Using CC253X or CC254X with Dipole PCB Antennas

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Keywords

- *Half wave dipole*
- *RF*
- *Antenna*
- *Efficiency*
- *Gain*
- *TRP (Total Radiated Power)*
- *CC2530*
- *CC2531*
- *CC2533*
- *CC2540*
- *CC2541*

1 Introduction

Many RFICs today use differential ports to transmit and receive RF power. This makes the use of balanced antennas an attractive proposition, as one can do away with the balun normally needed to convert the differential RF power at the IC ports to single ended signals that can be fed to an SMA connected antenna or RF instrument. This document describes a simple half wave dipole antenna that is easy to integrate on a PCB and works well with all CC253X and CC254X RFIC's from Texas Instruments.

Table of Contents

2 Abbreviations

BTM	Below Threshold of Measurability
EIRP	Equivalent Isotropic Radiated Power
FCC	Federal Communications Commission
PCB	Printed Circuit Board
SMA	SubMiniature version A connector
TRP	Total Radiated Power

3 The Half Wave Dipole Antenna in Brief

The half wave dipole is one of the simplest and most commonly used antenna structures in the RF world. It can be made from a piece of wire, or a trace on a PCB. The basic half wave dipole antenna is a wire or trace with a length of lambda/2 and a slot in the middle where the antenna is fed. The impedance is around 73 ohms, and the directivity is 2.15 dBi.

4 Designing a Half Wave Dipole Antenna on a PCB

This design note describes the antenna design process for the Zlight2 reference design, a 40 mm PCB disc that is used to demonstrate the capabilities of the CC2530 when used as a wireless LED controller. This places some constraints on the use of the basic dipole antenna structure, the main ones being that the antenna will be placed close to the edge of the board, and it will be curved with a radius of 20 mm. The width of the trace does have an impact on the antenna performance, particularly the bandwidth. In this design note we will stick to a width of 300 um (12 mils), and refer the reader to more thorough papers on antenna theory if they wish to probe deeper into this particular property of the dipole. Placing the antenna close to the edge means that the effective dielectric constant will be harder to determine, as a 2.5D EM simulation tool such as Momentum will not accurately capture the effects of our finite substrate. Changing the shape of the antenna from a straight line into a curve means that the radiation pattern will not be the same as that of an ideal dipole.

As a first step, we simulate a close-to-ideal dipole using ADS Momentum to verify that the simulation setup yields credible results. Then we add substrate, curvature and a ground plane in order to model the final board more accurately. Finally, we add some length to be able to manually fine tune the antenna length on the first prototypes. This latter step is a precautionary one, given the uncertainty in the effective dielectric constant seen by the antenna.

The prototype testing and optimization process involves trimming the antenna to the right length, and then adding matching and filtering components to obtain a good trade off of high output power at the carrier frequency and low harmonics.

5 Simulating the Antenna

5.1 Step 1: Close to Ideal

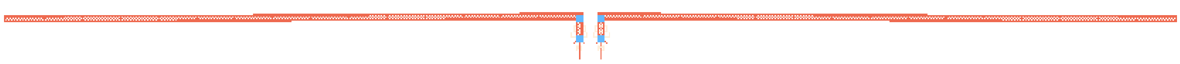


Figure 1. A 300 um Trace in Free Space

The structure shown in Figure 1 is composed of two arc segments, each with a width of 300 um, a radius of 3 m and an angular length of 0.56 degrees. The substrate definition is set to free space above and below the trace. Figure 2 shows the simulated return loss (S11) using ADS momentum.

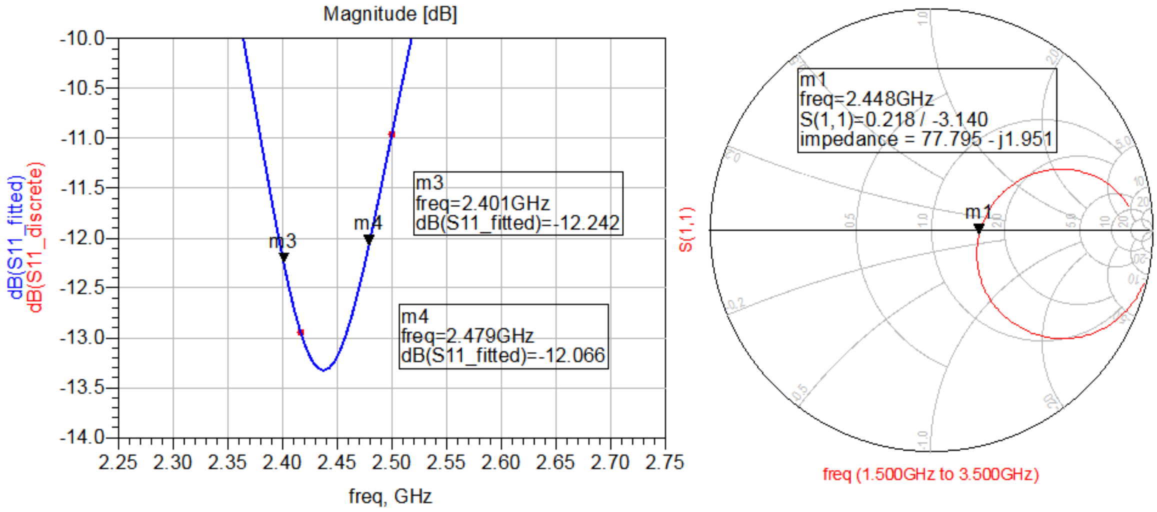


Figure 2. Simulated S11. Substrate: Free Space

Figure 2 shows a 1 dB return loss variation in our band of interest (2400 MHz to 2480 MHz), and an impedance of about 78 ohms.

5.2 Step 2: Add Substrate

The layout used in Section 5.1 is simulated again, this time on an 800 um FR4 substrate. The resonance frequency has now dropped to around 1.86 GHz, and we need to shorten the arcs to 0.416 degrees to move our pass band back to 2.45 GHz.

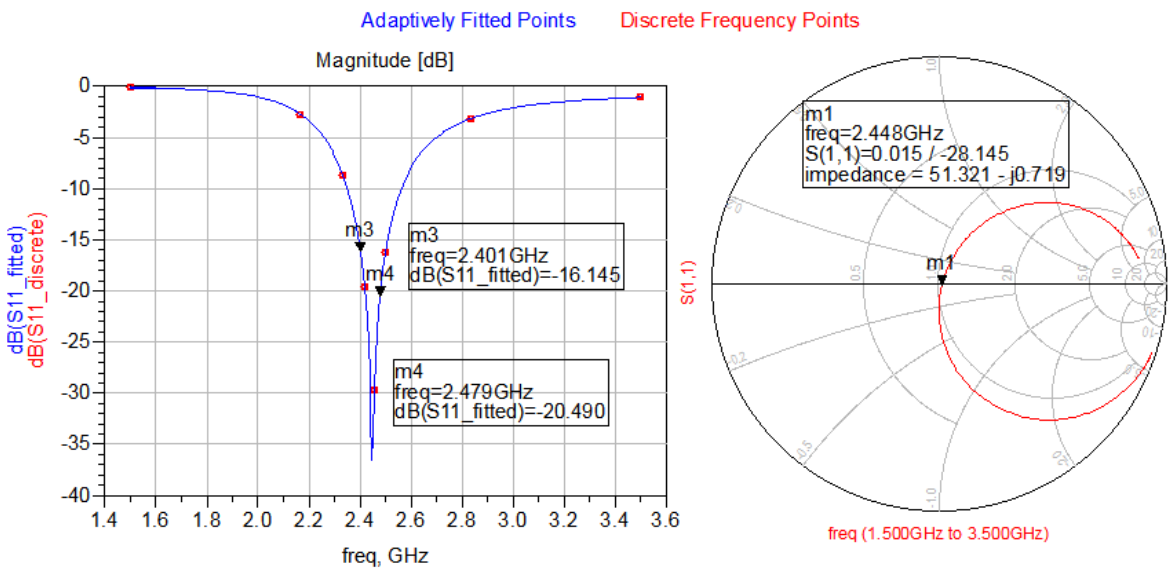


Figure 3. Simulated S11. Substrate: 800 um FR4

Adding a substrate has the effect of lowering the impedance of our antenna to 51 ohms, which also explains the very low return loss given that we used 50 ohm ports in these simulations.

