Miniature Helical PCB Antenna for 868 MHz or 915/920 MHz

By Richard Wallace

Keywords

- *Miniature Helical PCB Antenna*
- *Optimized for compact designs*
- *868 or 915/920 MHz ISM Bands*
- *CC11xx*
- *CC12xx*

1 Introduction

This document describes a compact PCB helical antenna that has been specifically designed for 868 MHz or 915/920 MHz ISM bands.

The PCB helical antenna requires two matching components for matching to a 50-ohm load.

When a large PCB area (38 mm x 24 mm) is available for the antenna then the recommended antenna is DN024 [1] since the impedance is closer to 50 ohm without any external matching components (868 MHz: 30+j11; VSWR 1.8) and the bandwidth is around 90 MHz.

The miniature PCB helical antenna is more compact (19 mm x 11 mm) with approximately quarter of the size of the DN024 [1] but requires matching components since the impedance is far from 50 ohms (868 MHz: 10-j88; VSWR 22).

When the miniature helical antenna is matched then the bandwidth is around 40 MHz and has similar efficiency as DN024 [1] antenna when measured on the TRXEB platform.

All measurement results presented in this document are based on measurements performed on the CC110L EM Rev 1.0 Reference Design [3], shown in Figure 1.

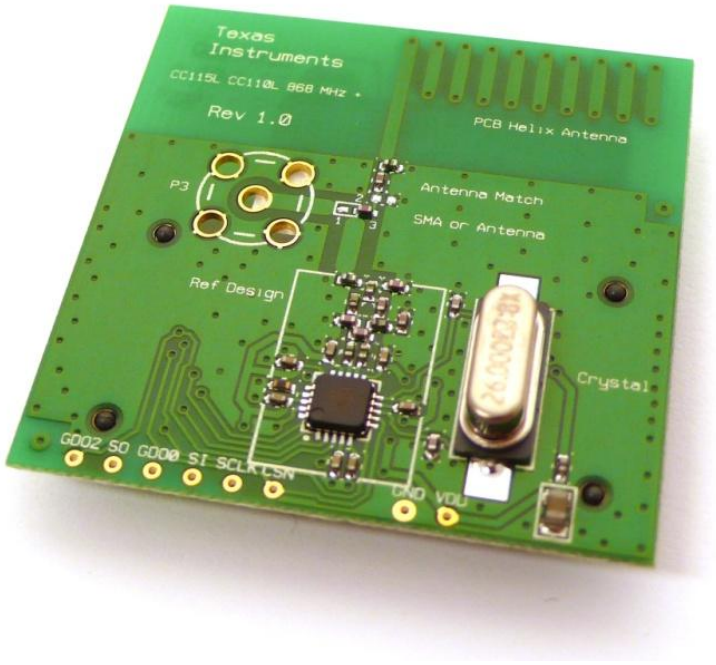

Figure 1. CC110L EM 868 / 915 MHz

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2 Abbreviations

ANT	Antenna
CTIA	Cellular Telephone Industry Association
DC	Direct Current
EM	Evaluation Module
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FR4	Material type used for producing PCB
ISM	Industrial, Scientific, Medical
NM	Not Mounted
OTA	Over The Air
PCB	Printed Circuit Board
SRD	Short Range Devices
TRP	Total Radiated Power
TRXEB	Evaluation Board

3 Antenna Design

3.1 Physical Dimensions

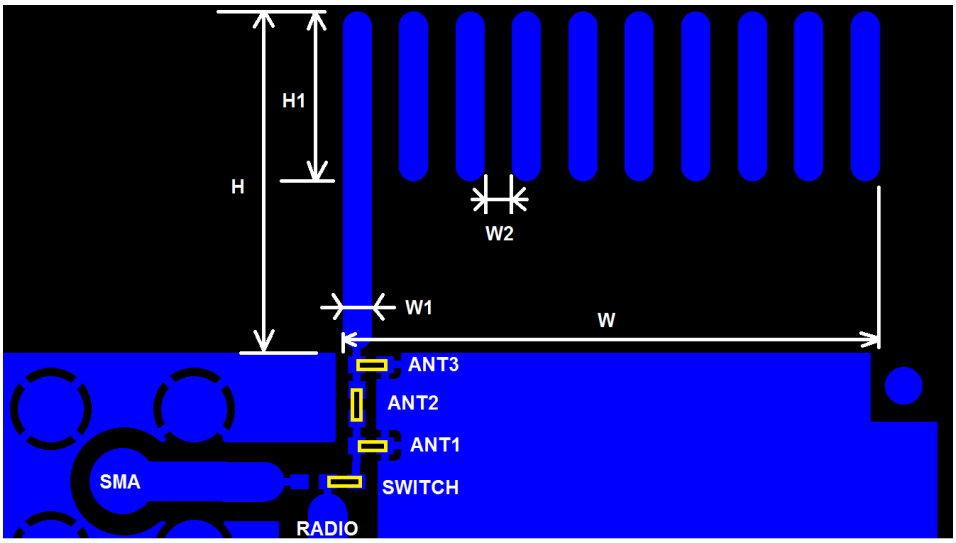

Figure 2. Top Layer Layout

Figure 3. Zoom of Top and Bottom Layer Layout with Via Markings

Dimension	H	H1	H2	W	W1	W2	Via dia
	12 mm	6 mm	0.5 mm	19 mm	1 mm	1 mm	0.38 mm

Table 1. Antenna Dimensions

Top layer is shown in blue and the bottom layer is shown in red for Figure 2 and Figure 3. The "X" markers indicate via positions which route between the top and bottom layers.

PCB board thickness for the CC110L EM 868 / 915 MHz reference design [3] is 0.8 mm. Another PCB thickness can be used but then the antenna match must be re-calculated.

Dimensions for the antenna can be found in Table 1 and the gerbers for the antenna design are also available for 868/915 MHz [3]

3.2 Antenna Match Network

There are several ways to tune an antenna to achieve better performance. For resonant antennas the main factor is the length. Ideally the frequency which gives least reflection should be in the middle of the frequency band of interest. Thus if the resonance frequency is too low, the antenna should be made shorter. If the resonance frequency is too high, the antenna length should be increased.

Even if the antenna resonates at the correct frequency it might not be well matched to the correct impedance. Size of ground plane, distance from antenna to ground plane, dimensions of antenna elements, feed point and plastic casing are factors that can affect the impedance.

Since the impedance will change depending on several parameters; with a pi-network as illustrated in Figure 4, the antenna match can always be restored to a 50 ohm match. Only two of the components (ANT2 + (ANT1 or ANT3)) are required to match the impedance to 50 ohm depending on the start impedance. For the PCB helical antenna at 868 / 915 MHz, only ANT2 and ANT3 are required.

