Airgain AC Fleet DVT 1 Antenna Passive Measurement Report

Prepared By: Delroy Rebello

Date: March 22nd, 2024

Airgain

Address：3611 Valley Centre Drive, Ste. 150, San Diego, CA 92130 USA

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Introduction

- This passive report describes the performance of Airgain AC Fleet 5G Vehicle Gateway
- The seven antennas integrated:
  - 2 Cell elements covering 5G/LTE cellular bands from 617MHz – 6000MHz
  - 2 Cell elements covering 5G/LTE cellular bands from 1700MHz – 6000MHz
  - 2 Wi-Fi elements covering from 2.4-2.49GHz, 5.15-5.85GHz and 5.925-7.125GHz WiFi Band
  - One Bluetooth antenna covering from 2.4GHz-2.49GHz band of operation
- 2 Cell elements are flex film mounted on a plastic carrier
- 2 Cell elements are PCB antenna mounted on PCBA
- 2 Wi-Fi and one Bluetooth antennas are stamped metal antenna mounted on heatsink
- All antennas use a 1.37mm coaxial cable, Cable lengths are mentioned in the report
- All measurements recorded and depicted in this report have cable losses included and was measured in free space

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Antenna Designator and Cable lengths

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Antenna List

No	Antenna PN	Bands Covered	Cable lengths (mm)/Cable /Connector	Antenna type	Antenna Manufacturer
Cell 1	CH56AGDKZ F56AGDKA-LB1X132BU4LI	5G/LTE: LB,MB, UHB C,LAA	132mm - 1.37 Low Loss MHF-4L	Monopole	Airgain
Cell 2	CH56AGDKZ F56AGDKB-LB1X130BU4LI	5G/LTE: LB,MB, UHB C, LAA	130mm - 1.37 Low Loss MHF-4L	Monopole	Airgain
Cell 3	N54AGDKC-LY1X255BU4LI	5G/LTE: MB, UHB C, LAA	255mm - 1.37 Low Loss MHF-4L	Monopole	Airgain
Cell 4	N54AGDKJ-LE1X272BU4LI	5G/LTE: MB, UHB C,LAA, GNSS:L1	272mm - 1.37 Low Loss MHF-4L	Monopole	Airgain
Bluetooth BT	M03AGDKG-LK1X137BU	Bluetooth 2.4-2.49GHz	137mm - 1.37 U.FL	Monopole	Airgain

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Antenna Requirement

Item	Value
Frequency range	Depending on the frequency band(s) provided by the network operator, the customer must use the most suitable antenna for that/those band(s). The bands supported by the FN990 Family are provided in Section 2.2 Frequency Bands and CA / EN-DC Combinations
Impedance	50 Ohm
Input power	> 24 dBm average power in WCDMA & LTE & 5G Sub-6
VSWR absolute max	<= 10:1
VSWR recommended	<= 2:1

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Antenna Measurement Architecture

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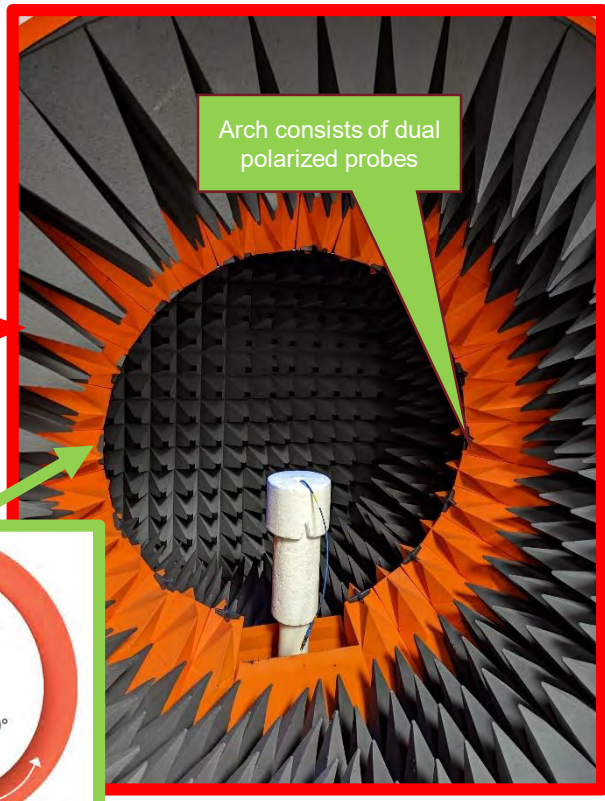
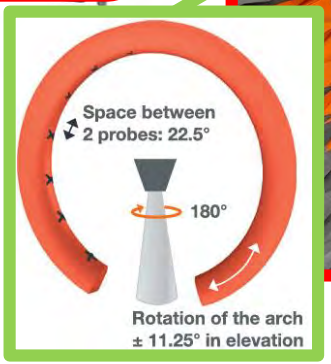
Measurement setup Architecture





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Measurement setup Architecture for Passive Near-Field measurement

- Starlab uses an Active Switching Unit to switch between near-field passive measurement and OTA measurement
- For near-field passive measurement a Vector Network analyzer is used as RF source/receiver
- The power and control unit supplies the power and driver the RF units on the arch
- Starlab performs a over sampling by mechanically rotating the arch by ±11.25° in elevation
- The software translates the measured near-field into far-field
- All the AUT/DUT are measured with phase center located in the quite zone of the chamber for calibration, Validation and performance evaluation
- Starlab can accommodate AUT/DUT up to 45 cm in diameter

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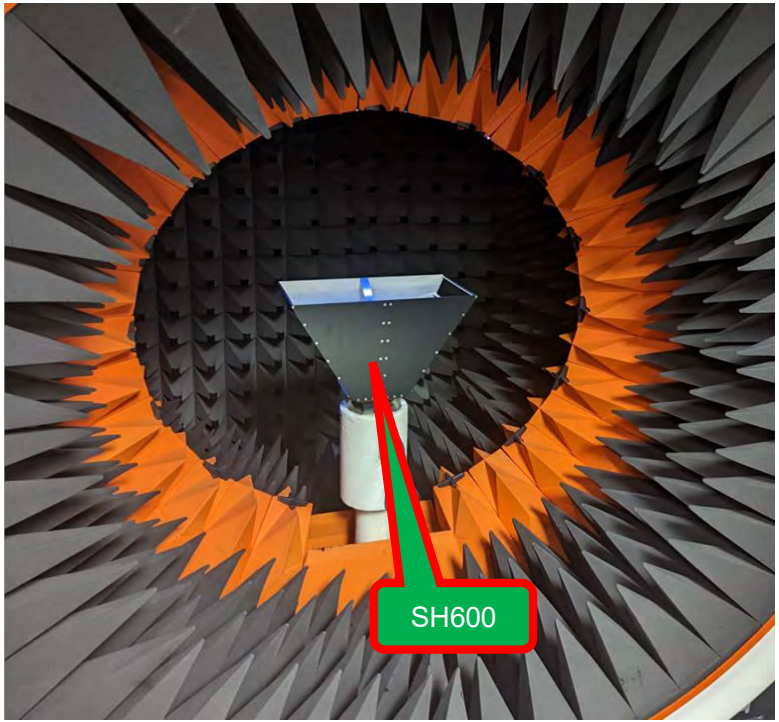
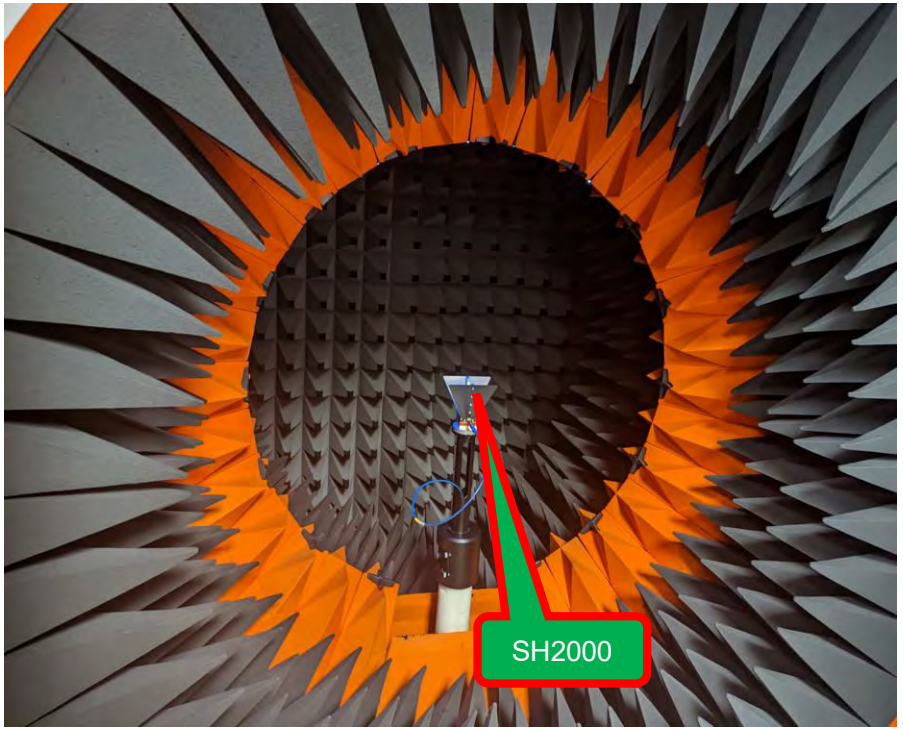
Passive Antenna Calibration Setup





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Passive Antenna Calibration (Gain Substitution Mehod)

- Starlab is calibrated on a monthly basis by using MVG calibration method
- A standard Satimo horn antenna SH600 and SH2000 are used for calibrating the changer in low and high frequency bands of operation
- The horn antennas are measured in the chamber and the calibration is performed in post processing with reference to standard gain values of the horn which are certified and provided by MVG
- During postposing a ***gain substitution*** method is used and the measured gain/efficiency data is computed against the standard gain/efficiency values of the horn antenna and a new calibration file is generated
- The calibrated file generated is stored as a new primary calibration file which will be recalled automatically during post processing of any AUT/DUT measurements

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Passive Antenna Validation Dipoles

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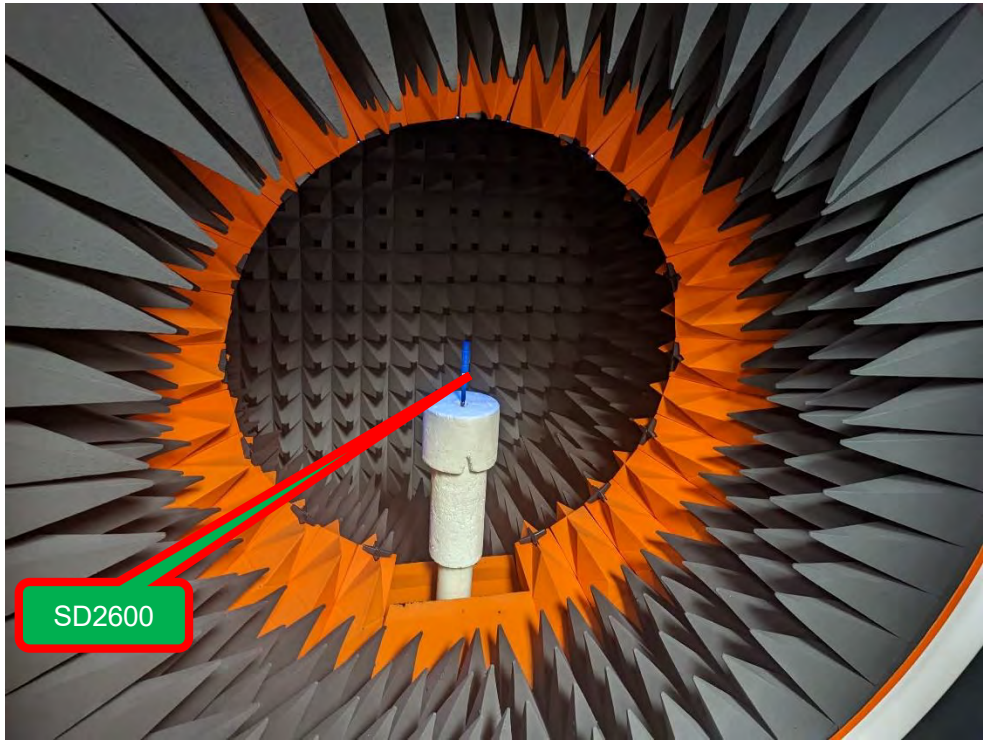
Passive Antenna Validation Setup



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Passive Antenna Validation

- Starlab is validated after the calibration process is completed, and a routine validation is performed every week to ensure the calibration has not been drifted over the time.
- Standard Satimo dipoles are measured in different frequency range based upon the dipole specs.
- Standard dipole include SD900, SD1800, SD1900, SD1900, SD2050, SD2450, SD2600, SD5150, SD5650
- Dipoles are measured and post processed with standard AUT/DUT measurement steps
- Upon postprocessing the output gain and efficiency of the dipole is compared to the standard dipole data provided and certified by MVG/Satimo
- If the measured values are out of limit a new calibration is performed if needed

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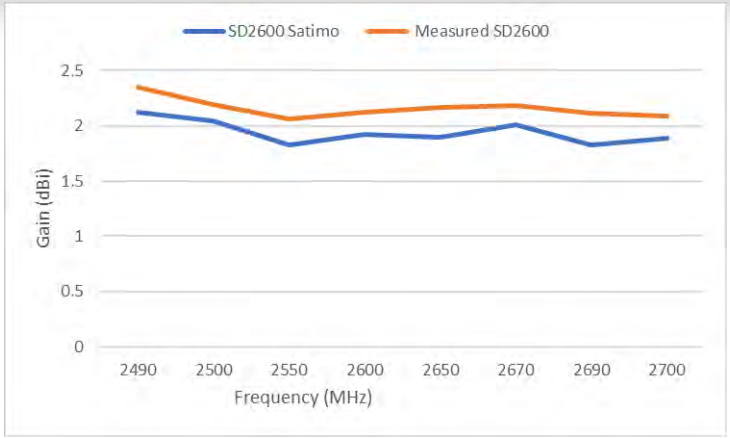
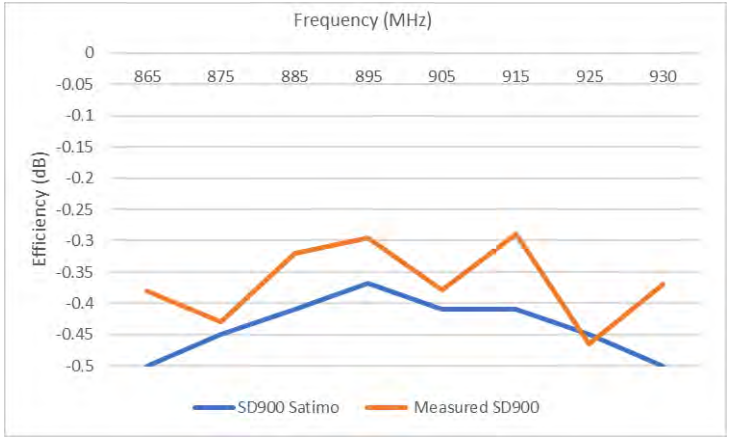
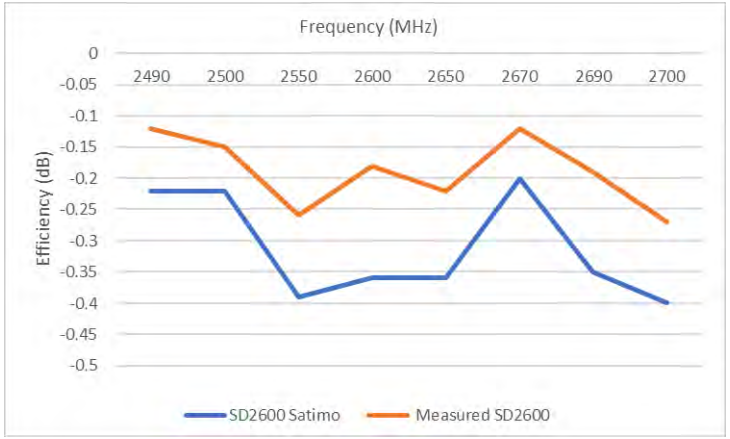
Passive Antenna Validation Results







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Chamber stability certified by MVG

- MVG visits on site every year and performs a full set of system calibration which is valid for a year
- During the calibration and validation process MVG checks the performance of the full system and ensures the measured/validated data is in the tolerance limit of Starlab specs

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MVG Chamber Validations/ Calibrations Data

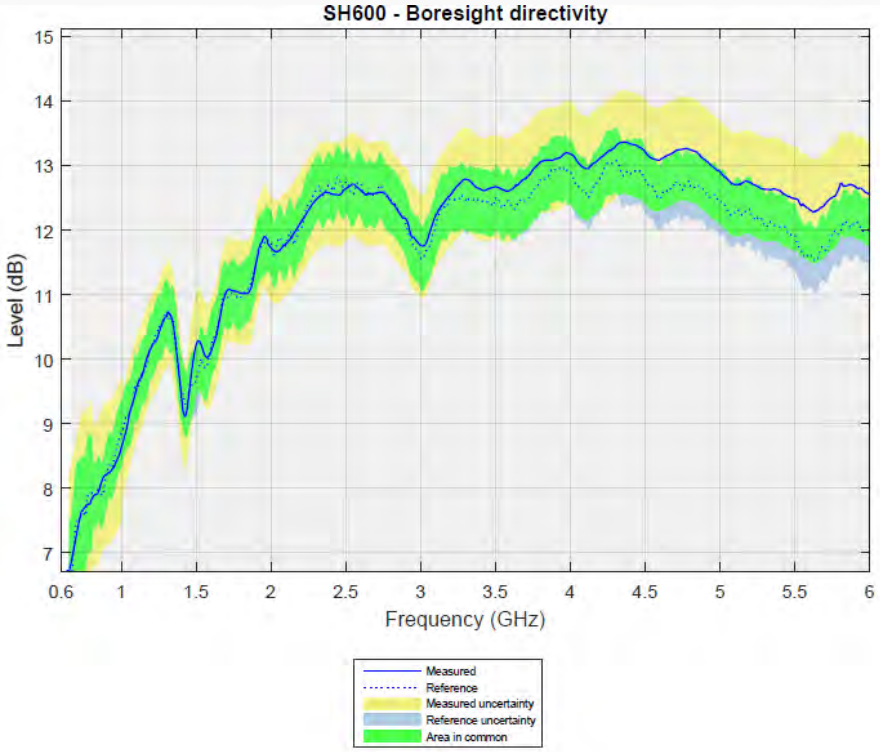

Figure 5.1: Boresight directivity

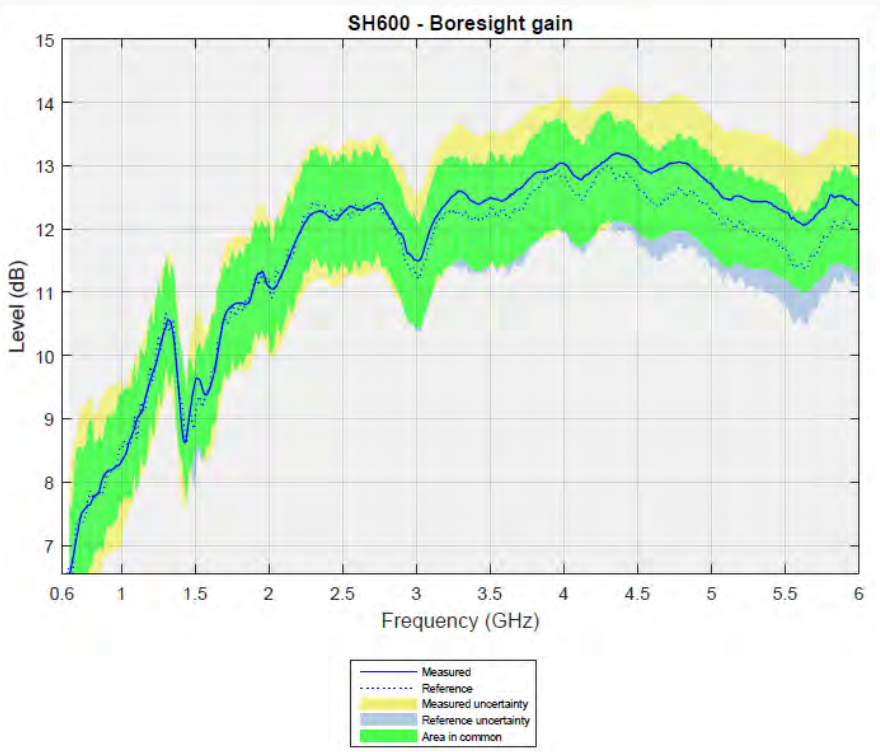

Figure 5.2: Boresight gain

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MVG Chamber Validations/ Calibrations Data

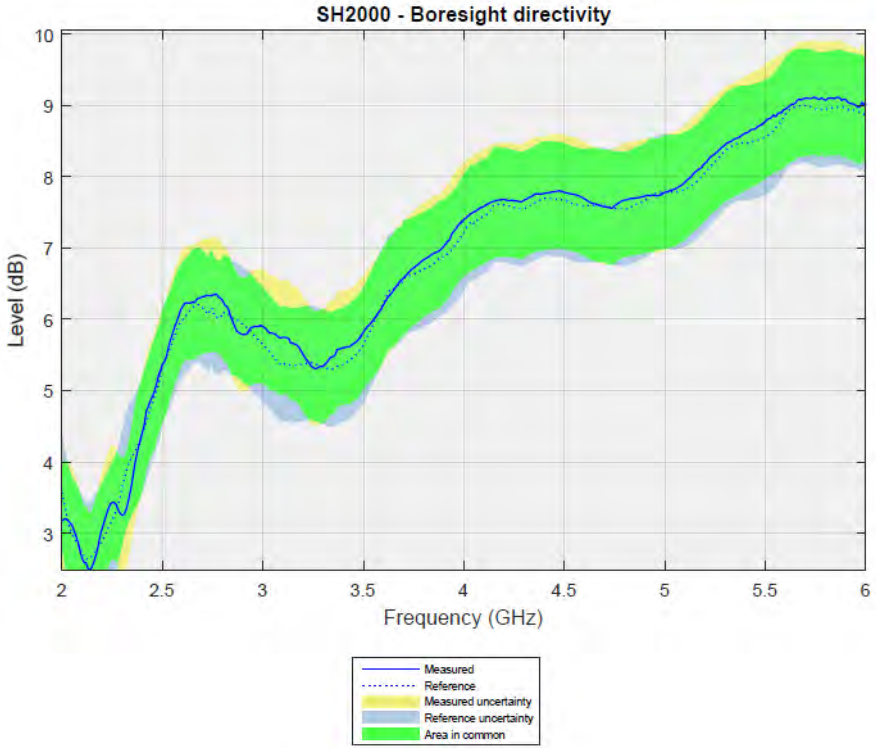

Figure 5.60: Boresight directivity

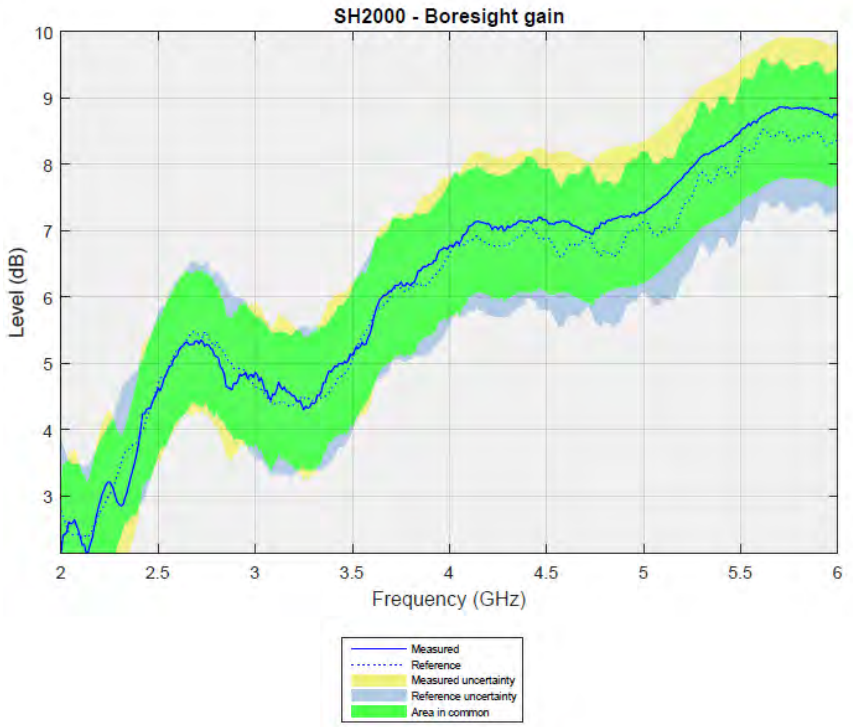

Figure 5.61: Boresight gain

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MVG Chamber Validations/ Calibrations Data

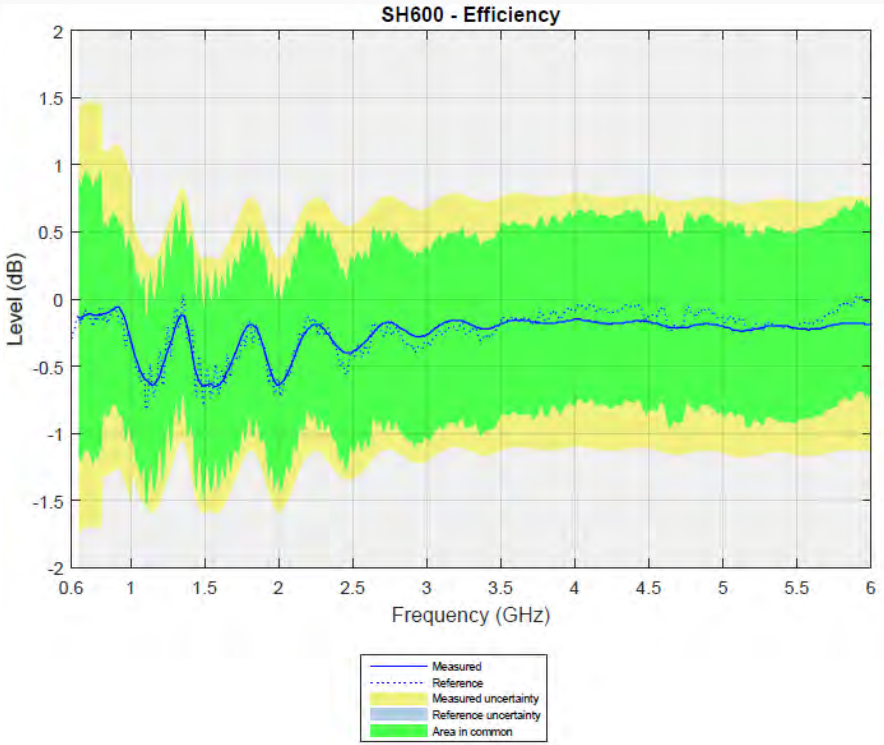

Figure 5.3: Efficiency

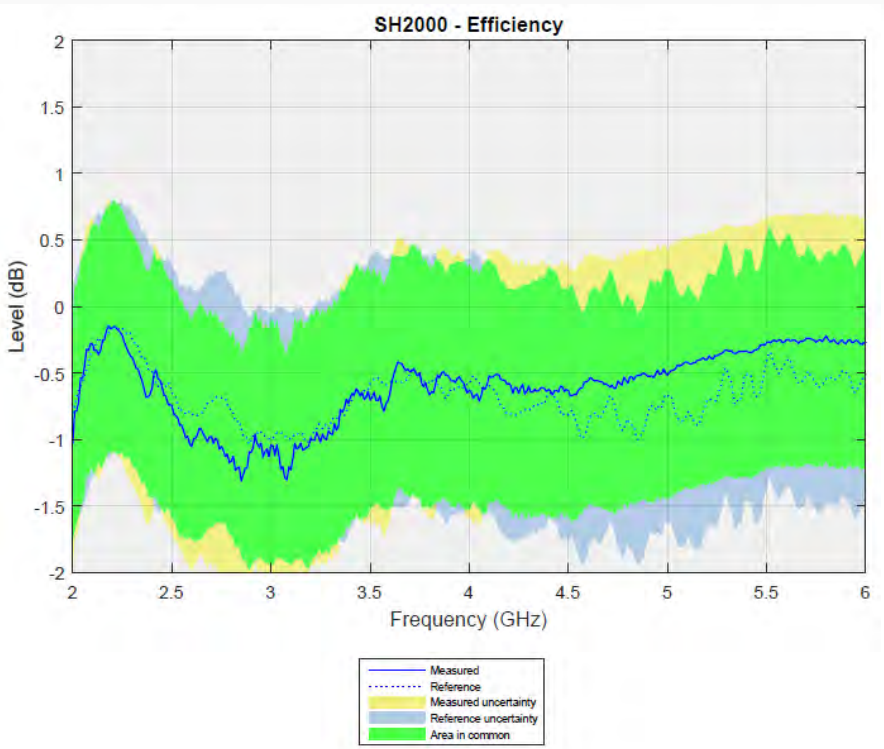

Figure 5.62: Efficiency

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S-Parameters

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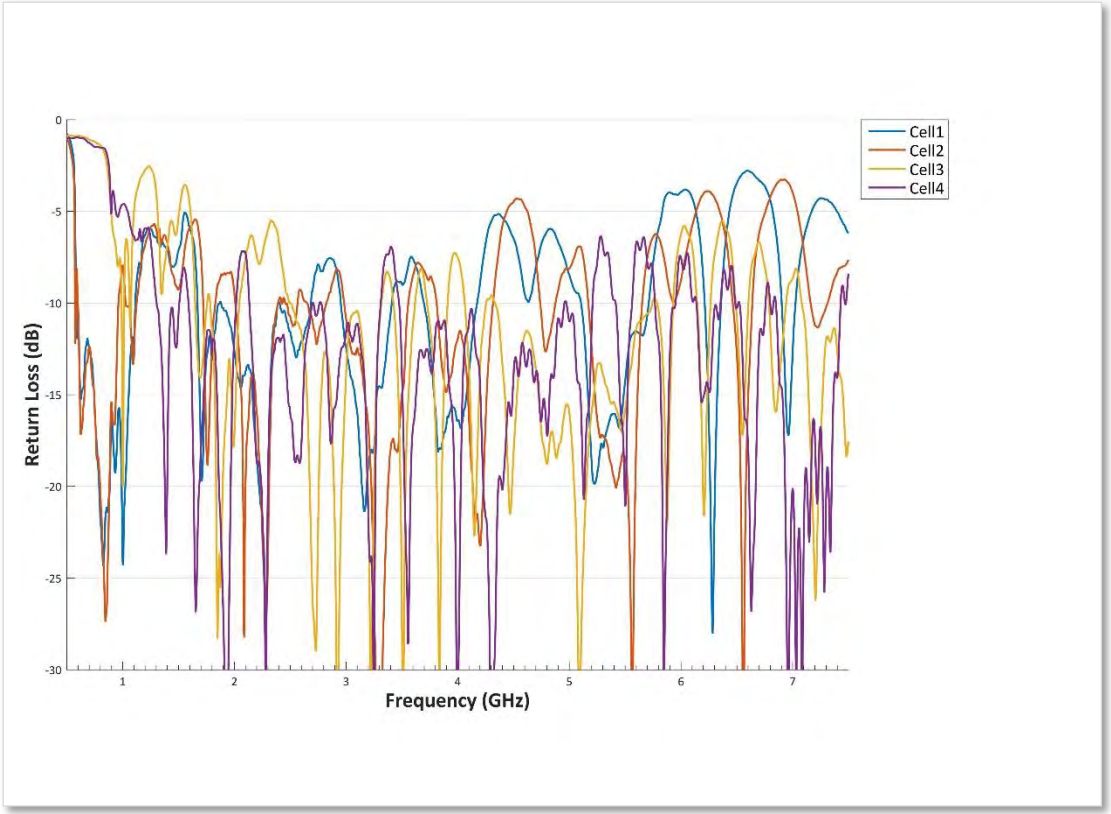
Return Loss Cell