5.3 Step 3: Adding Curvature

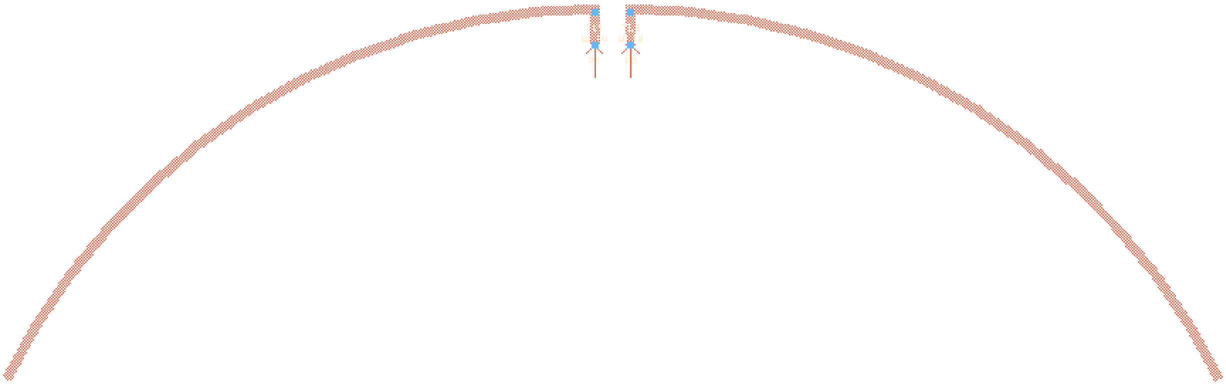


Figure 4. Curved Half Wave Dipole

The structure shown in Figure 4 is composed of two arc segments, each with a width of 300 um, a radius of 20 mm and an angular length of 64 degrees.

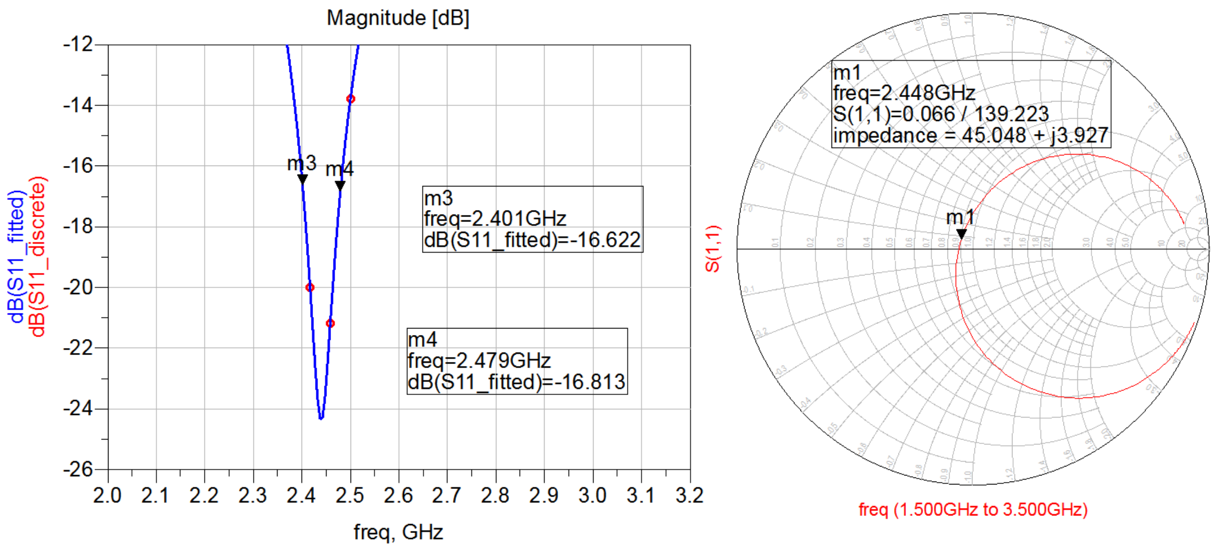


Figure 5. S11 Looking into the Curved Dipole

The impedance drops slightly (from ~51 ohms to ~45 ohms) as the shape is changed from an almost straight trace to a curved trace with a 20mm radius.

5.4 Step 4: Adding a Ground Plane

A ground plane is added as shown in Figure 6. This further reduces the impedance to around 37 ohms, but does not change the frequency response by much.

