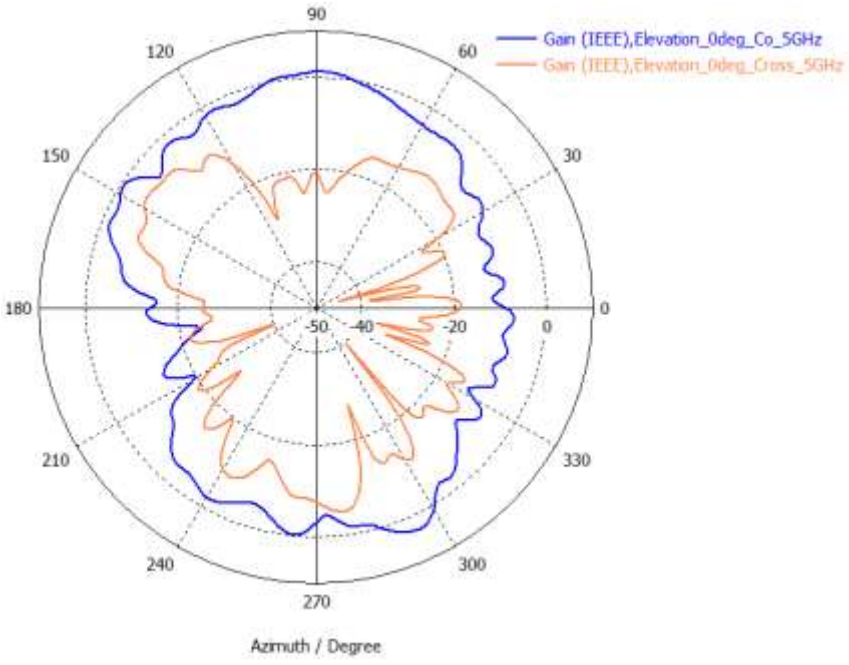


Figure 56: Measurement result of the front side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 5 GHz.

Front side antenna measured realized gain pattern together with parts of the vehicle at the frequency 6 GHz is demonstrated.

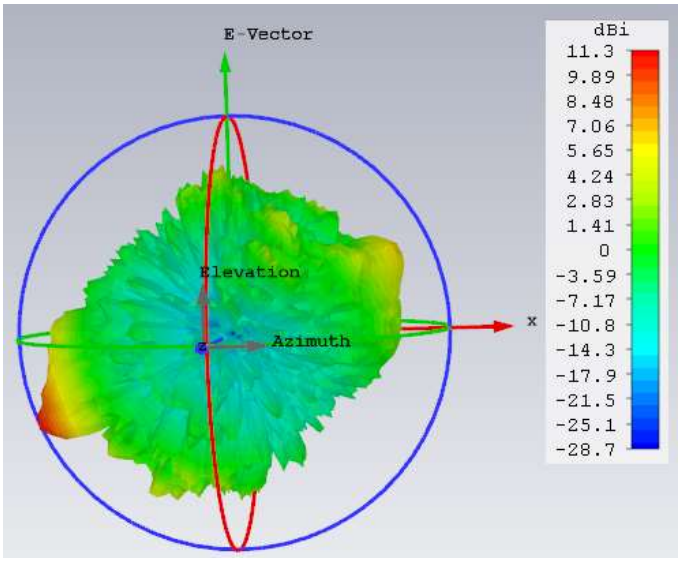


Figure 57: 3D Co-polarization measured realized gain at 6 GHz of the front side antenna, together with the vehicle parts.