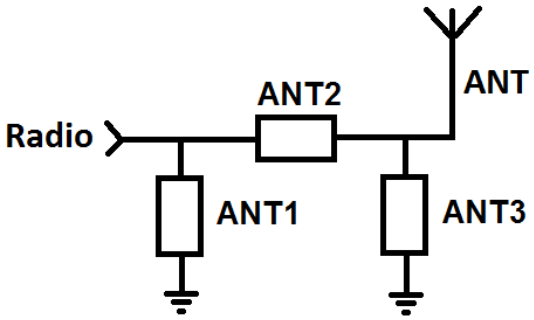

Figure 4. Antenna Match Network

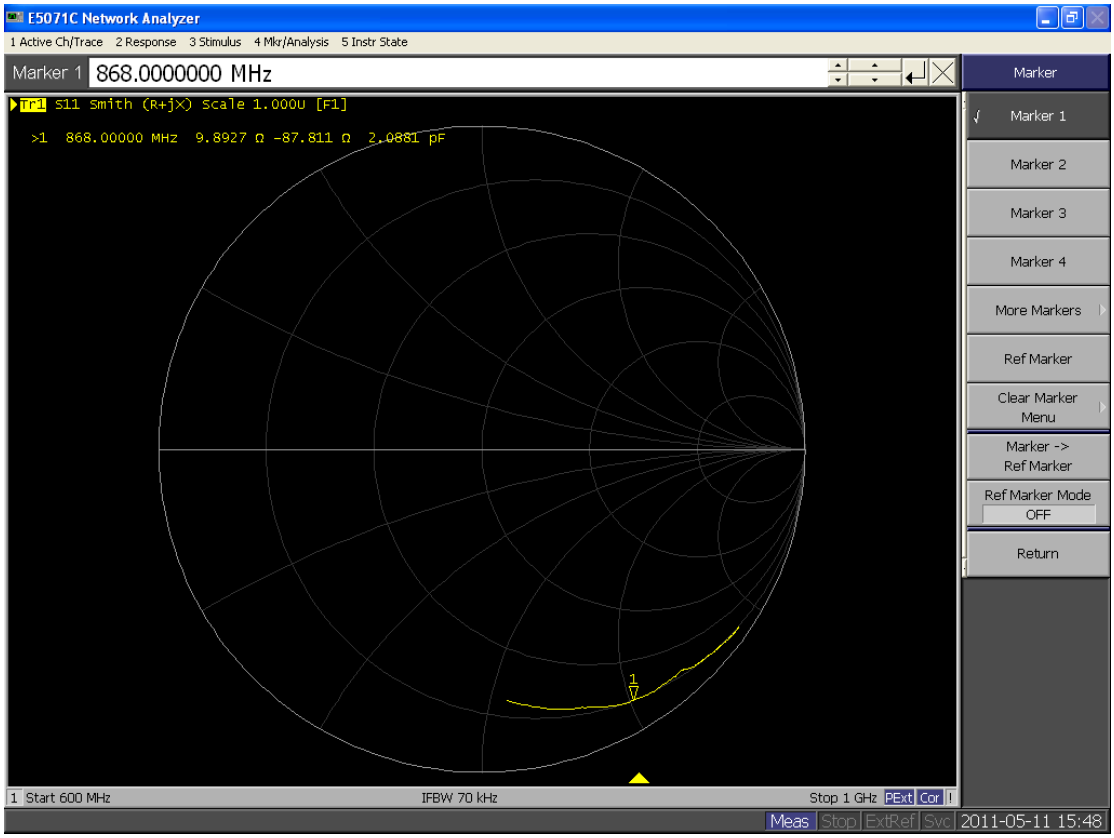

Figure 5. Start Impedance with 0-ohm (ANT2) Resistor in Antenna Match

The impedance of the PCB helical antenna is far from 50 ohm without the antenna matching network so the matching network acts as a load and matching network for the antenna. The impedance of the antenna can be seen in Figure 5 when ANT2 is set to 0 ohm.

Figure 6 shows the theoretical load and match to at 868 MHz. The Smith diagram shows a shunt component of 11.4 nH (ANT3) and a series capacitor of 1.0 pF (ANT2). ANT1 component is not required and can be left open. 11.4 nH value does not exist so a 12 nH is used instead.

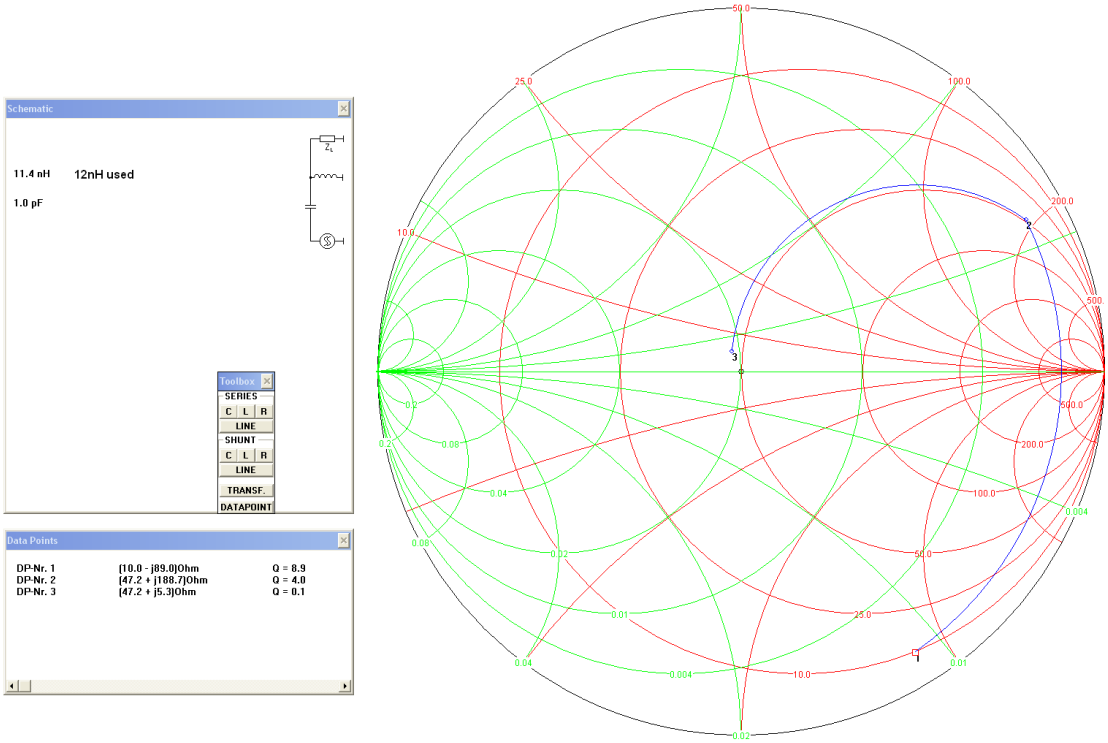

Figure 6. Theoretical Antenna Match

Assembling ANT2 (1.0 pF) and ANT3 (12 nH) based on the theoretical calculated match, then the impedance can be re-measured and a good match is measured and can be seen in Figure 7.