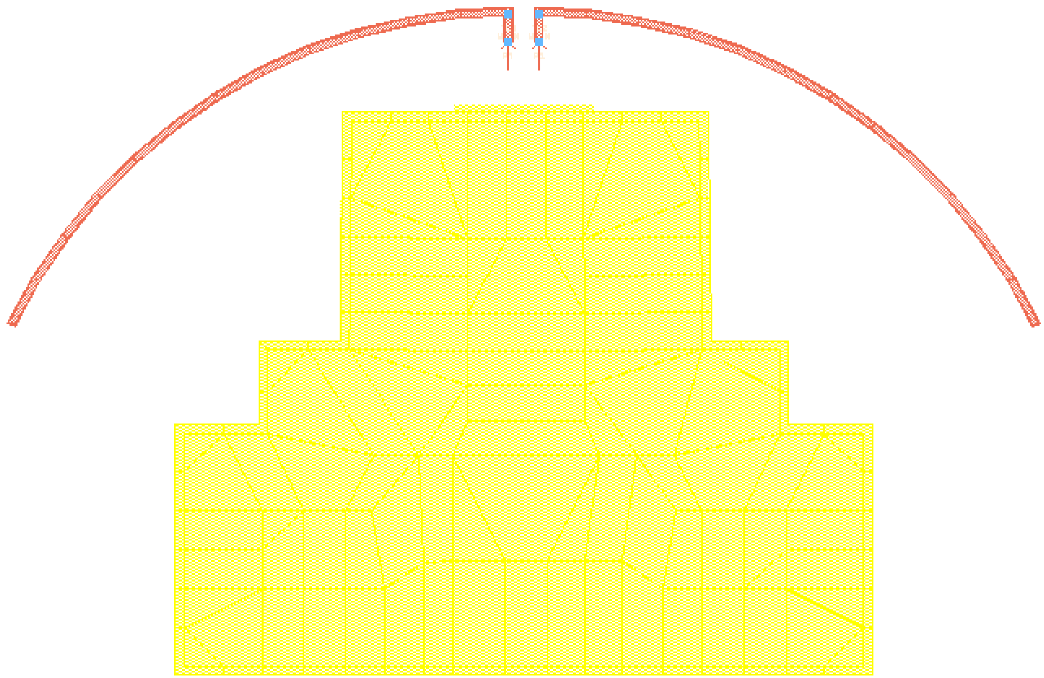


Figure 6. A Ground Plane is Added to Improve the Accuracy of the Board Model

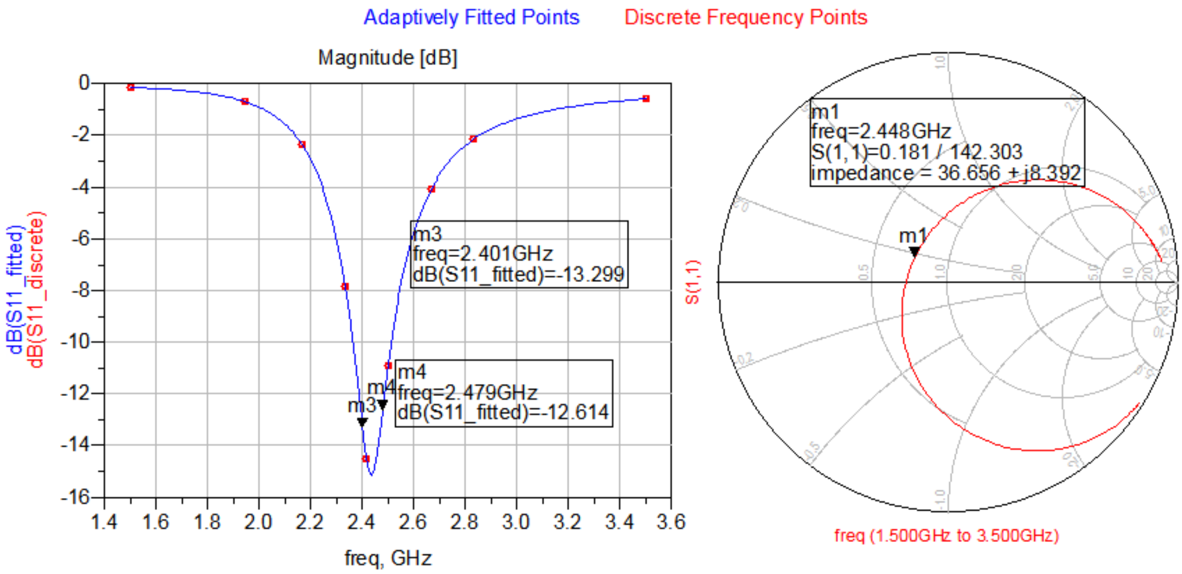


Figure 7. S11 Looking into the Curved Dipole with Added Ground Plane

We will use this pattern as a starting point for our prototypes. The length of each of the two arcs is 2π·20mm·64/360 = 22.3 mm, thus the total length of the dipole is about 45 mm.

6 Designing the Prototypes

In vacuum (or air), a half wavelength at 2.44 GHz is 61.5 mm. Our first simulations suggested a length of 2 times 29.3 mm (0.56 degrees with a radius of 3000 mm). When we added the 800 um FR4 substrate, this dropped to 2 times 21.8 mm (0.416 degrees) for the straight dipole and 2 times 22.3 mm for the curved dipole. Since the effects of a finite substrate is not taken into account by our tool (ADS Momentum), we will extend the antenna slightly to allow us to physically cut the traces back to the optimum length by experimentation. We know that the optimum length will be somewhere between 2·22.3 mm and 2·29.3 mm since a finite substrate will give an effective dielectric constant somewhere between that of an infinite substrate and that of no substrate at all.

With that in mind, we choose an arc length of 75 degrees. This corresponds to an antenna length of 2·26.2 mm.

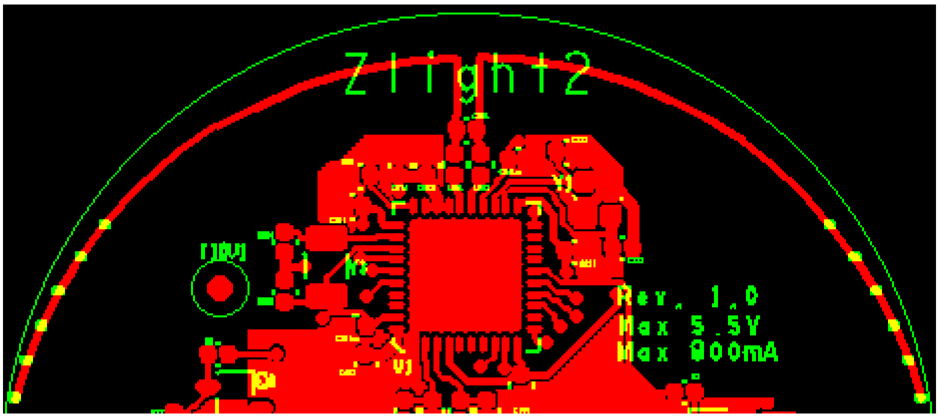


Figure 8. First Prototype Layout with Tuning Marks and Filtering Components

To facilitate the antenna tuning, we add some silk print markings to make it easier to relate the end result back to the layout in our CAD tool. We also add a simple series/shunt filtering network to help suppress harmonics if needed (see Figure 8).

7 Prototype Testing and Optimization

7.1 Antenna Length Tuning

With the prototypes back, the first step is to tune the antenna to the right length. This is done by mounting 0 ohms resistors as series elements in the filtering network, and leaving the shunt element empty. Then, the emitted RF power at 2.44GHz is measured in an antenna test chamber while the antenna length is reduced by half a notch at a time. Since the information of interest is the signal strength relative to that of the previous measurement, it would also have been possible to measure range or RSSI when communicating between two Zlight2 boards.

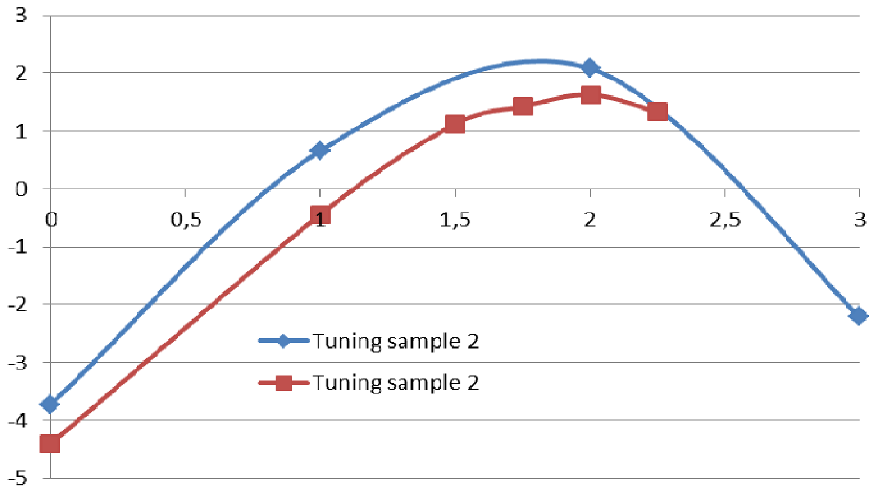


Figure 9. TRP (in dBm) versus the Number of Notches Cut (x-axis)

Two samples were tested, and they both indicated that the optimum length would be achieved by cutting two notches.

7.2 Filtering Harmonics

When fed from a differential source, the half wave dipole antenna will radiate odd harmonics rather well, while even harmonics will not be transmitted. However, in practice, some of the unwanted harmonic contents will be common mode, i.e. the currents and voltages at the two antenna terminals have zero phase difference. This means that our antenna will also radiate even harmonics of the carrier frequency unless our filter is able to suppress common mode signals as well as differential signals.