Antenna	Return Loss (dB)							
	.617 GHz	.960 GHz	1.7 GHz	2.7 GHz	3.3 GHz	4.2 GHz	5.15 GHz	5.85 GHz
Cell 1	-14.9	-15.9	-18.4	-9	-14.6	-6.8	-9.8	-4.4
Cell 2	-16.2	-10.3	-9.7	-11.4	-43	-16.6	-6.9	-7.6
Cell 3			-12.9	-27.1	-10.5	-10.2	-30.7	-15.3
Cell 4			-15.9	-10.1	-10.1	-21.7	-14.9	-32

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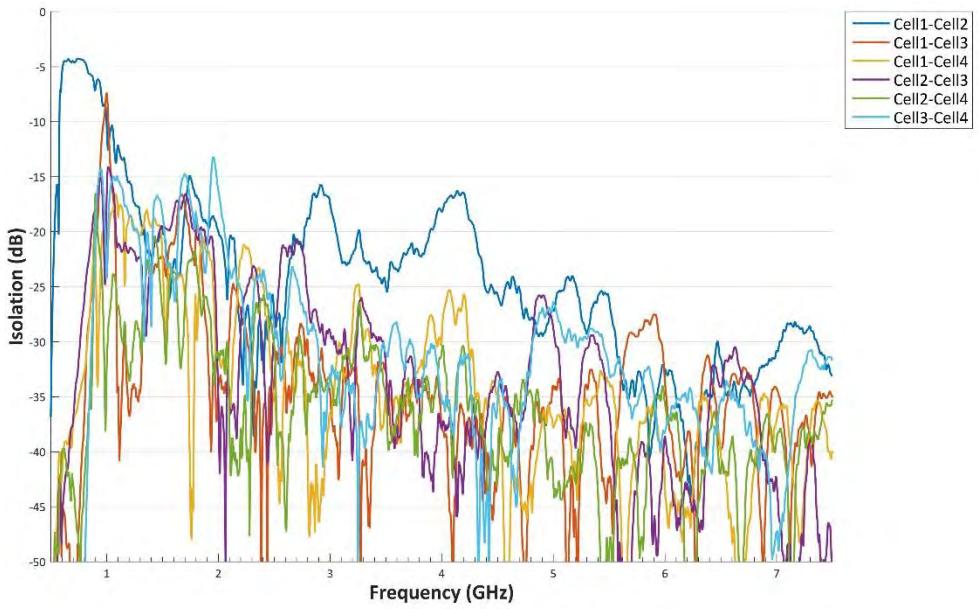
Antenna Isolation Cell



Antenna Pair	Minimum Isolation (dB)			
	.617 - .960 GHz	1.7 - 2.7 GHz	3.3 – 4.2 GHz	5.15 – 5.85 GHz
Cell 1-Cell 2	-4.3	-14.9	-16.3	-24
Cell 1-Cell 3	-11.1	-19	-31.8	-28
Cell 1-Cell 4	-19.1	-20.5	-25.3	-32.6
Cell 2-Cell 3	-15.1	-16.9	-27.2	-29.4
Cell 2-Cell 4	-16.5	-21.7	-30.2	-37.3
Cell 3-Cell 4	-14.2	-13.2	-28.2	-28.8

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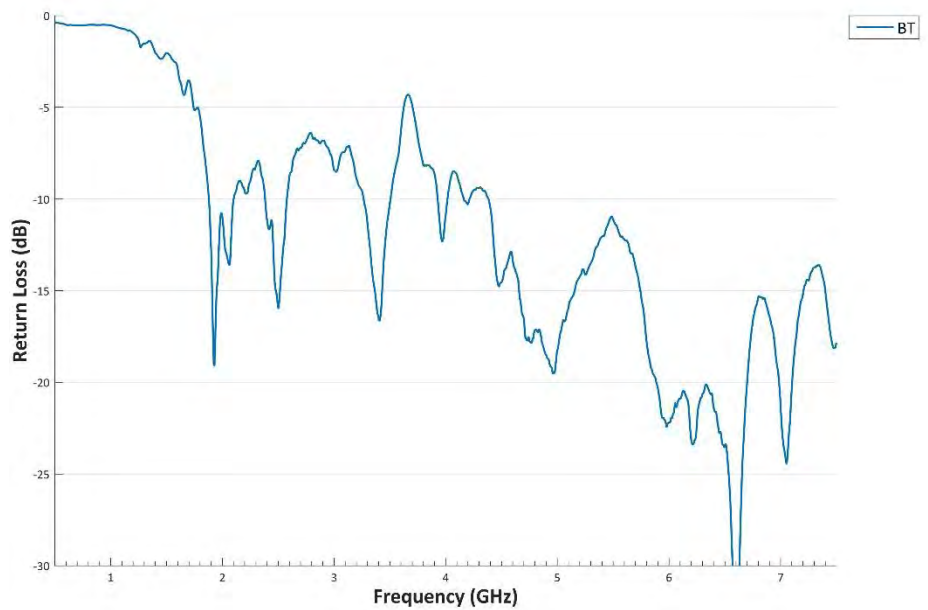
Return Loss Bluetooth Antenna



Antenna	Return Loss (dB)	
	2.4 GHz	2.49 GHz
Bluetooth	-11.1	-15.4

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Radiated Measurements – EVT-2 As Received

Gain and Efficiency

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Antenna Efficiency (%) Cell 5G NR/ LTE Low Band

Frequency (MHz)	Cell1	Cell2
617	49	45
620	49	45
630	49	45
640	49	45
650	47	44
660	47	43
670	46	45
680	47	45
690	47	45
Average	48	45

Frequency (MHz)	Cell1	Cell2
700	44	45
720	45	46
740	48	49
760	47	50
780	48	49
800	48	49
820	48	49
840	48	49
860	48	49
880	47	46
900	43	41
920	45	48
940	52	44
960	43	45
Average	47	47

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Antenna Efficiency (%) Cell 5G NR/LTE Mid Band

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
1700	61	65	52	54
1750	71	68	51	52
1800	75	72	47	55
1850	74	68	48	50
1900	71	62	47	47
1950	70	61	43	44
2000	74	73	35	48
2020	77	78	35	43
2100	80	80	43	55
2150	78	73	42	53
2200	74	58	45	62
2250	69	65	43	66
2300	77	78	41	63
2350	80	83	40	57
2400	80	82	43	60
2450	81	81	53	63
2500	78	80	53	60
2550	77	79	52	62
2600	76	76	52	63
2650	74	76	56	63
2700	70	73	63	63
Average	75	73	47	56

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Antenna Efficiency (%) Cell 5GNR/LTE UHB

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
3300	76	77	58	57
3400	72	77	46	52
3500	67	76	56	57
3600	61	62	52	66
3700	71	66	48	65
3800	76	75	58	63
3900	77	73	55	59
4000	77	69	47	62
4100	74	67	55	53
4200	57	78	57	57
Average	71	72	53	59

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
4300	47	64	47	57
4400	46	47	49	52
4500	49	36	55	57
4600	59	39	55	66
4700	56	54	49	65
4800	55	59	47	63
4900	53	52	49	59
5000	54	51	48	62
Average	52	50	50	59

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Antenna Efficiency (%) Cell 5GNR/LTE LAA

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
5150	53	51	51	43
5250	59	58	48	39
5350	60	61	51	37
5450	62	62	54	42
5500	60	61	52	40
5650	53	56	48	43
5750	44	44	44	42
5850	30	44	49	51
5950	30	48	43	43
Average	40	43	39	42

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Antenna Efficiency (%) Bluetooth

Frequency (MHz)	Bluetooth
2400	69
2410	69
2420	69
2430	71
2440	73
2450	74
2460	73
2470	71
2480	73
2490	71
Average	71

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Antenna Peak Gain (dBi) Cell 5G NR/ LTE Low Band

Frequency (MHz)	Cell1	Cell2
617	1.6	1.3
620	1.6	1.4
630	1.7	1.5
640	1.7	1.4
650	1.6	1.3
660	1.5	1.2
670	1.5	1
680	1.4	1.4
690	1.4	1.4

Frequency (MHz)	Cell1	Cell2
700	1.4	1.4
720	1.5	1.6
740	1.8	2
760	1.8	2
780	2	2
800	2.1	2.2
820	2.2	2.3
840	2	2.2
860	1.7	2.2
880	1.4	2.3
900	1.3	1.3
920	1.8	2.8
940	2.4	3
960	1.1	2.9

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Antenna Peak Gain (dBi) Cell 5G NR/LTE Mid Band

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
1700	5.2	3.9	1.7	2.5
1750	4.6	4.4	2.2	3.3
1800	4.5	5.9	2.7	3
1850	5.1	5.4	2.2	2.1
1900	5.3	4.6	2.1	0.9
1950	5	4.8	1.6	1.8
2000	4.6	5.3	0.5	3.3
2020	4.7	5.6	0.9	3.2
2100	5.6	6.1	2.2	4.6
2150	5.8	5.5	2	4.1
2200	4.6	4.6	3.1	3.9
2250	4.8	5.1	3.5	4.1
2300	5.7	6.2	3.1	3.9
2350	5.7	6.5	3.5	3.9
2400	6.1	6.4	4.1	3.6
2450	5.7	5.6	5.3	3.4
2500	5.2	5.3	4.9	3.9
2550	5.7	5.1	4.2	3.5
2600	5.6	5.5	3.7	4.4
2650	5.4	5.8	4.1	4.7
2700	5.3	5.9	3.6	4.9

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Antenna Peak Gain (dBi) Cell 5GNR/LTE UHB

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
3300	4.4	5.1	3.8	4.5
3400	4	3.8	2.5	4.6
3500	4.2	3.6	4.1	4
3600	4.4	4.7	2.9	4.4
3700	4.6	5.9	2.7	4.9
3800	4.9	6.7	2.8	5.3
3900	5.7	6.4	3.1	5.5
4000	5.7	6.2	2	5.1
4100	5.6	6.7	3.4	4.4
4200	4.7	5.6	4.6	3.1
4300	4.6	4.1	4.4	3.9
4400	4.4	4	4.3	5.6
4500	4.6	4.6	5.4	6.1
4600	6.3	4.3	5.1	7
4700	4.7	4.6	3.7	7.4
4800	4.8	4.2	4.8	7.2
4900	4.5	5	4.6	7
5000	5.5	5	5.2	6.8

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Antenna Peak Gain (dBi) Cell 5GNR/LTE LAA

Frequency (MHz)	Cell1	Cell2	Cell3	Cell4
5150	4.5	4.9	4.8	4.3
5250	5.3	5.6	3.5	4.9
5350	4.8	4.9	4.8	3.5
5450	5.4	6.5	5	3
5500	5.6	6.7	5	3.2
5650	5.8	5.9	4.6	6.1
5750	3.4	4.8	4.4	6.3
5850	2.7	4	4.5	6.1
5950	2.8	4	3.7	5.7

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Antenna Peak Gain (dBi) Bluetooth

Frequency (MHz)	Bluetooth
2400	6.3
2410	6.3
2420	6.2
2430	6.1
2440	6
2450	5.8
2460	5.6
2470	5.4
2480	5.3
2490	4.9

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Antenna Gain(dBi) and Efficiency (%) GNSS L1 Cell3

Frequency (MHz)	E Total. (dB)
1560	1.6
1570	2
1580	2.2
1590	2.5
1600	2.6
1610	2.7

Frequency (MHz)	Efficiency (%)
1560	48
1570	49
1580	49
1590	48
1600	49
1610	50
Average	49

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Antenna Peak Gain Directions

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Antenna peak gain (dBi) directional angles (°)

Frequency (MHz)	Cell1	θ / φ	Cell2	θ / φ	Cell3	θ / φ	Cell4	θ / φ
650	1.6	40° / 192°	1.3	38° / 10°				
740	1.8	36° / 212°	2	30° / 356°				
840	2	20° / 217°	2.2	21° / 349°				
940	2.4	13° / 130°	3	19° / 352°				
1700	5.2	42° / 197°	3.9	51° / 17°	1.7	74° / 158°	2.5	58° / 142°
1800	4.5	36° / 181°	5.9	32° / 343°	2.7	68° / 176°	3	72° / 291°
2100	5.6	22° / 215°	6.1	25° / 40°	2.2	40° / 341°	4.6	35° / 277°
2200	4.6	20° / 180°	4.6	38° / 327°	3.1	24° / 139°	3.9	51° / 305°
2600	5.6	53° / 183°	5.5	58° / 42°	3.7	50° / 140°	4.4	51° / 20°
3700	4.6	21° / 189°	5.9	1° / 173°	2.7	46° / 345°	4.9	40° / 182°
5500	5.6	58° / 329°	6.7	36° / 32°	5	11° / 130°	3.2	67° / 7°

Frequency (MHz)	Bluetooth	θ / φ
2450	5.8	15° / 43°

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Antenna System Composite Gain

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- The composite gain is based on FCC document 662911. Part d (ii)

d) *Unequal antenna gains, with equal transmit powers.* For antenna gains given by G_1, G_2, …, G_N dBi

(i) If transmit signals are *correlated*, then

Directional gain = $10 \log[(10^{G1/20} + 10^{G2/20} + \ldots + 10^{GN/20})^2 / N_{ANT}]$ dBi [Note the "20"s in the denominator of each exponent and the square of the sum of terms; the object is to combine the signal levels coherently.]

(ii) If all transmit signals are *completely uncorrelated*, then

Directional gain = $10 \log[(10^{G1/10} + 10^{G2/10} + \ldots + 10^{GN/10})/N_{ANT}]$ dBi

Reference: FCC document, "Emissions Testing of Transmitters with Multiple Outputs in the Same Band", 662911 D01 Multiple Transmitter Output v02r01

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Composite Gain (dBi) 5G Band of operation

Airgain

N38 Cell1 + Cell 2						
Freq (MHz)	Correlated Composite Gain			Uncorrelated Composite Gain		
	Total (dBi)	Phi (dBi)	Theta (dBi)	Total (dBi)	Phi (dBi)	Theta (dBi)
2550	7.9	6.1	6.1	4.9	3.1	3.1
2600	7.9	6.1	6.1	4.9	3.1	3.1

N41 Cell1 + Cell 2						
Freq (MHz)	Correlated Composite Gain			Uncorrelated Composite Gain		
	Total (dBi)	Phi (dBi)	Theta (dBi)	Total (dBi)	Phi (dBi)	Theta (dBi)
2500	8.0	5.8	5.7	4.9	2.8	2.7
2550	7.9	6.1	6.1	4.9	3.1	3.1
2600	7.9	6.1	6.1	4.9	3.1	3.1
2650	7.7	6.0	6.1	4.6	3.0	3.1

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Composite Gain (dBi) 5G Band of operation

N48 Cell 3 + Cell 4						
Freq (MHz)	Correlated Composite Gain			Uncorrelated Composite Gain		
	Total (dBi)	Phi (dBi)	Theta (dBi)	Total (dBi)	Phi (dBi)	Theta (dBi)
3600	5.6	4.8	3.5	2.7	1.9	1.1
3700	5.2	2.9	4.3	2.9	1.1	1.9

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Composite Gain (dBi) 5G Band of operation

N77 Cell 3 + Cell 4						
Freq (MHz)	Correlated Composite Gain			Uncorrelated Composite Gain		
	Total (dBi)	Phi (dBi)	Theta (dBi)	Total (dBi)	Phi (dBi)	Theta (dBi)
3300	6.9	3.8	4.5	3.9	1.2	1.5
3400	5.4	3.1	3.0	2.4	0.2	0.3
3500	6.4	5.4	4.2	3.4	2.4	1.2
3600	5.6	4.8	3.5	2.7	1.9	1.1
3700	5.2	2.9	4.3	2.9	1.1	1.9
3800	6.5	3.4	5.2	3.7	1.1	2.4
3900	6.3	2.2	5.3	3.4	-0.5	2.5
4000	5.2	2.9	4.5	2.3	-0.1	1.9
4100	5.3	4.3	4.5	2.3	1.3	1.6
4200	6.8	5.8	6.1	3.8	2.8	3.2

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Composite Gain (dBi) 5G Band of operation

N78 Cell 3 + Cell 4						
Freq (MHz)	Correlated Composite Gain			Uncorrelated Composite Gain		
	Total (dBi)	Phi (dBi)	Theta (dBi)	Total (dBi)	Phi (dBi)	Theta (dBi)
3300	6.9	3.8	4.5	3.9	1.2	1.5
3400	5.4	3.1	3.0	2.4	0.2	0.3
3500	6.4	5.4	4.2	3.4	2.4	1.2
3600	5.6	4.8	3.5	2.7	1.9	1.1
3700	5.2	2.9	4.3	2.9	1.1	1.9
3800	6.5	3.4	5.2	3.7	1.1	2.4

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Composite Gain (dBi) 5G Band of operation

N79 Cell 3 + Cell 4						
Freq (MHz)	Correlated Composite Gain			Uncorrelated Composite Gain		
	Total (dBi)	Phi (dBi)	Theta (dBi)	Total (dBi)	Phi (dBi)	Theta (dBi)
4200	6.8	5.8	6.1	3.8	2.8	3.2
4300	7.5	6.7	6.8	4.5	3.8	3.9
4400	7.9	6.9	6.9	5.0	4.0	4.1
4500	8.2	6.1	6.5	5.1	3.6	4.1
4600	8.5	6.3	6.3	5.2	3.3	4.2
4700	7.9	5.8	6.0	5.0	2.8	3.9
4800	8.0	3.9	5.2	4.8	0.9	3.8
4900	7.3	5.2	4.6	4.3	2.4	2.0
5000	7.4	4.3	5.7	4.8	1.3	3.8