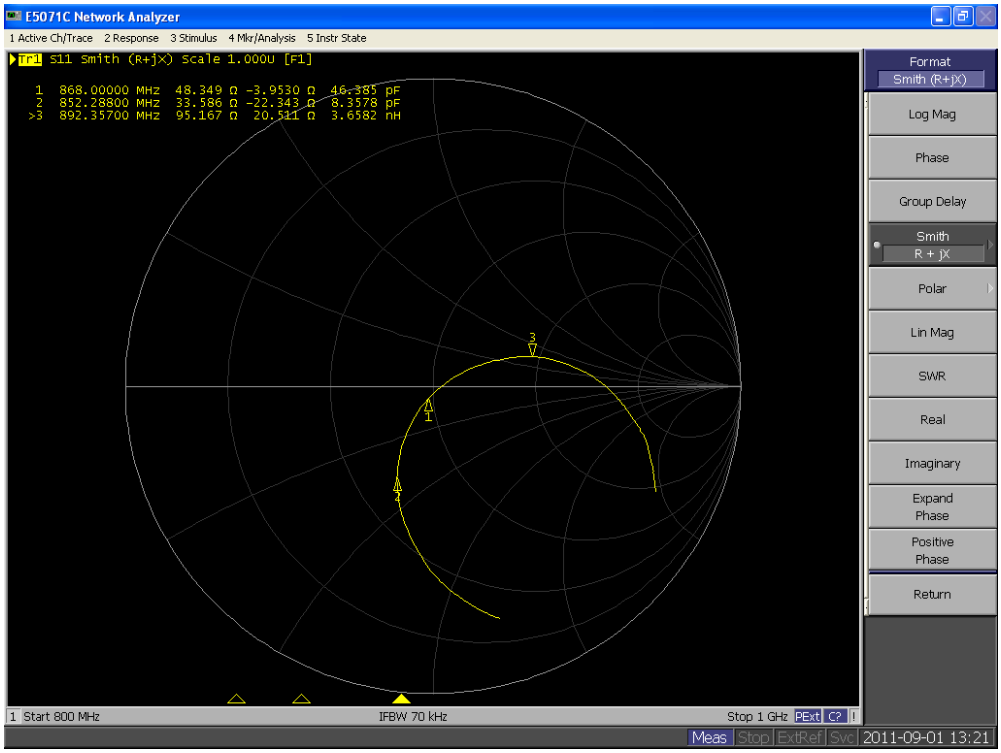

Figure 7. With Antenna Match Components - ANT2: 1.0 pF and ANT3: 12 nH

3.3 Antenna Bandwidth Measurement

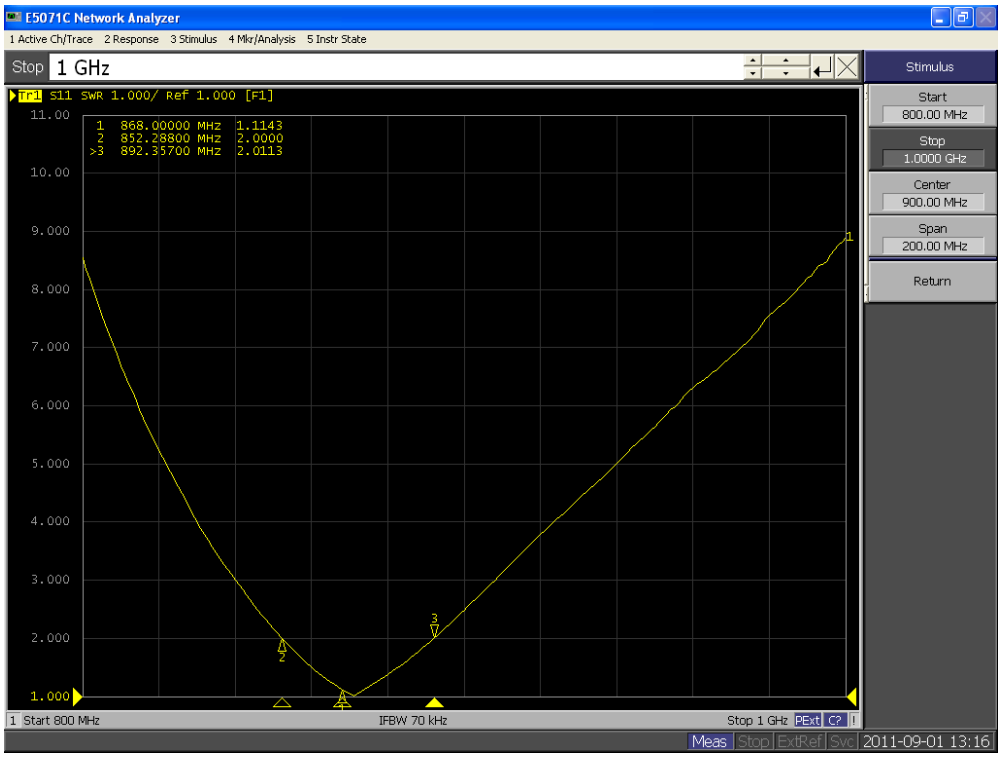

Figure 8. Bandwidth Measurement at VSWR 2

As can be seen from Figure 8, the bandwidth is 40 MHz with a VSWR 2 and 68 MHz with a VSWR 3.

3.4 Antenna OTA Measurement

The conducted output power from the radio is 0 dBm and the results shown in section 3.4.1 show the performance of the antenna of the CC110L EM 868 / 915 MHz on the TRXEB platform.

3.4.1 868 MHz OTA Measurement Summary

Total Radiated Power	**-1.83 dBm**
Peak EIRP	**2.33 dBm**
Directivity	4.16 dBi
Efficiency	-1.83 dB
Efficiency	**65.55 %**
Gain	2.33 dBi
NHPRP 45°	-4.06 dBm
NHPRP 45° / TRP	-2.23 dB
NHPRP 45° / TRP	59.86 %
NHPRP 30°	-5.89 dBm
NHPRP 30° / TRP	-4.05 dB
NHPRP 30° / TRP	39.32 %
NHPRP 22.5°	-7.26 dBm
NHPRP 22.5° / TRP	-5.42 dB
NHPRP 22.5° / TRP	28.69 %
UHRP	-4.91 dBm
UHRP / TRP	-3.07 dB
UHRP / TRP	49.28 %

LHRP	-4.78 dBm
LHRP / TRP	-2.95 dB
LHRP / TRP	50.72 %
Front/Back Ratio	2.52
PhiBW	332.2 deg
PhiBW Up	238.7 deg
PhiBW Down	93.4 deg
ThetaBW	82.9 deg
ThetaBW Up	46.3 deg
ThetaBW Down	36.6 deg
Boresight Phi	90 deg
Boresight Theta	15 deg
Maximum Power	2.33 dBm
Minimum Power	-12.00 dBm
Average Power	-0.91 dBm
Max/Min Ratio	14.33 dB
Max/Avg Ratio	3.24 dB
Min/Avg Ratio	-11.10 dB
Best Single Value	1.11 dBm
Best Position	Phi = 45 deg; Theta = 165 deg; Pol = Ver

For the full CTIA report including 3D radiated plots at 868 MHz please refer to section 7.1.

The antenna was also measured at 915 MHz to show the performance degradation whilst keeping the same matching network at 868 MHz; this is shown in section 7.2. For optimum performance at 915 MHz, the antenna needs to be re-matched at this frequency.

For the Over-The-Air (OTA) Measurements performed in the chamber, please refer to Figure 9 for coordinate correlation to the CTIA reports.

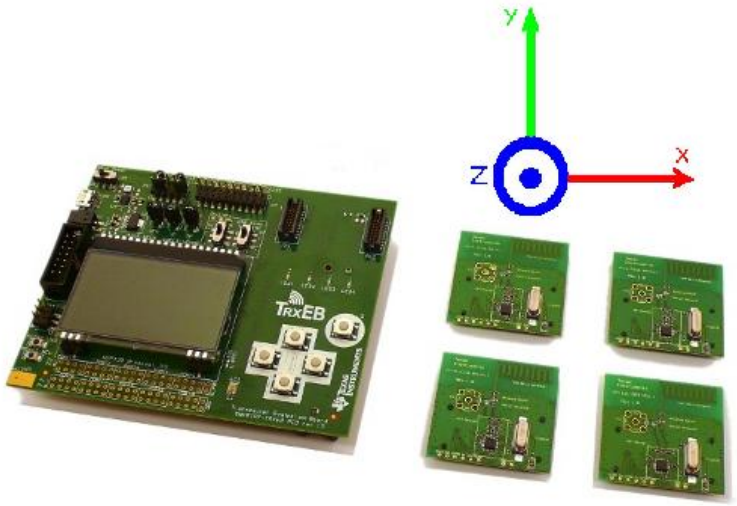

Figure 9. Coordinates Correlation to CTIA OTA Reports

4 Conclusion

When a large PCB area (38 mm x 24 mm) is available for the antenna then the recommended antenna is DN024 [1] since the impedance is closer to 50 ohm without any external matching components (868 MHz: 30+j11; VSWR 1.8) and the bandwidth is around 90 MHz.

When there is a need for a more compact antenna then the miniature PCB helical antenna is ideal (19 mm x 11 mm) with approximately quarter of the DN024 antenna size [1] but requires matching components since the impedance is far from 50 ohms (868 MHz: 10-j88; VSWR 22). It is important to match this antenna since the match network is also used for loading the antenna to 868 MHz or 915 / 920 MHz.

When the miniature helical antenna is matched then the bandwidth is around 40 MHz and has similar efficiency as DN024 [1] antenna when measured on the TRXEB platform.

A single match network can be used for 868 MHz and 915 / 920 MHz but due to the reduce bandwidth compared to DN024 antenna [1] then there will be some degradation in performance. For the antenna matching network components it is recommended to use tight tolerance components.

Optimal antenna match for the CC110L EM 868 / 915 MHz reference design [3] is a series 1.0 pF capacitor (ANT2) and a shunt inductor of 12 nH (ANT3) for 868 MHz operation.

The PCB board thickness for the CC110L EM 868 / 915 MHz reference design [3] is 0.8 mm. The same match has been tested at 1.24 mm thick PCB and the performance was still good but generally if the PCB thickness is changed then the antenna match should be re-calculated.

5 References

[1] DN024 Monopole PCB Antenna (DN024)

[2] DN035 Antenna Quick Selection Guide (DN035)

[3] CC11xL EM 868/915 MHz Ref Design (swrr082)

[4] AN058 Antenna Measurement with Network Analyzer (AN058)

6 General Information

6.1 Document History

Revision	Date	Description/Changes
SWRA416	2012.11.27	Initial release.

7 Appendices

7.1 CTIA OTA Report – 868 MHz (Antenna matched at 868 MHz)

7.1.1 OTA Evaluation Results

Total Radiated Power	-1.83 dBm
Peak EIRP	2.33 dBm
Directivity	4.16 dBi
Efficiency	-1.83 dB
Efficiency	65.55 %
Gain	2.33 dBi
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LHRP	-4.78 dBm
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Front/Back Ratio	2.52
PhiBW	332.2 deg
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ThetaBW Down	36.6 deg
Boresight Phi	90 deg
Boresight Theta	15 deg
Maximum Power	2.33 dBm
Minimum Power	-12.00 dBm
Average Power	-0.91 dBm
Max/Min Ratio	14.33 dB
Max/Avg Ratio	3.24 dB
Min/Avg Ratio	-11.10 dB
Best Single Value	1.11 dBm
Best Position	Phi = 45 deg; Theta = 165 deg; Pol = Ver