The initial filter was a purely differential design, which proved to be insufficient to handle the 2nd harmonic. A new version was therefore made, where shunt components were connected to ground to filter common mode signals. The antenna length was also updated according to the results found in Section 7.1.

To keep component count, cost, and insertion loss to a minimum, the new filter is simply a parallel resonant LC circuit (tuned to the carrier frequency) where the C is split into two capacitors of double capacitance connected to ground.

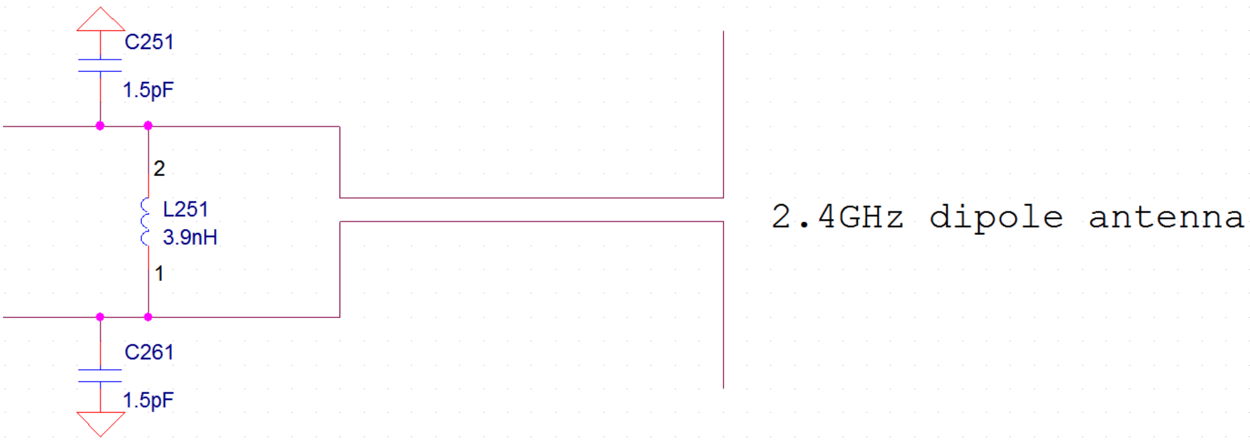


Figure 10. Parallel Resonant Circuit with Differential as well as Common Mode Rejection

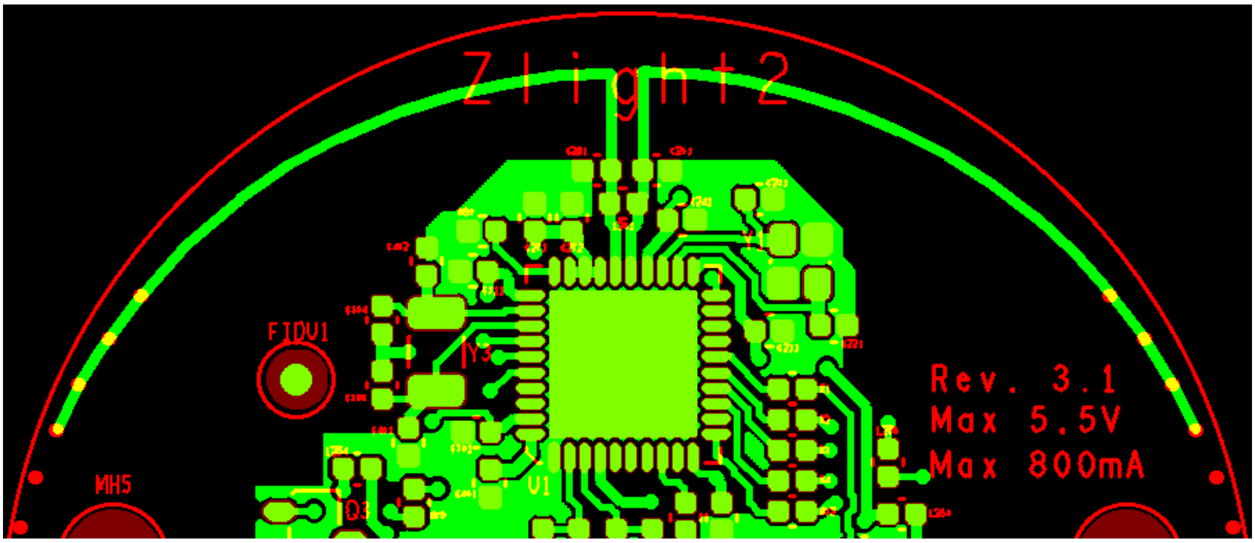


Figure 11. The Final Layout of the Antenna and Filtering Components

After tuning, the total length of the antenna is now 2·22.6 mm, which is very close to the simulated value found in Section 5.4.

The next step was to test different values of L and C to obtain a good trade off between output power and harmonic suppression. The tables below show the measured TRP for different values of L and C, and the corresponding harmonic levels.

	L [nH]					
C [pF]	**1.8**	**3.3**	**3.6**	**3.9**	**4.3**	**4.7**
1		2.14				2.6
1.2						
1.5				2.14	2.52	
1.8			1.99	2.04	2.18	
2.2			1.32	1.56	1.37	
2.7	-0.06		-0.78	-0.54	-0.61	

Table 1. TRP in dBm for Different Values of L and C

	L [nH]					
C [pF]	**1.8**	**3.3**	**3.6**	**3.9**	**4.3**	**4.7**
1		-44.2				-44.3
1.2				-44.8		
1.5						
1.8			-46.4	-45.8		
2.2				-45.1		
2.7	-47.1					

Table 2. 2nd Harmonic Levels in dBm (max EIRP)

	L [nH]					
C [pF]	**1.8**	**3.3**	**3.6**	**3.9**	**4.3**	**4.7**
1		-31.5				-32.5
1.2				-35.5		
1.5				-36.0		
1.8			-37.2	-36.2		
2.2				-38.1		
2.7	-39.7					

Table 3. 3rd Harmonic Levels in dBm (max EIRP)

The most obvious observation is that the 2nd harmonic level is more or less independent of the TRP and L values, but has a tendency to decrease with increasing capacitance to ground. This is most likely a result of the 2.7 pF cap being resonant close to the 2nd harmonic, so the closer we get to 2.7 pF the better the decoupling/filtering.

The 3rd harmonic level seems to depend mostly on the carrier power, and since we want to get it down towards -41.2 dBm to avoid strict duty cycle requirements from the FCC, we choose an inductance of 3.9 nH and a capacitance of 1.5 pF (which is equivalent to 0.75 pF in parallel with the inductor in the LC parallel resonant circuit). This gives us a safe level of the 2nd harmonic, a 3rd harmonic that is compliant with up to almost 50% duty cycle, and just above +2 dBm TRP. If we reduce the output power slightly, the 3rd harmonic will pass FCC even with 100% duty cycle.

	TXPOWER = 0xF5			TXPOWER = 0xE5			TXPOWER = 0xD5		
Sample	**TRP**	**2nd**	**3rd**	**TRP**	**2nd**	**3rd**	**TRP**	**2nd**	**3rd**
S1	2.35								
S2	2.32	BTM	-37.1				-1.61	BTM	-48.6
S3	2.21								
S4	2.79	-45.1	-35.4	0.16	BTM	-42.8	-1.06	BTM	-46.0

Table 4: TRP and Harmonics Levels with 3 Different Power Settings (TXPOWER = 0xF5, E5 and D5)

The available power from CC2531 when using power setting 0xF5 is +4 dBm, which means that our measured TRP is less than 2 dB short of the efficiency reference. This gives an efficiency of at least $100*10^{-0.2}$ = 63% even though this design has not been tuned for maximum TRP.