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Radiation Patterns

2D Patterns – System Coverage Cell

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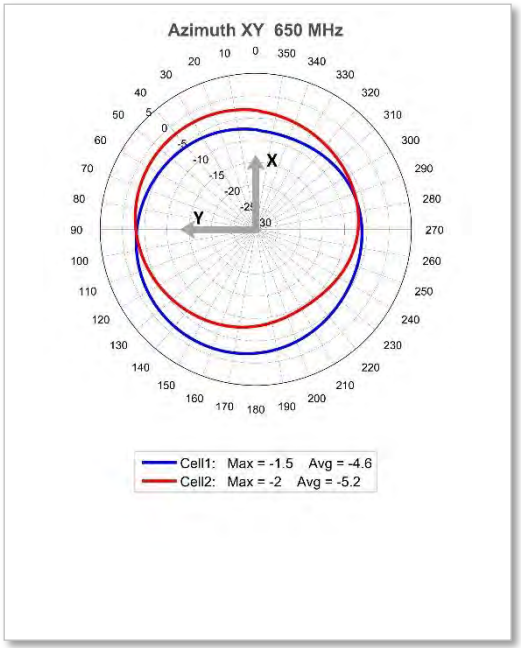
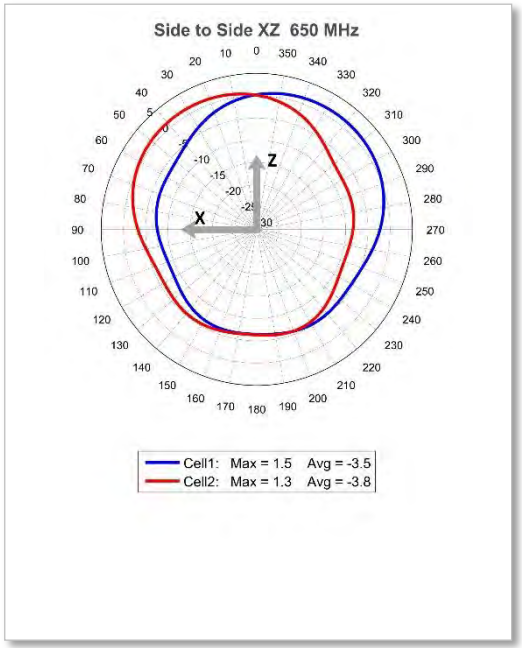
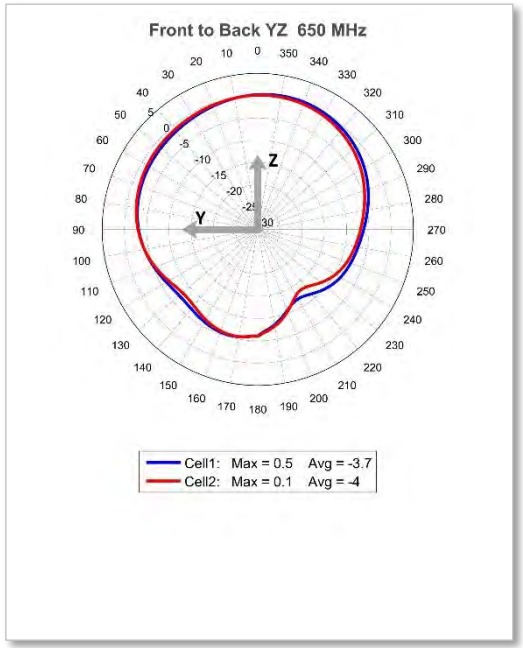
System Coverage: 650 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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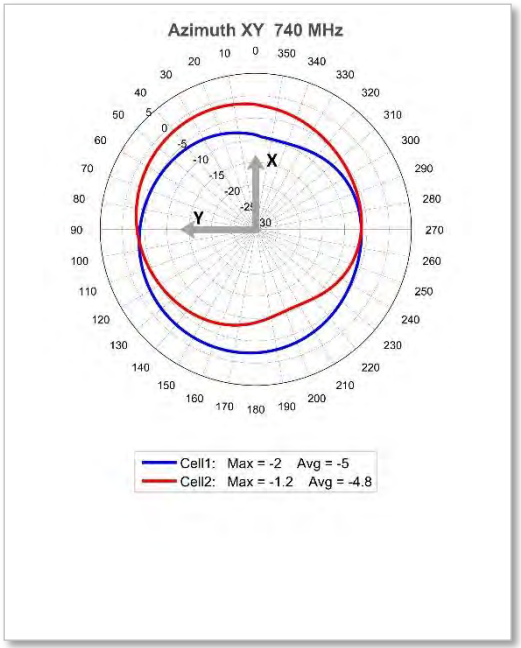
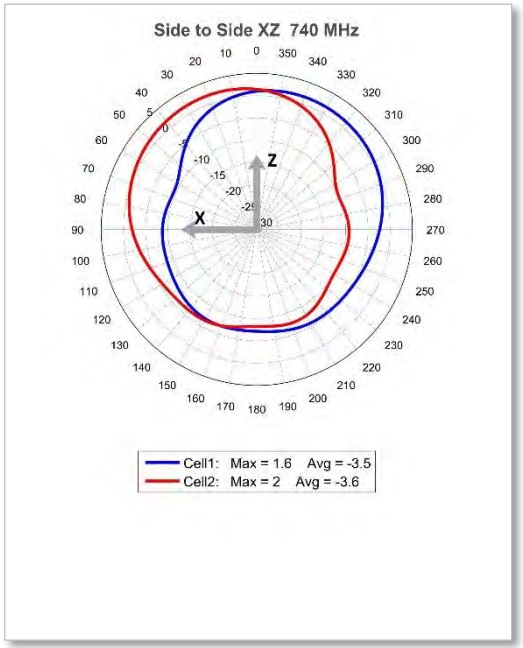
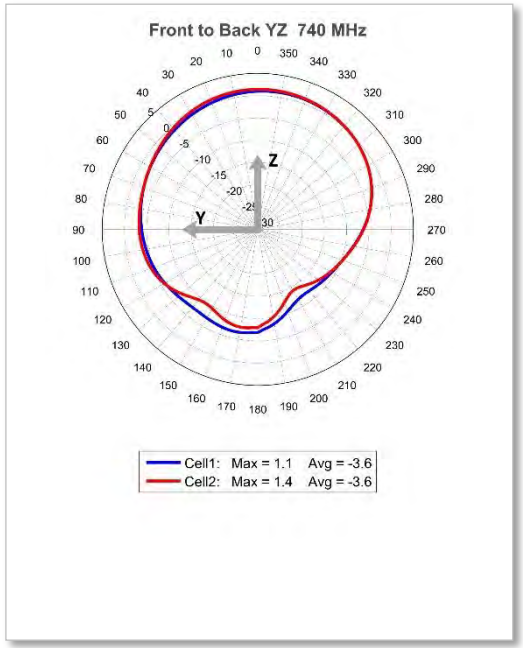
System Coverage: 740 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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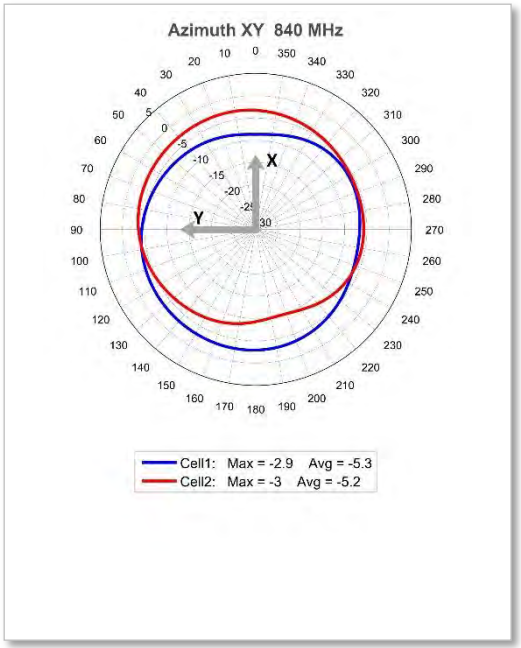
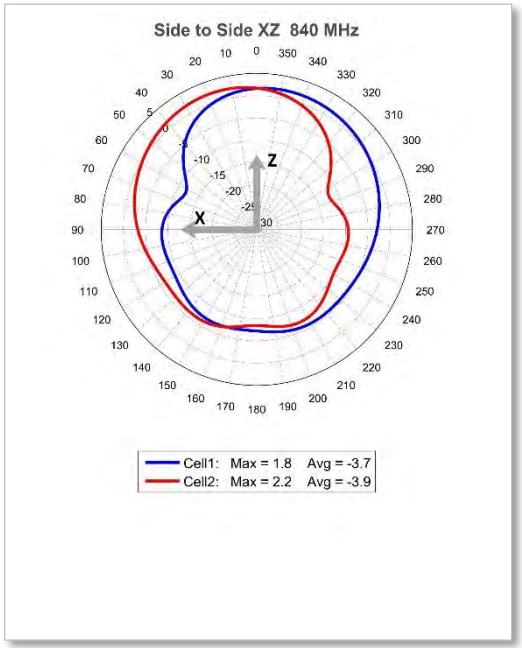
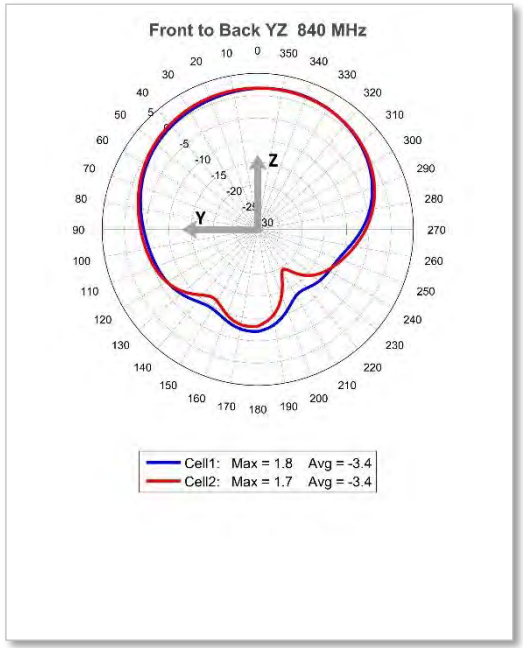
System Coverage: 840 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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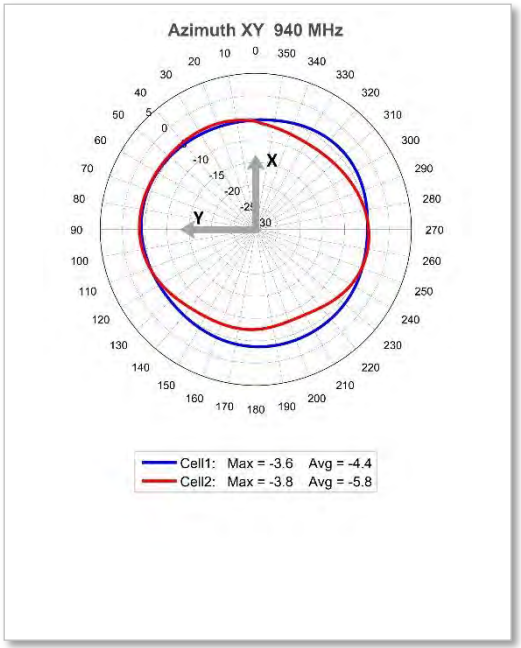
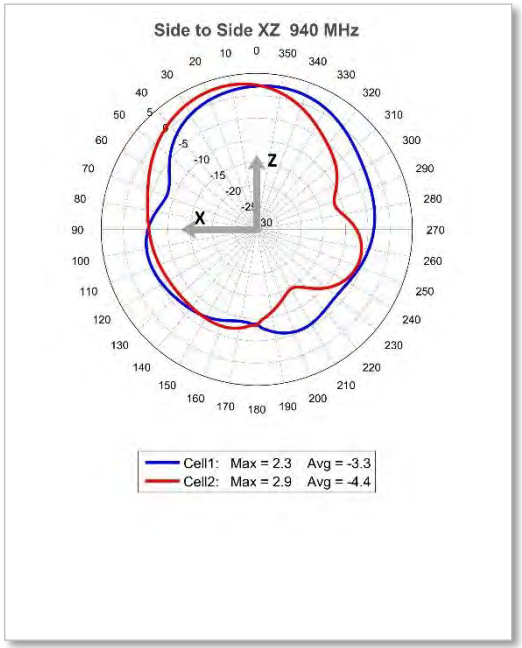
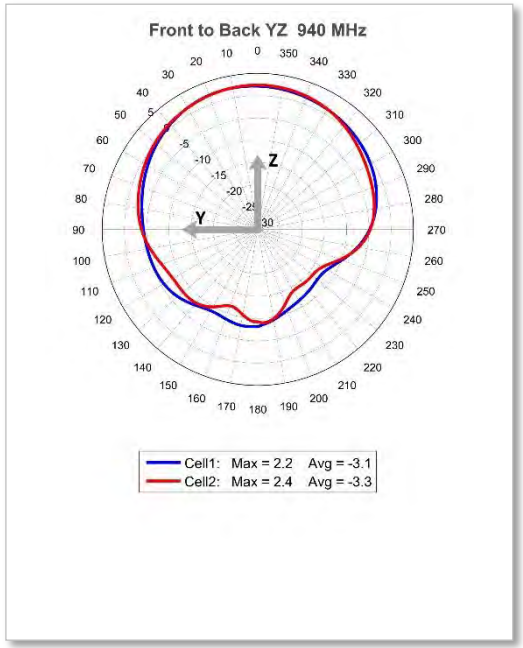
System Coverage: 940 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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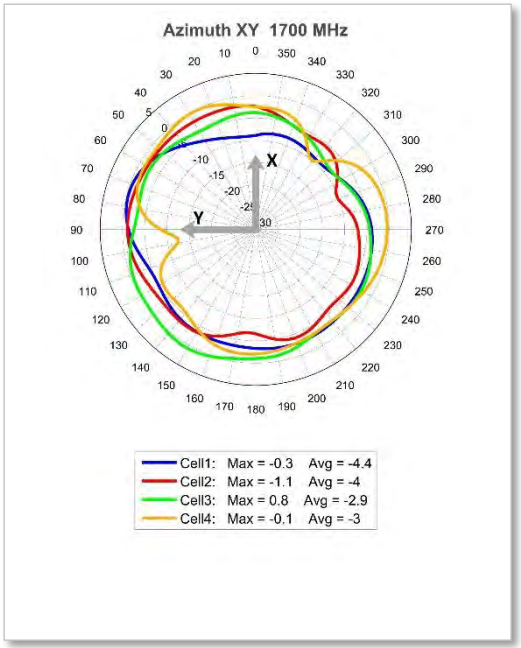
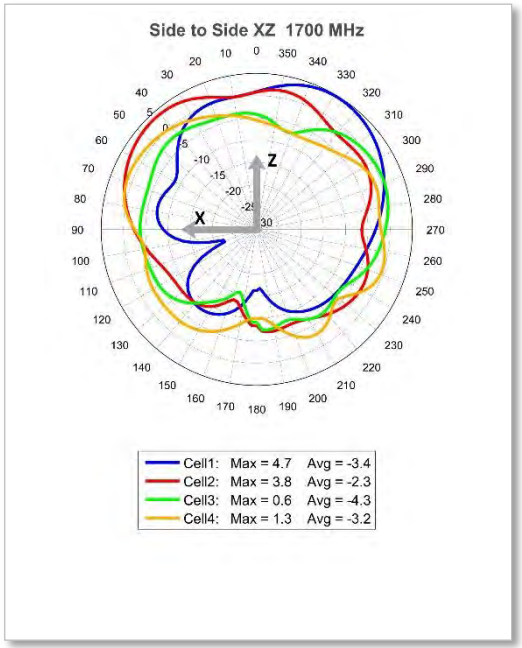
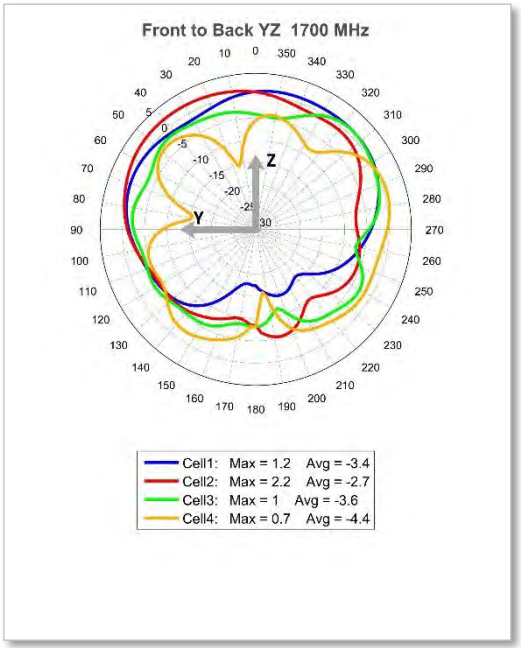
System Coverage: 1700 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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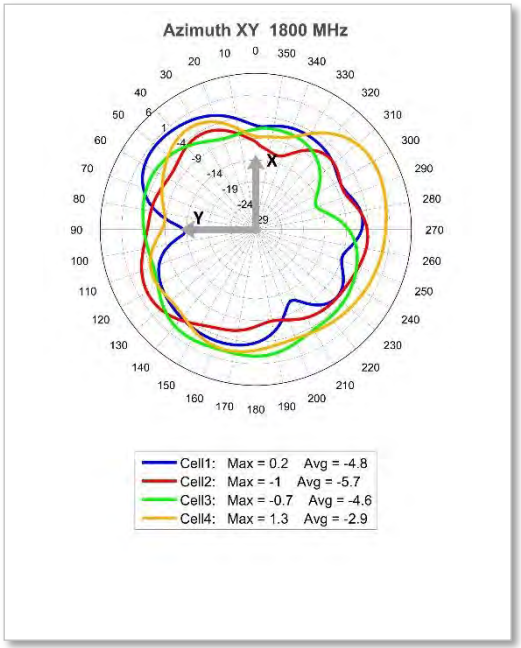
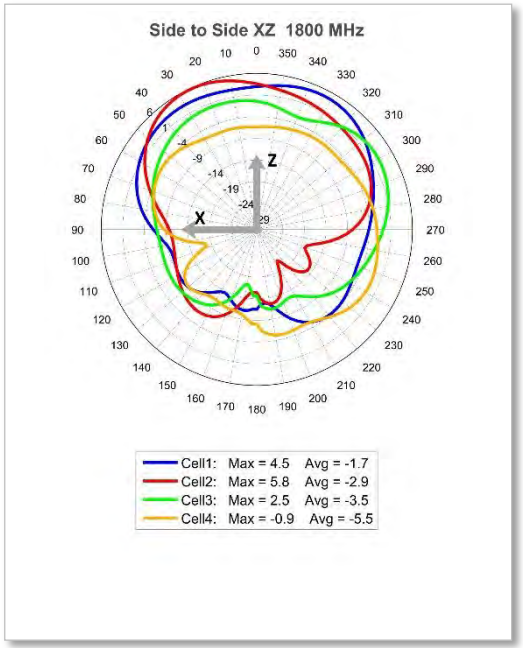
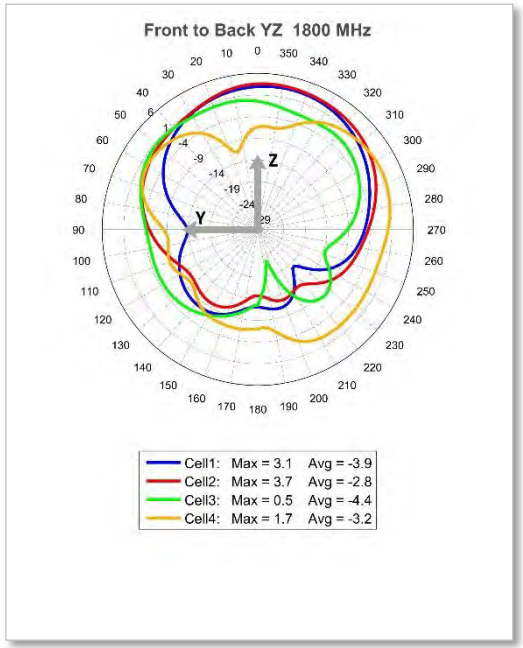
System Coverage: 1800 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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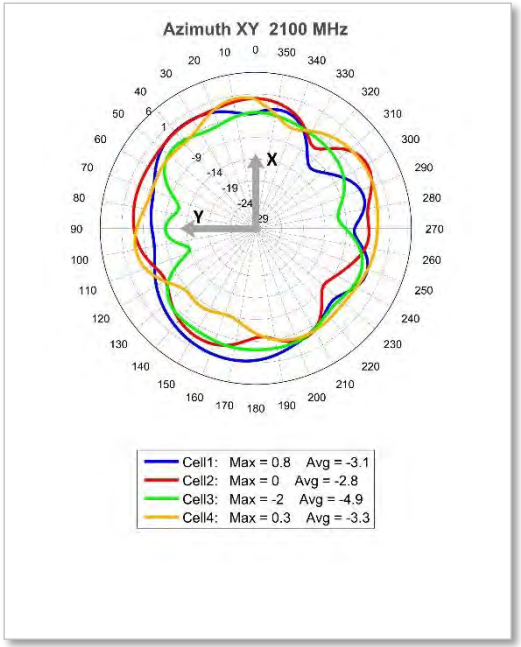
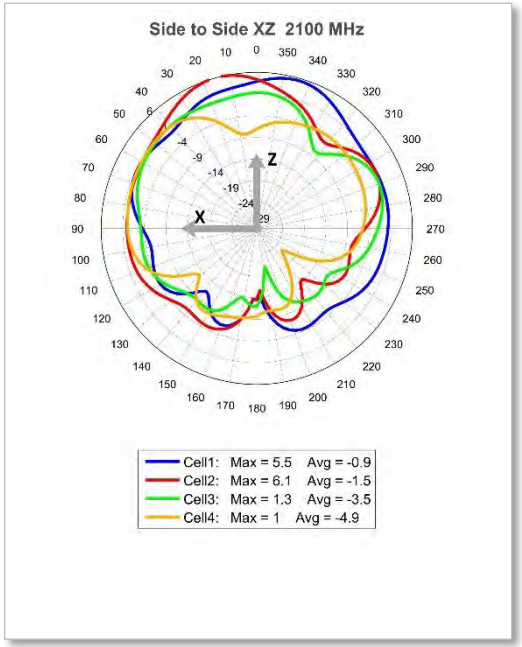
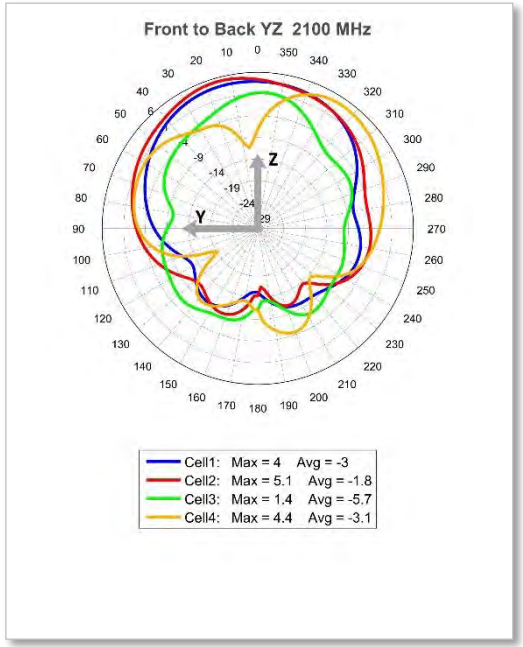
System Coverage: 2100 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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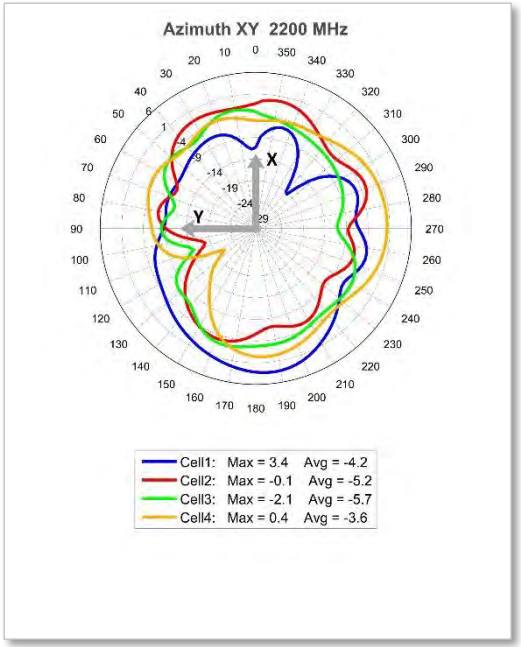
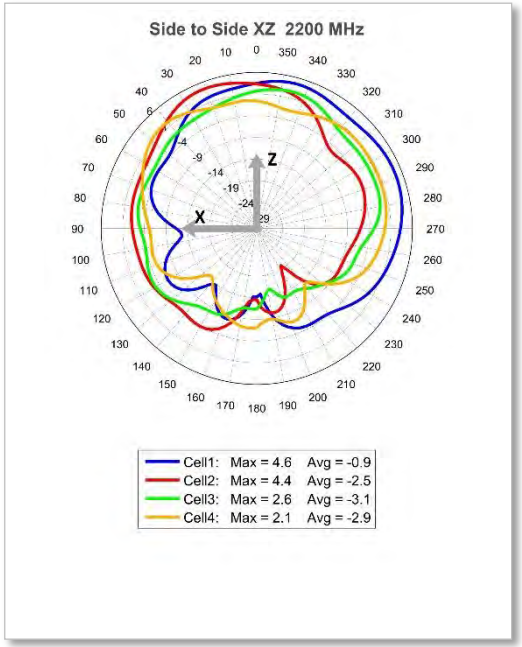
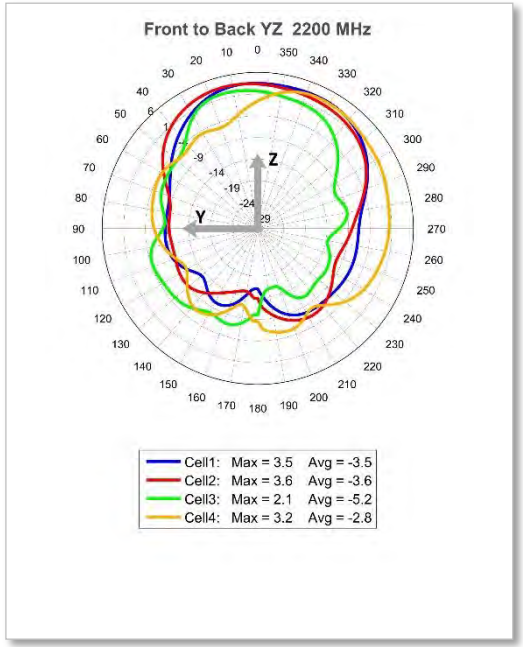
System Coverage: 2200 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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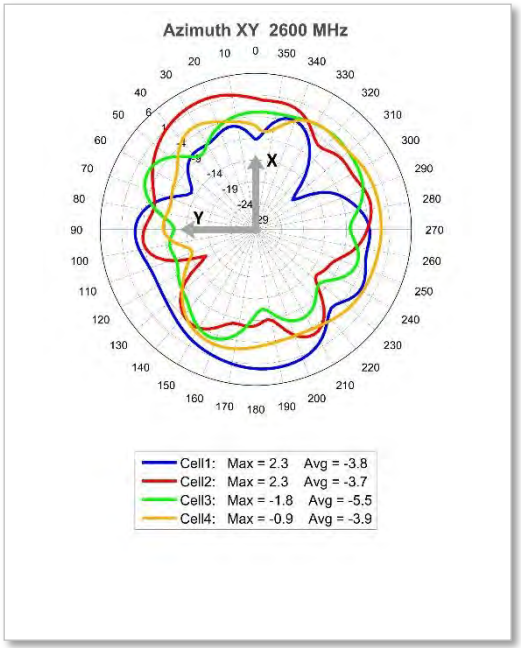
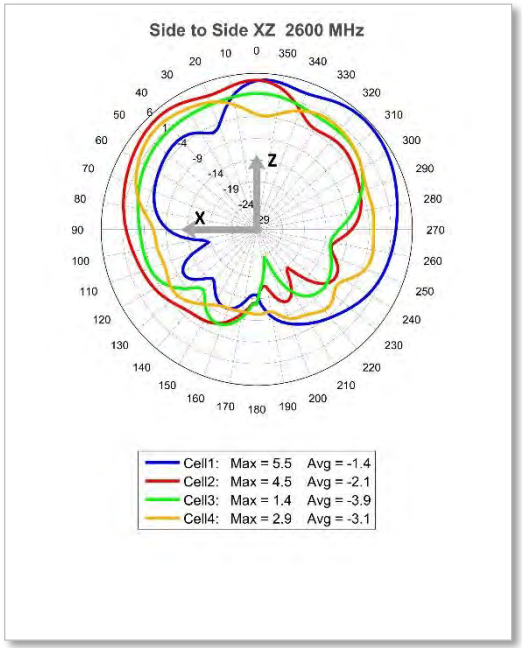
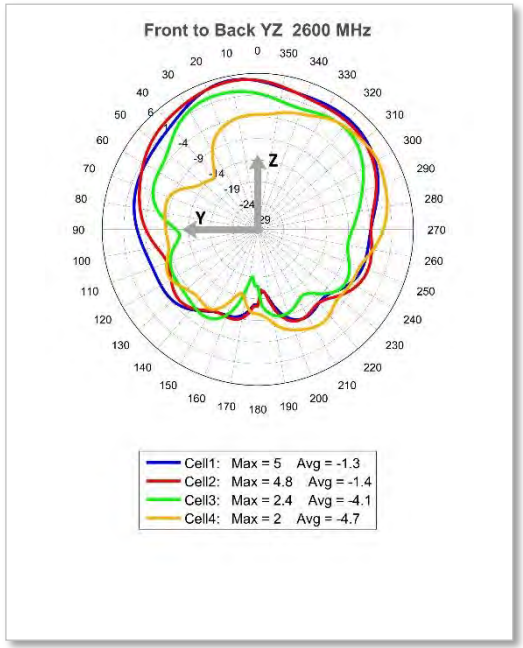
System Coverage: 2600 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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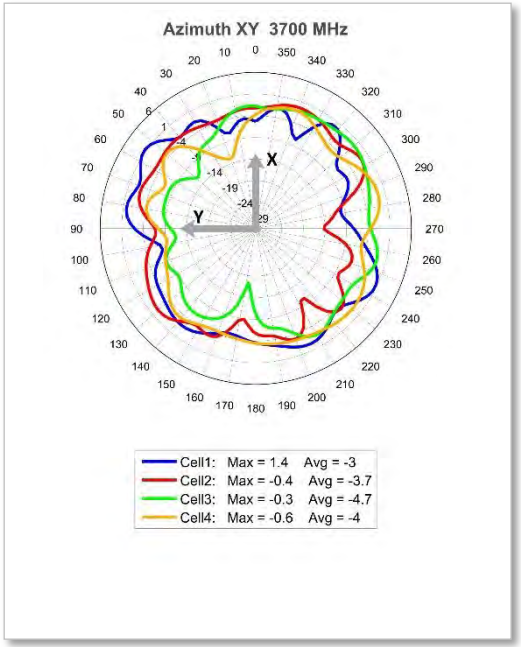
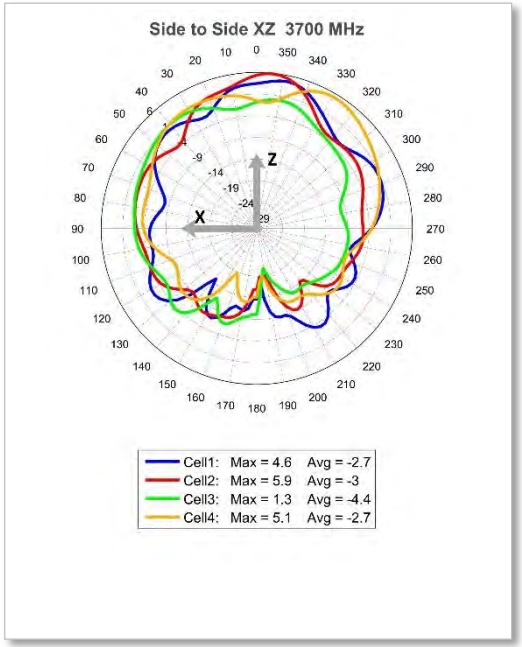
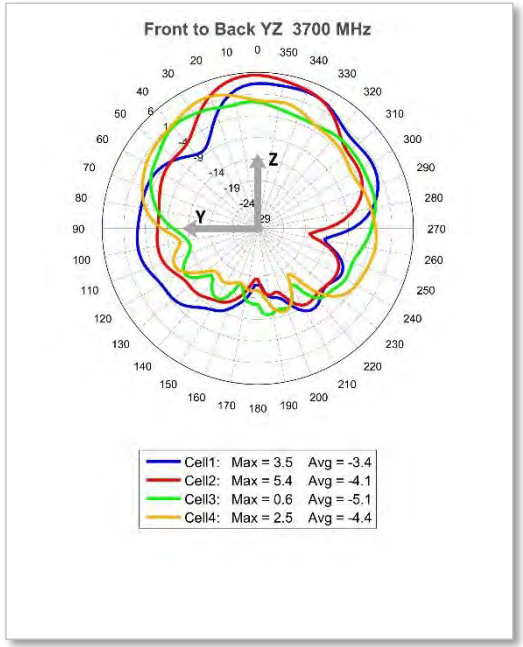
System Coverage: 3700 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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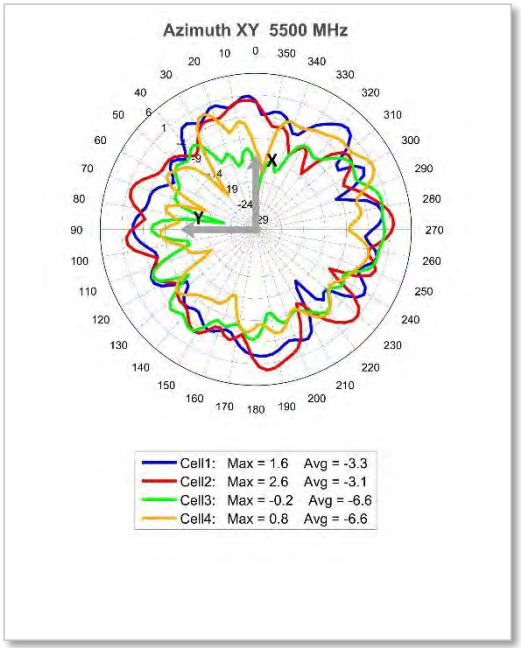
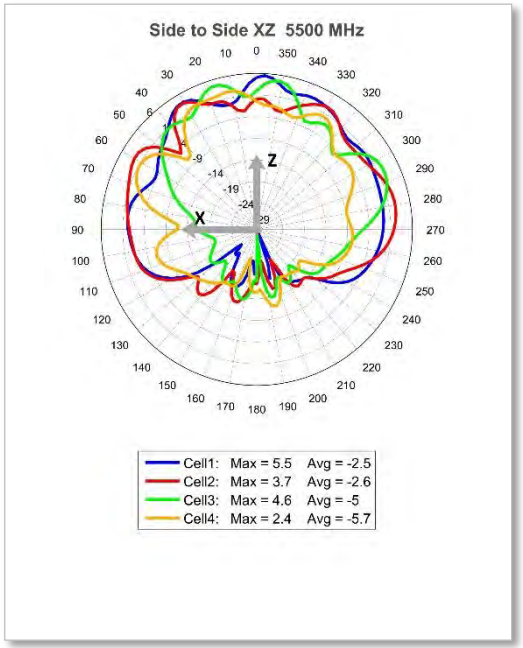
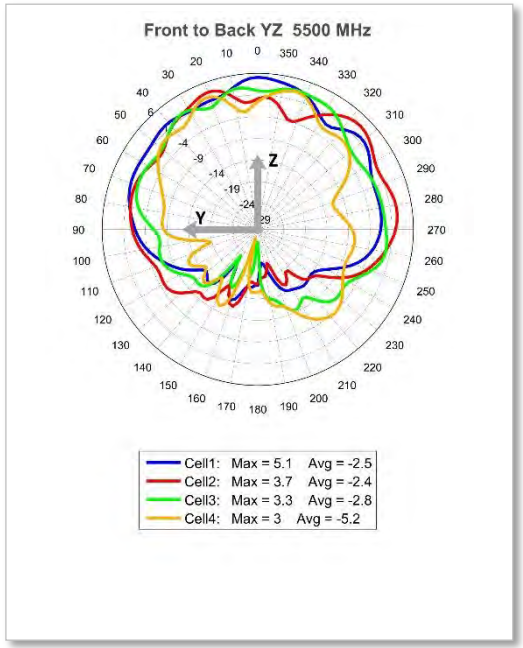
System Coverage: 5500 MHz for Cell Antennas



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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Radiation Patterns

2D Patterns –Bluetooth Antenna

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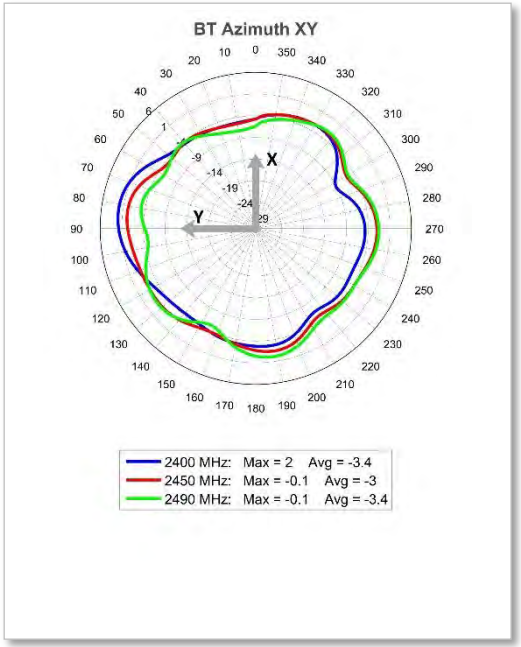
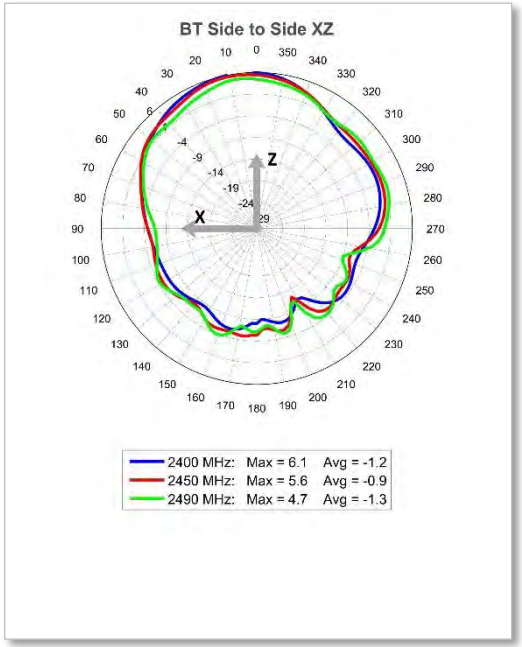
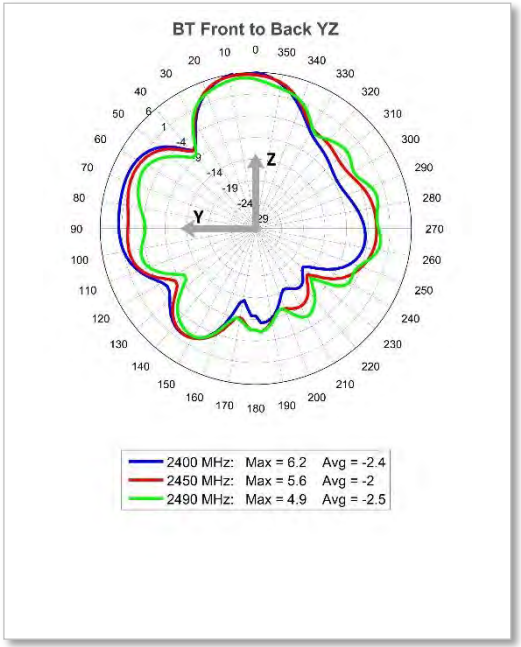
2D Cuts: Bluetooth Antenna