7.1.2 RP_868.000_tot

Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.00	0.02	-0.55	-1.69	-3.23	-2.91	-2.06	-1.31	-0.58
15.00	-0.04	-0.48	-0.80	-2.29	-1.12	-0.76	-0.52	-1.20
30.00	0.08	0.04	0.05	-0.56	0.06	0.48	-1.00	-1.71
45.00	0.46	0.80	0.81	0.59	0.92	0.74	-1.25	-1.39
60.00	0.63	1.34	1.42	1.60	1.02	0.60	-2.04	-1.20
75.00	1.19	1.85	1.99	1.78	0.57	-0.25	-2.81	-1.24
90.00	1.12	2.33	2.00	1.95	-0.58	-1.64	-4.64	-2.42
105.00	1.37	2.21	1.97	1.65	-1.54	-3.80	-7.33	-4.84
120.00	1.47	1.92	1.68	0.57	-2.67	-6.03	-11.79	-6.83
135.00	1.20	1.25	1.22	-0.69	-3.29	-6.70	-12.00	-7.10
150.00	1.04	0.65	0.65	-1.58	-3.26	-5.29	-7.51	-5.75
165.00	1.04	0.25	0.64	-2.14	-3.25	-3.79	-4.77	-3.39
180.00	0.96	0.14	0.33	-2.17	-2.97	-2.32	-2.90	-1.64
195.00	0.80	0.15	0.24	-2.14	-2.70	-1.86	-2.48	-0.39
210.00	0.91	0.58	-0.06	-2.21	-3.18	-1.65	-2.80	-0.09
225.00	0.71	0.70	-0.32	-2.75	-3.63	-2.49	-4.01	-0.41
240.00	0.88	0.77	-0.90	-3.48	-4.99	-3.50	-5.53	-1.75
255.00	0.85	0.76	-1.59	-4.90	-6.85	-5.37	-7.83	-3.27
270.00	0.98	0.64	-2.34	-6.81	-7.89	-7.40	-9.26	-5.09
285.00	0.94	0.29	-3.49	-8.36	-7.48	-8.68	-11.38	-7.19
300.00	0.86	0.09	-3.82	-8.52	-6.04	-8.61	-9.86	-6.42
315.00	0.85	-0.23	-3.65	-7.17	-5.33	-7.12	-8.26	-4.34
330.00	0.45	-0.71	-3.37	-5.39	-4.28	-7.11	-5.75	-2.38
345.00	0.33	-1.06	-2.72	-4.77	-3.70	-5.69	-3.32	-1.22
360.00	-0.35	-0.55	-2.02	-3.50	-3.23	-2.91	-1.78	-0.68

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.00	-0.76	-2.14	0.37	1.33	0.87
15.00	-1.03	-1.52	1.09	1.31	0.85
30.00	-0.65	-0.91	1.35	1.53	0.76
45.00	0.19	-0.33	1.21	1.31	0.45
60.00	0.15	0.13	0.65	0.89	0.17
75.00	-0.60	-0.27	-0.24	0.79	-0.10
90.00	-1.84	-0.98	-1.34	0.26	-0.26
105.00	-3.63	-1.76	-2.10	0.20	-0.06
120.00	-4.61	-2.51	-2.33	-0.20	0.09
135.00	-3.93	-2.41	-1.83	-0.29	0.70
150.00	-2.76	-2.06	-0.94	-0.06	1.32
165.00	-1.84	-1.90	-0.46	0.21	1.81
180.00	-1.28	-1.51	-0.15	0.31	1.98
195.00	-0.87	-1.60	-0.32	0.54	1.65
210.00	-0.70	-1.57	-0.80	0.21	1.33
225.00	-1.46	-1.79	-1.02	0.08	0.61
240.00	-2.37	-1.91	-0.86	-0.10	-0.01
255.00	-3.54	-1.96	-1.24	-0.10	-0.56
270.00	-4.36	-2.45	-1.54	-0.19	-0.61
285.00	-4.49	-2.45	-1.31	-0.31	-0.74
300.00	-3.36	-2.34	-1.29	-0.15	-0.50
315.00	-1.91	-2.28	-0.73	-0.03	-0.03
330.00	-0.78	-2.28	-0.43	0.37	0.43
345.00	-0.13	-2.07	0.01	0.66	0.69
360.00	-0.81	-2.13	0.39	1.19	0.52

7.1.3 RP_868.000_hor

Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.0	-4.16	-5.12	-6.99	-9.59	-12.40	-18.01	-10.47	-6.31
15.0	-6.76	-7.78	-8.26	-11.23	-15.26	-12.98	-9.90	-8.02
30.0	-10.53	-9.87	-9.14	-13.25	-16.86	-10.46	-11.90	-10.38
45.0	-9.41	-7.61	-9.08	-11.76	-11.68	-9.79	-14.69	-11.82
60.0	-6.02	-5.10	-6.47	-7.35	-9.39	-9.50	-18.97	-11.68
75.0	-3.19	-2.47	-3.22	-4.56	-7.23	-10.27	-19.30	-11.80
90.0	-1.25	-0.48	-1.14	-2.24	-6.06	-10.02	-16.55	-11.80
105.0	0.14	0.57	0.09	-1.25	-4.56	-9.49	-14.42	-10.88
120.0	0.94	1.07	0.66	-1.17	-4.13	-8.71	-15.05	-10.39
135.0	0.90	0.81	0.68	-1.62	-4.06	-8.04	-17.48	-10.19
150.0	0.47	0.01	-0.31	-2.79	-4.71	-8.16	-19.20	-11.48
165.0	-0.60	-1.40	-1.56	-4.71	-6.59	-8.59	-16.45	-14.01
180.0	-2.38	-4.03	-3.98	-7.25	-9.81	-10.30	-14.79	-19.31
195.0	-5.40	-8.08	-7.44	-11.65	-14.07	-11.99	-15.21	-16.76
210.0	-8.54	-13.22	-11.98	-17.44	-18.71	-14.46	-15.42	-14.48
225.0	-10.51	-10.14	-15.98	-21.30	-17.17	-17.02	-17.49	-12.57
240.0	-7.07	-6.29	-11.62	-14.77	-14.74	-20.18	-22.70	-12.50
255.0	-3.64	-3.82	-8.03	-13.01	-13.77	-22.70	-21.66	-10.78
270.0	-1.81	-2.37	-5.92	-12.33	-12.56	-22.70	-18.08	-9.96
285.0	-0.68	-1.63	-5.86	-11.25	-12.19	-22.70	-17.50	-9.78
300.0	-0.07	-1.38	-5.66	-11.20	-11.60	-21.61	-17.27	-8.39
315.0	0.20	-1.52	-5.28	-10.46	-11.06	-18.27	-18.37	-6.73
330.0	-0.69	-2.21	-5.85	-9.82	-9.10	-16.50	-16.84	-5.62
345.0	-1.68	-3.39	-6.33	-9.63	-9.44	-22.62	-13.44	-5.71
360.0	-3.92	-4.37	-6.90	-9.18	-11.27	-22.70	-10.75	-6.34

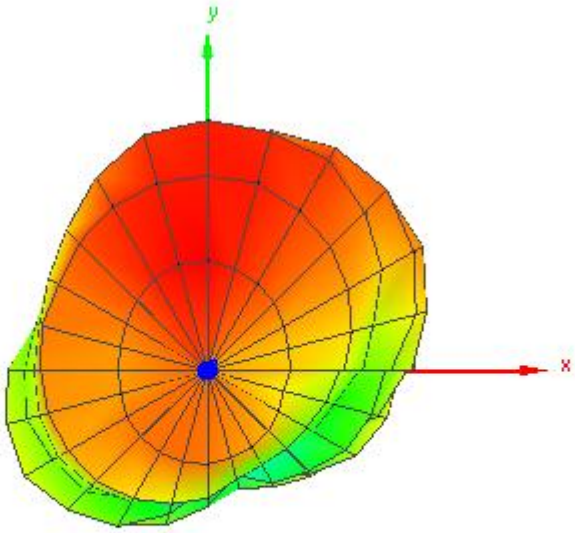
Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.0	-5.95	-5.72	-2.33	-2.15	-3.58
15.0	-7.74	-6.58	-3.13	-4.16	-6.26
30.0	-10.02	-8.42	-4.56	-7.56	-9.99
45.0	-12.26	-9.58	-7.20	-12.25	-16.62
60.0	-14.37	-9.62	-9.34	-11.88	-10.12
75.0	-13.44	-8.08	-9.03	-6.38	-5.53
90.0	-10.31	-5.75	-6.02	-3.44	-2.83
105.0	-7.97	-3.99	-3.94	-1.46	-0.98
120.0	-6.03	-3.09	-2.63	-0.64	-0.05
135.0	-4.71	-2.49	-2.09	-0.34	0.57
150.0	-4.53	-2.69	-2.01	-0.66	0.58
165.0	-5.42	-3.82	-2.99	-1.59	0.11
180.0	-7.81	-5.62	-4.68	-3.52	-1.09
195.0	-12.81	-9.68	-7.88	-6.24	-3.56
210.0	-22.70	-19.50	-13.80	-12.67	-7.29
225.0	-13.82	-15.45	-18.70	-17.43	-17.19
240.0	-10.53	-9.04	-9.58	-9.64	-13.11
255.0	-7.85	-5.76	-5.83	-5.25	-6.89
270.0	-6.50	-4.35	-3.44	-2.53	-3.42
285.0	-5.38	-3.44	-2.22	-1.26	-1.56
300.0	-4.58	-3.04	-1.52	-0.40	-0.61
315.0	-3.94	-3.32	-0.94	-0.13	-0.27
330.0	-3.52	-3.77	-0.98	-0.19	-0.57
345.0	-3.98	-4.29	-1.31	-0.86	-1.50
360.0	-5.47	-5.69	-1.82	-1.64	-3.33