The part numbers of the 3.9 nH inductor and 1.5pF capacitors are:

- GRM1555C1H1R5CZ01 (0402 capacitor with C0G/NP0 dielectric from Murata)
- LQG15HS3N3S02 (0402 multilayer chip inductor from Murata)

A full measurement report on this antenna can be found in Appendix A: CTIA Report

8 Conclusion

A half wave dipole can be an excellent antenna choice for low cost RF nodes. A simple 3-component filter is all that is needed to ensure regulatory compliance. The antenna designed in this Design Note has an efficiency of more than 63%, and a directivity of 5.04 dBi.

9 General Information

9.1 Document History

Revision	Date	Description/Changes
SWRA421	2013.01.25	Initial release.

Appendix A: CTIA Report

With the board placed in the XZ-plane as shown in Figure 12, the radiation diagram was measured in an antenna chamber. The reference level used to calculate efficiency and gain was 0 dBm, which means that 4 dB needs to be subtracted from the gain given that the available power from CC2531 is 4 dBm.

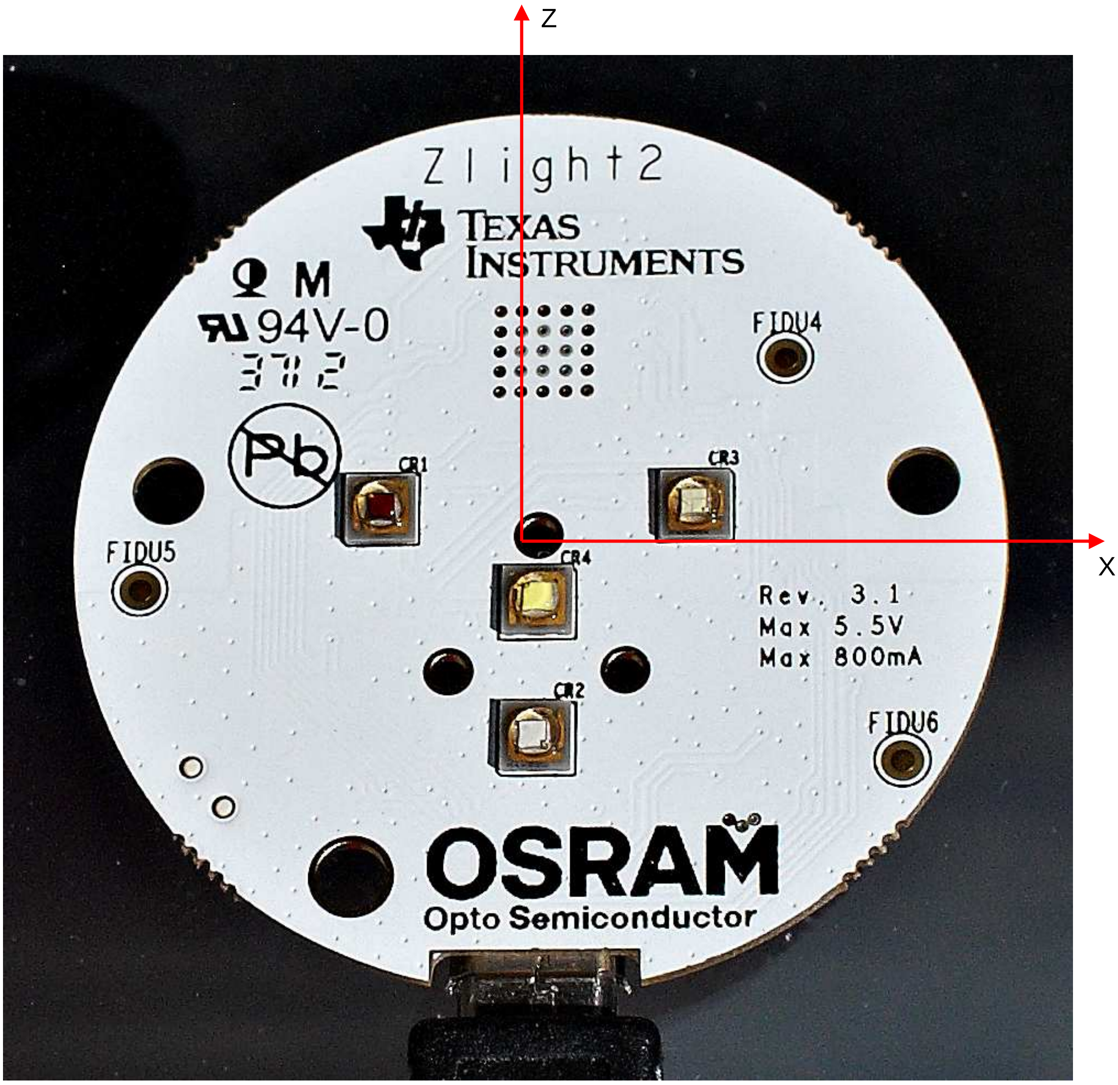


Figure 12. Board Orientation During the Antenna Measurements

CTIA Report (RP_2440.000_tot)

Test Information:

Test Method:	Radiated Power Passive Antenna
Test Condition:	FS: Free Space
Frequency:	2440.000 MHz
Test Time:	Start: 12-10-2012 15:01:02; Stop: 12-10-2012 15:28:59
Cal Data Hor:	43.80 dB (Range Calibration RadPower Hor Eval 200 to 6000)
Cal Data Ver:	46.53 dB (Range Calibration RadPower Ver Eval 400 to 6000)

OTA Evaluation Results:

Total Radiated Power	2,12 dBm
Peak EIRP	7,16 dBm
Directivity	5,04 dBi
Efficiency	2,12 dB
Efficiency	162,80 %
Gain	7,16 dBi
NHPRP 45°	-0,22 dBm
NHPRP 45° / TRP	-2,34 dB
NHPRP 45° / TRP	58,34 %
NHPRP 30°	-2,06 dBm
NHPRP 30° / TRP	-4,18 dB
NHPRP 30° / TRP	38,18 %
NHPRP 22.5°	-3,33 dBm
NHPRP 22.5° / TRP	-5,44 dB
NHPRP 22.5° / TRP	28,56 %
UHRP	-0,69 dBm
UHRP / TRP	-2,80 dB
UHRP / TRP	52,46 %
LHRP	-1,11 dBm
LHRP / TRP	-3,23 dB
LHRP / TRP	47,54 %
Front/Back Ratio	3,13
PhiBW	100,0 deg
PhiBW Up	57,7 deg
PhiBW Down	42,3 deg
ThetaBW	59,2 deg
ThetaBW Up	39,6 deg
ThetaBW Down	19,5 deg
Boresight Phi	75 deg
Boresight Theta	150 deg
Maximum Power	7,16 dBm
Minimum Power	-8,52 dBm
Average Power	2,92 dBm
Max/Min Ratio	15,68 dB
Max/Avg Ratio	4,24 dB
Min/Avg Ratio	-11,44 dB
Best Single Value	6,96 dBm
Best Position	Phi = 90 deg; Theta = 150 deg; Pol = Ver