Azimuth (XY)



Side to Side (XZ)



Front to Back (YZ)

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Radiation Patterns

3D Patterns - Cell

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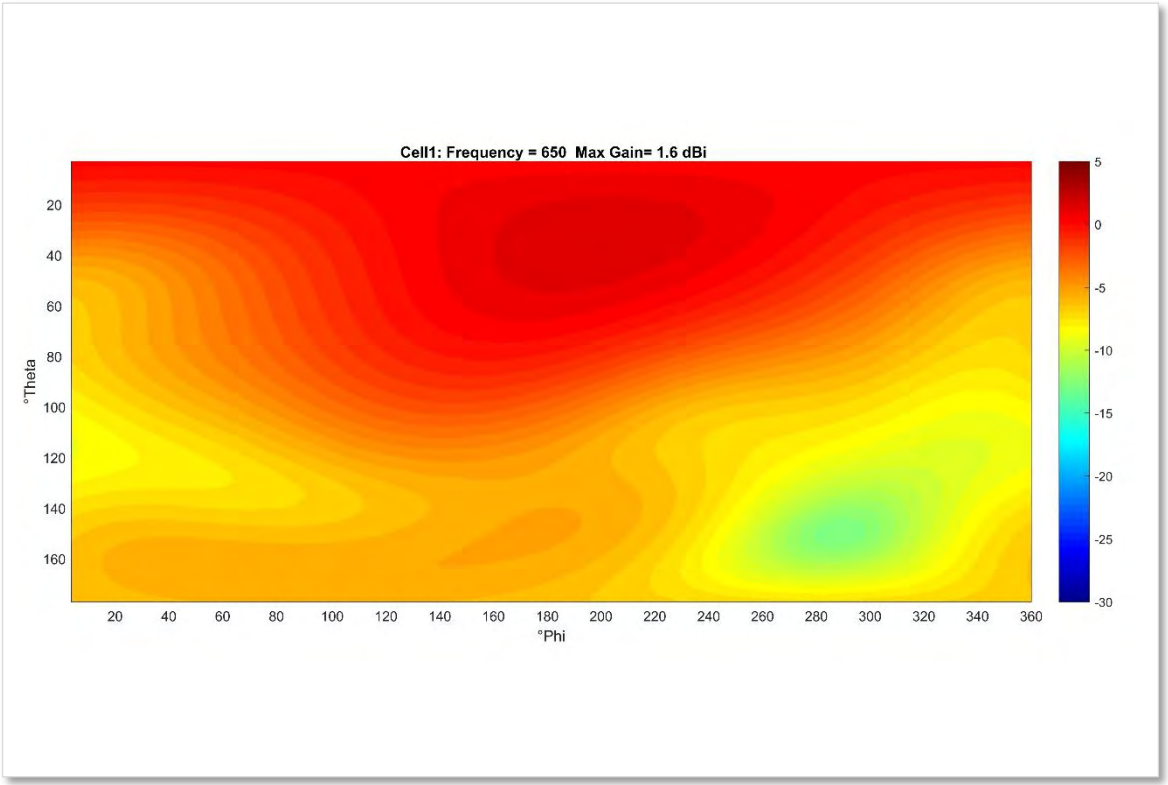
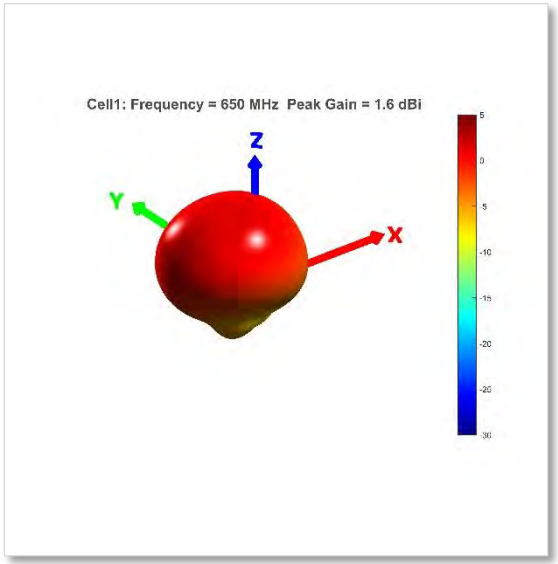
3D Gain Pattern and Heatmap: Cell 1 at 650 MHz





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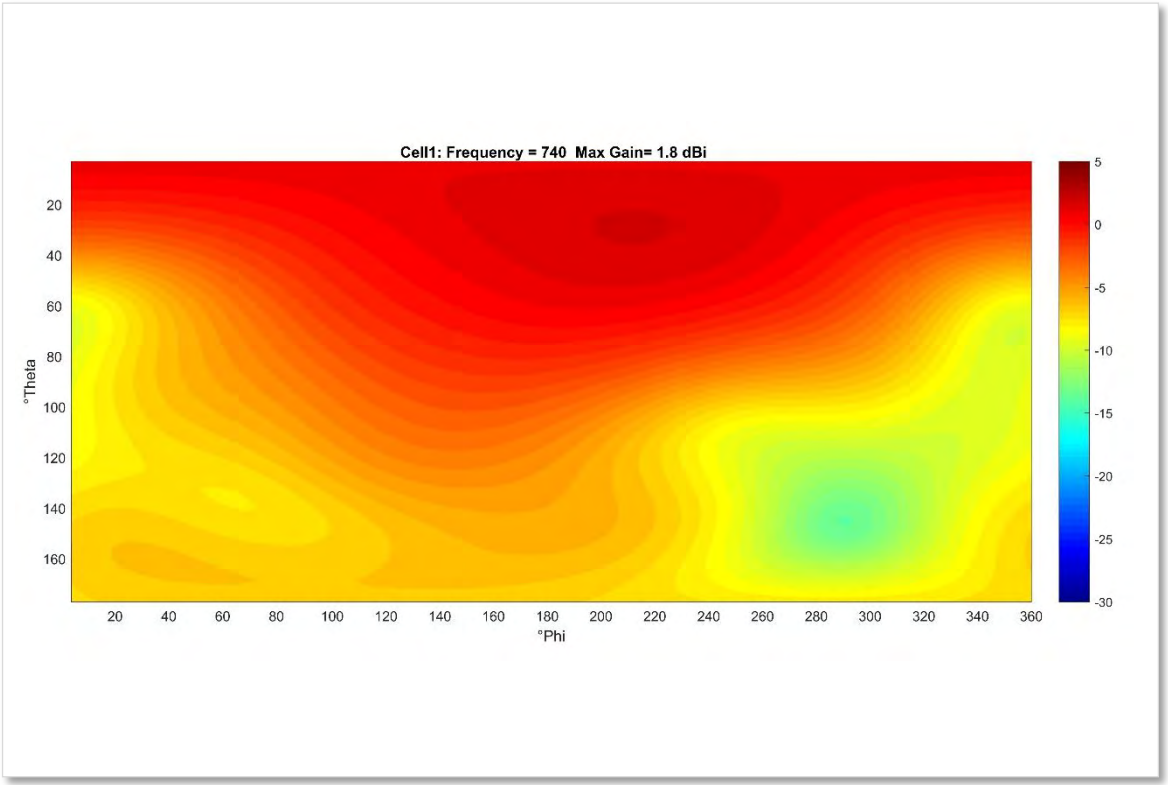
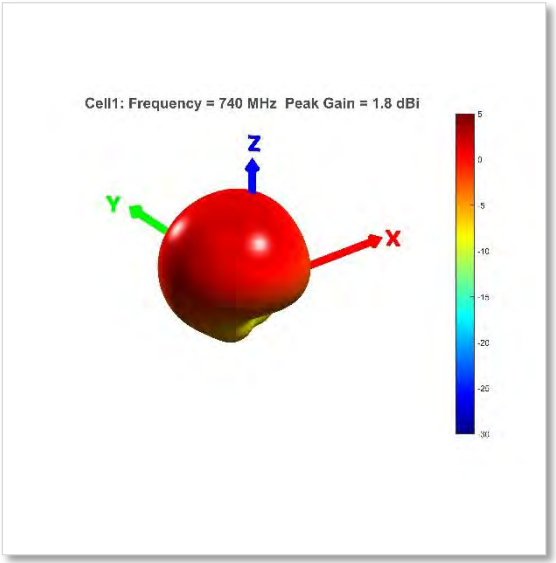
3D Gain Pattern and Heatmap: Cell1 at 740 MHz





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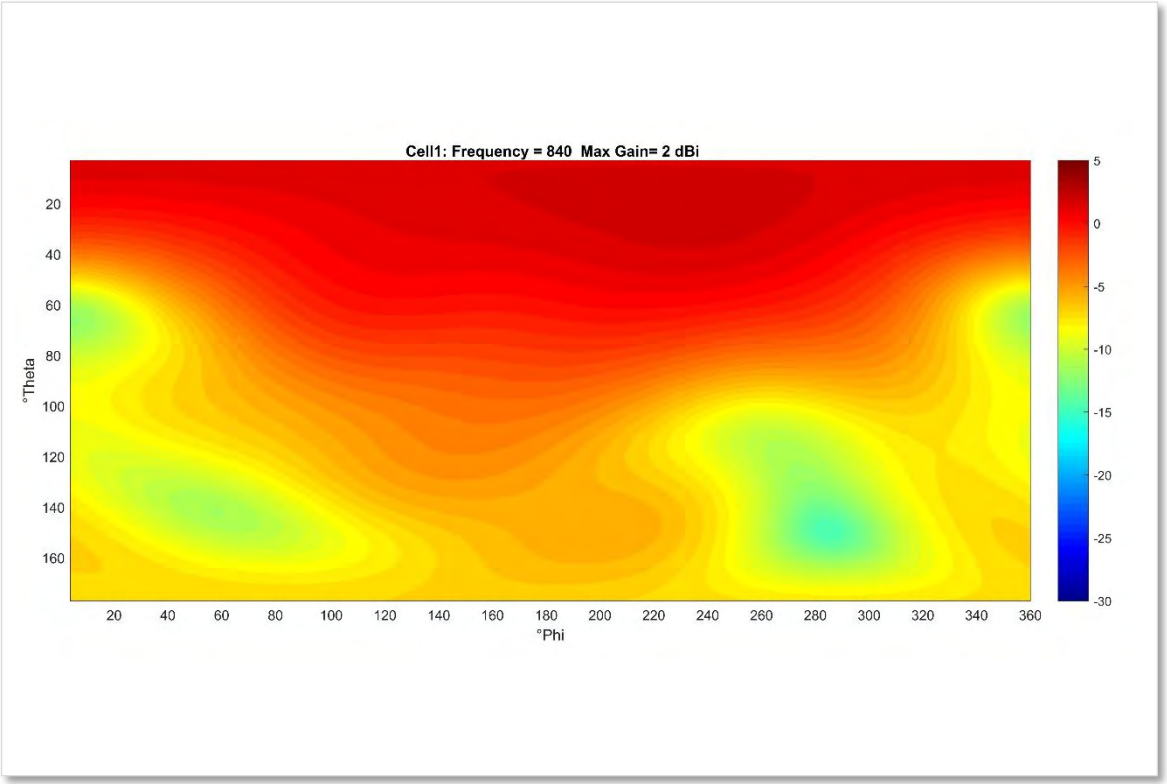
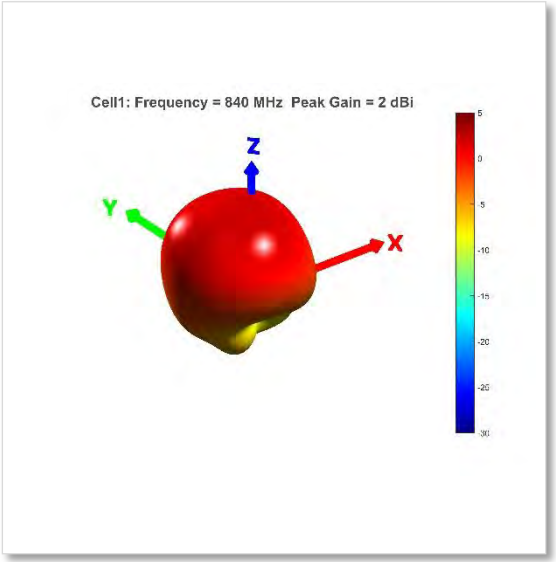
3D Gain Pattern and Heatmap: Cell1 at 840 MHz





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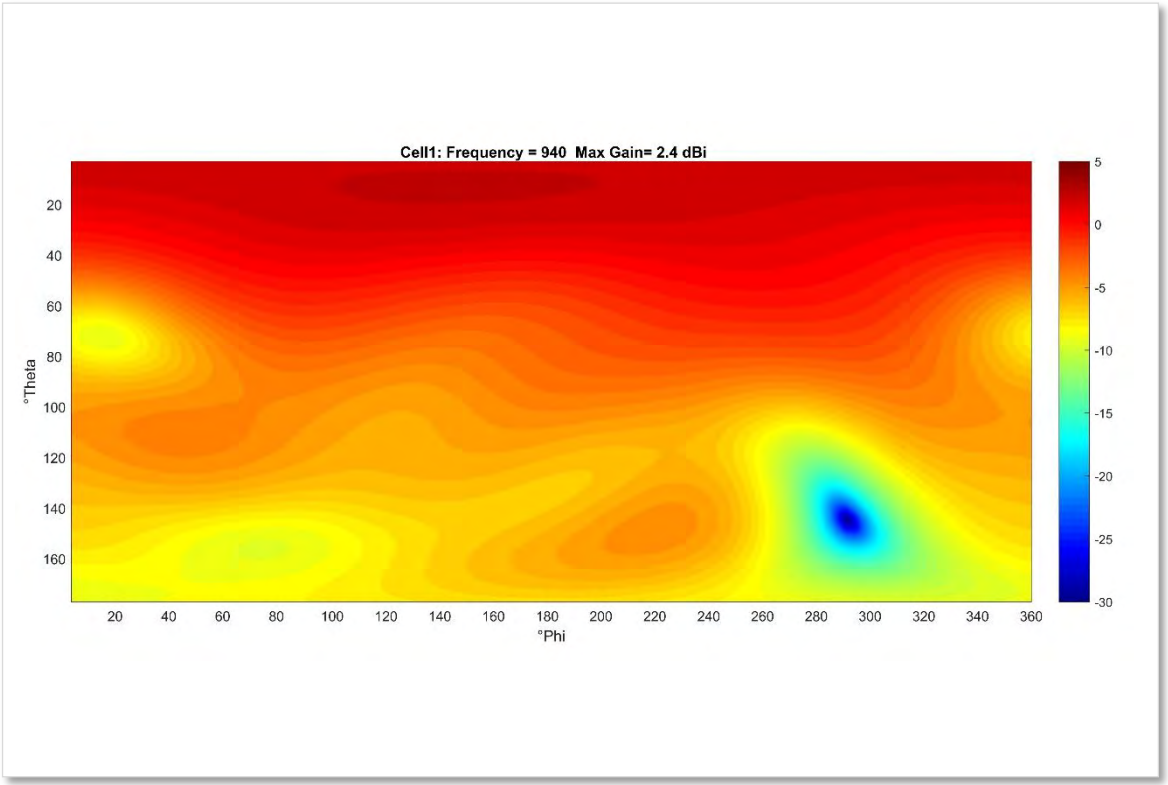
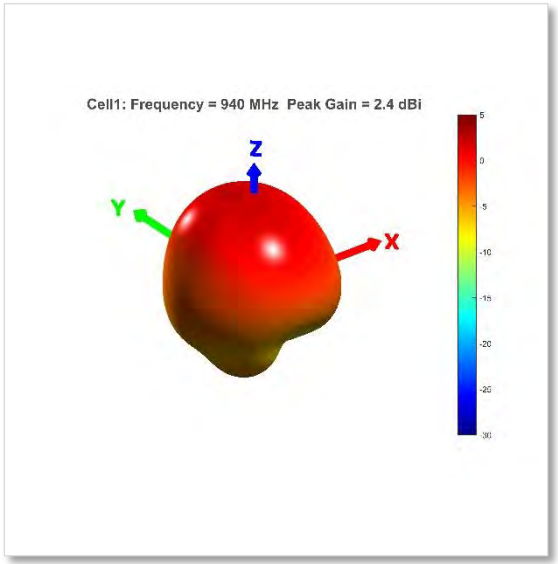
3D Gain Pattern and Heatmap: Cell1 at 940 MHz





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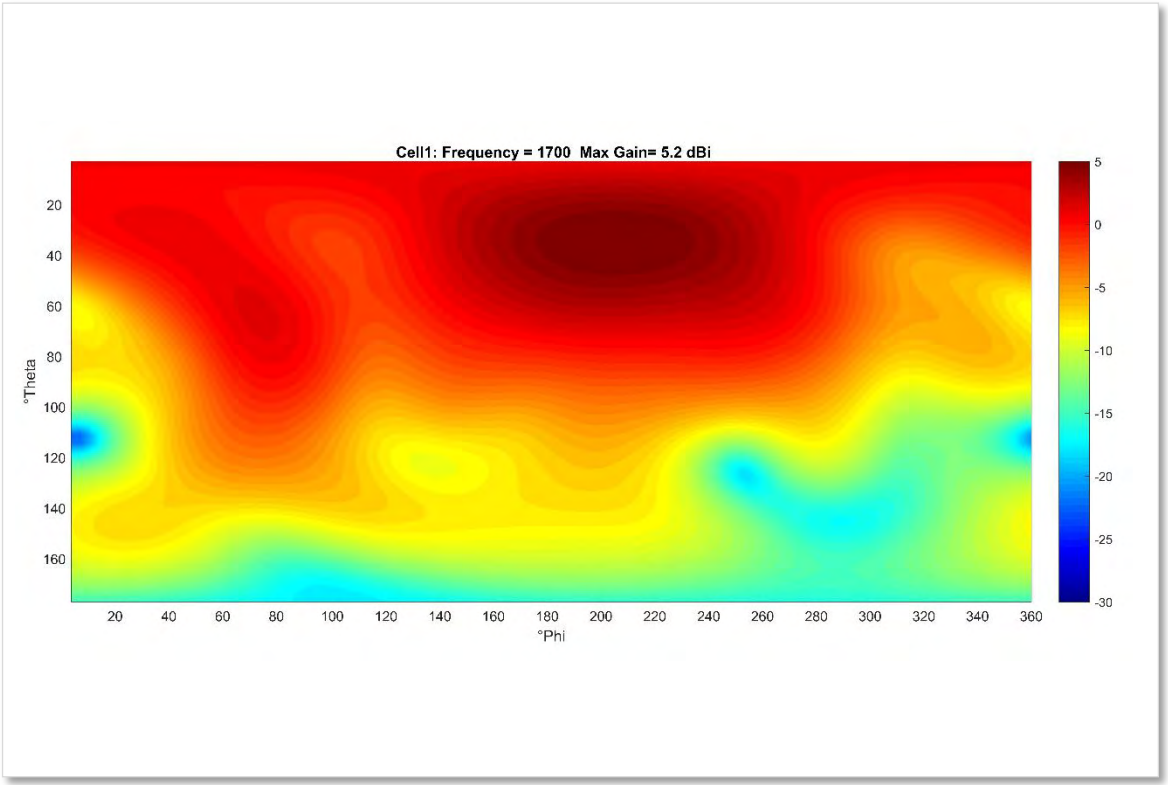
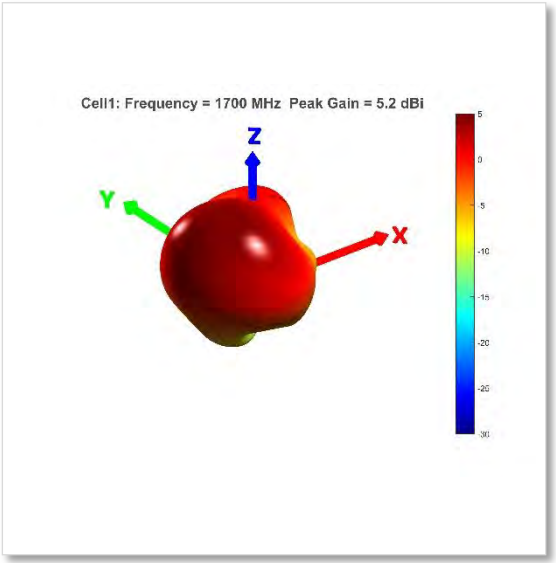
3D Gain Pattern and Heatmap: Cell 1 at 1700 MHz





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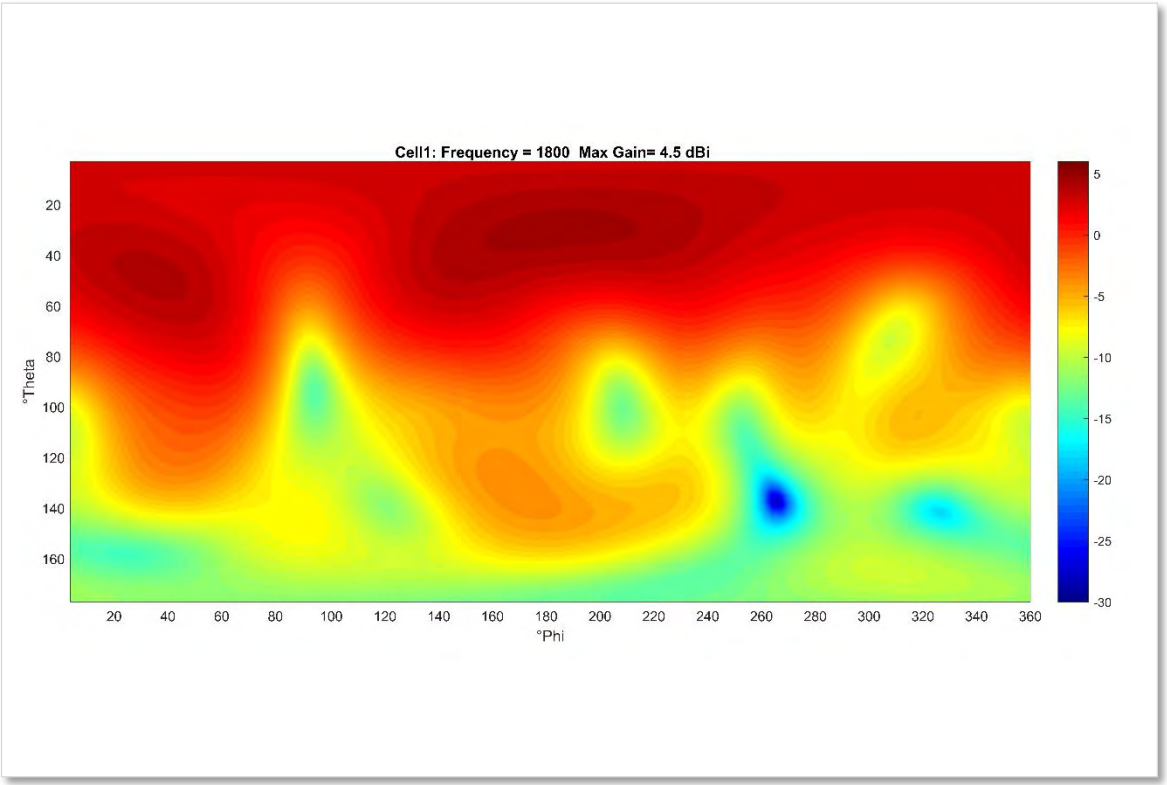
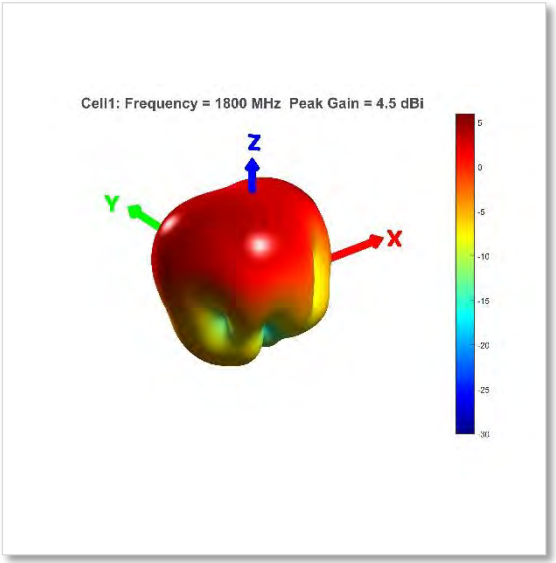
3D Gain Pattern and Heatmap: Cell 1 at 1800 MHz





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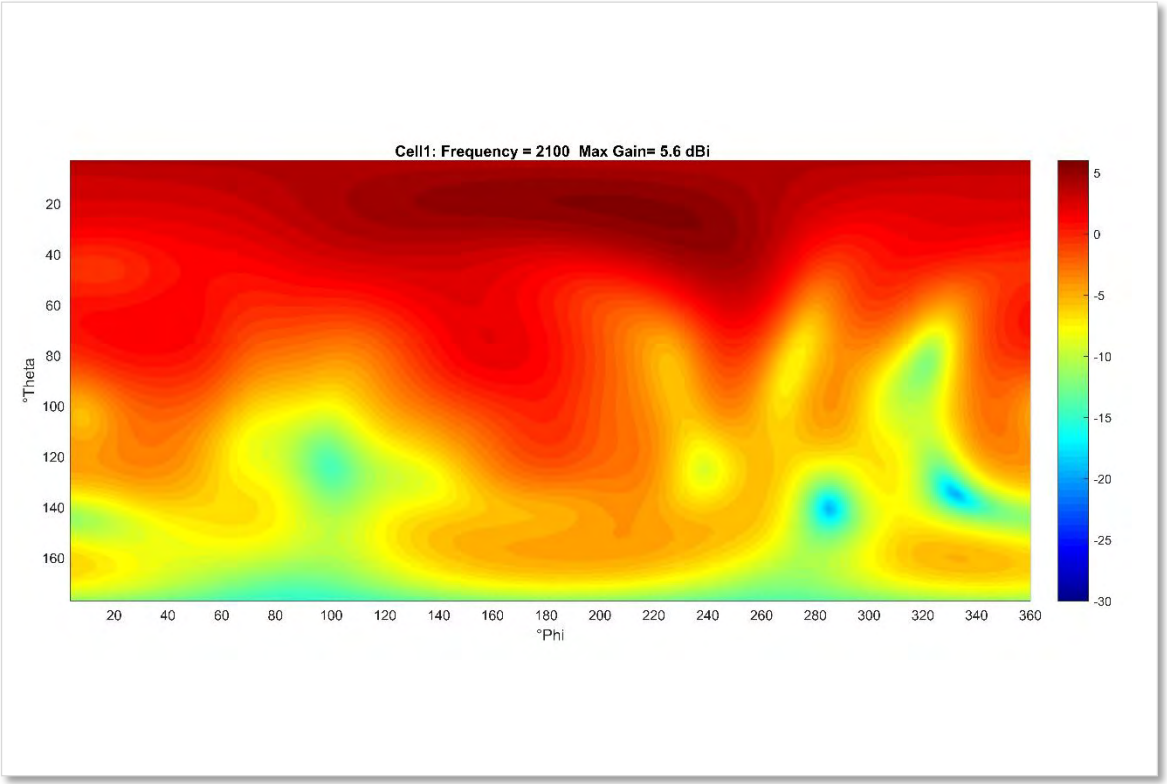
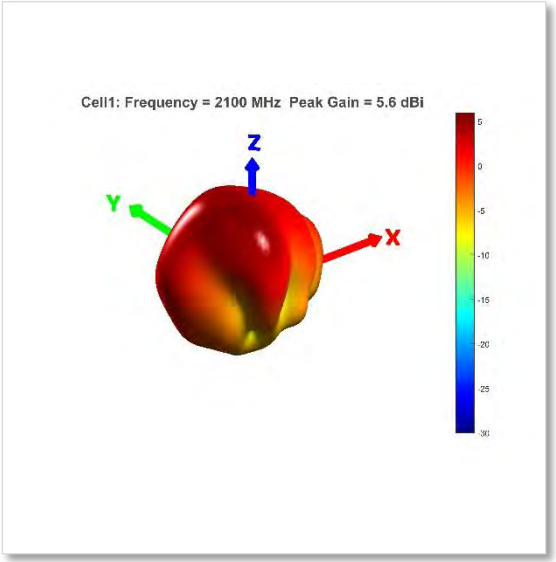
3D Gain Pattern and Heatmap: Cell 1 at 2100 MHz





