868 MHz, 915 MHz and 955 MHz Monopole PCB Antenna

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Keywords

- CC1000
- CC1010
- CC1020
- CC1021
- CC1050
- CC1070
- CC1100
- CC1101
- CC1100E
- CC1150
- CC430
- PCB Antenna
- 868 MHz
- 915 MHz
- 955 MHz
- Monopole

1 Introduction

This document describes a PCB antenna designed for operation in the 868 MHz, 915 MHz and 955 MHz ISM bands. This antenna can be used with all transceivers and transmitters from Texas Instruments, which operates in these frequency bands. Maximum gain is measured to be 4.6 dB and overall size requirements for this antenna are 39 x 37 mm. Thus this is a medium size, low cost antenna solution. Figure 1 shows a picture the board being used to develop and characterize this antenna. The board is pin compatible with CC1100EM and can be plugged into SmartRF®04EB for test and characterization purpose.

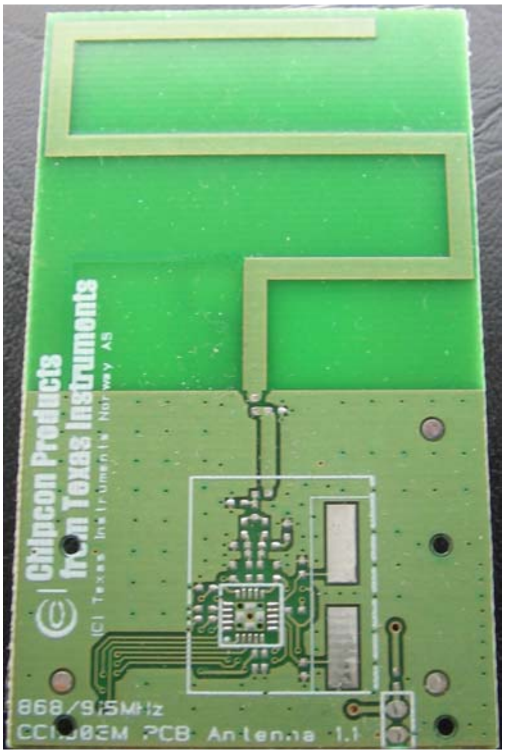

Figure 1. Prototype Board for 868 MHz, 915 MHz and 955 MHz PCB Antenna

Table of Contents

KEYWORDS **1**
1 INTRODUCTION **1**
2 ABBREVIATIONS **2**
3 DESCRIPTION OF THE PCB ANTENNA **3**
3.1 IMPLEMENTATION OF THE BENT MONOPOLE ANTENNA 3
4 RESULTS **5**
4.1 RADIATION PATTERN 5
4.2 BANDWIDTH 13
4.3 HARMONIC EMISSION 13
5 CONCLUSION **14**
6 REFERENCES **15**
7 GENERAL INFORMATION **16**
7.1 DOCUMENT HISTORY 16

2 Abbreviations

CF	Correction Factor
EM	Evaluation Module
ISM	Industrial, Scientific, Medical
PCB	Printed Circuit Board
RF	Radio Frequency

3 Description of the PCB Antenna

The antenna described in this document is a bent monopole. Since the impedance of this antenna is approximately matched to 50 ohm no external matching components are needed. The size of the ground plane affects the impedance of the antenna. Thus the length of the antenna should be tuned according to the size of the ground plane. Experiments show that a smaller ground plane requires a longer antenna. This PCB antenna reference design has included the option for one series and one shunt capacitors, at the feed point of the antenna. These can be used to compensate for detuning caused by plastic encapsulation and other object in the vicinity of the antenna. For further information on impedance matching and impedance measurements, see DN001 Antenna Measurement with Network Analyzer [1] and ISM-Band and Short Range Device Antennas [2].