RP 2440.000 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	2.52	3.56	2.65	-0.14	-1.15	-4.35	-7.33	-7.89
15.00	2.68	3.39	2.58	-0.05	0.42	-3.08	-4.98	-6.47
30.00	3.15	3.27	3.34	0.58	2.27	-1.12	-2.03	-3.48
45.00	3.46	3.30	4.04	1.49	3.63	0.54	0.27	-0.97
60.00	3.67	3.53	4.61	2.29	4.37	1.70	1.85	0.80
75.00	3.83	3.89	4.97	2.76	4.59	2.48	2.97	2.16
90.00	3.79	4.30	4.98	2.86	4.45	2.89	3.59	2.98
105.00	3.63	4.75	4.72	2.71	3.95	2.98	3.65	3.14
120.00	3.35	4.91	4.28	2.14	3.11	2.67	3.14	2.67
135.00	2.91	4.85	3.75	1.47	1.95	1.94	1.93	1.67
150.00	2.39	4.55	3.27	1.00	0.78	0.65	0.12	-0.06
165.00	2.04	4.04	2.98	0.80	-0.07	-0.77	-2.21	-2.61
180.00	1.96	3.46	3.05	0.80	-0.06	-1.77	-4.12	-5.14
195.00	2.31	3.07	3.37	1.15	0.84	-1.64	-3.56	-5.01
210.00	2.88	2.89	3.71	1.90	2.06	-0.37	-1.46	-2.62
225.00	3.48	2.90	4.00	2.93	3.17	1.20	0.39	-0.48
240.00	4.02	3.09	4.07	3.93	3.93	2.48	1.81	1.07
255.00	4.38	3.23	4.03	4.72	4.40	3.38	2.76	2.16
270.00	4.42	3.48	3.83	5.00	4.35	3.80	3.07	2.57
285.00	4.30	3.70	3.69	4.94	3.71	3.59	2.73	2.27
300.00	3.95	3.82	3.54	4.46	2.63	2.88	1.62	1.36
315.00	3.49	3.87	3.14	3.51	1.05	1.54	-0.11	-0.25
330.00	3.00	3.91	2.68	2.21	-0.73	-0.44	-2.50	-2.44
345.00	2.61	3.77	2.33	0.90	-2.04	-3.01	-5.41	-5.40
360.00	2.50	3.33	2.22	0.33	-1.77	-4.33	-7.09	-8.52

(continuation of the "RP_2440.000_tot" table from column 9 ...)

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.00	-3.73	-0.51	2.21	-0.29	4.90
15.00	-2.91	-0.10	2.93	0.00	5.75
30.00	-1.74	1.12	3.87	1.29	6.12
45.00	-0.26	2.69	5.47	2.99	6.40
60.00	1.39	4.01	6.73	4.49	6.67
75.00	2.46	4.89	7.16	5.60	6.72
90.00	2.68	5.05	6.98	6.14	6.63
105.00	2.01	4.52	6.37	6.16	6.35
120.00	0.55	3.22	5.41	5.61	6.00
135.00	-1.20	1.21	3.94	4.34	5.71
150.00	-2.75	-0.82	2.16	2.44	5.38
165.00	-3.58	-1.48	1.09	0.58	5.07
180.00	-3.18	-1.27	2.17	0.20	4.85
195.00	-2.14	-0.56	3.94	1.07	4.84
210.00	-0.82	0.58	4.99	1.90	4.93
225.00	0.54	1.94	5.41	2.45	5.25
240.00	1.56	3.24	5.57	2.92	5.60
255.00	2.09	4.07	5.77	3.24	5.81
270.00	2.28	4.53	5.87	3.51	5.78
285.00	2.11	4.44	5.69	3.67	5.60
300.00	1.60	3.93	5.43	3.62	5.26
315.00	0.54	2.79	5.12	3.13	5.01
330.00	-0.80	1.32	4.72	2.17	4.91
345.00	-2.19	-0.11	4.03	0.84	5.02
360.00	-2.92	-1.16	3.27	1.83	5.38

RP_2440.000_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	2.46	3.50	2.56	-0.39	-1.86	-4.62	-7.64	-8.46
15.0	2.10	3.00	1.82	-0.99	-2.38	-4.61	-7.91	-8.88
30.0	1.23	1.80	1.12	-2.45	-3.02	-5.18	-8.68	-9.71
45.0	-0.54	-0.46	-0.28	-4.93	-4.38	-6.65	-10.02	-10.78

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)
60.0	-3.42	-4.40	-2.92	-8.80	-6.97	-9.73	-13.20	-12.72
75.0	-8.77	-12.45	-7.92	-16.12	-13.13	-16.14	-19.22	-14.37
90.0	-23.05	-13.18	-23.71	-15.34	-21.80	-18.74	-16.45	-12.91
105.0	-8.87	-4.42	-9.08	-8.35	-9.14	-9.95	-10.82	-9.46
120.0	-3.73	-0.50	-3.22	-4.83	-4.78	-5.83	-7.49	-7.06
135.0	-0.94	1.80	-0.07	-2.39	-2.29	-3.49	-5.47	-6.17
150.0	0.70	3.01	1.64	-0.75	-1.00	-2.50	-4.67	-6.36
165.0	1.64	3.51	2.59	0.35	-0.45	-2.15	-4.57	-6.97
180.0	1.93	3.41	2.97	0.73	-0.60	-2.32	-4.92	-8.13
195.0	1.62	2.80	2.74	0.40	-1.33	-2.90	-5.74	-9.73
210.0	0.69	1.56	1.87	-0.45	-2.64	-4.02	-7.13	-12.18
225.0	-1.09	-0.56	0.24	-1.99	-4.70	-6.09	-9.18	-16.57
240.0	-4.10	-4.04	-2.69	-4.47	-7.90	-9.20	-12.39	-24.63
255.0	-9.88	-11.73	-7.86	-9.43	-13.12	-14.82	-17.02	-18.40
270.0	-18.99	-17.78	-24.14	-17.07	-19.92	-24.99	-18.83	-13.15
285.0	-8.25	-5.97	-9.40	-9.09	-12.17	-14.23	-14.28	-10.46
300.0	-3.34	-1.71	-3.78	-4.63	-7.52	-9.59	-11.33	-8.93
315.0	-0.48	0.97	-0.82	-2.32	-4.71	-7.04	-9.32	-7.96
330.0	1.25	2.57	0.87	-1.08	-3.14	-5.63	-8.29	-7.62
345.0	2.12	3.40	1.83	-0.42	-2.35	-4.96	-7.67	-7.83
360.0	2.42	3.29	2.14	0.07	-2.09	-4.40	-7.40	-8.81

(continuation of the "RP_2440.000_hor" table from column 9 ...)