7.1.4 RP_868.000_ver

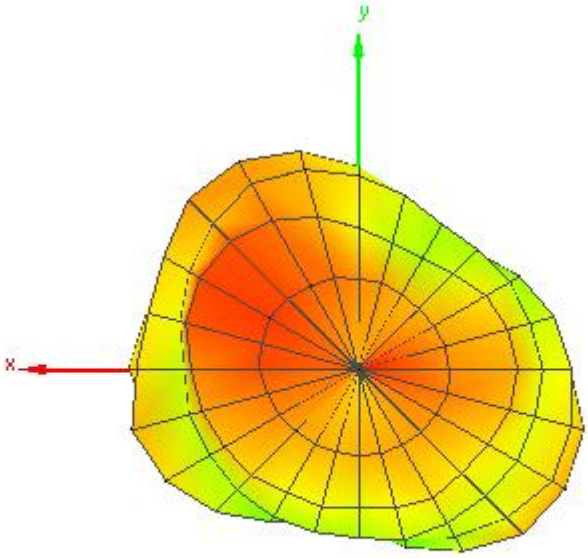
Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.0	-2.07	-2.41	-3.21	-4.37	-3.42	-2.18	-1.87	-1.93
15.0	-1.08	-1.37	-1.66	-2.88	-1.29	-1.03	-1.05	-2.21
30.0	-0.31	-0.42	-0.50	-0.80	-0.03	0.11	-1.36	-2.35
45.0	-0.01	0.13	0.34	0.33	0.67	0.33	-1.45	-1.81
60.0	-0.43	0.23	0.65	1.01	0.60	0.15	-2.13	-1.60
75.0	-0.79	-0.15	0.43	0.64	-0.22	-0.70	-2.91	-1.64
90.0	-2.65	-0.89	-0.88	-0.14	-2.03	-2.32	-4.93	-2.95
105.0	-4.69	-2.82	-2.57	-1.48	-4.53	-5.17	-8.28	-6.08
120.0	-7.89	-5.58	-5.11	-4.24	-8.11	-9.39	-14.56	-9.35
135.0	-10.56	-8.91	-8.10	-7.86	-11.18	-12.47	-13.45	-10.04
150.0	-8.05	-7.96	-6.38	-7.71	-8.71	-8.45	-7.81	-7.10
165.0	-3.97	-4.75	-3.38	-5.63	-5.94	-5.54	-5.08	-3.79
180.0	-1.75	-1.96	-1.68	-3.79	-3.98	-3.07	-3.20	-1.72
195.0	-0.40	-0.56	-0.57	-2.65	-3.02	-2.30	-2.72	-0.49
210.0	0.39	0.40	-0.34	-2.34	-3.31	-1.89	-3.05	-0.25
225.0	0.37	0.33	-0.44	-2.81	-3.82	-2.65	-4.21	-0.68
240.0	0.13	-0.18	-1.28	-3.81	-5.47	-3.59	-5.62	-2.13
255.0	-1.05	-1.10	-2.71	-5.63	-7.83	-5.45	-8.01	-4.12
270.0	-2.25	-2.38	-4.84	-8.24	-9.71	-7.53	-9.87	-6.81
285.0	-4.12	-4.18	-7.26	-11.49	-9.27	-8.86	-12.59	-10.67
300.0	-6.30	-5.33	-8.44	-11.90	-7.46	-8.84	-10.73	-10.81
315.0	-7.73	-6.12	-8.69	-9.93	-6.68	-7.46	-8.70	-8.08
330.0	-5.93	-6.05	-6.98	-7.33	-6.02	-7.64	-6.10	-5.17
345.0	-3.99	-4.87	-5.20	-6.49	-5.05	-5.78	-3.77	-3.13
360.0	-2.86	-2.89	-3.72	-4.86	-3.97	-2.96	-2.36	-2.05

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.0	-2.33	-4.65	-2.98	-1.26	-1.05
15.0	-2.08	-3.14	-0.98	-0.14	-0.09
30.0	-1.18	-1.76	0.07	0.96	0.38
45.0	-0.07	-0.88	0.53	1.11	0.36
60.0	0.00	-0.35	0.19	0.65	-0.26
75.0	-0.83	-1.06	-0.86	-0.13	-1.56
90.0	-2.50	-2.75	-3.15	-2.16	-3.75
105.0	-5.62	-5.74	-6.70	-4.78	-7.27
120.0	-10.17	-11.57	-14.09	-10.39	-14.67
135.0	-11.78	-19.62	-14.19	-19.71	-14.33
150.0	-7.52	-10.79	-7.55	-8.95	-6.75
165.0	-4.34	-6.37	-3.99	-4.48	-3.10
180.0	-2.37	-3.64	-2.04	-2.01	-0.97
195.0	-1.16	-2.34	-1.16	-0.48	0.09
210.0	-0.73	-1.64	-1.03	-0.02	0.69
225.0	-1.72	-1.98	-1.10	0.00	0.54
240.0	-3.09	-2.85	-1.48	-0.61	-0.23
255.0	-5.54	-4.30	-3.10	-1.68	-1.72
270.0	-8.48	-6.97	-6.05	-3.99	-3.83
285.0	-11.83	-9.34	-8.55	-7.35	-8.40
300.0	-9.47	-10.64	-14.24	-12.74	-16.57
315.0	-6.20	-9.01	-14.06	-16.80	-12.83
330.0	-4.08	-7.65	-9.69	-8.78	-6.44
345.0	-2.44	-6.05	-5.79	-4.63	-3.33
360.0	-2.63	-4.65	-3.61	-2.01	-1.79