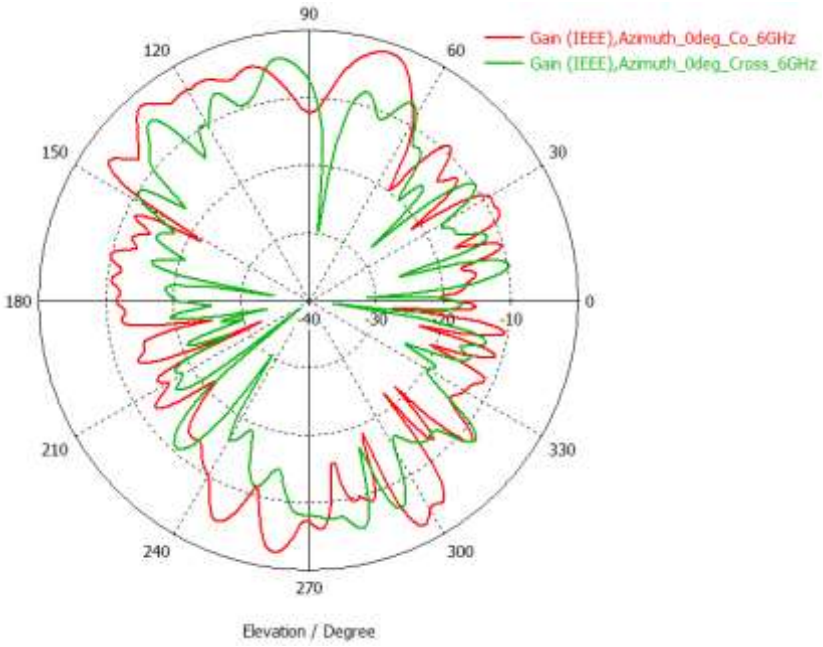


Figure 58: Measurement result of the front side antenna together with the vehicle parts at constant azimuth, co and cross polarizations at 6 GHz.

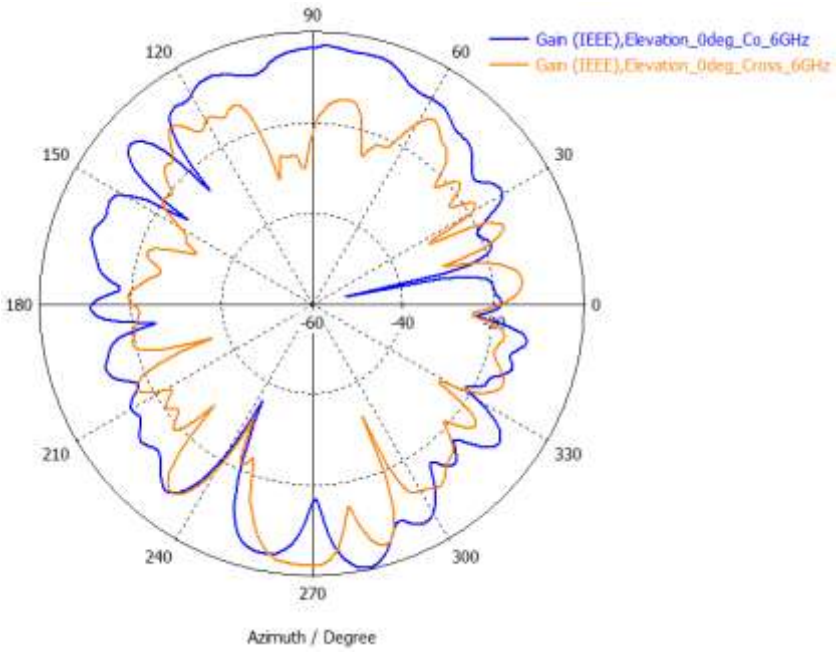


Figure 59: Measurement result of the front side antenna together with the vehicle parts at constant elevation, co and cross polarizations at 6 GHz.