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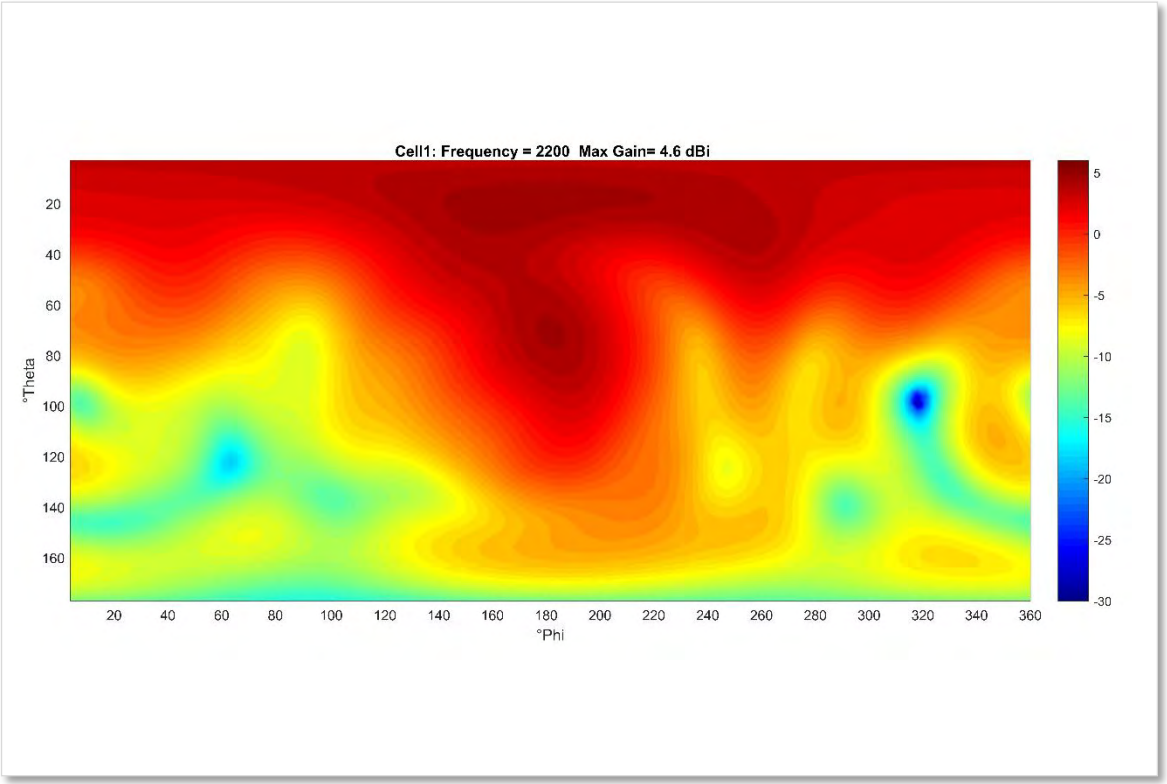
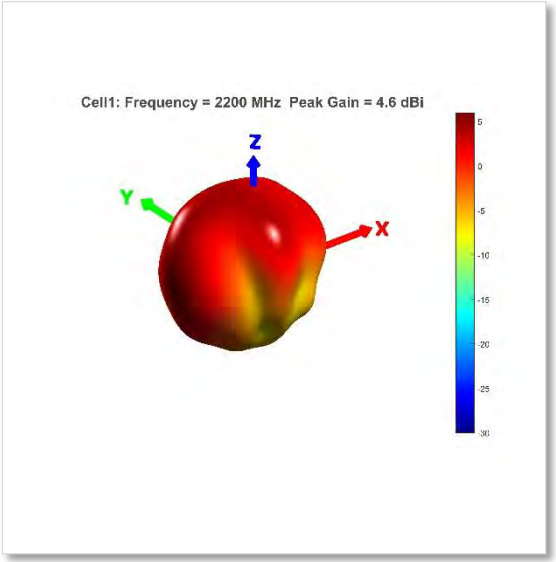
3D Gain Pattern and Heatmap: Cell 1 at 2200 MHz





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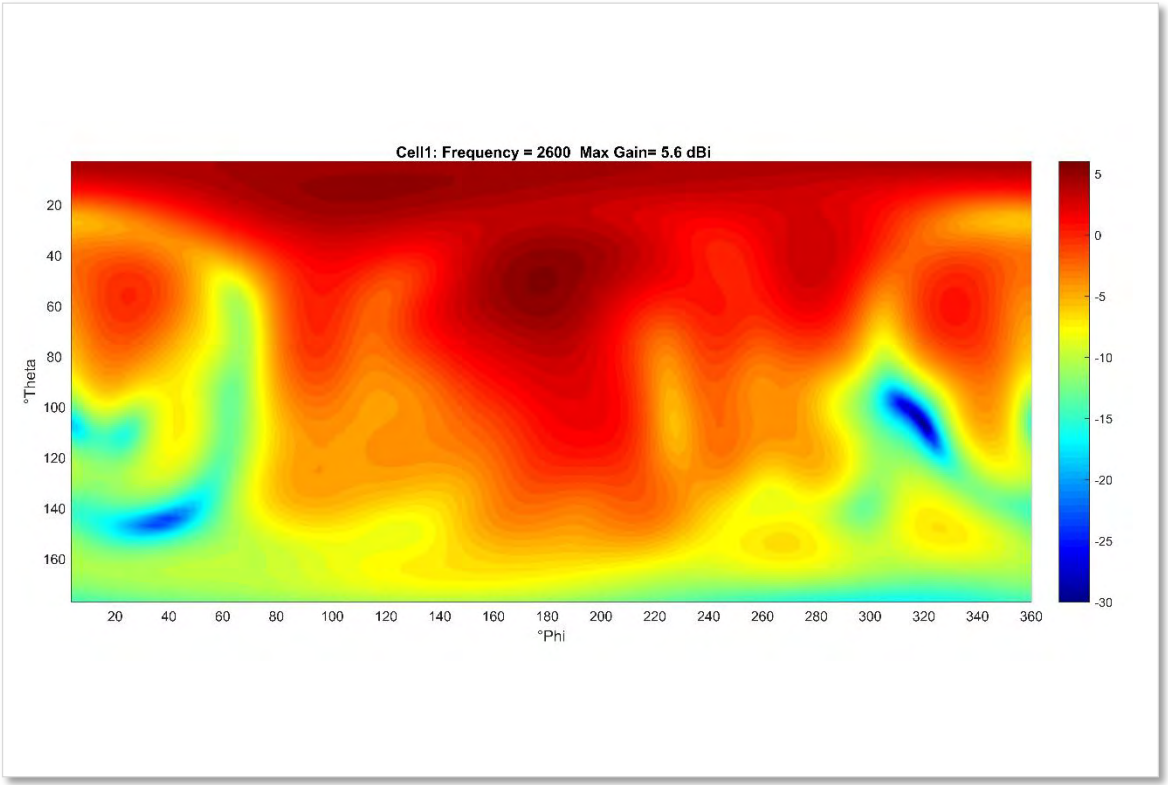
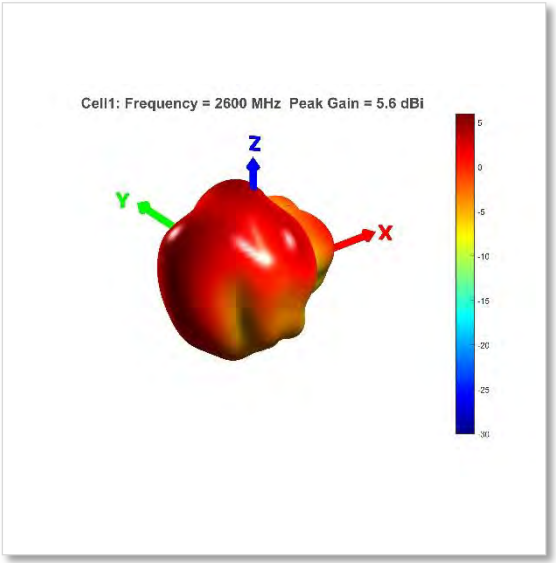
3D Gain Pattern and Heatmap: Cell1 at 2600 MHz





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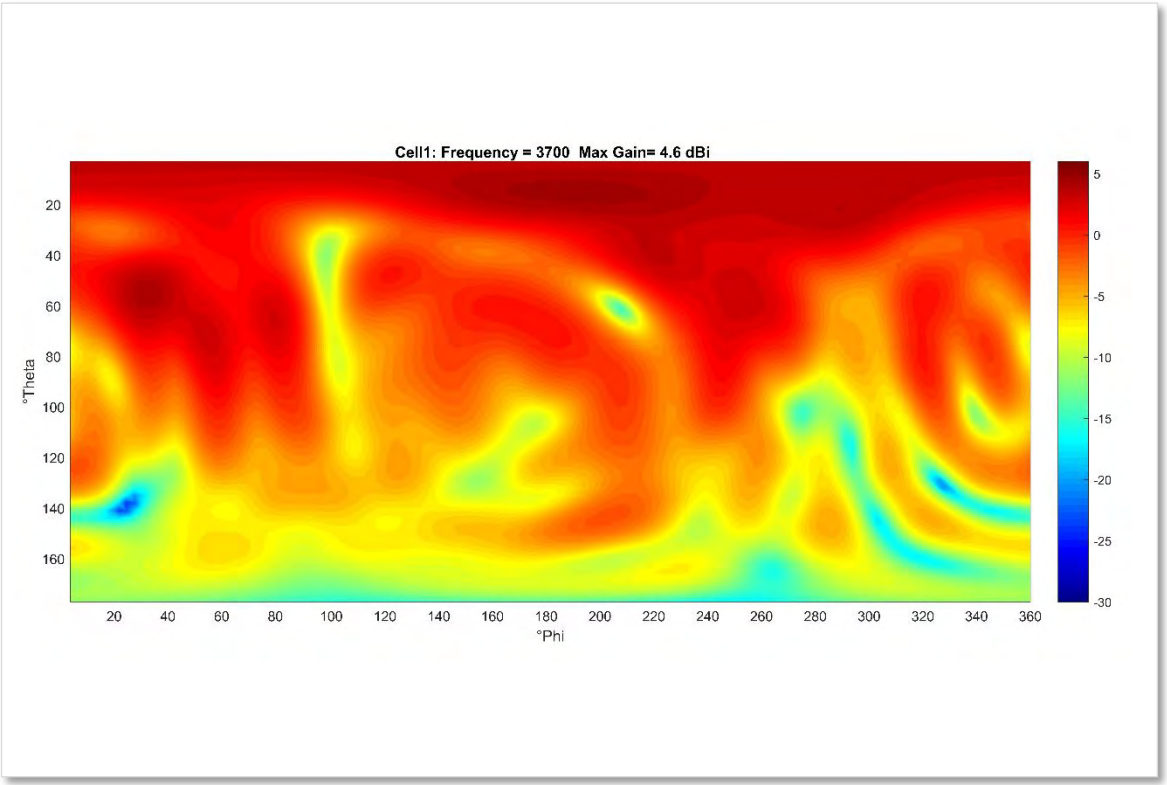
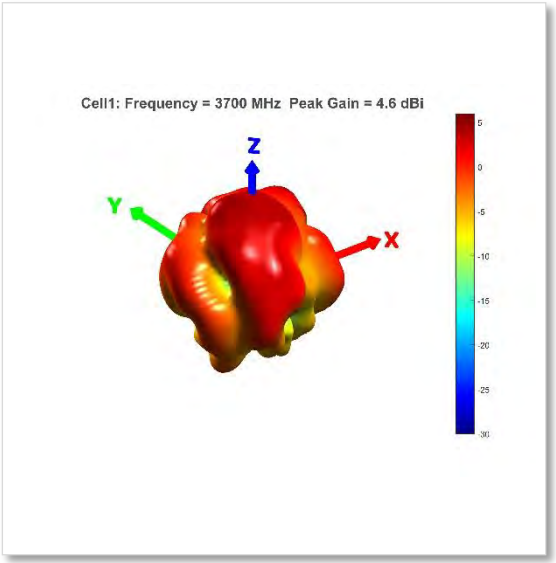
3D Gain Pattern and Heatmap: Cell 1 at 3700 MHz





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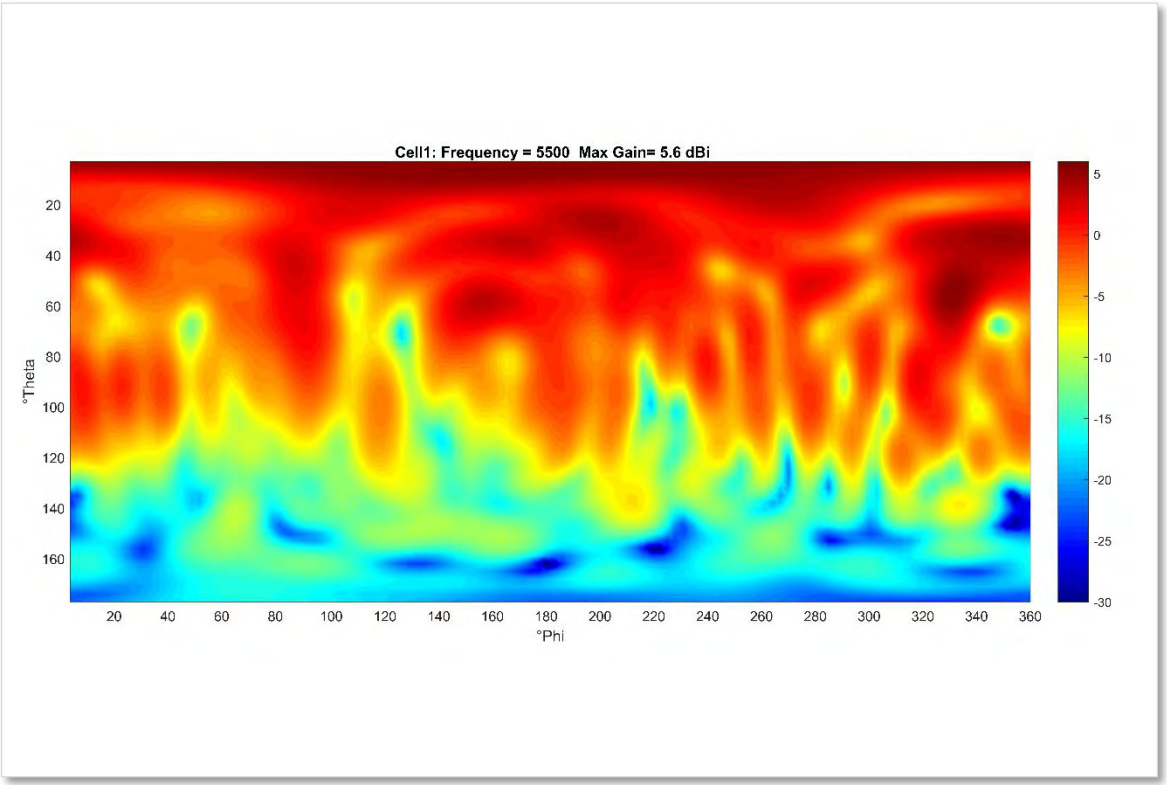
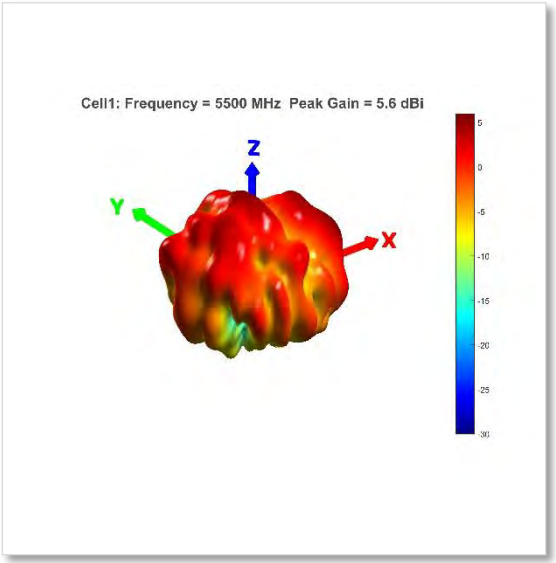
3D Gain Pattern and Heatmap: Cell 1 at 5500 MHz





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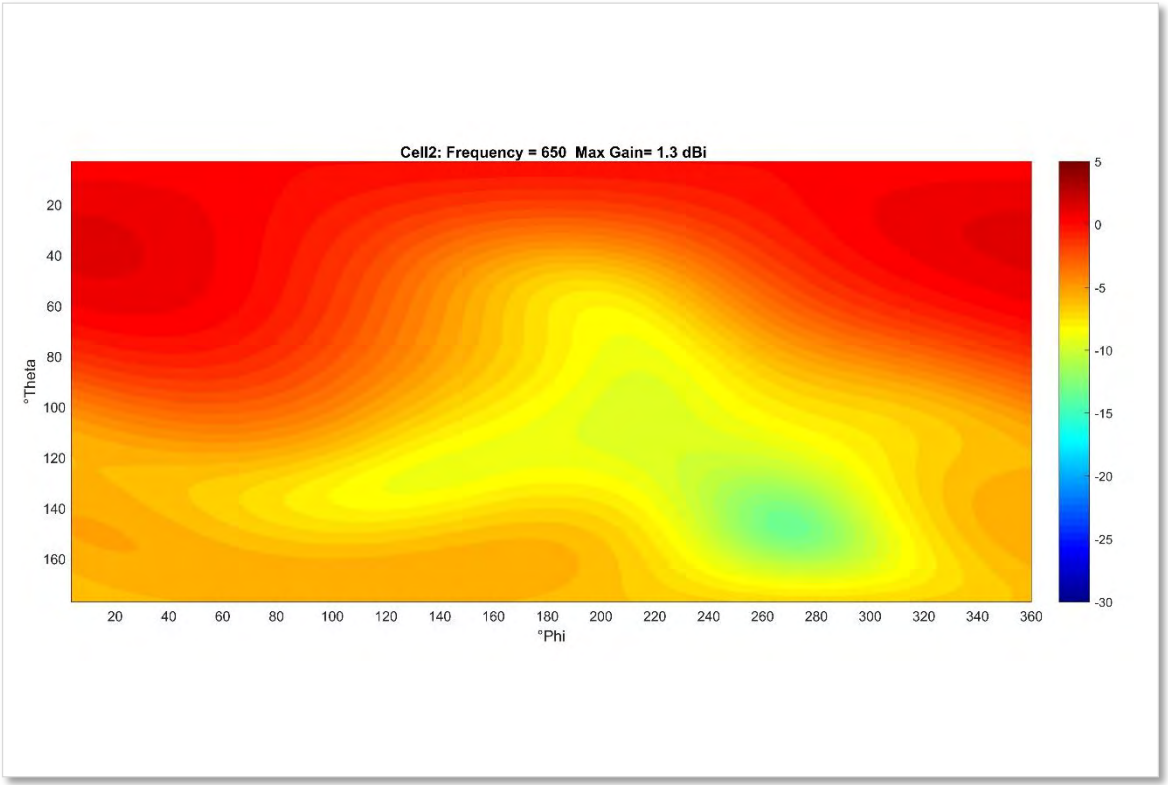
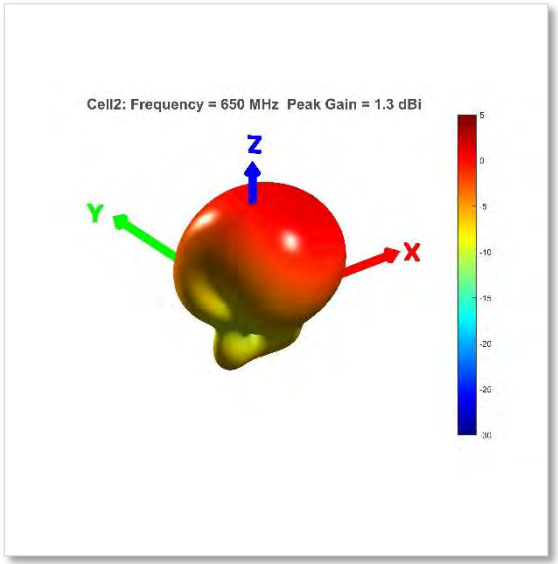
3D Gain Pattern and Heatmap: Cell 2 at 650 MHz





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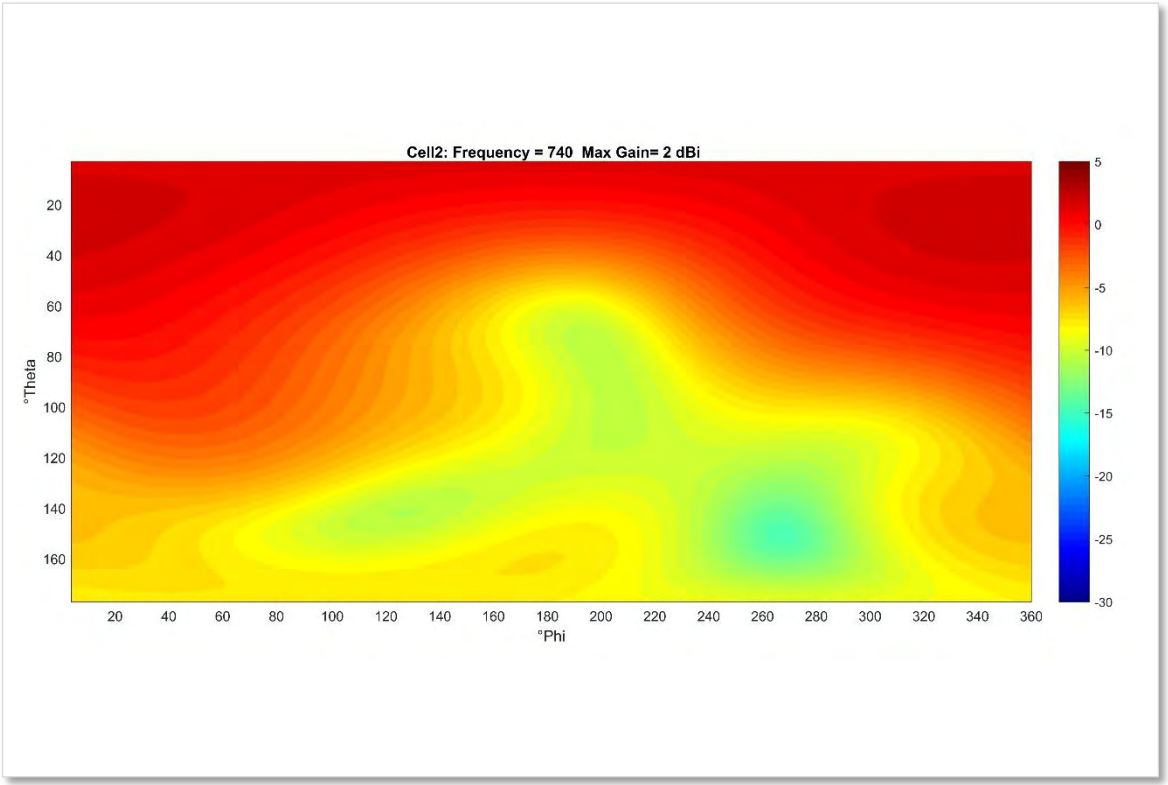
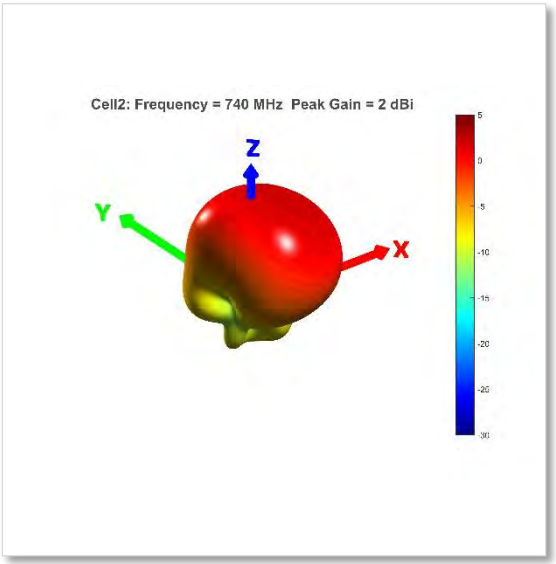
3D Gain Pattern and Heatmap: Cell 2 at 740 MHz





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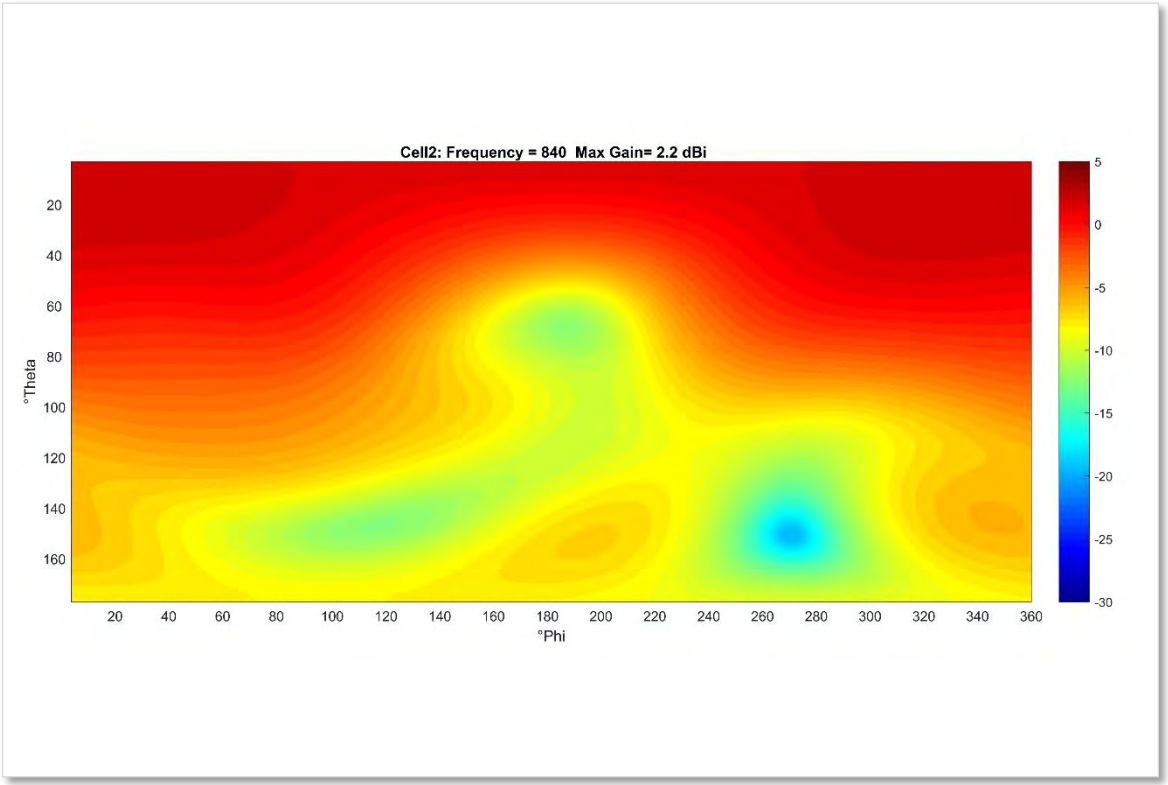
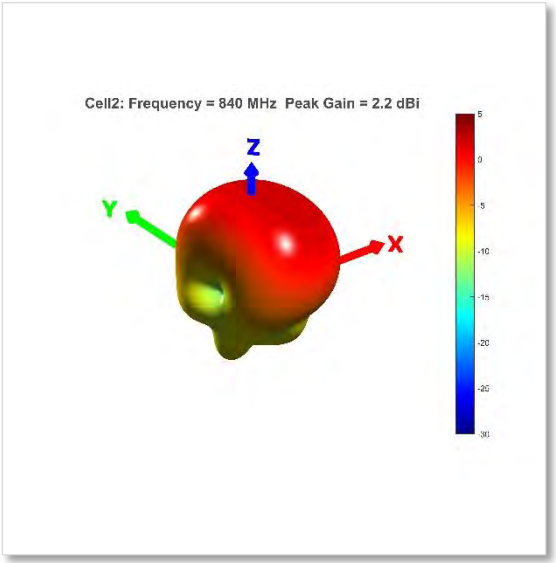
3D Gain Pattern and Heatmap: Cell 2 at 840 MHz





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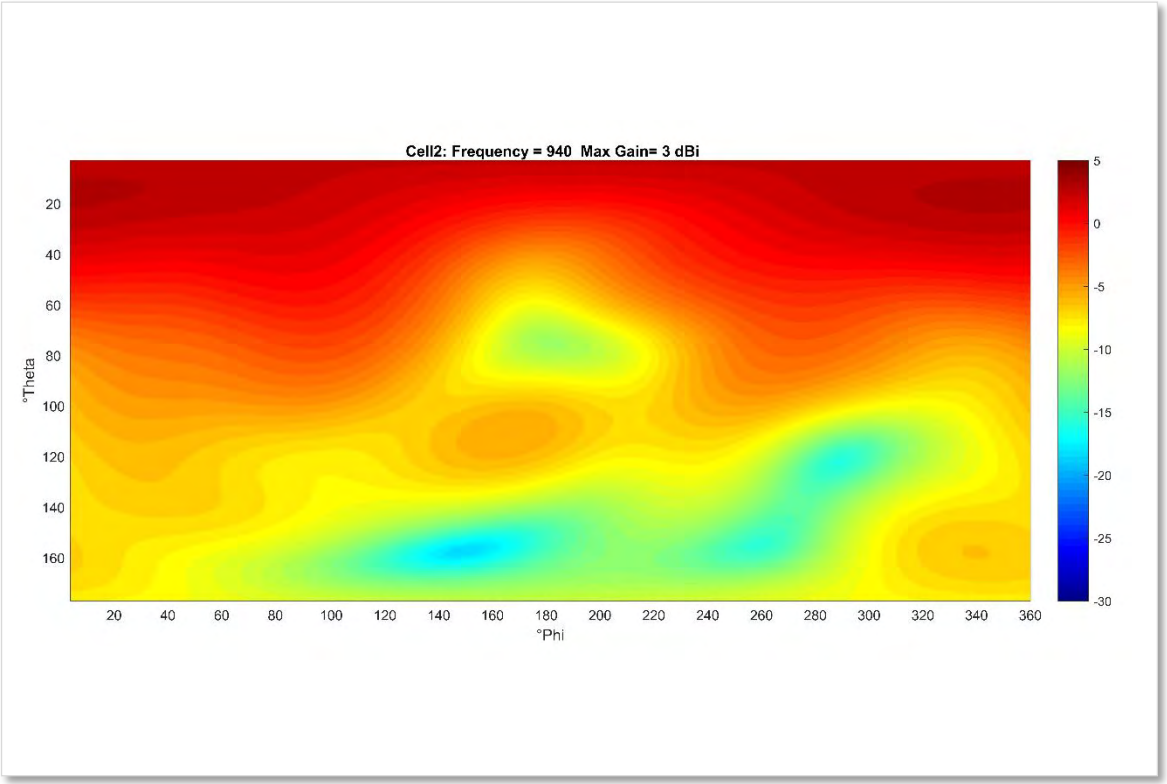
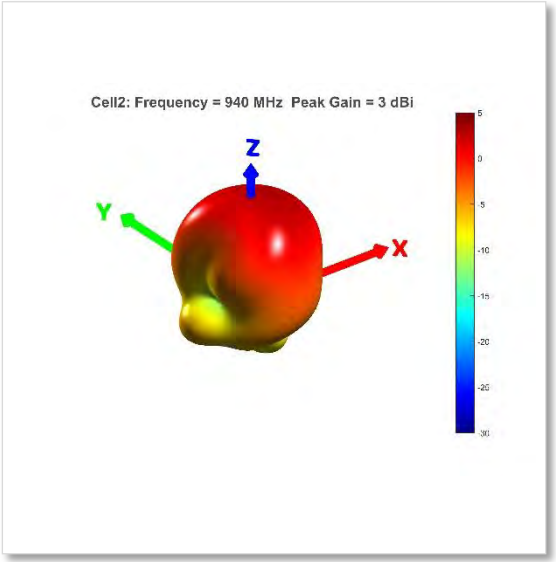
3D Gain Pattern and Heatmap: Cell 2 at 940 MHz