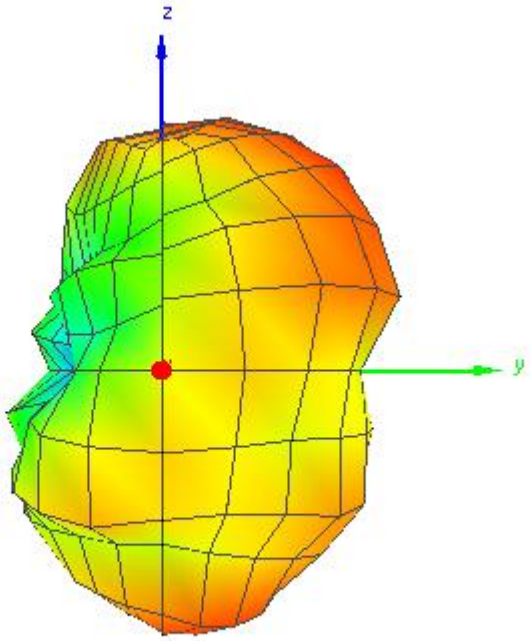
7.1.5 Theta = 0, Phi = 0



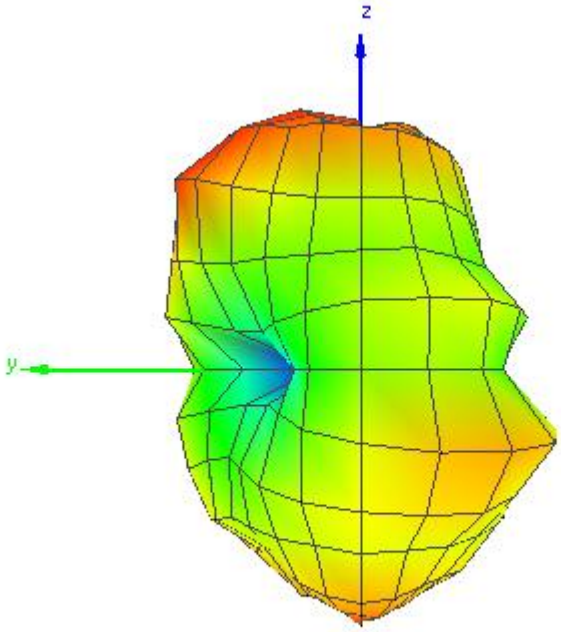
7.1.6 Theta = 180, Phi = 0



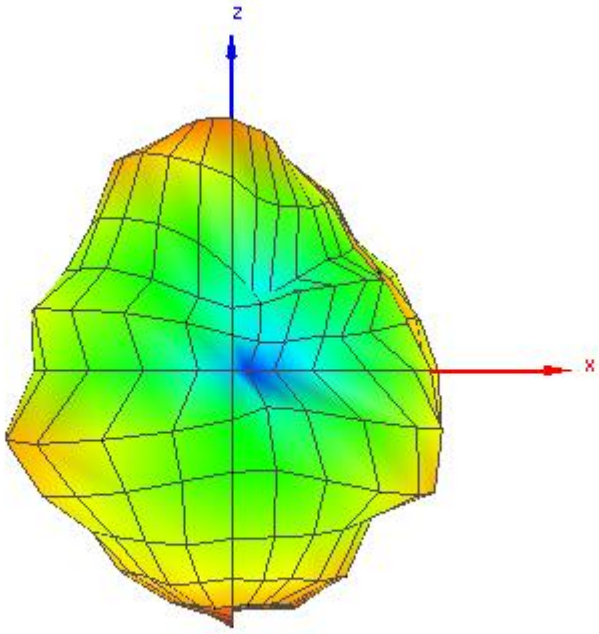
7.1.7 Theta = 90, Phi = 0



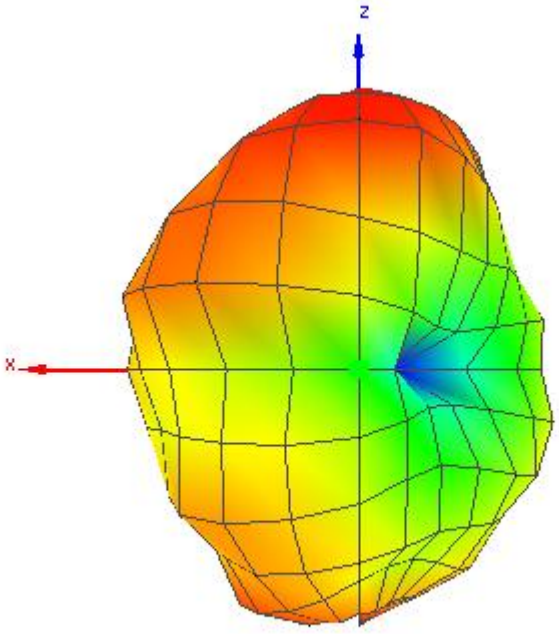
7.1.8 Theta = 90, Phi = 180



7.1.9 Theta = 90, Phi = 270



7.1.10 Theta = 90, Phi = 90



7.2 CTIA OTA Report – 915 MHz (Antenna matched at 868 MHz)

7.2.1 OTA Evaluation Results:

Total Radiated Power	-3.35 dBm
Peak EIRP	0.01 dBm
Directivity	3.37 dBi
Efficiency	-3.35 dB
Efficiency	46.20 %
Gain	0.01 dBi
NHPRP 45°	-5.54 dBm
NHPRP 45° / TRP	-2.19 dB
NHPRP 45° / TRP	60.42 %
NHPRP 30°	-7.39 dBm
NHPRP 30° / TRP	-4.04 dB
NHPRP 30° / TRP	39.49 %
NHPRP 22.5°	-8.72 dBm
NHPRP 22.5° / TRP	-5.37 dB
NHPRP 22.5° / TRP	29.05 %
UHRP	-6.28 dBm
UHRP / TRP	-2.92 dB
UHRP / TRP	51.01 %
LHRP	-6.45 dBm
LHRP / TRP	-3.10 dB
LHRP / TRP	48.99 %
Front/Back Ratio	4.40
PhiBW	85.3 deg
PhiBW Up	40.5 deg
PhiBW Down	44.8 deg
ThetaBW	272.4 deg
ThetaBW Up	118.8 deg
ThetaBW Down	153.5 deg
Boresight Phi	210 deg
Boresight Theta	105 deg
Maximum Power	0.01 dBm
Minimum Power	-15.33 dBm
Average Power	-2.61 dBm
Max/Min Ratio	15.34 dB
Max/Avg Ratio	2.62 dB
Min/Avg Ratio	-12.72 dB
Best Single Value	-0.16 dBm
Best Position	Phi = 210 deg; Theta = 105 deg; Pol = Ver

7.2.2 RP_915.000_tot

Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.00	-1.09	-2.11	-2.67	-3.21	-6.21	-7.46	-7.02	-6.05
15.00	-1.29	-2.11	-2.21	-3.23	-5.40	-5.93	-5.16	-5.56
30.00	-1.24	-1.80	-1.61	-2.63	-4.14	-4.38	-3.52	-4.43
45.00	-1.31	-1.26	-1.82	-1.96	-2.98	-3.29	-2.76	-3.39
60.00	-1.51	-1.20	-1.54	-1.21	-2.09	-2.39	-2.36	-2.48
75.00	-1.54	-1.00	-1.76	-0.66	-1.73	-2.82	-2.75	-2.86
90.00	-1.87	-0.83	-1.77	-0.65	-2.03	-3.90	-4.55	-4.72
105.00	-2.24	-0.90	-1.61	-0.77	-3.02	-5.23	-7.19	-8.17
120.00	-2.37	-1.11	-1.05	-1.20	-3.40	-6.89	-12.40	-13.73
135.00	-2.45	-1.41	-0.56	-1.38	-3.29	-6.70	-13.49	-10.32
150.00	-2.33	-1.40	-0.26	-1.33	-2.57	-4.63	-8.31	-5.78
165.00	-2.26	-1.45	-0.19	-1.42	-1.81	-2.49	-4.92	-3.01
180.00	-2.32	-1.49	-0.07	-1.35	-1.47	-1.17	-2.67	-1.34
195.00	-2.03	-1.42	-0.32	-1.41	-1.75	-0.68	-1.96	-0.23
210.00	-2.26	-1.42	-0.66	-1.46	-2.13	-1.04	-2.35	0.01
225.00	-2.05	-1.12	-0.87	-1.87	-2.80	-1.70	-3.32	-0.52
240.00	-1.78	-1.42	-1.48	-2.69	-4.50	-3.24	-5.18	-1.64
255.00	-1.57	-1.43	-2.17	-3.49	-6.35	-4.76	-7.75	-3.56
270.00	-1.39	-1.80	-2.71	-4.99	-8.18	-6.66	-11.21	-5.51
285.00	-1.20	-2.25	-3.41	-5.66	-8.97	-8.81	-14.00	-7.68
300.00	-1.31	-2.55	-3.62	-6.05	-8.69	-10.09	-15.33	-8.97
315.00	-1.24	-2.58	-3.72	-5.53	-8.54	-10.57	-14.59	-8.42
330.00	-1.15	-2.71	-3.40	-4.94	-7.90	-10.23	-11.90	-7.50
345.00	-1.10	-2.81	-3.10	-3.94	-7.34	-9.36	-9.25	-6.90
360.00	-1.38	-2.29	-2.77	-3.35	-6.74	-8.00	-7.42	-6.26

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.00	-5.15	-5.17	-2.23	-1.10	-0.45
15.00	-4.56	-4.45	-1.75	-1.39	-0.59
30.00	-3.45	-3.11	-1.54	-1.38	-0.69
45.00	-2.44	-2.29	-1.76	-1.13	-0.99
60.00	-2.04	-1.92	-2.02	-0.96	-1.10
75.00	-2.64	-2.14	-2.55	-0.81	-0.81
90.00	-4.14	-2.87	-3.26	-0.70	-1.11
105.00	-6.22	-3.71	-3.98	-0.75	-0.80
120.00	-7.19	-4.78	-3.75	-0.77	-0.72
135.00	-6.89	-4.75	-3.15	-1.25	-0.56
150.00	-4.91	-3.95	-2.43	-1.63	-0.45
165.00	-3.36	-3.28	-1.93	-1.67	-0.69
180.00	-2.42	-2.48	-1.59	-1.61	-0.88
195.00	-1.81	-1.96	-1.28	-1.73	-1.25
210.00	-1.81	-1.70	-1.38	-1.55	-1.69
225.00	-2.13	-1.54	-1.56	-1.31	-1.87
240.00	-2.58	-1.75	-1.79	-1.48	-2.12
255.00	-3.76	-2.01	-1.93	-1.42	-1.93
270.00	-4.80	-2.81	-2.21	-1.57	-2.17
285.00	-5.12	-3.09	-2.20	-1.42	-1.65
300.00	-5.04	-3.96	-2.32	-1.31	-1.05
315.00	-4.92	-5.05	-2.38	-1.27	-0.53
330.00	-5.22	-5.78	-2.28	-1.05	-0.20
345.00	-4.90	-5.78	-2.04	-1.25	-0.09
360.00	-5.13	-5.74	-2.02	-1.06	-0.52