3.4.4 Measurement of the final layout of the antenna with nearby vehicle components

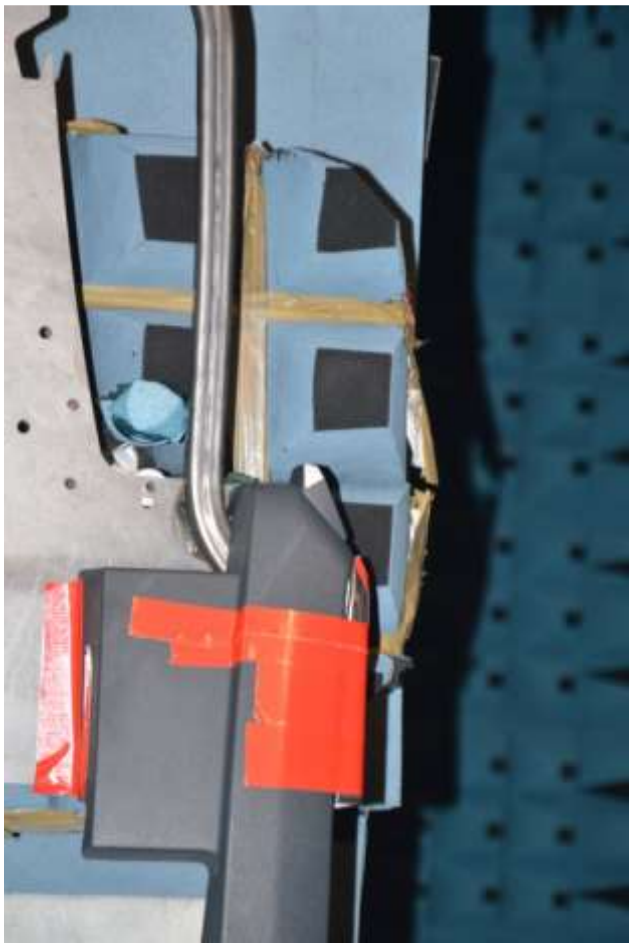


Figure 60: Back side nearby vehicle components and the antenna positioned for the measurement.

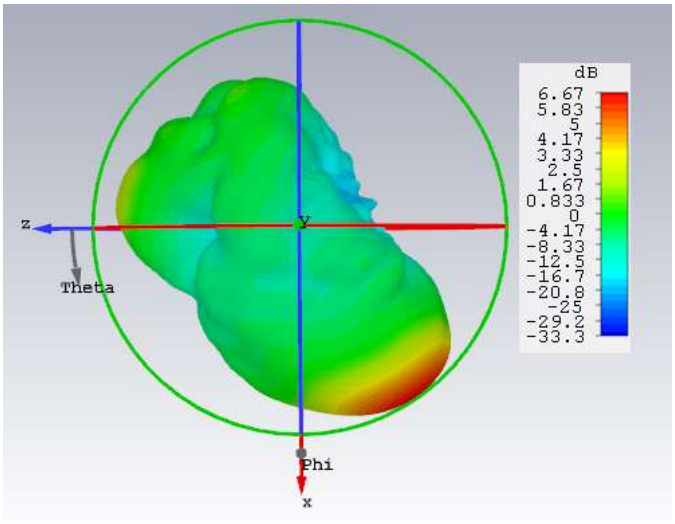


Figure 61: Back side antenna 3D realized gain plot at 4 GHz.

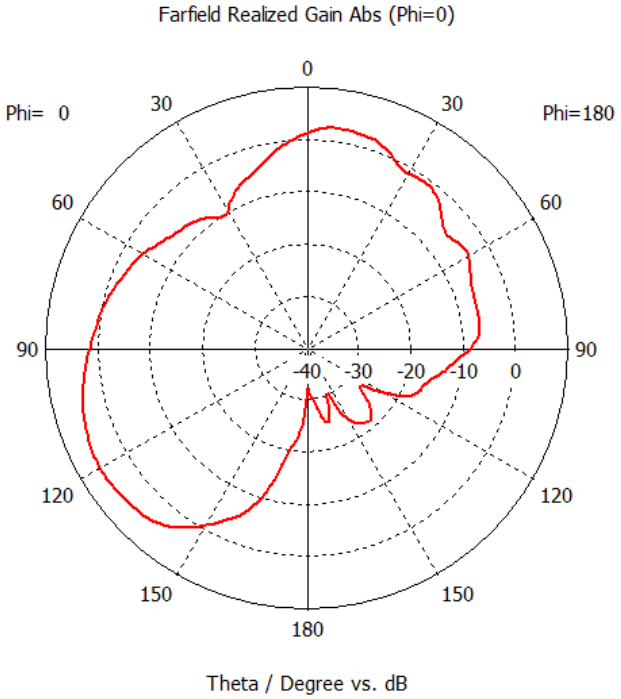


Figure 62: Back side antenna polar plot at phi=0° cut, 4 GHz.