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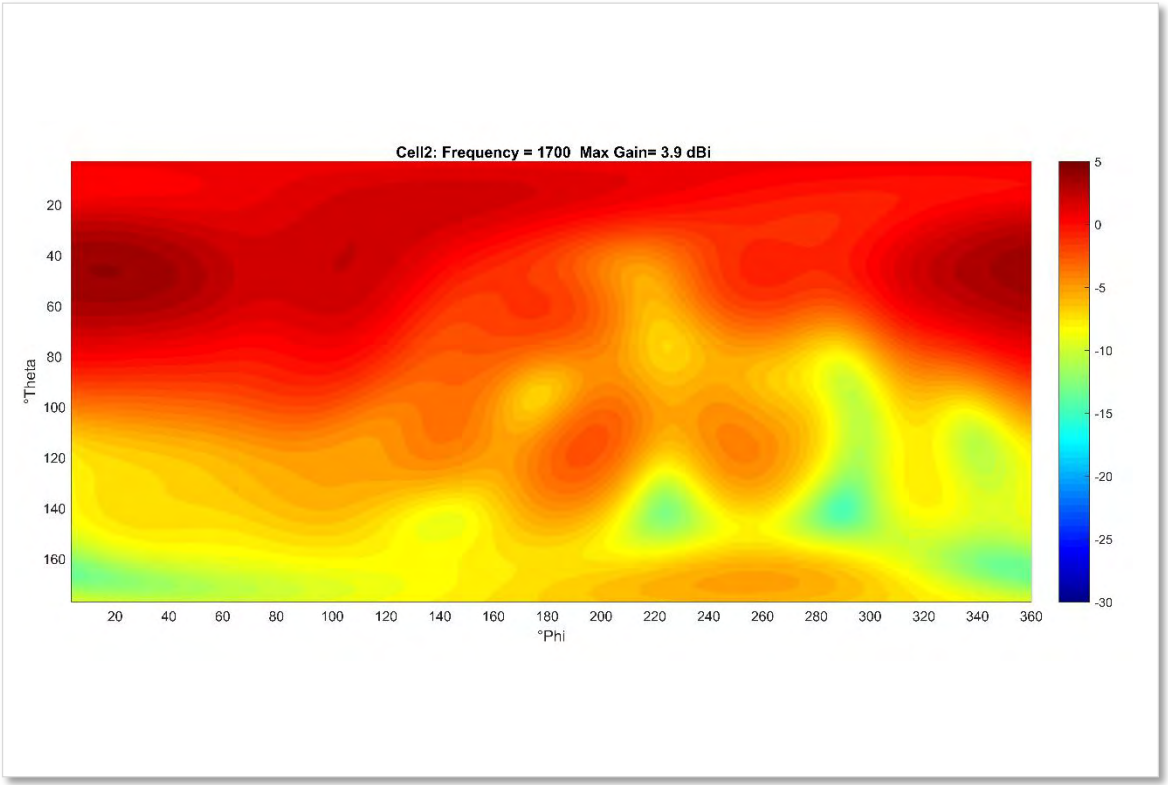
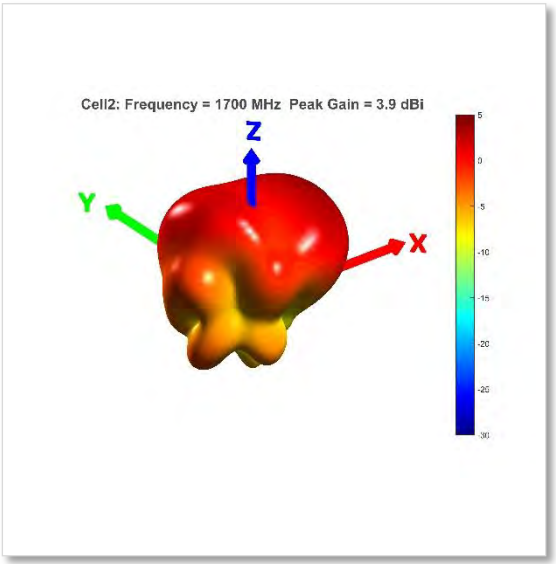
3D Gain Pattern and Heatmap: Cell 2 at 1700 MHz





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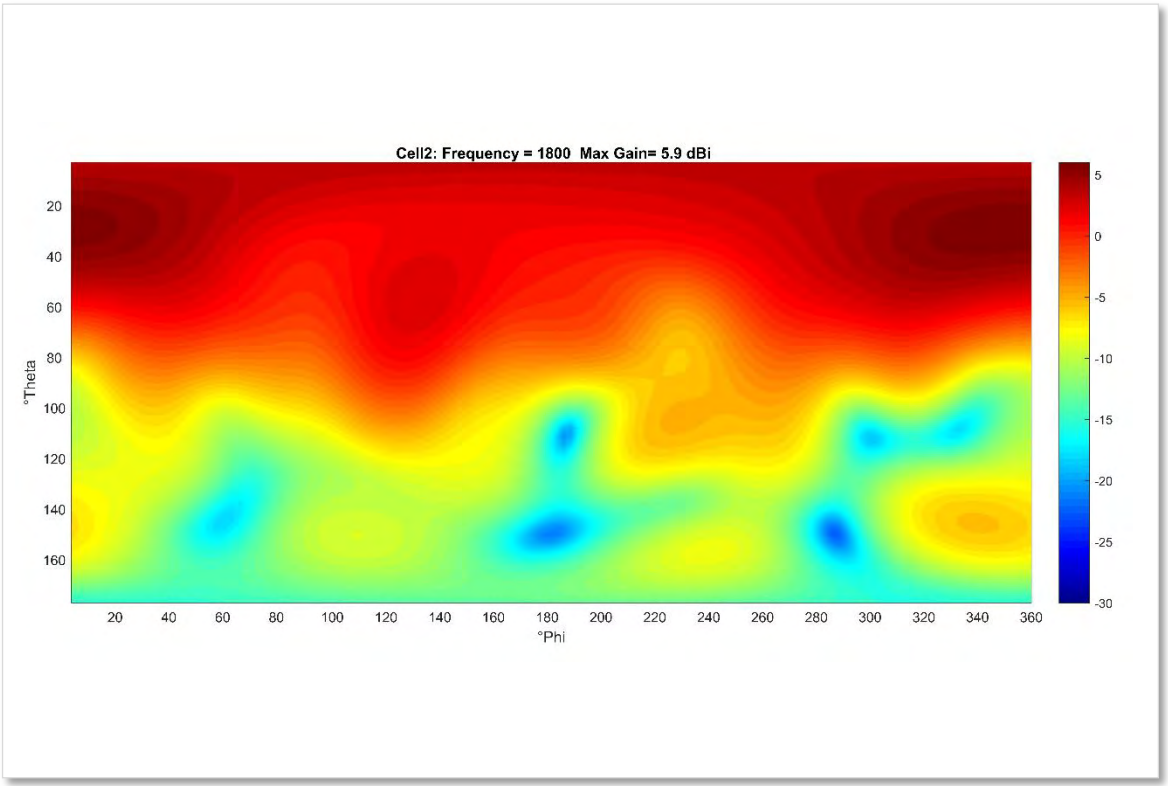
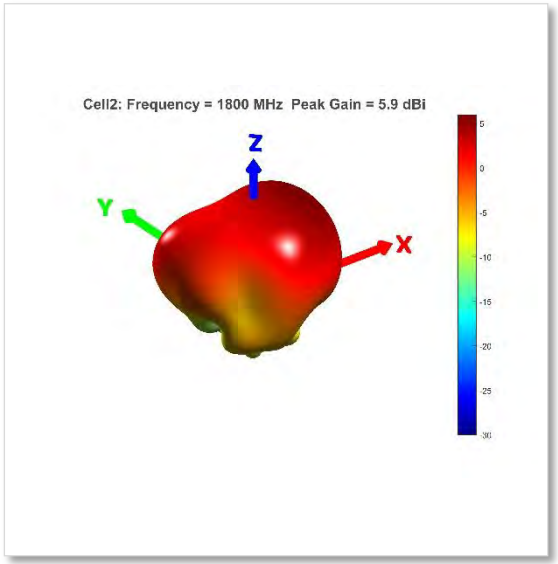
3D Gain Pattern and Heatmap: Cell 2 at 1800 MHz





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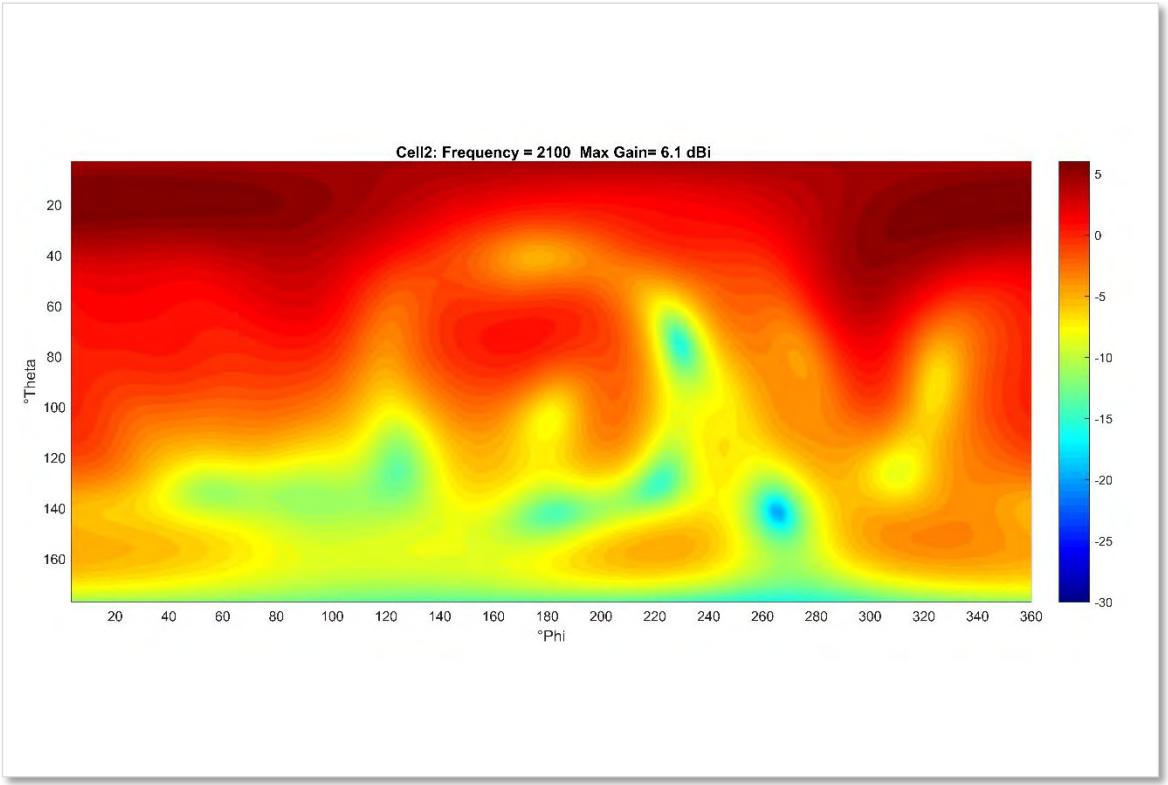
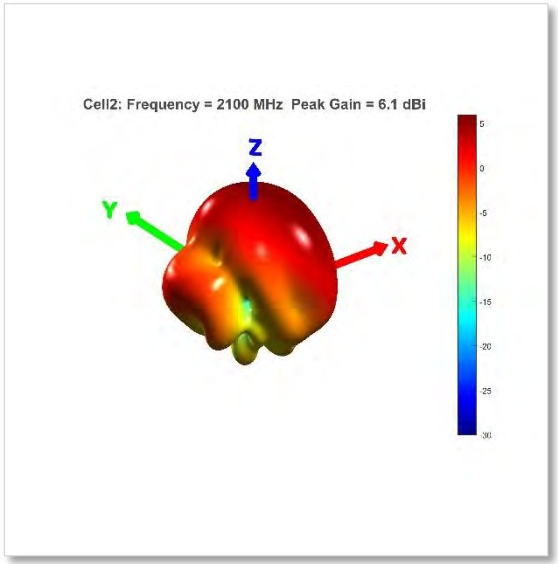
3D Gain Pattern and Heatmap: Cell 2 at 2100 MHz





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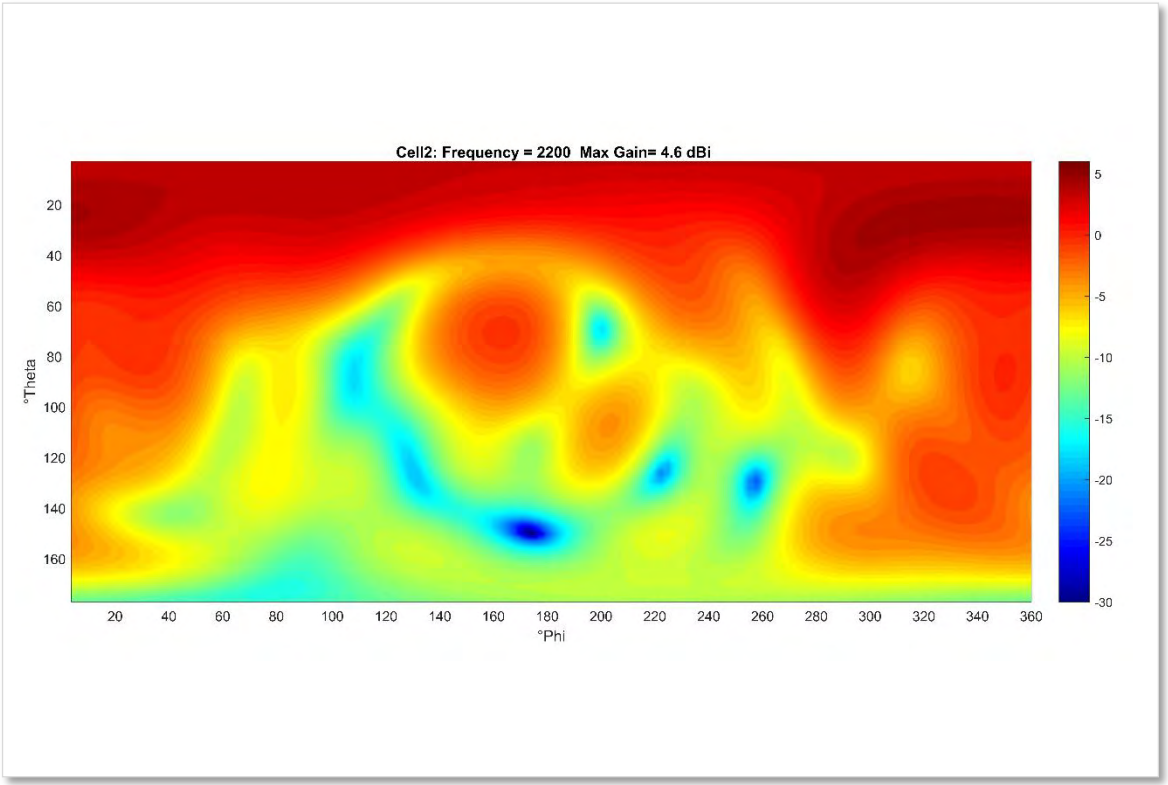
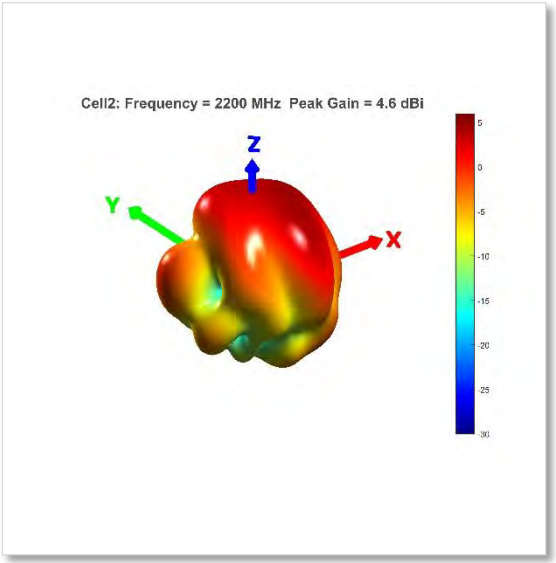
3D Gain Pattern and Heatmap: Cell 2 at 2200 MHz





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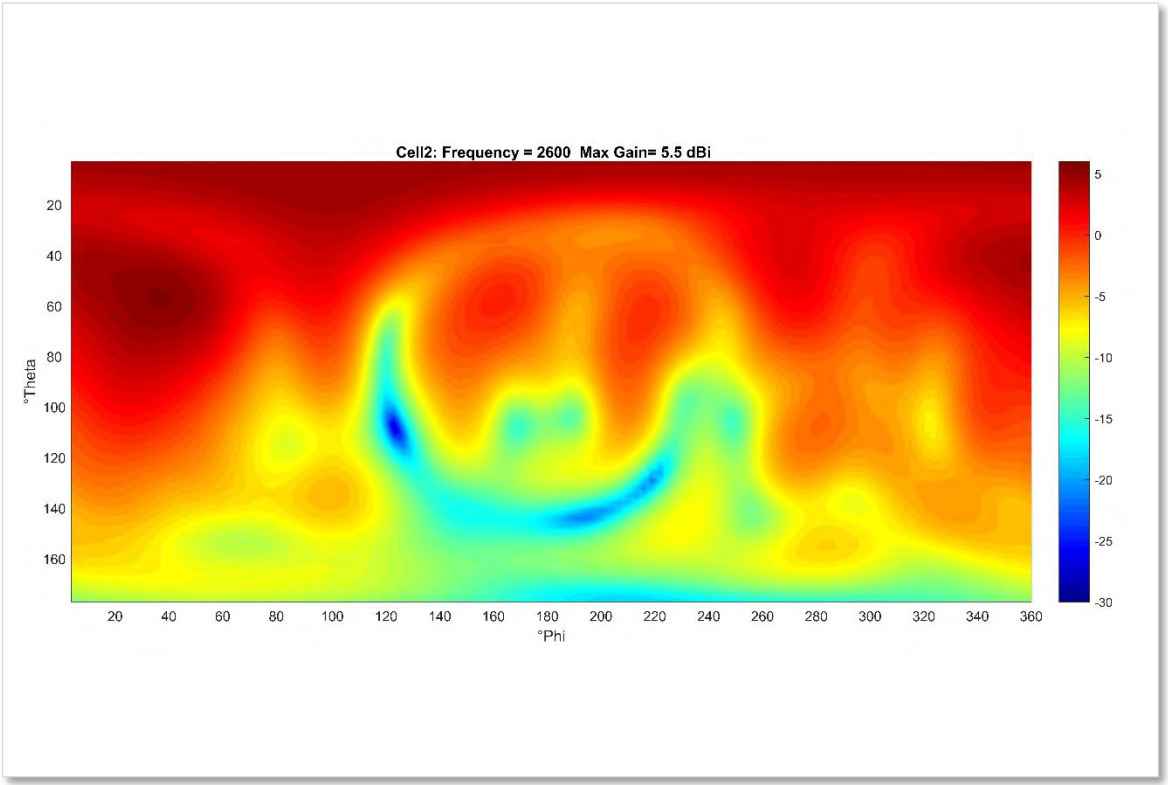
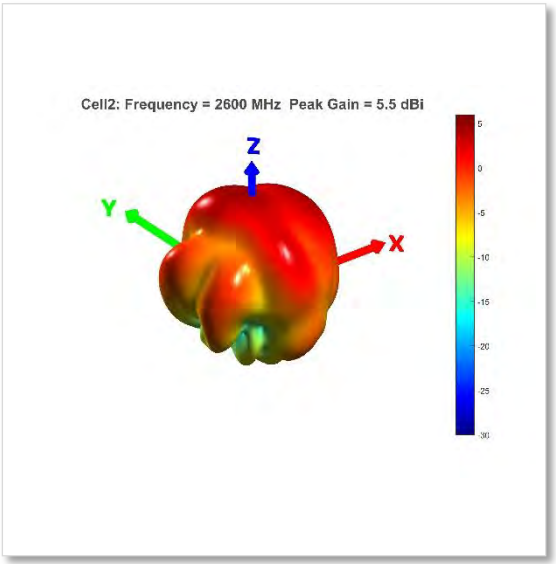
3D Gain Pattern and Heatmap: Cell 2 at 2600 MHz





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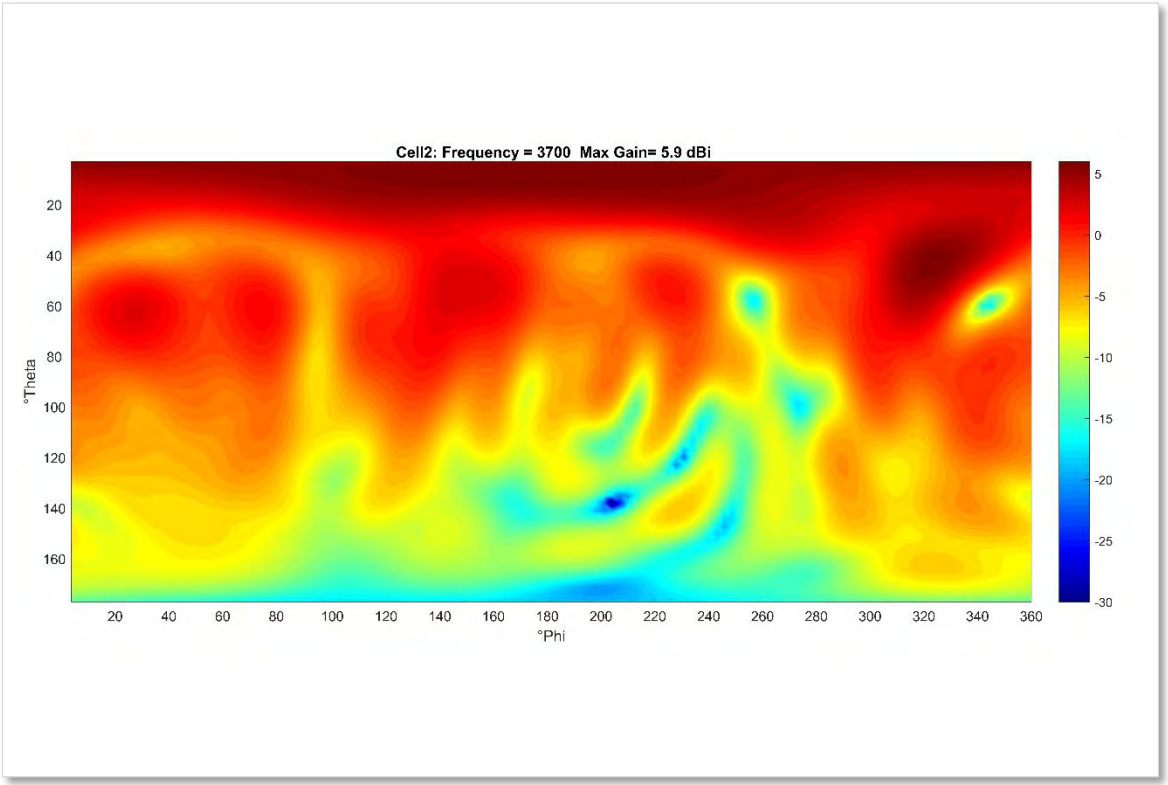
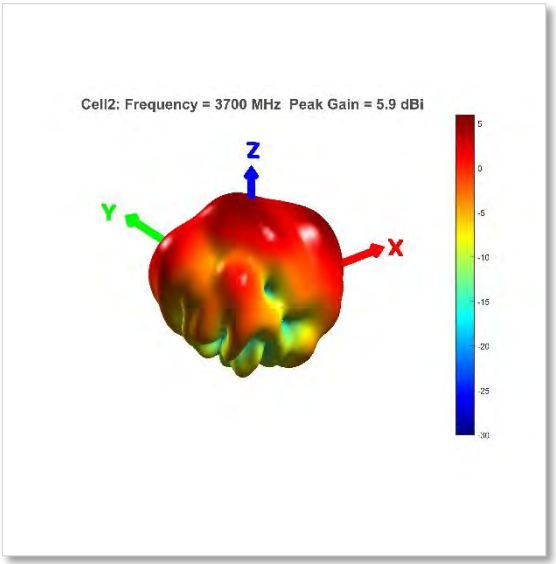
3D Gain Pattern and Heatmap: Cell 2 at 3700 MHz





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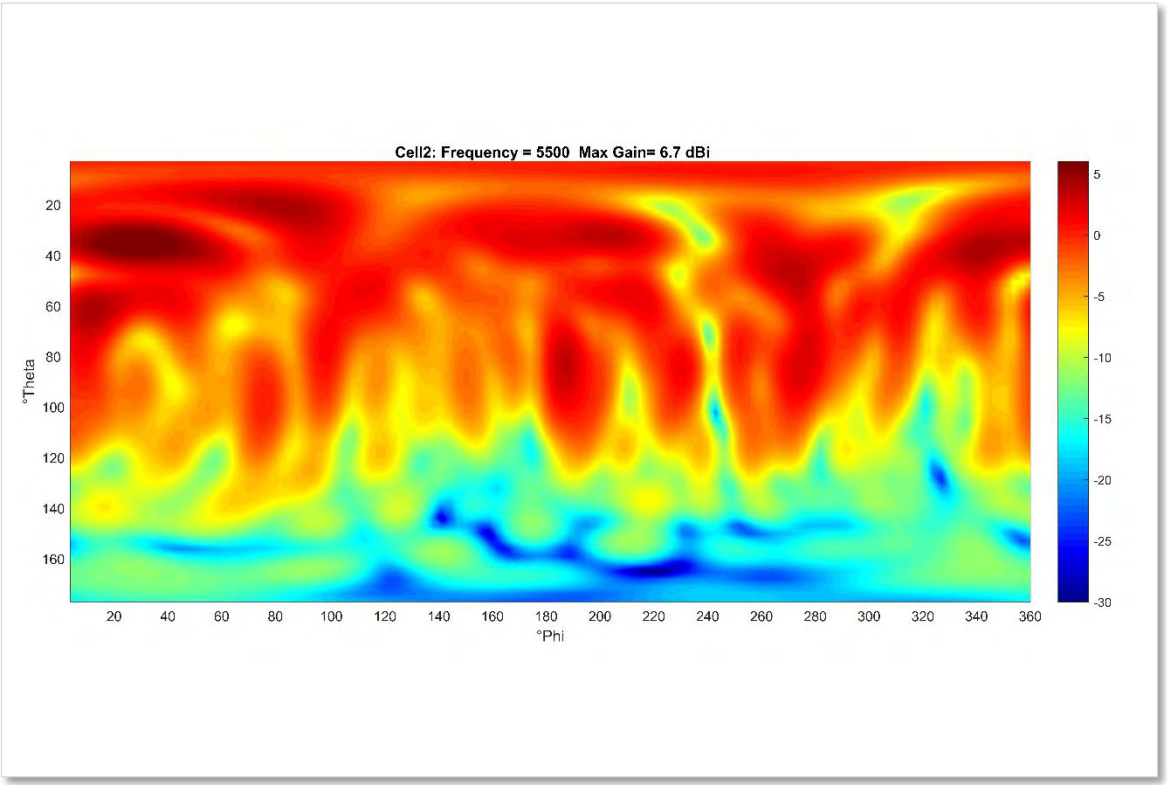
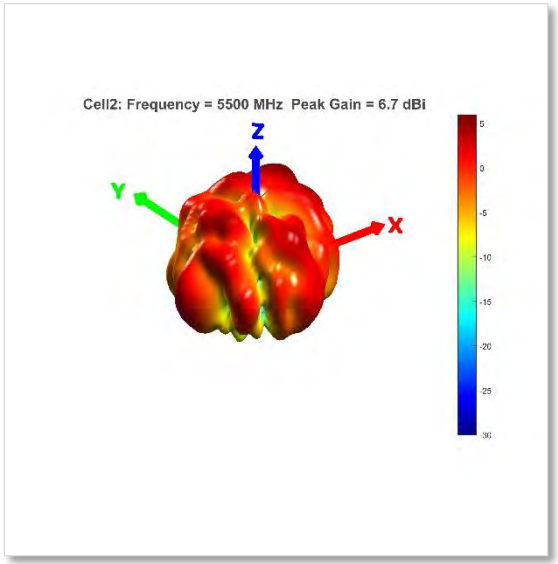
3D Gain Pattern and Heatmap: Cell 2 at 5500 MHz