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Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.0	-5.94	-7.73	-8.14	-7.43	-11.86	-17.06	-13.93	-12.37
15.0	-8.64	-9.66	-9.28	-9.11	-13.79	-17.09	-13.79	-13.93
30.0	-11.34	-11.09	-11.32	-10.70	-16.72	-17.39	-13.19	-16.91
45.0	-11.19	-11.23	-13.18	-10.66	-14.84	-15.17	-13.74	-16.93
60.0	-8.60	-8.44	-10.43	-8.20	-11.28	-12.36	-14.86	-15.84
75.0	-6.50	-5.78	-7.36	-5.27	-8.07	-12.08	-15.99	-14.05
90.0	-4.42	-3.56	-4.41	-3.41	-5.76	-10.82	-17.80	-13.93
105.0	-3.65	-2.28	-2.67	-2.26	-5.02	-9.19	-16.46	-14.61
120.0	-3.18	-1.78	-1.58	-1.94	-4.05	-7.93	-16.27	-14.53
135.0	-3.10	-1.95	-1.46	-2.14	-3.88	-7.37	-15.70	-14.36
150.0	-3.61	-2.64	-2.15	-3.11	-4.43	-7.74	-15.07	-14.98
165.0	-4.67	-4.38	-3.69	-5.38	-5.90	-8.34	-14.86	-17.32
180.0	-6.61	-6.61	-6.08	-8.28	-8.49	-9.48	-13.82	-24.22
195.0	-9.20	-10.13	-8.91	-11.62	-11.75	-11.60	-14.53	-18.21
210.0	-12.09	-12.92	-11.64	-11.30	-14.18	-14.35	-14.23	-14.21
225.0	-10.64	-10.41	-10.31	-10.59	-14.40	-15.25	-16.41	-12.86
240.0	-7.46	-7.71	-8.14	-9.35	-14.35	-18.25	-17.74	-11.80
255.0	-5.09	-5.60	-6.74	-8.56	-14.72	-20.89	-22.62	-11.90
270.0	-3.52	-4.57	-5.73	-8.61	-14.80	-21.74	-24.22	-11.33
285.0	-2.42	-4.04	-5.57	-8.01	-14.86	-20.89	-23.74	-11.91
300.0	-2.25	-3.96	-5.62	-8.46	-14.28	-22.09	-21.88	-11.37
315.0	-2.33	-4.21	-6.13	-8.28	-13.69	-21.93	-21.81	-10.50
330.0	-2.91	-5.02	-6.69	-8.06	-12.50	-21.43	-17.15	-10.06
345.0	-4.08	-6.32	-7.02	-7.48	-11.70	-17.58	-14.45	-10.65
360.0	-5.87	-7.16	-7.91	-6.99	-11.67	-17.16	-13.44	-11.62

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.0	-10.25	-10.26	-5.37	-5.43	-5.89
15.0	-12.10	-10.81	-6.04	-8.45	-8.80
30.0	-13.54	-10.83	-8.16	-12.64	-13.95
45.0	-15.14	-11.47	-11.00	-12.96	-12.58
60.0	-15.91	-11.56	-12.65	-8.18	-7.78
75.0	-16.34	-9.84	-10.26	-5.17	-4.36
90.0	-13.65	-7.55	-6.87	-2.91	-2.71
105.0	-10.47	-5.91	-5.28	-1.75	-1.43
120.0	-8.50	-5.14	-3.91	-1.03	-0.85
135.0	-8.49	-5.00	-3.73	-1.42	-0.76
150.0	-8.58	-5.64	-4.63	-2.56	-1.34
165.0	-9.88	-7.56	-6.12	-4.13	-2.50
180.0	-12.47	-10.42	-9.03	-6.54	-4.49
195.0	-18.10	-15.90	-13.95	-10.81	-7.72
210.0	-16.44	-18.39	-15.79	-12.95	-12.09
225.0	-10.94	-11.95	-10.92	-9.39	-13.28
240.0	-8.60	-7.67	-7.32	-6.68	-8.84
255.0	-7.11	-5.73	-4.94	-4.25	-5.23
270.0	-6.38	-4.95	-3.43	-2.85	-3.51
285.0	-5.92	-4.27	-2.61	-1.78	-1.97
300.0	-5.75	-4.75	-2.50	-1.40	-1.17
315.0	-6.00	-6.03	-2.78	-1.58	-1.06
330.0	-6.98	-7.32	-3.13	-2.10	-1.52
345.0	-7.68	-8.73	-3.81	-3.30	-2.78
360.0	-9.74	-10.81	-4.79	-4.58	-4.95

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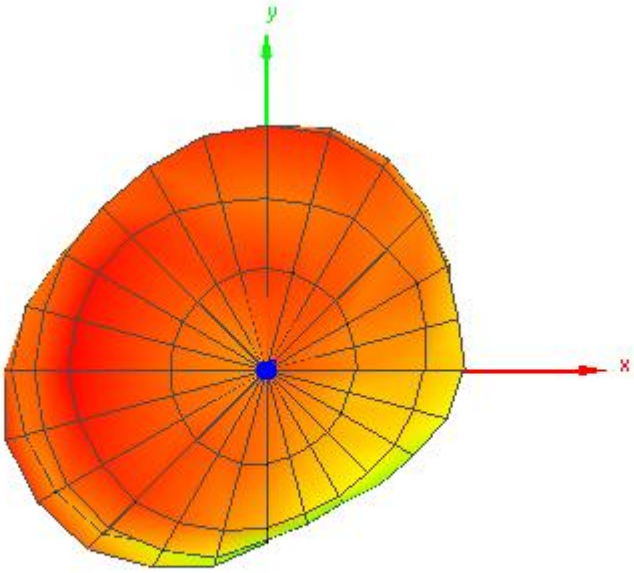
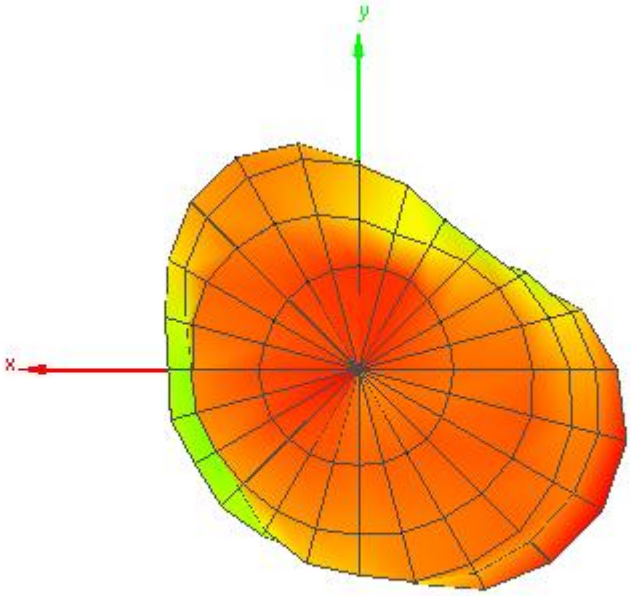
Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.0	-2.81	-3.50	-4.12	-5.27	-7.59	-7.96	-8.01	-7.20
15.0	-2.17	-2.96	-3.16	-4.53	-6.08	-6.28	-5.80	-6.24
30.0	-1.68	-2.34	-2.10	-3.37	-4.39	-4.61	-4.01	-4.68
45.0	-1.78	-1.72	-2.15	-2.59	-3.27	-3.58	-3.12	-3.58
60.0	-2.45	-2.11	-2.14	-2.17	-2.64	-2.85	-2.62	-2.69
75.0	-3.21	-2.76	-3.16	-2.50	-2.87	-3.37	-2.96	-3.21
90.0	-5.40	-4.13	-5.19	-3.92	-4.42	-4.89	-4.76	-5.28
105.0	-7.81	-6.56	-8.26	-6.14	-7.36	-7.46	-7.74	-9.29
120.0	-10.07	-9.59	-10.38	-9.27	-11.95	-13.64	-14.70	-21.45
135.0	-11.00	-10.72	-7.86	-9.28	-12.26	-15.16	-17.48	-12.49
150.0	-8.28	-7.43	-4.78	-6.06	-7.16	-7.54	-9.33	-6.34
165.0	-5.98	-4.56	-2.76	-3.65	-3.95	-3.80	-5.38	-3.17
180.0	-4.35	-3.09	-1.33	-2.33	-2.43	-1.86	-3.01	-1.36
195.0	-2.95	-2.05	-0.97	-1.84	-2.21	-1.05	-2.20	-0.30
210.0	-2.73	-1.74	-1.02	-1.93	-2.41	-1.24	-2.64	-0.16
225.0	-2.70	-1.67	-1.40	-2.50	-3.11	-1.89	-3.54	-0.79
240.0	-3.15	-2.58	-2.53	-3.74	-4.98	-3.38	-5.43	-2.08
255.0	-4.12	-3.54	-4.04	-5.11	-7.03	-4.86	-7.90	-4.25
270.0	-5.49	-5.07	-5.72	-7.46	-9.25	-6.79	-11.43	-6.83
285.0	-7.31	-6.97	-7.49	-9.45	-10.26	-9.08	-14.49	-9.75
300.0	-8.43	-8.13	-7.93	-9.77	-10.09	-10.37	-16.41	-12.69
315.0	-7.78	-7.63	-7.43	-8.81	-10.12	-10.90	-15.50	-12.62
330.0	-5.94	-6.55	-6.16	-7.85	-9.75	-10.57	-13.44	-11.03
345.0	-4.13	-5.38	-5.36	-6.47	-9.32	-10.06	-10.81	-9.28
360.0	-3.28	-4.00	-4.35	-5.81	-8.43	-8.56	-8.67	-7.76