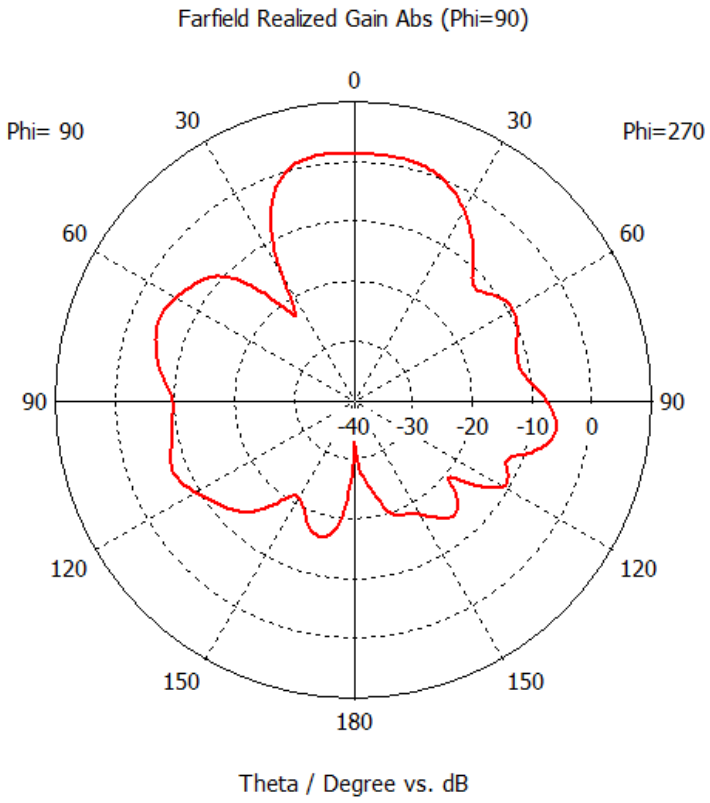


Figure 63: Back side antenna polar plot at phi=90° cut, 4 GHz.

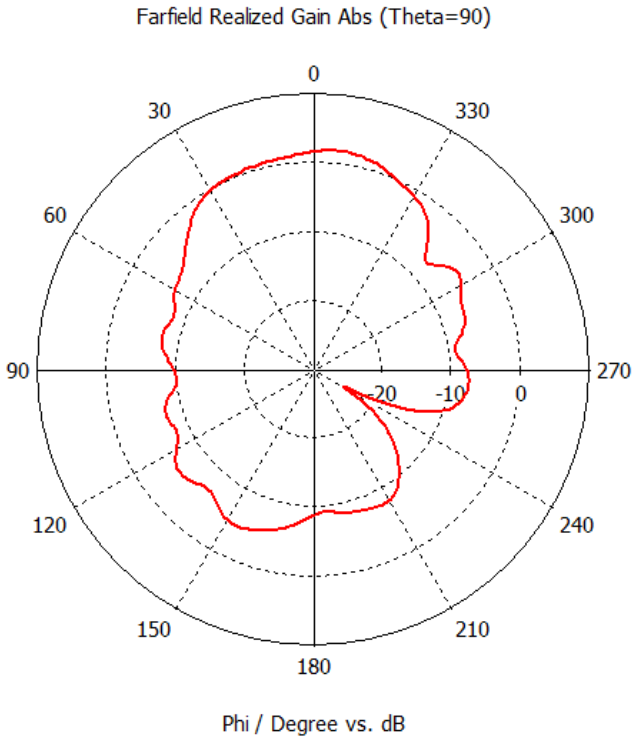


Figure 64: Back side antenna polar plot at theta=90° cut, 4 GHz.