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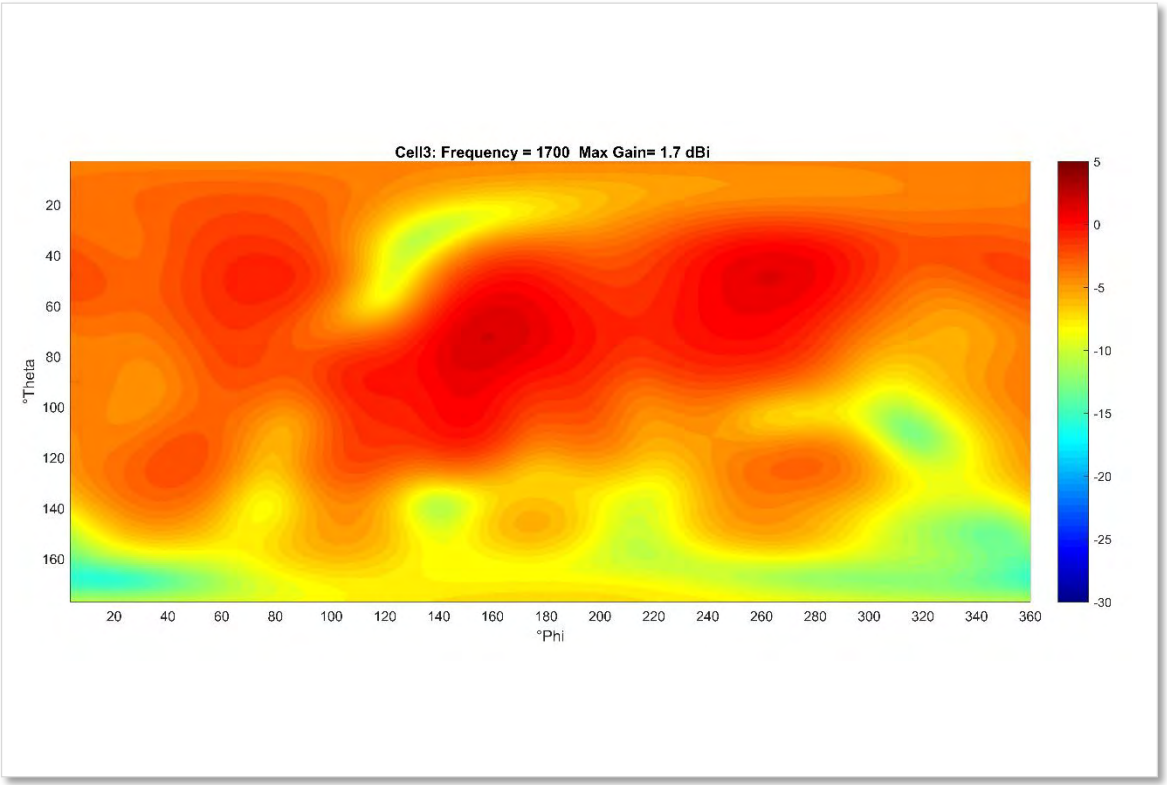
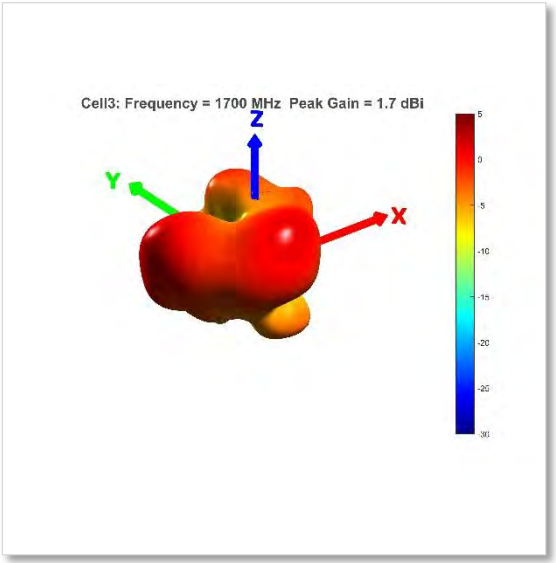
3D Gain Pattern and Heatmap: Cell 3 at 1700 MHz





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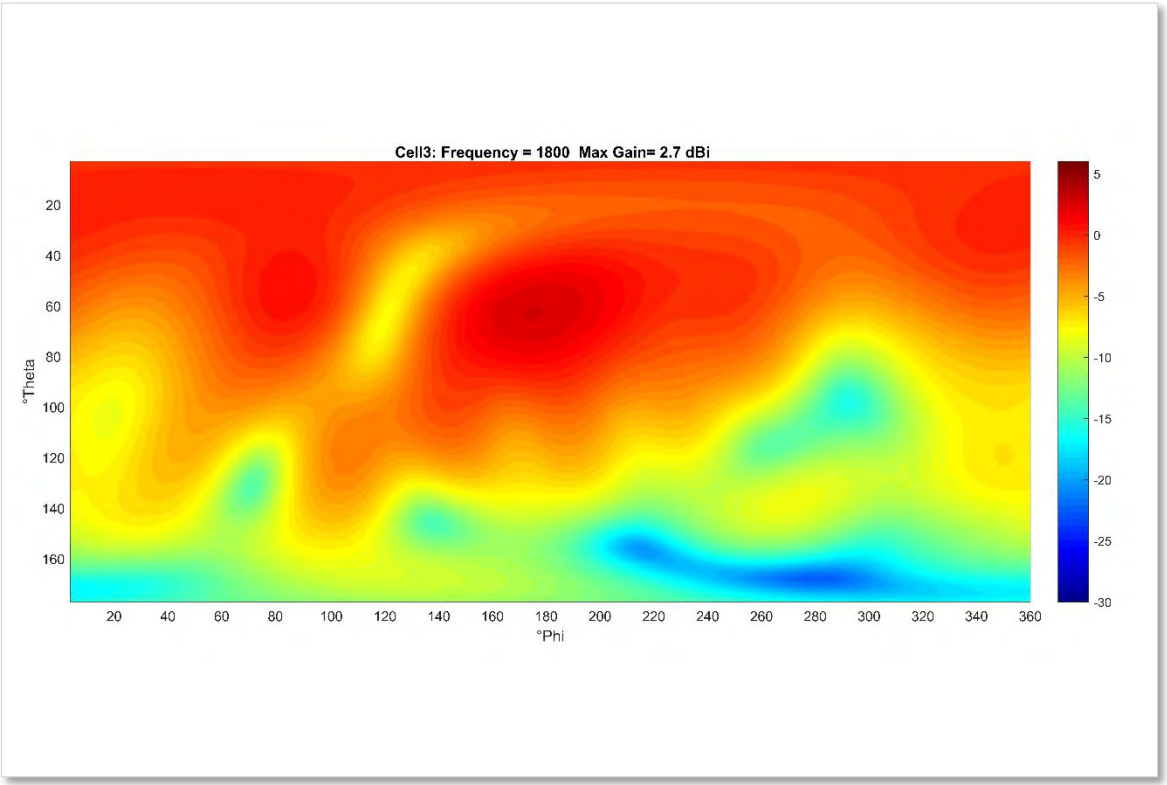
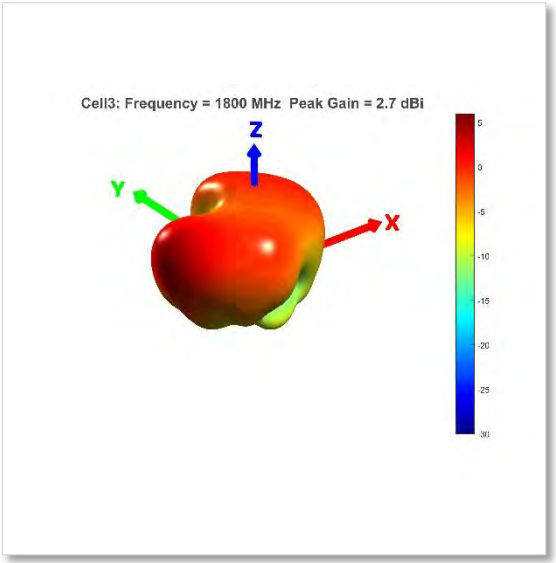
3D Gain Pattern and Heatmap: Cell 3 at 1800 MHz





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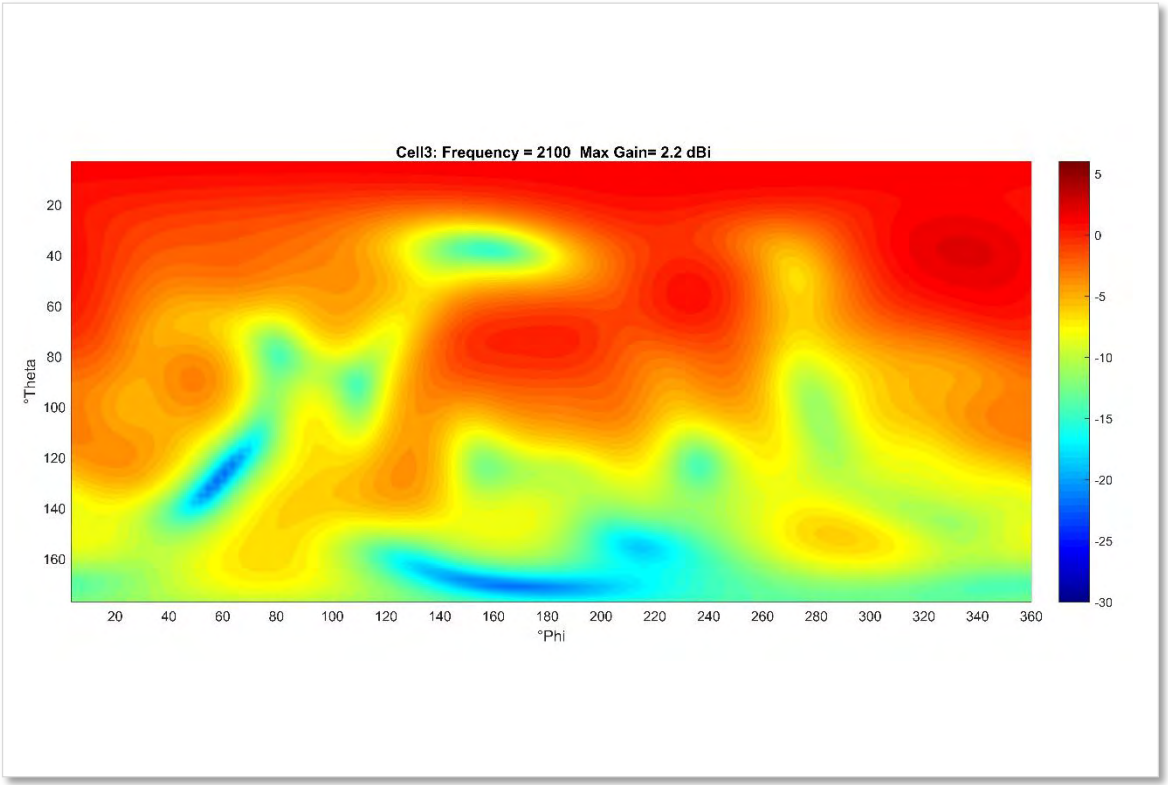
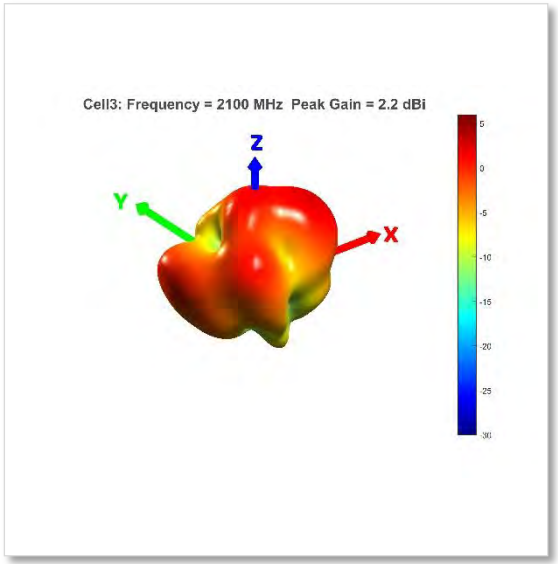
3D Gain Pattern and Heatmap: Cell 3 at 2100 MHz





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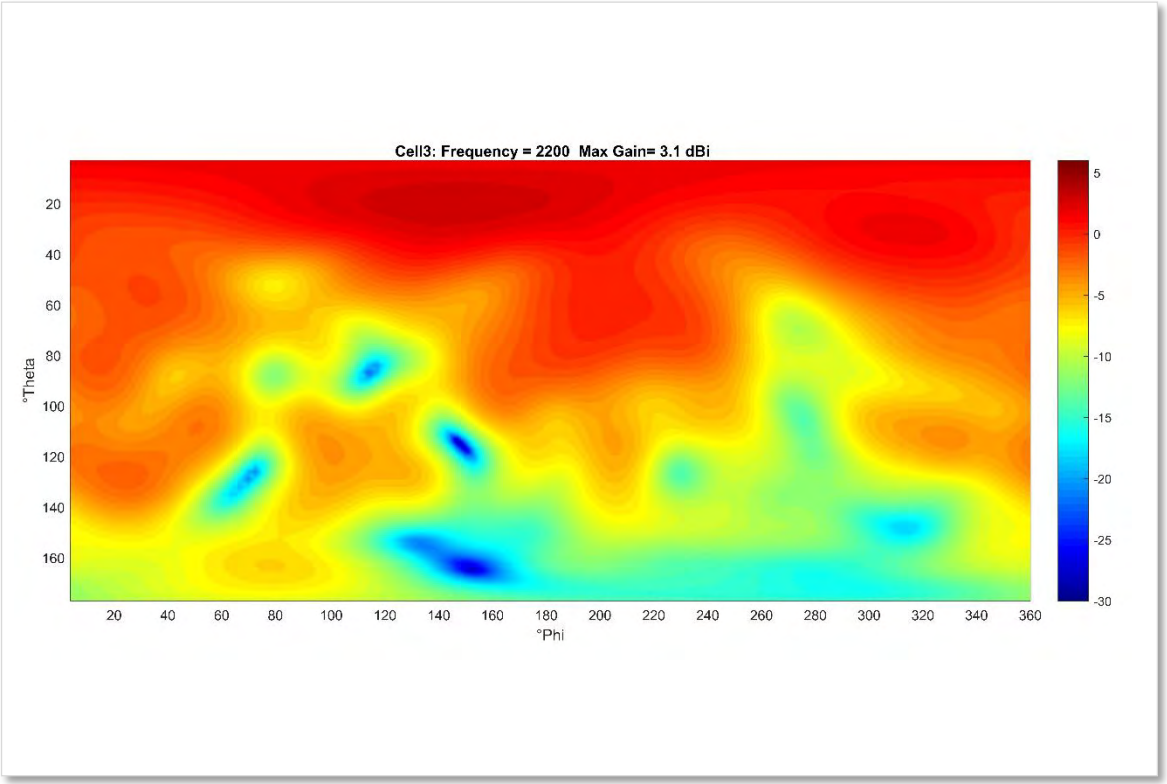
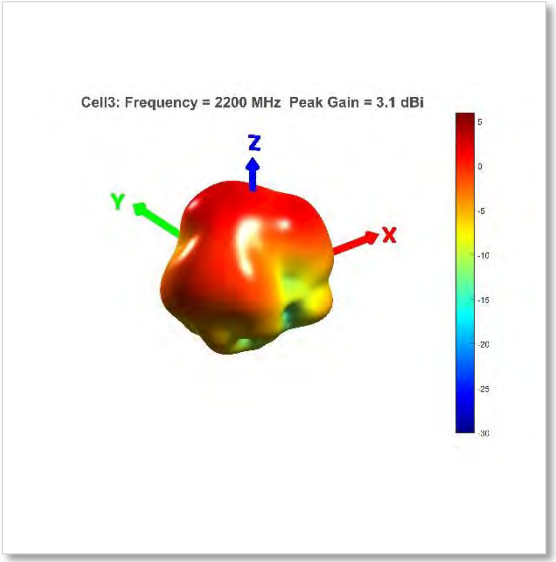
3D Gain Pattern and Heatmap: Cell 3 at 2200 MHz





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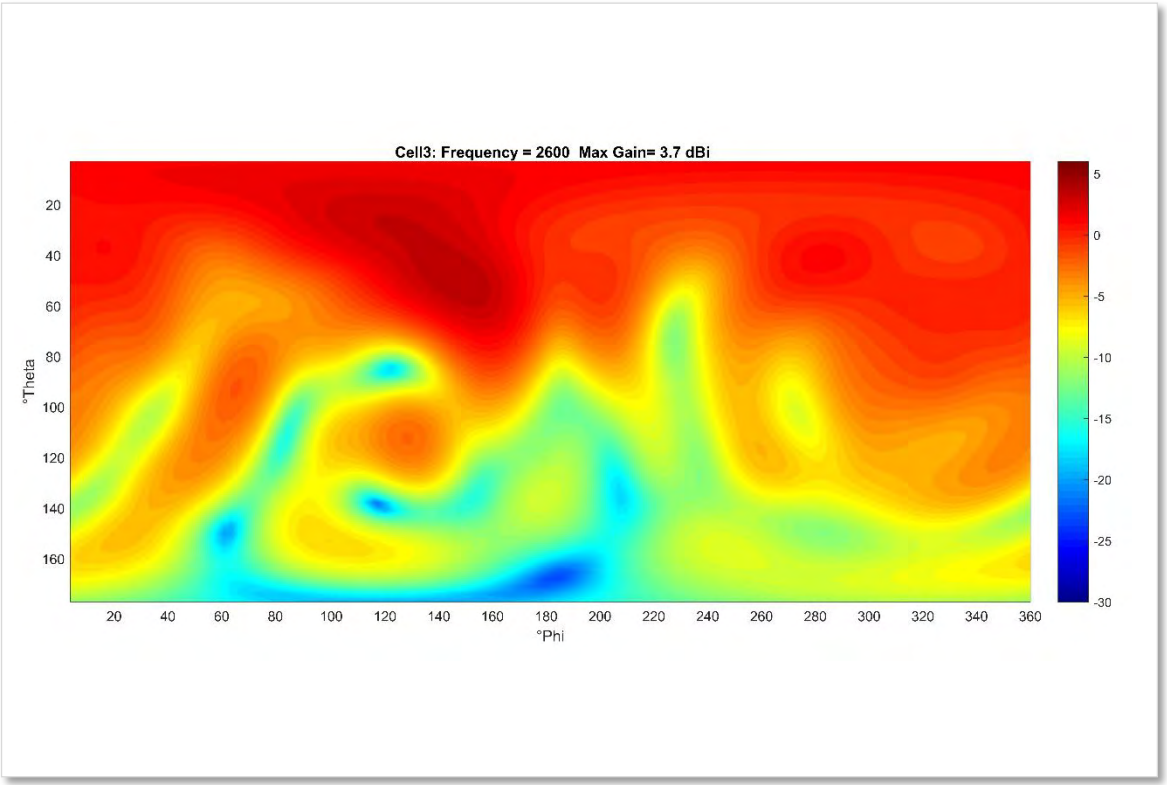
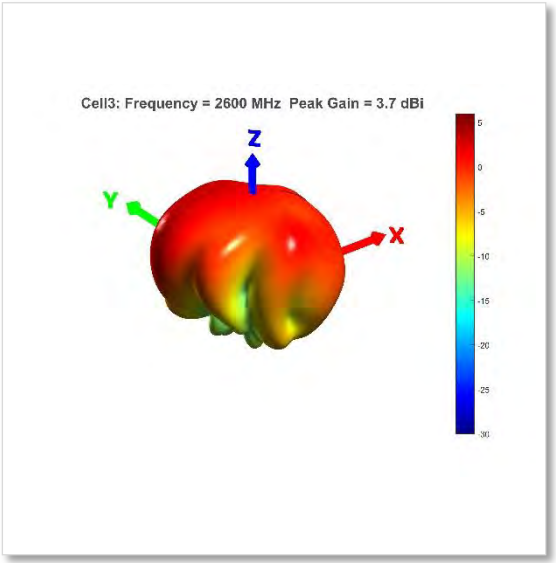
3D Gain Pattern and Heatmap: Cell 3 at 2600 MHz





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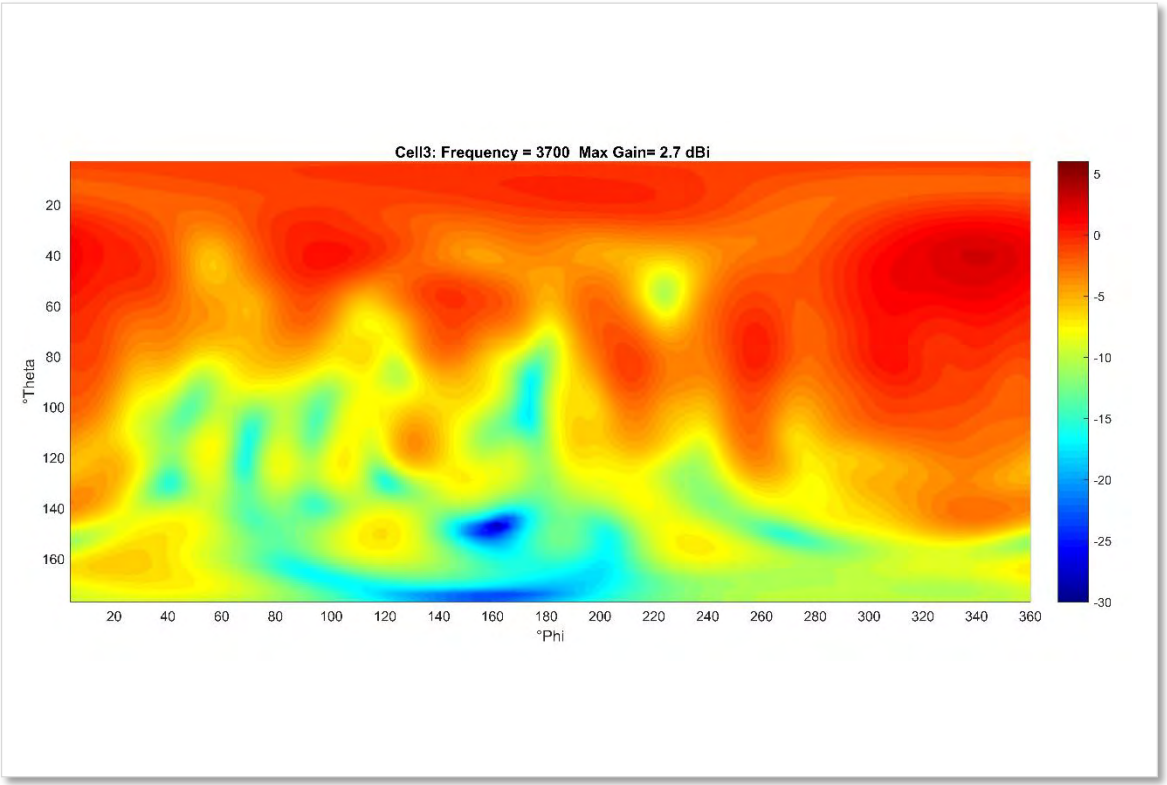
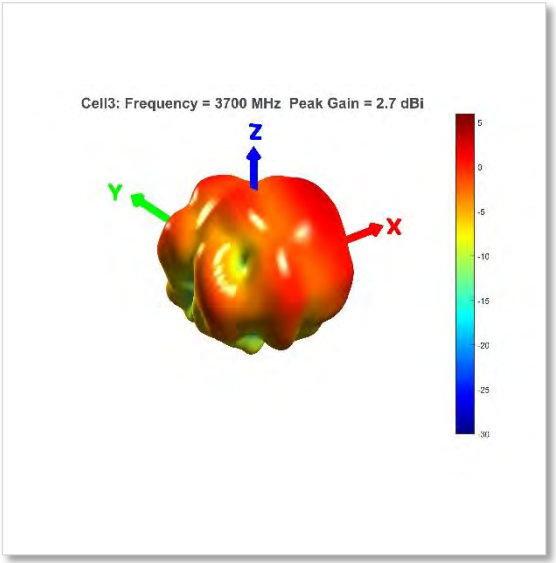
3D Gain Pattern and Heatmap: Cell 3 at 3700 MHz





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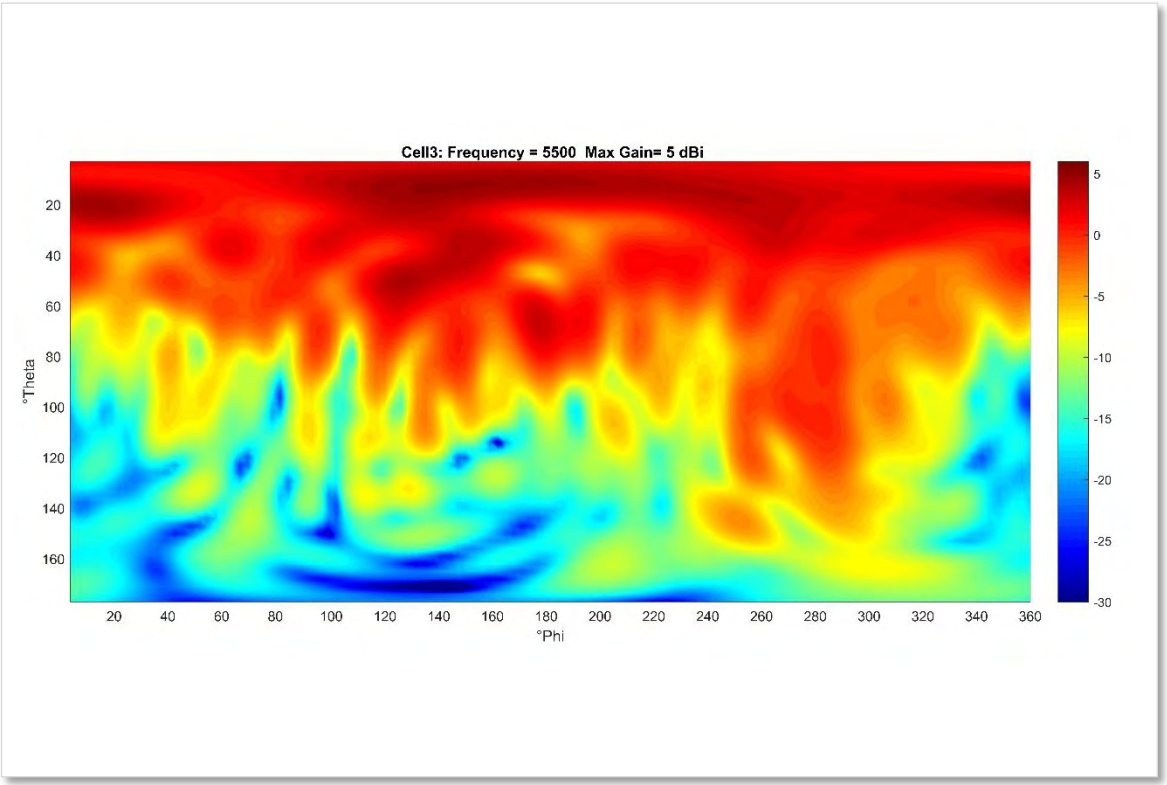
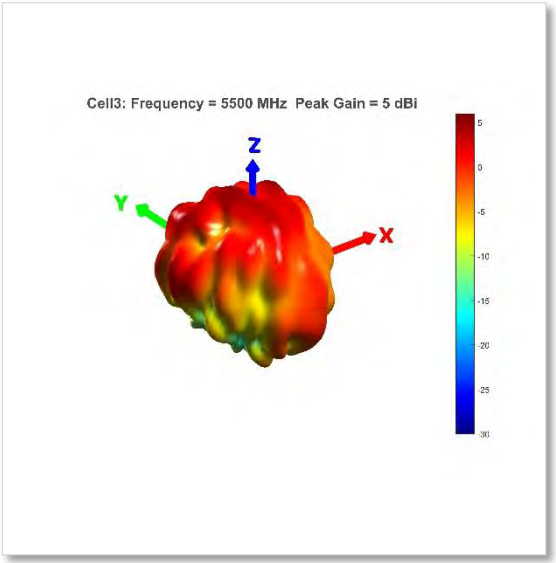
3D Gain Pattern and Heatmap: Cell 3 at 5500 MHz