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.0	-3.80	-0.64	2.13	-0.39	4.87
15.0	-3.80	-1.10	2.30	-0.53	5.50
30.0	-4.92	-1.91	1.68	-0.54	4.97
45.0	-6.37	-3.01	1.02	-1.22	3.60
60.0	-8.79	-5.36	-0.83	-3.44	1.26
75.0	-13.40	-10.70	-5.01	-9.06	-3.14
90.0	-16.02	-24.99	-15.81	-21.22	-14.31
105.0	-9.79	-9.48	-9.74	-6.07	-8.81
120.0	-6.05	-5.07	-3.29	-1.87	-1.67
135.0	-4.35	-3.19	-0.69	-0.09	1.81
150.0	-3.81	-2.32	0.04	0.14	3.69
165.0	-3.67	-1.66	0.52	-0.05	4.61
180.0	-4.04	-1.60	1.89	0.17	4.82
195.0	-5.12	-2.35	2.99	0.55	4.47
210.0	-6.91	-3.54	2.73	0.21	3.55
225.0	-9.37	-5.27	1.09	-1.45	2.08
240.0	-13.43	-8.18	-1.69	-4.60	-0.23
255.0	-22.27	-14.65	-6.18	-11.26	-4.44
270.0	-15.82	-21.47	-14.80	-19.78	-13.26
285.0	-9.97	-10.27	-10.52	-7.24	-10.29
300.0	-6.66	-6.13	-3.93	-2.95	-2.98
315.0	-4.80	-3.74	-0.16	-0.66	0.82
330.0	-3.73	-2.36	2.16	0.26	3.03
345.0	-3.29	-1.34	3.24	0.20	4.44
360.0	-3.09	-1.31	3.10	1.78	5.26

RP_2440.000_ver

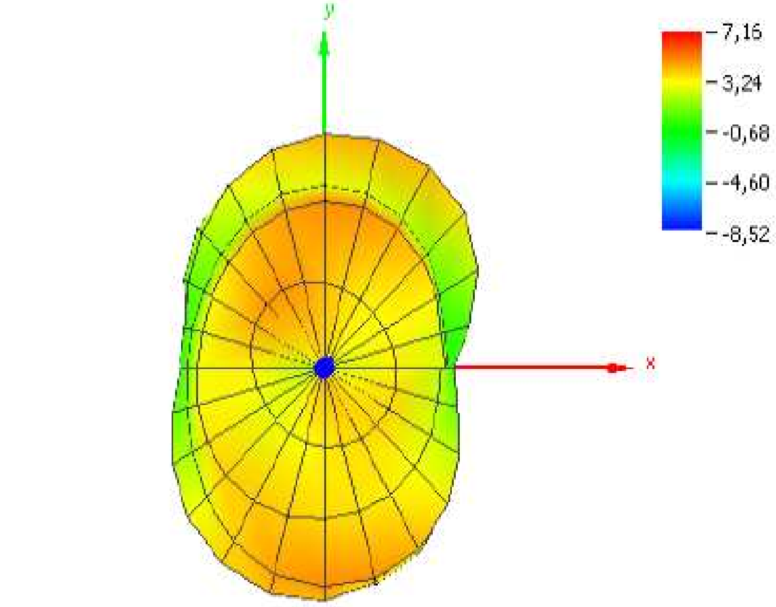
Azimuth (deg)	Elevation 0 deg (dB)	Elevation 15 deg (dB)	Elevation 30 deg (dB)	Elevation 45 deg (dB)	Elevation 60 deg (dB)	Elevation 75 deg (dB)	Elevation 90 deg (dB)	Elevation 105 deg (dB)
0.0	-16.24	-15.30	-14.07	-12.74	-9.39	-16.57	-19.03	-17.00
15.0	-6.29	-7.19	-5.36	-7.18	-2.82	-8.34	-8.08	-10.17
30.0	-1.32	-2.15	-0.63	-2.41	0.74	-3.29	-3.09	-4.66
45.0	1.25	0.92	2.03	0.36	2.89	-0.37	-0.15	-1.45
60.0	2.73	2.77	3.76	1.94	4.03	1.38	1.72	0.60
75.0	3.59	3.79	4.74	2.71	4.51	2.42	2.94	2.06
90.0	3.78	4.23	4.97	2.79	4.44	2.86	3.55	2.87
105.0	3.38	4.19	4.54	2.35	3.73	2.76	3.49	2.89
120.0	2.41	3.43	3.43	1.16	2.34	2.01	2.75	2.18
135.0	0.60	1.88	1.42	-0.83	-0.11	0.48	1.06	0.89

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)
150.0	-2.52	-0.71	-1.78	-3.78	-3.96	-2.22	-1.64	-1.22
165.0	-8.57	-5.40	-7.71	-9.31	-10.91	-6.41	-5.99	-4.60
180.0	-19.27	-16.17	-14.44	-17.57	-9.40	-11.04	-11.84	-8.17
195.0	-6.04	-9.18	-5.32	-6.82	-3.21	-7.66	-7.61	-6.79
210.0	-1.15	-2.89	-0.93	-1.89	0.25	-2.82	-2.83	-3.13
225.0	1.61	0.30	1.62	1.23	2.39	0.30	-0.12	-0.59
240.0	3.29	2.16	3.05	3.25	3.64	2.17	1.64	1.06
255.0	4.21	3.09	3.74	4.55	4.32	3.31	2.72	2.12
270.0	4.40	3.45	3.83	4.98	4.34	3.79	3.05	2.46
285.0	4.05	3.21	3.47	4.77	3.60	3.51	2.65	2.03
300.0	3.06	2.39	2.65	3.89	2.19	2.63	1.40	0.94
315.0	1.26	0.75	0.91	2.20	-0.29	0.89	-0.66	-1.05
330.0	-1.77	-1.86	-2.00	-0.55	-4.43	-2.01	-3.83	-4.01
345.0	-7.13	-7.05	-7.29	-4.90	-13.68	-7.43	-9.32	-9.08
360.0	-14.78	-17.46	-14.83	-12.08	-13.25	-22.26	-18.79	-20.43

(continuation of the "RP_2440.000_ver" table from column 9 ...)

Azimuth (deg)	Elevation 120 deg (dB)	Elevation 135 deg (dB)	Elevation 150 deg (dB)	Elevation 165 deg (dB)	Elevation 180 deg (dB)
0.0	-21.46	-15.86	-15.13	-16.83	-16.42
15.0	-10.23	-6.95	-5.71	-9.45	-6.75
30.0	-4.60	-1.87	-0.15	-3.33	-0.20
45.0	-1.47	1.33	3.54	0.91	3.17
60.0	0.96	3.48	5.89	3.73	5.20
75.0	2.35	4.77	6.89	5.45	6.24
90.0	2.62	5.04	6.96	6.13	6.60
105.0	1.72	4.35	6.26	5.89	6.22
120.0	-0.52	2.52	4.78	4.76	5.19
135.0	-4.08	-0.76	2.10	2.41	3.44
150.0	-9.39	-6.17	-1.97	-1.41	0.46
165.0	-20.60	-15.42	-7.97	-8.14	-4.88
180.0	-10.64	-12.61	-9.92	-21.49	-17.64
195.0	-5.18	-5.25	-3.15	-8.41	-6.05
210.0	-2.04	-1.55	1.07	-3.00	-0.71
225.0	0.08	1.02	3.40	0.17	2.40
240.0	1.43	2.92	4.67	2.07	4.29
255.0	2.07	4.01	5.48	3.08	5.38
270.0	2.21	4.52	5.83	3.49	5.72
285.0	1.84	4.29	5.58	3.31	5.48
300.0	0.90	3.48	4.90	2.54	4.55
315.0	-0.96	1.70	3.59	0.79	2.93
330.0	-3.90	-1.11	1.21	-2.31	0.39
345.0	-8.71	-6.18	-3.76	-7.75	-3.98
360.0	-17.11	-15.66	-10.93	-18.19	-10.27