Figure 65: Front side nearby vehicle components and the antenna positioned for the measurement.

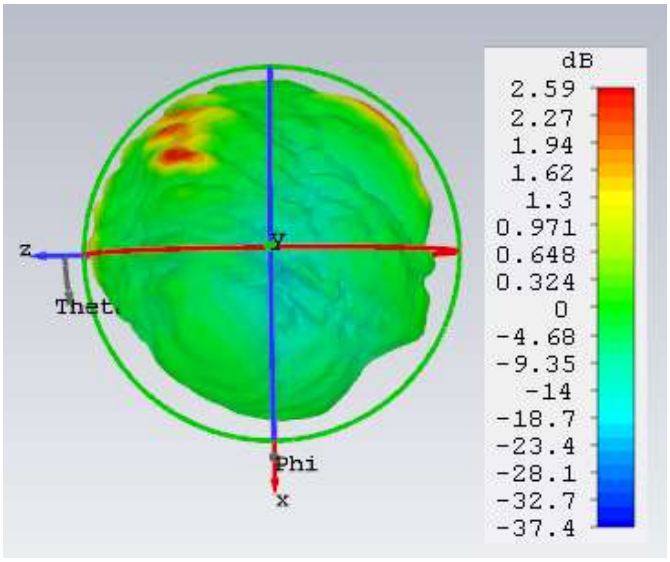


Figure 66: Front side antenna 3D realized gain plot at 4 GHz.

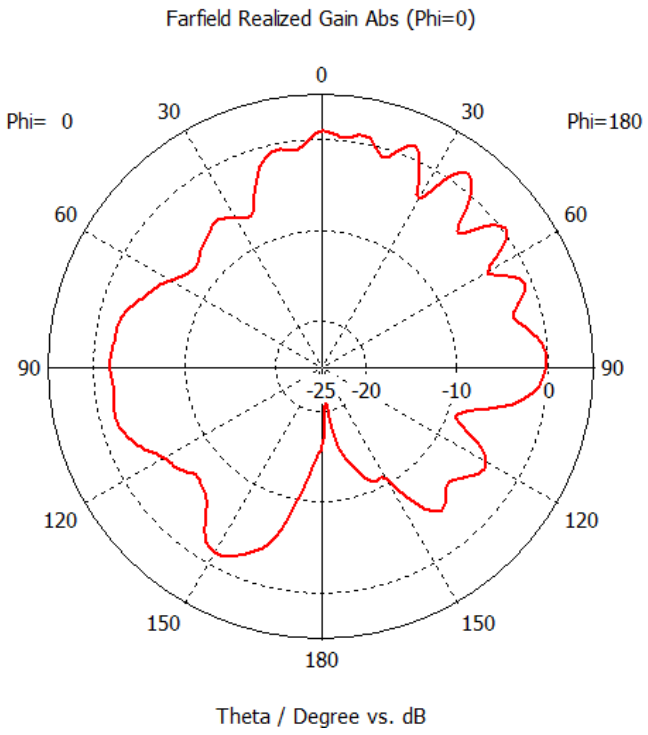


Figure 67: Front side antenna polar plot at phi=0° cut, 4 GHz.