For test purpose the antenna has been implemented on an evaluation module that can be plugged into SmartRF®04EB. Plugging the EM into SmartRF®04EB increases the size of the ground plane. Therefore the silk print layer on the reference designs has two markings showing the recommended lengths of the antenna, dependent on the EM is plugged into SmartRF04®EB or not.

3.1 Implementation of the Bent Monopole Antenna

To obtain optimum performance it is important to make an exact copy of the antenna dimensions. The antenna was implemented on a 1 mm thick, FR4 substrate. Since there is no ground plane beneath the antenna the PCB thickness is not critical, but if a different thickness is being used it might be necessary to tune the length of the antenna to obtain optimum performance.

The easiest approach to implement the antenna in a PCB CAD tool is to import the antenna layout from either a gerber or DXF file. Such files are included in the CC1100EM PCB Antenna Reference Design [3]. The gerber file is called “antenna.spl” and the DXF file is called “antenna.dxf”. If the antenna is implemented on a PCB that is wider than the antenna it is important to avoid placing component or having a ground plane close to each side of the antenna. If the CAD tool being used doesn’t support import of gerber or DXF files, Figure 2 and Table 1 can be used.

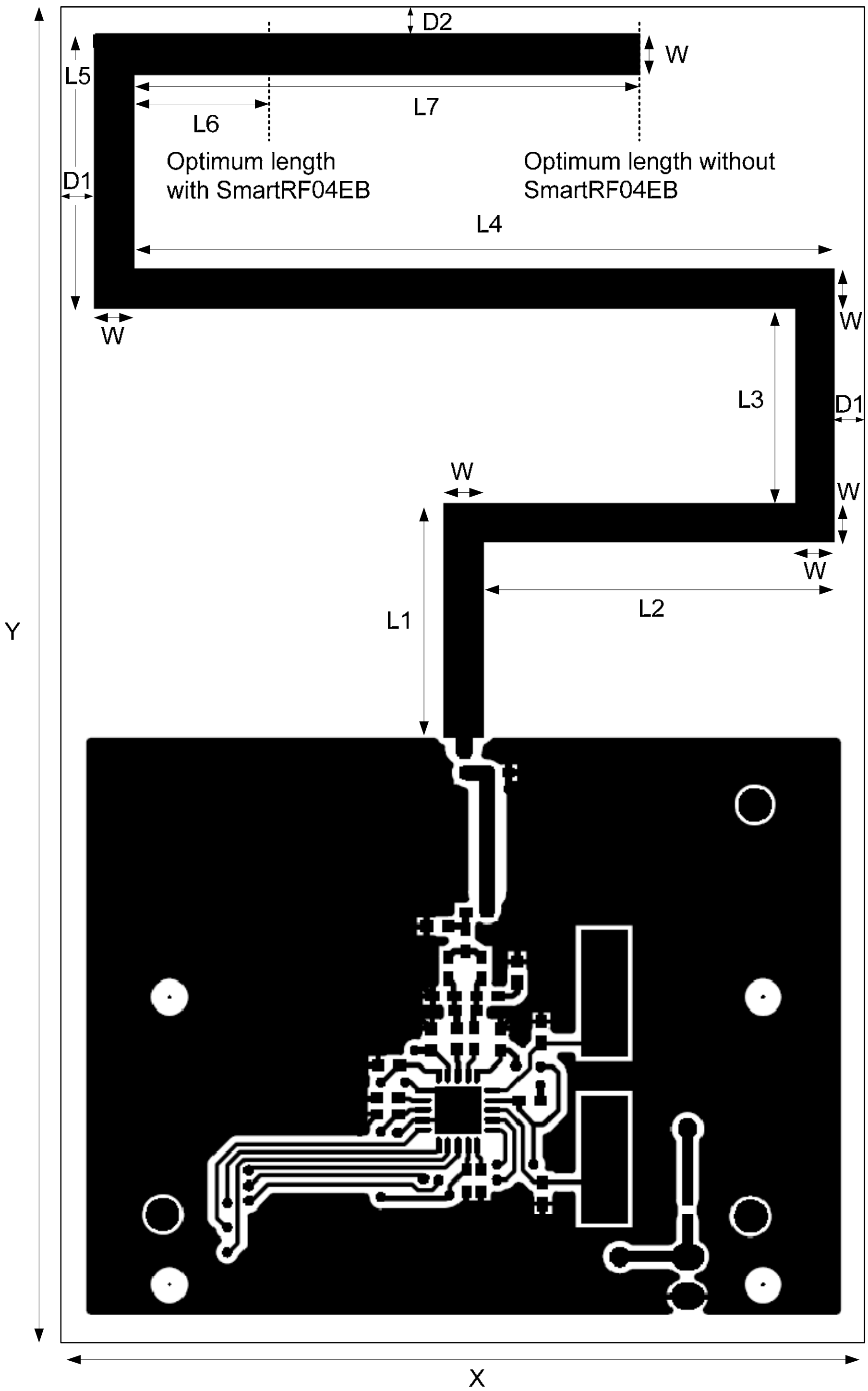

Figure 2. Antenna Dimensions

D1	0.5 mm	L5	14.0 mm
D2	1.0 mm	L6	7.0 mm
L1	12.0 mm	L7	26.0 mm
L2	18.0 mm	X	39.0 mm
L3	10.0 mm	Y	67.0 mm
L4	36.0 mm	W	2.0 mm

Table 1. Antenna Dimensions

4 Results

Measurement results are presented in this section. Notice that the performance will be affected by the size and shape of the ground plane.

4.1 Radiation Pattern

Figure 3 shows how to relate the radiation patterns in this section to the orientation of the antenna. The pictures in Figure 3 shows how the board was placed when measuring the different planes. For all measurements the board was turned around a vertical axis and 0° corresponds to the direction out of the picture and. The radiation patterns were measured with 0 dBm output power.

Notice that the size of the ground plane will affect the radiation pattern. Thus implementing this antenna on a board with a different size and shape of the ground plane will most likely affect the radiation pattern. To investigate how the size of the ground plane influences the radiation patter, measurements were also performed without connecting the module to SmartRF®04EB. To be able to do such measurements the antenna was implemented on a board with CC1110. This board has the same ground plane size as the CC1100 board and was powered by two AA batteries. By comparing Figure 14 and Figure 15 it can be seen how the ground plane affects the radiation pattern. When the PCB antenna board is connected to SmartRF®04EB the asymmetric ground plane will result in higher gain in the direction of the extended ground plane, see Figure 14. Figure 15 show that a more symmetrical ground plane results in a lower peak gain and a more omni directional radiation pattern.