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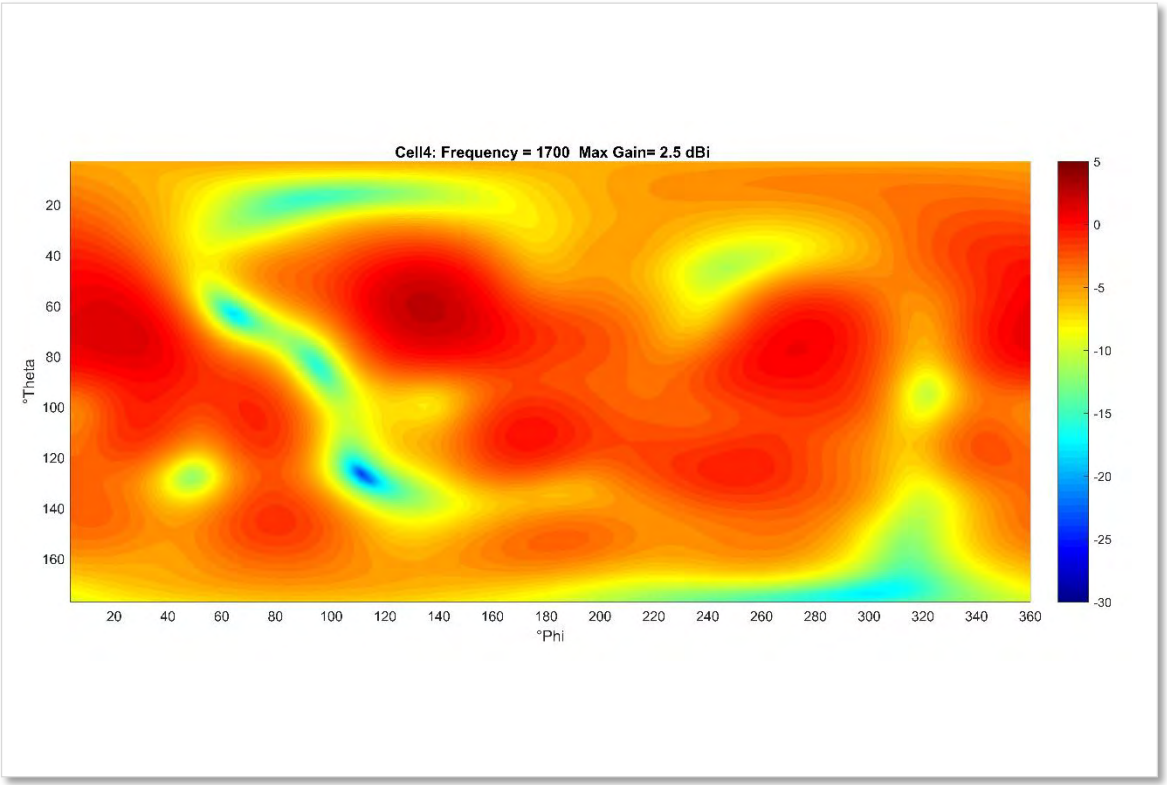
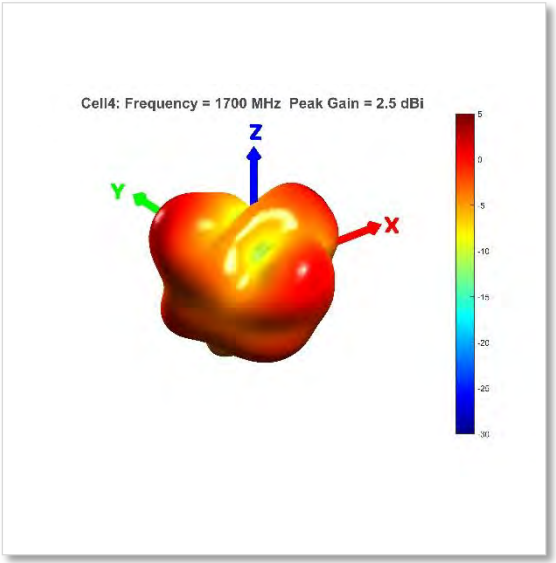
3D Gain Pattern and Heatmap: Cell 4 at 1700 MHz





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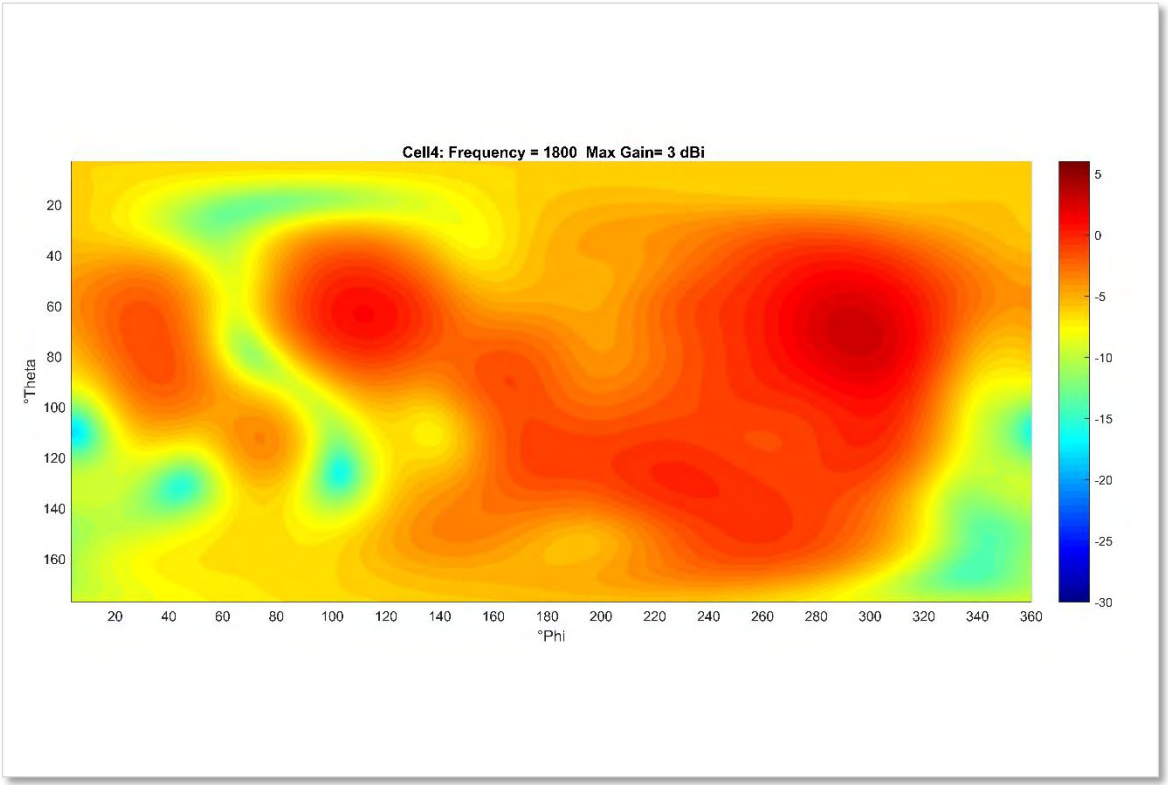
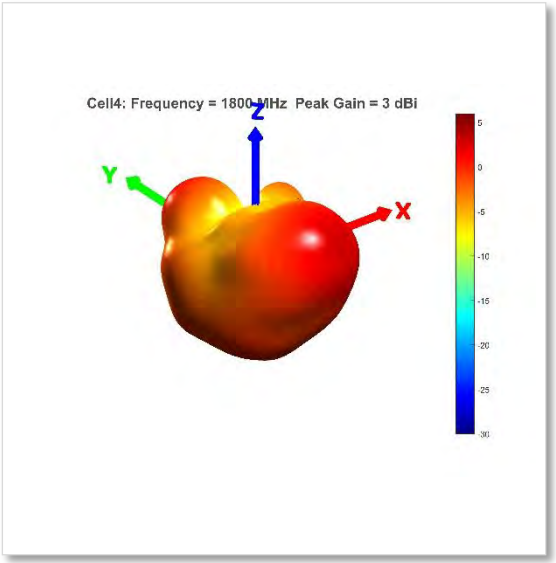
3D Gain Pattern and Heatmap: Cell 4 at 1800 MHz





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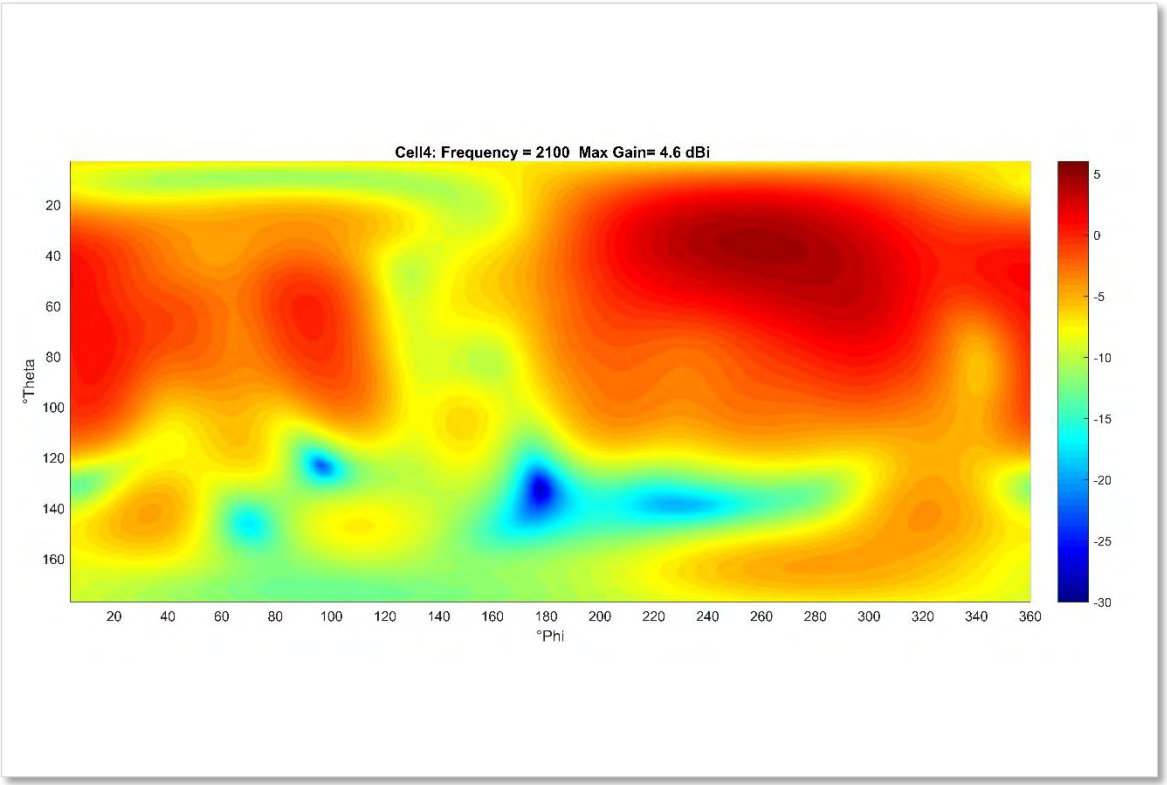
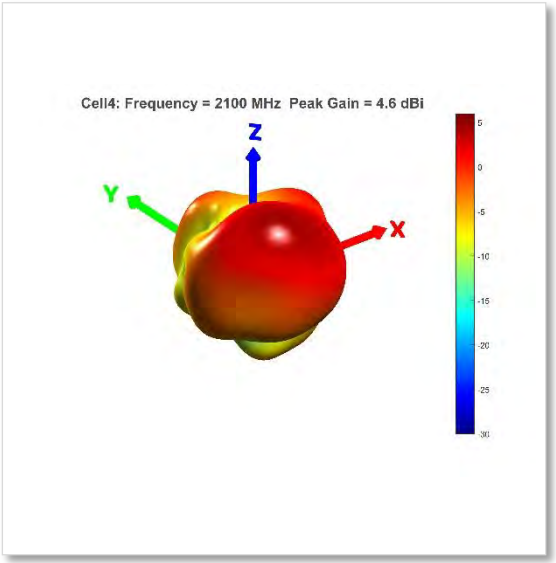
3D Gain Pattern and Heatmap: Cell 4 at 2100 MHz





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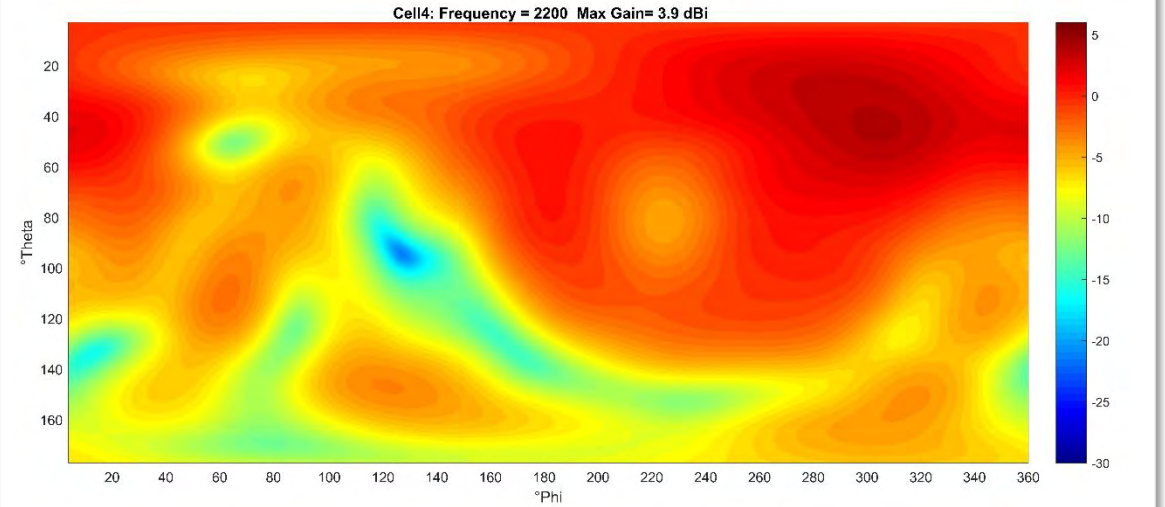
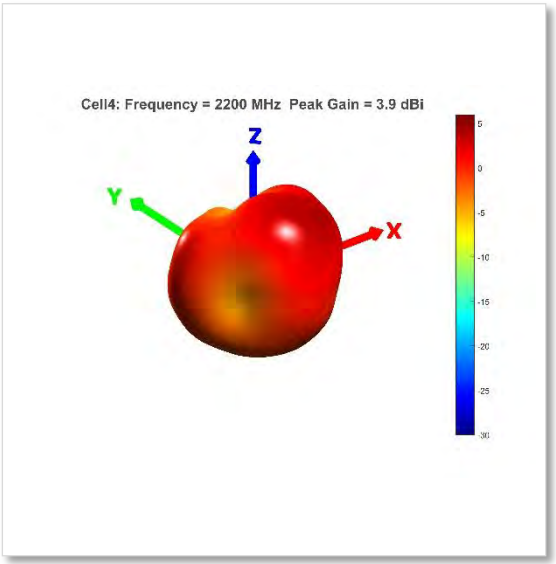
3D Gain Pattern and Heatmap: Cell 4 at 2200 MHz





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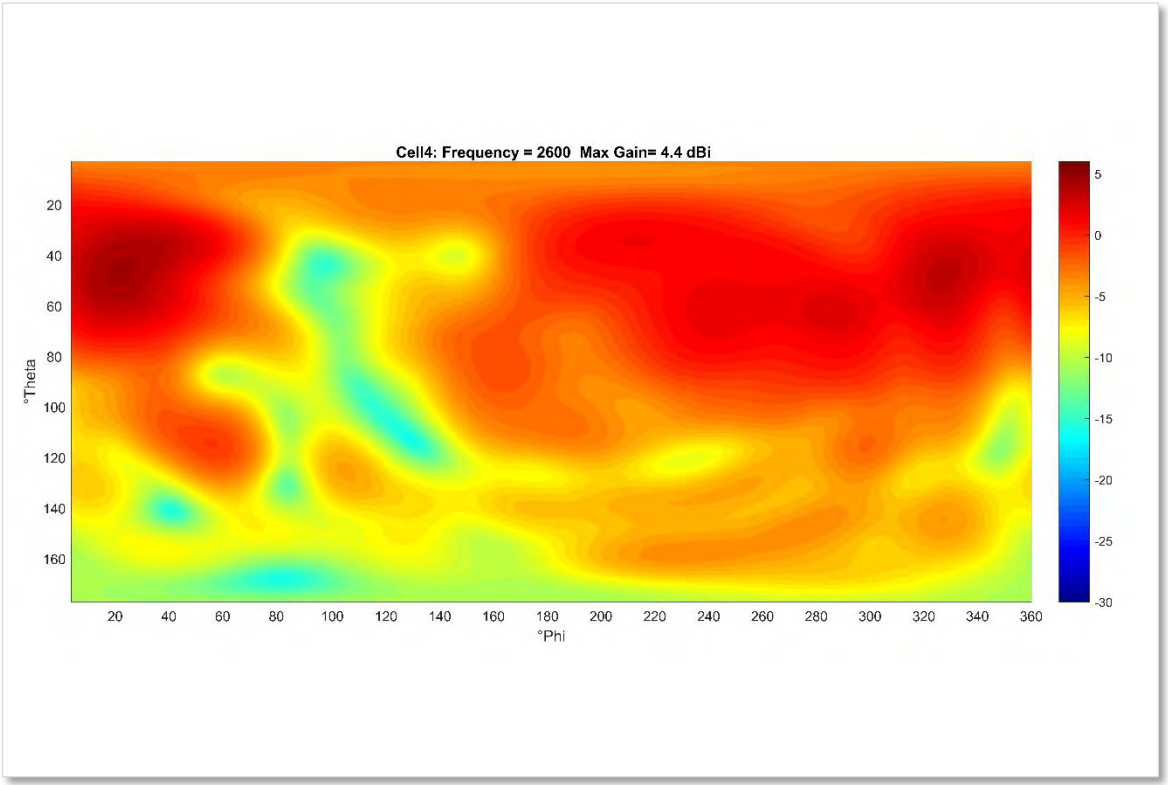
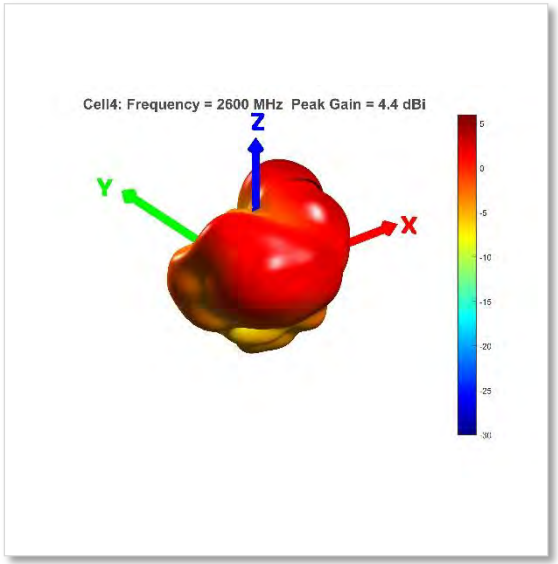
3D Gain Pattern and Heatmap: Cell 4 at 2600 MHz





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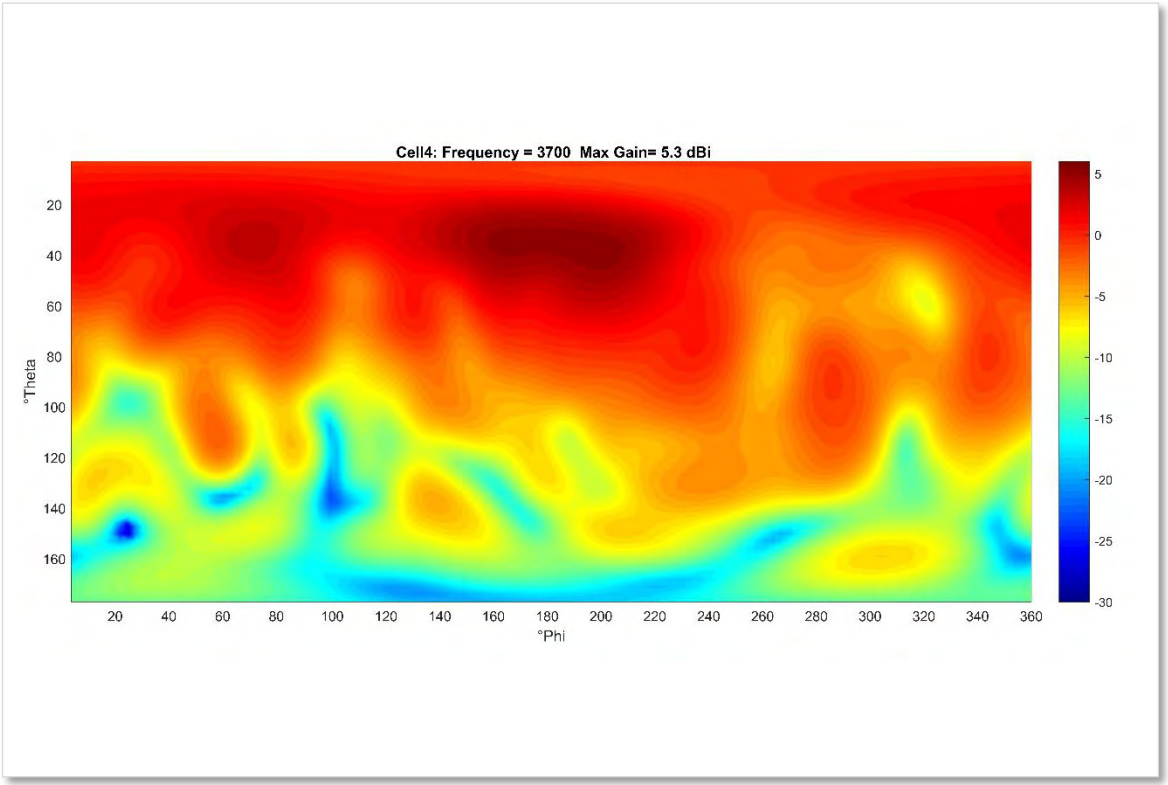
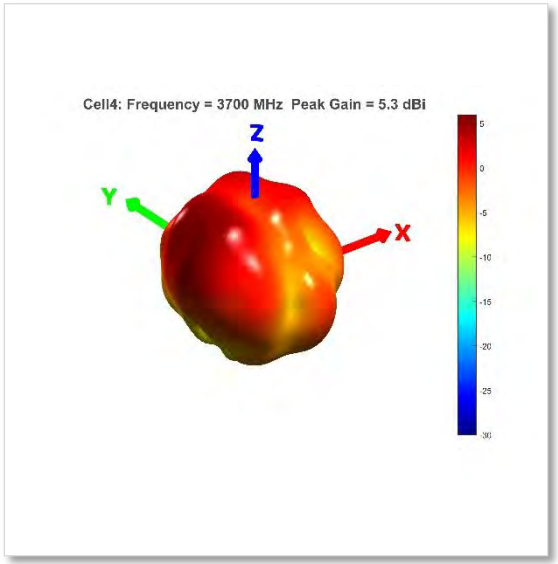
3D Gain Pattern and Heatmap: Cell 4 at 3700 MHz





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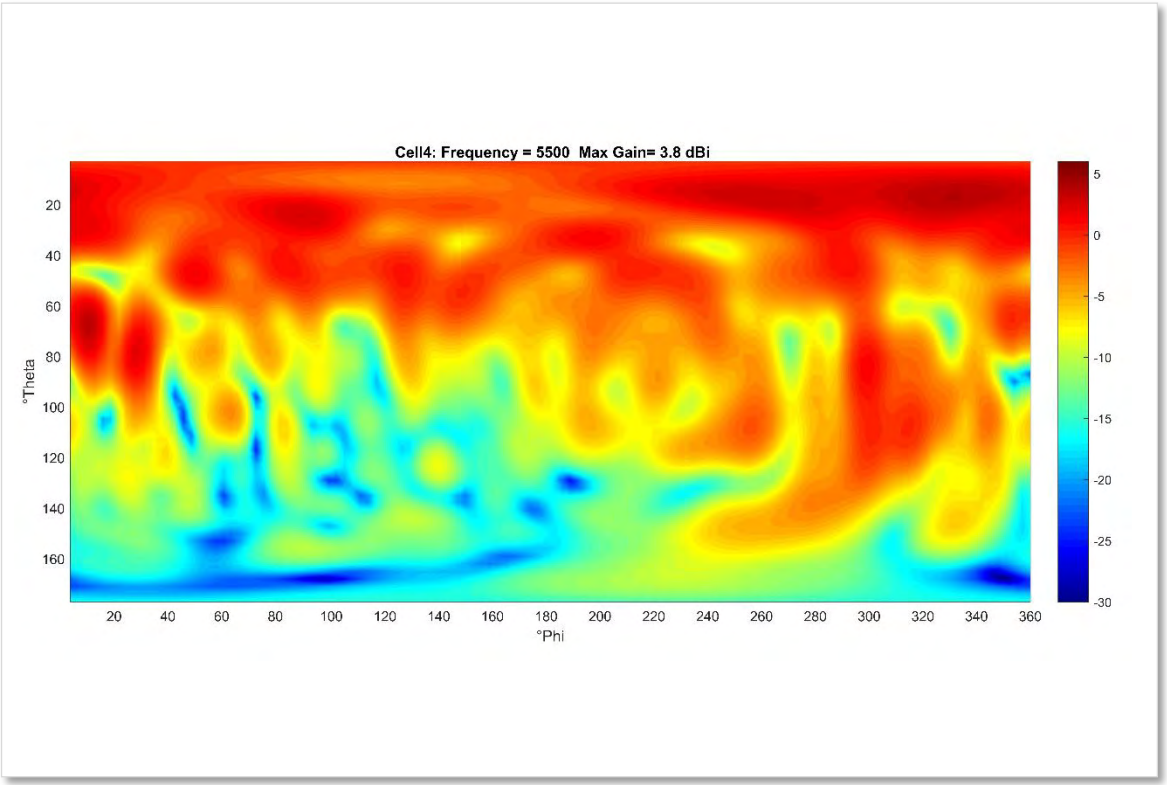
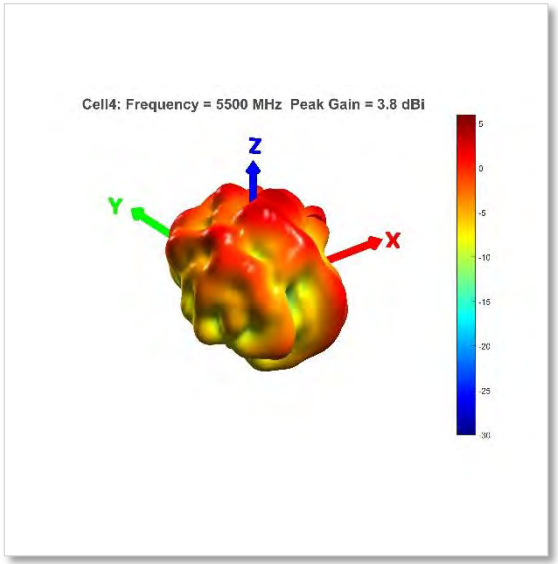
3D Gain Pattern and Heatmap: Cell 4 at 5500 MHz





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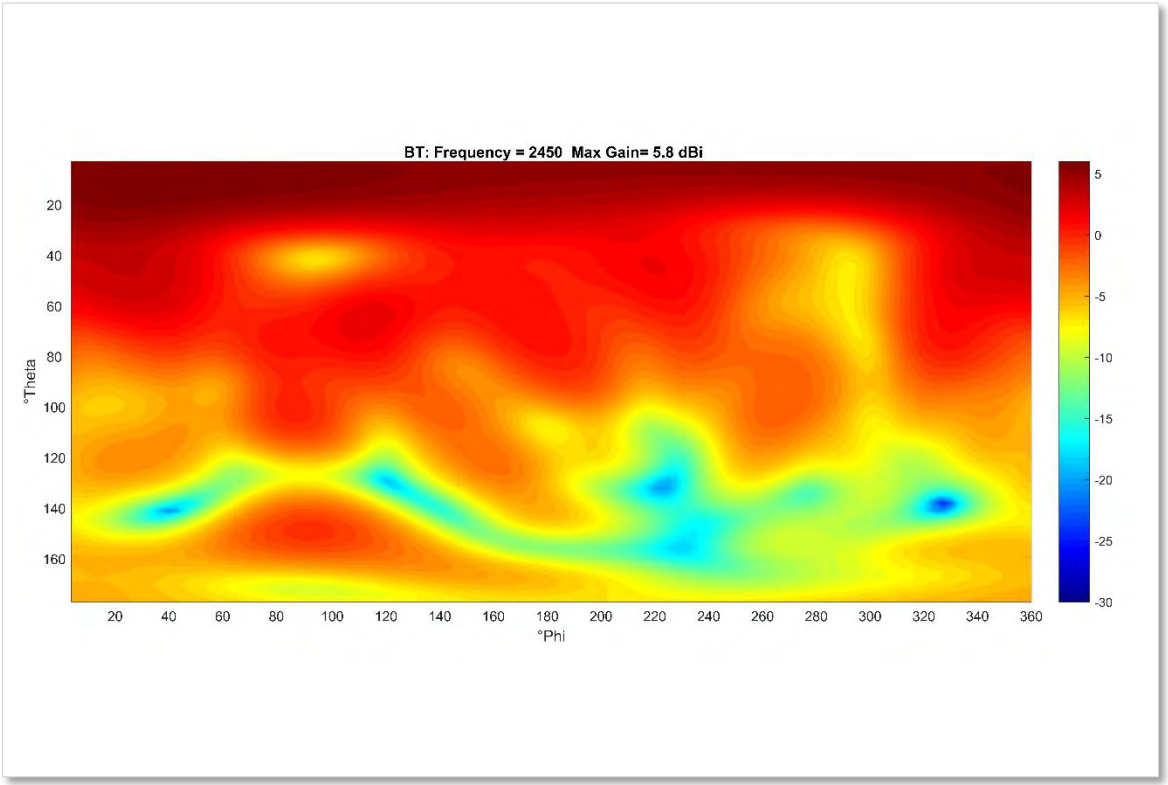
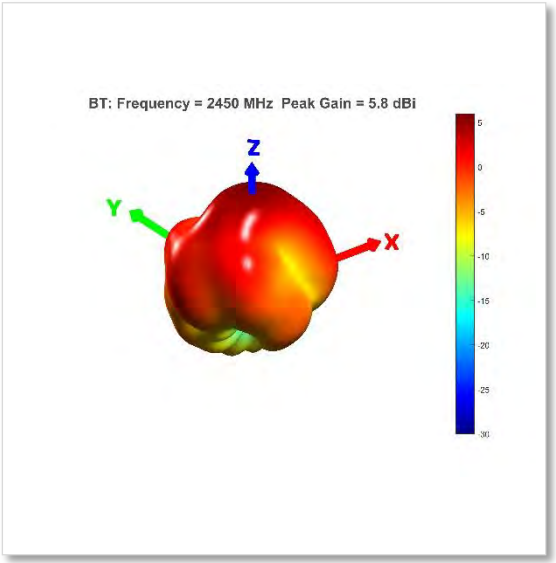
3D Gain Pattern and Heatmap: Bluetooth at 2450 MHz





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