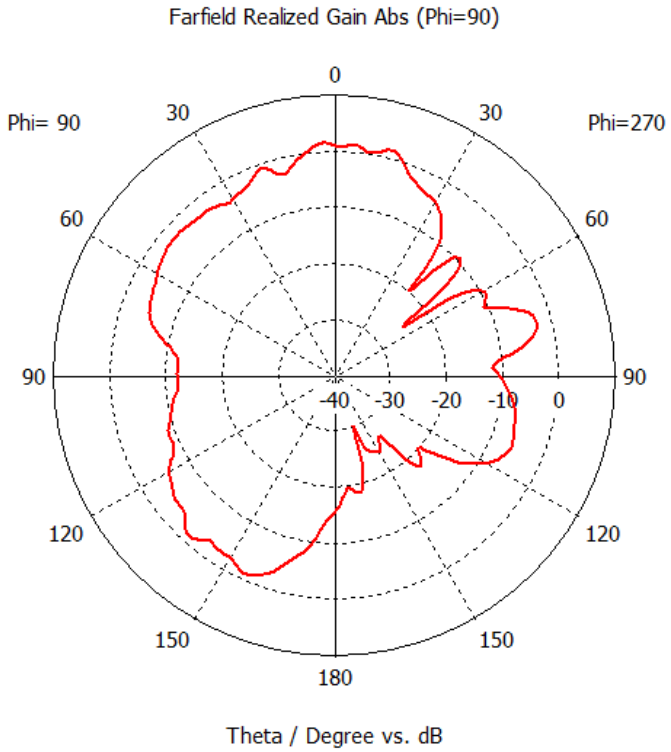


Figure 68: Front side antenna polar plot at phi=90° cut, 4 GHz.

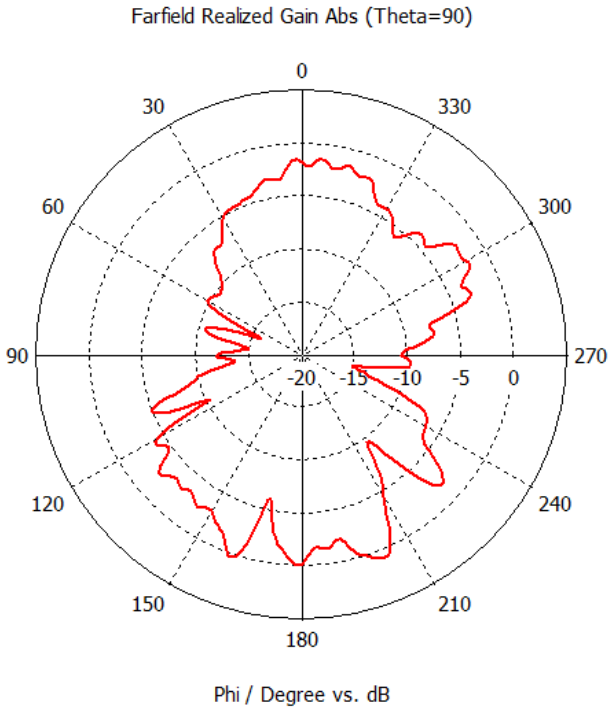


Figure 69: Front side antenna polar plot at theta=90° cut, 4 GHz.

Units:	GHz,	dB							
	Front side, right				Back side, right				
Frequency	**MaxFF_Glc**	**Directivity**	**Gain [dBi]**	**Efficiency**		**MaxFF_Glc**	**Directivity**	**Gain [dBi]**	**Efficiency**
3.0	-7.08	5.40	**1.68**	42%		-5.70	6.81	**3.05**	42%
3.5	-5.40	7.59	**4.62**	51%		-7.18	7.73	**2.84**	32%
4.0	-9.03	6.22	**2.62**	44%		-7.02	7.73	**4.62**	49%
4.5	-8.08	7.77	**4.08**	43%		-8.00	7.65	**4.17**	45%
5.0	-9.89	6.84	**2.87**	40%		-8.99	7.53	**3.76**	42%
5.5	-10.98	6.64	**2.95**	43%		-10.01	7.85	**3.91**	40%
6.0	-11.72	6.51	**3.67**	52%		-12.48	6.56	**2.91**	43%

Figure 70: Measured values for the antenna gain and efficiency for different frequencies and front and back antennas that are located on the right side. Every element (the cables, balun, etc.) are included. The interface is UFL connector at main pcb.