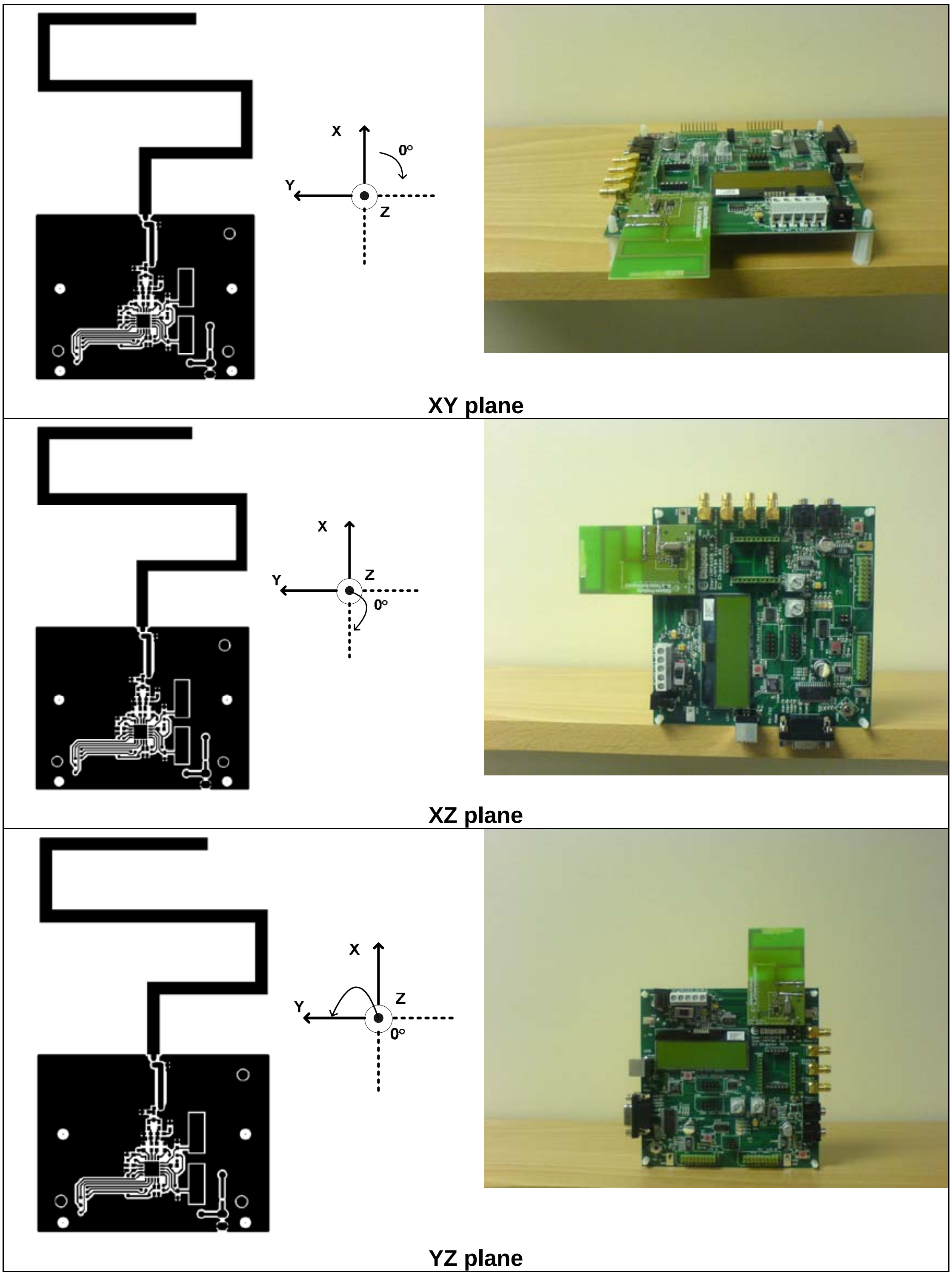

Figure 3. How to Relate the Antenna to the Radiation Patterns

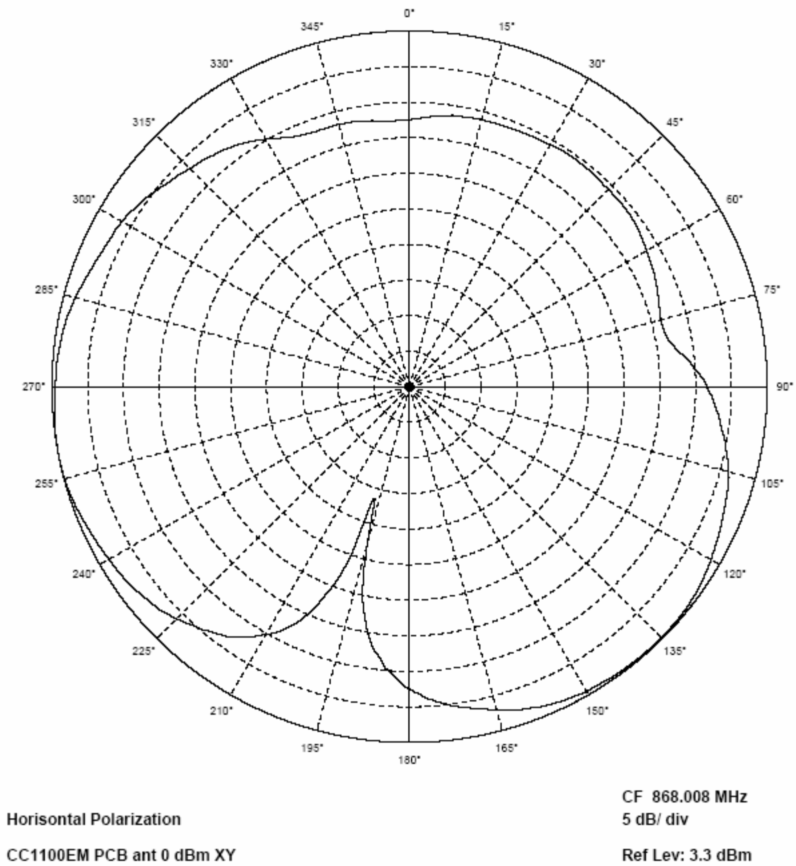