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.0	-6.75	-6.77	-5.12	-3.09	-1.91
15.0	-5.40	-5.59	-3.77	-2.34	-1.30
30.0	-3.90	-3.92	-2.60	-1.72	-0.90
45.0	-2.68	-2.85	-2.31	-1.42	-1.30
60.0	-2.22	-2.42	-2.41	-1.88	-2.15
75.0	-2.83	-2.94	-3.36	-2.79	-3.34
90.0	-4.65	-4.68	-5.75	-4.68	-6.21
105.0	-8.26	-7.73	-9.83	-7.61	-9.45
120.0	-13.01	-15.76	-18.06	-12.98	-16.31
135.0	-11.99	-17.34	-12.18	-15.57	-13.97
150.0	-7.34	-8.86	-6.43	-8.79	-7.76
165.0	-4.46	-5.32	-4.01	-5.31	-5.37
180.0	-2.87	-3.24	-2.45	-3.29	-3.36
195.0	-1.91	-2.14	-1.52	-2.30	-2.36
210.0	-1.97	-1.79	-1.55	-1.88	-2.11
225.0	-2.75	-1.95	-2.10	-2.05	-2.20
240.0	-3.83	-3.04	-3.21	-3.05	-3.16
255.0	-6.45	-4.41	-4.95	-4.62	-4.66
270.0	-9.94	-6.92	-8.35	-7.51	-7.93
285.0	-12.83	-9.34	-12.66	-12.43	-13.22
300.0	-13.25	-11.78	-16.18	-18.26	-16.54
315.0	-11.50	-12.01	-12.94	-12.92	-9.96
330.0	-9.98	-11.03	-9.77	-7.72	-6.00
345.0	-8.15	-8.85	-6.79	-5.49	-3.44
360.0	-6.98	-7.36	-5.28	-3.62	-2.46

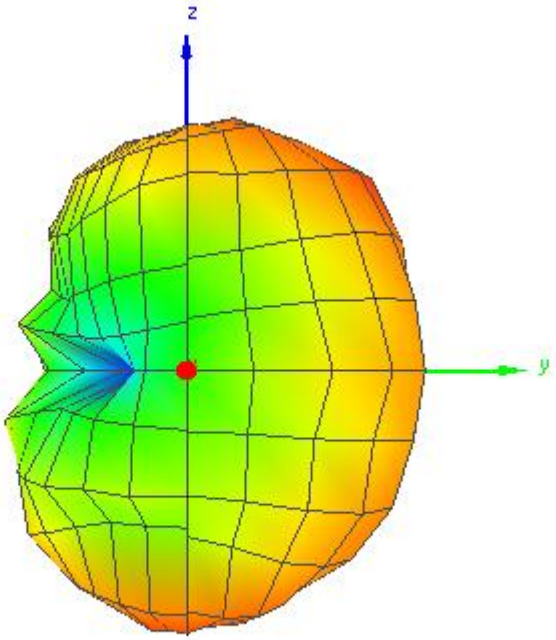
7.2.5 Theta = 0, Phi = 0



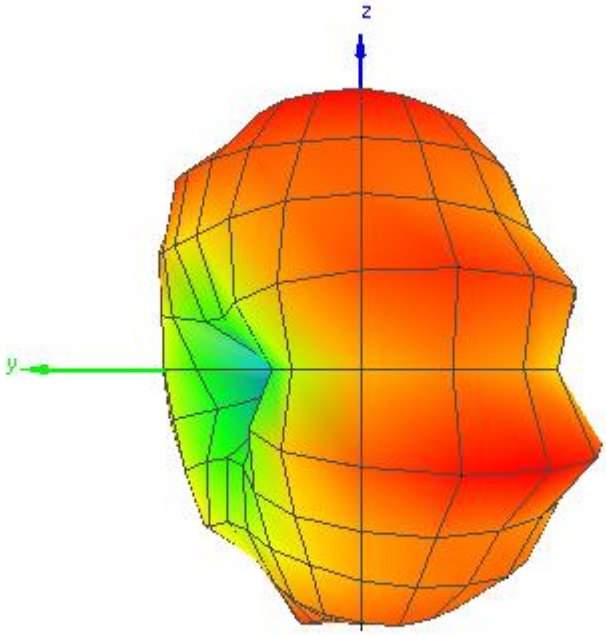
7.2.6 Theta = 180, Phi = 0



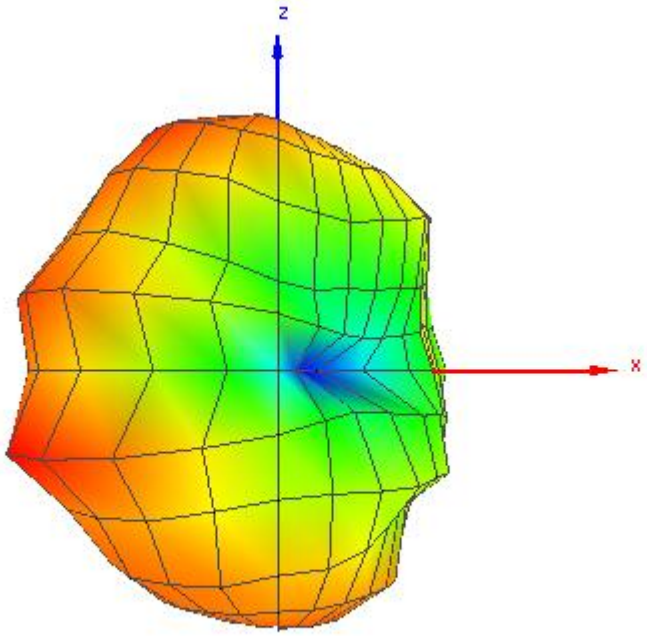
7.2.7 Theta = 90, Phi = 0



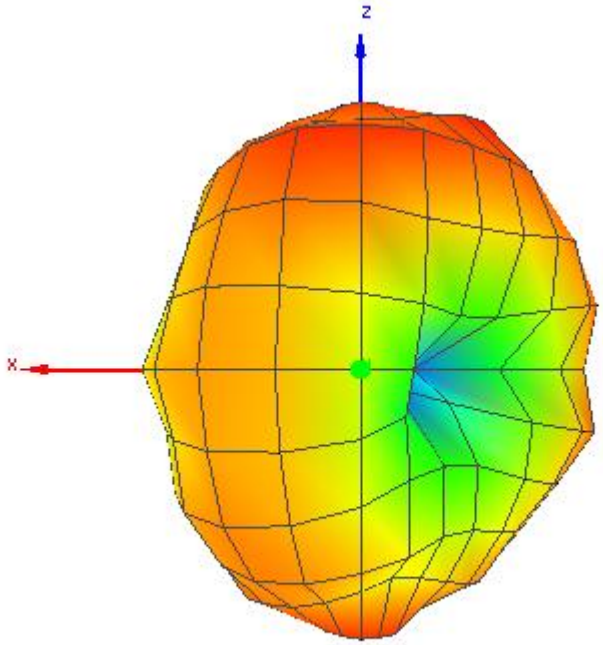
7.2.8 Theta = 90, Phi = 180



7.2.9 Theta = 90, Phi = 270



7.2.10 Theta = 90, Phi = 90



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