Theta = 0, Phi = 0



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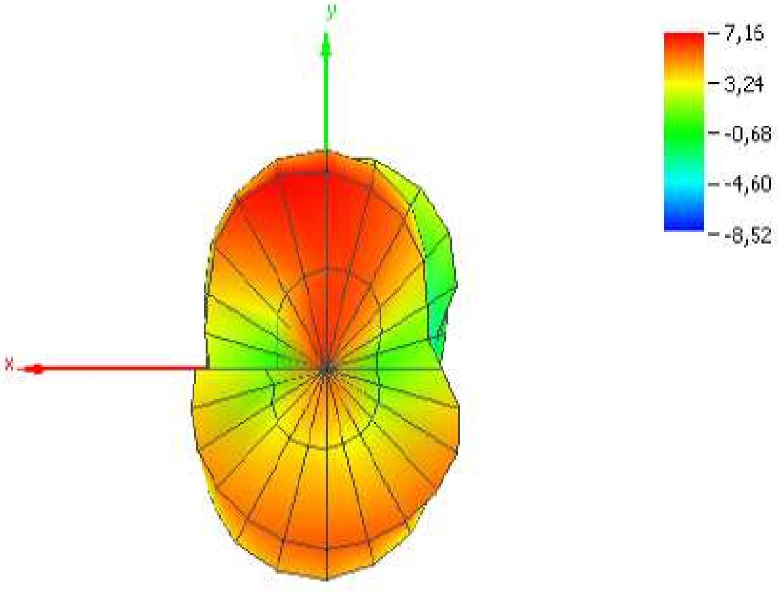

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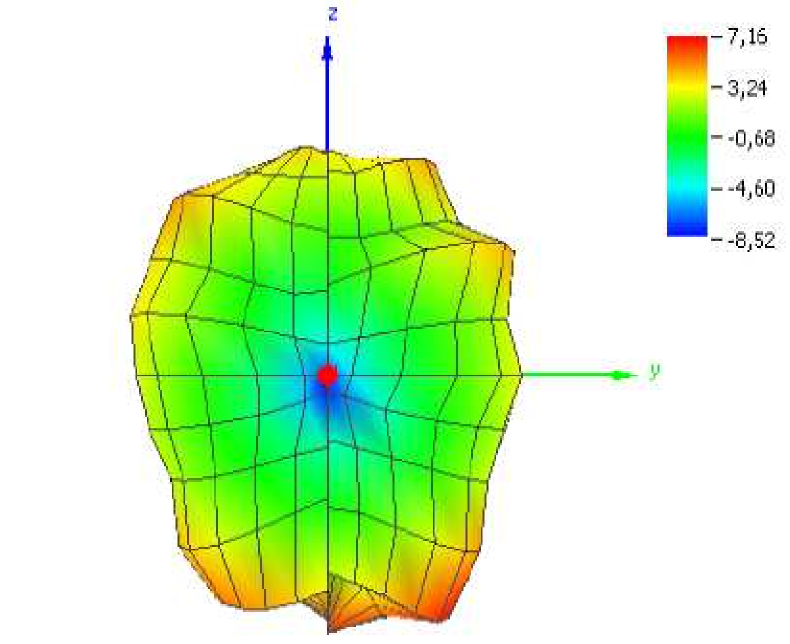

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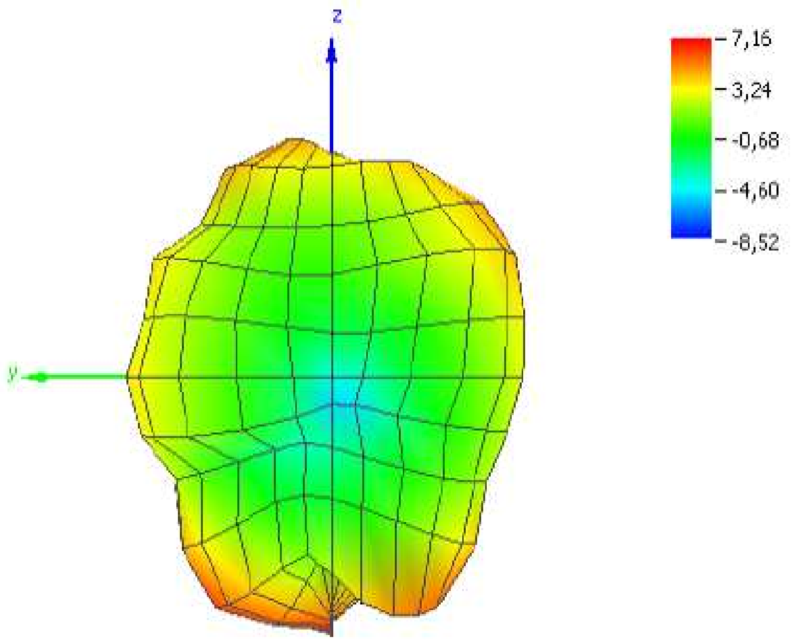

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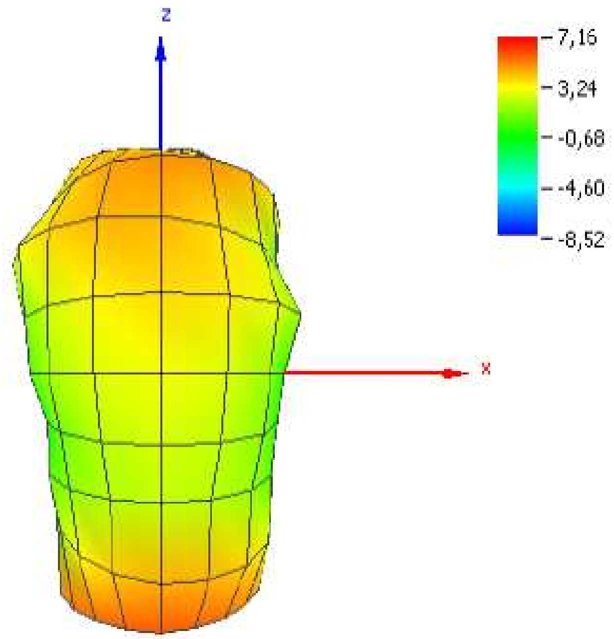

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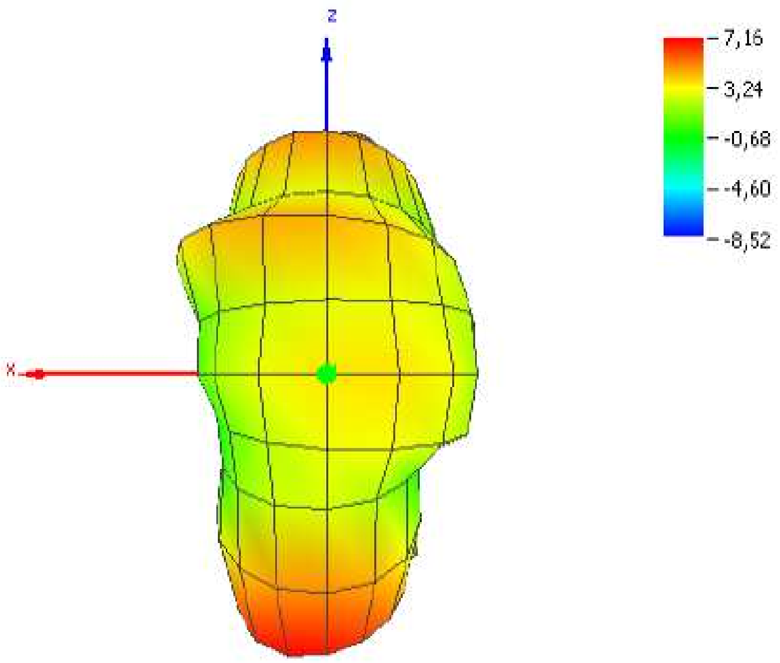

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