Figure 4. XY Plane Horizontal Polarization, Measured with SmartRF®04EB

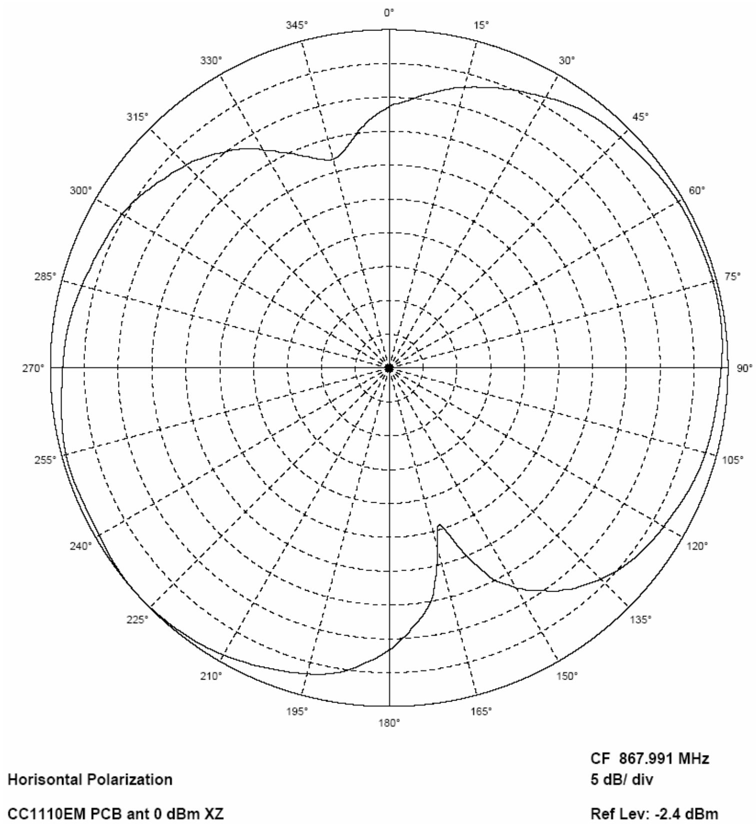

Figure 5. XY Plane Horizontal Polarization, Measured without SmartRF®04EB