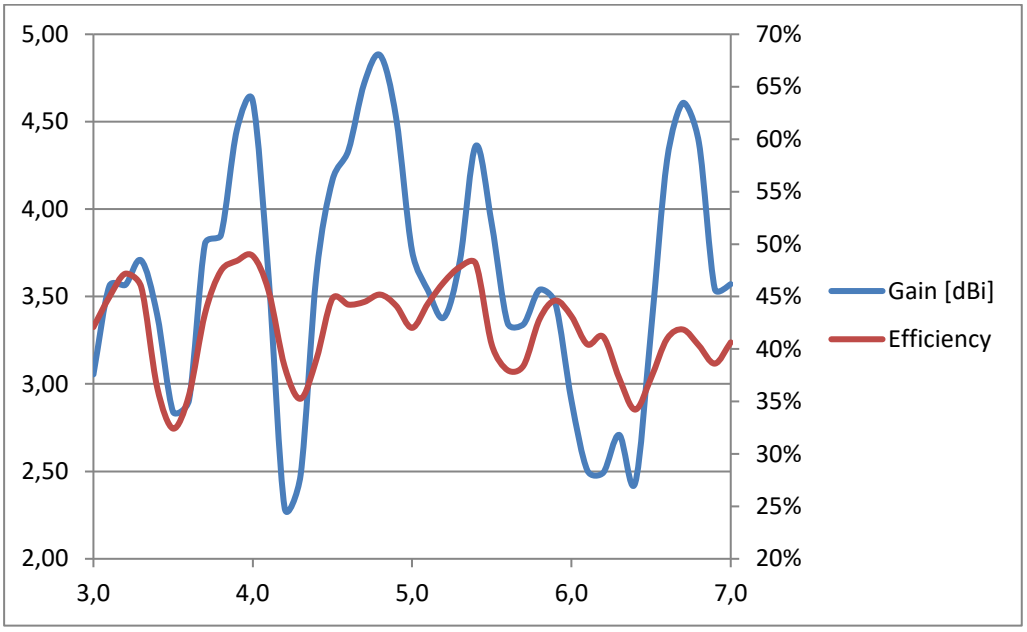


Figure 71: Antenna gain in dBi and efficiency for the UWB antennas with vehicle parts in position back right.

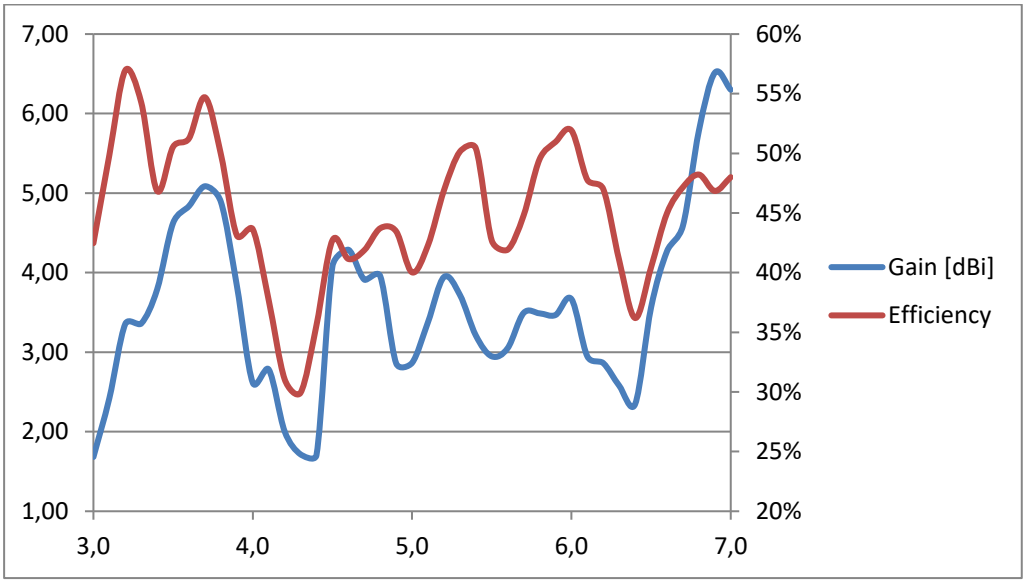


Figure 72:Antenna gain in dBi and efficiency for the UWB antennas with vehicle parts in position front right.

*** End of document***