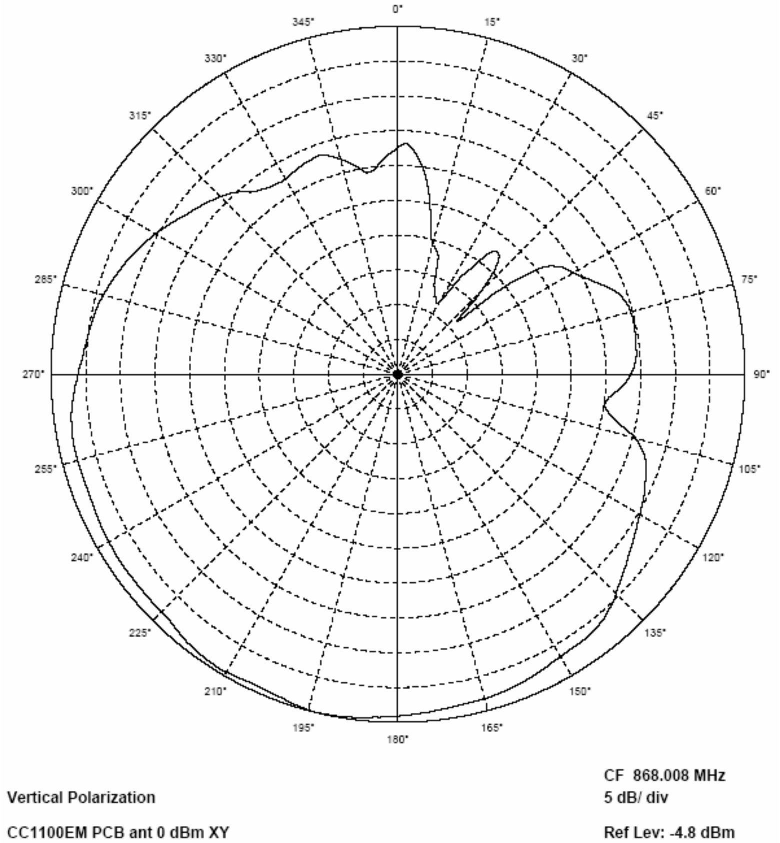

Figure 6. XY Plane Vertical Polarization, Measured with SmartRF®04EB

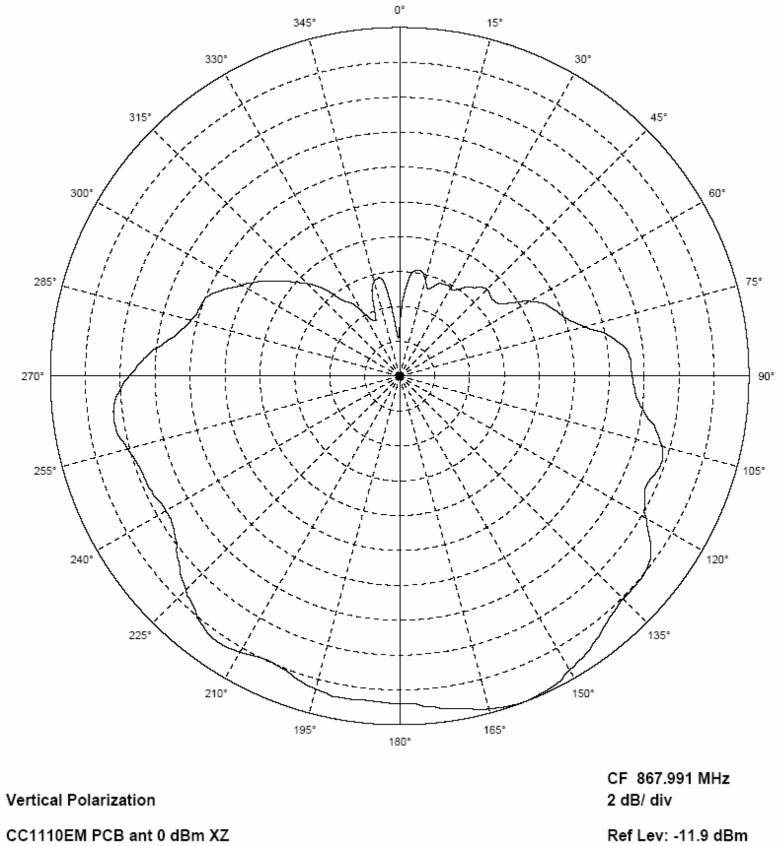

Figure 7. XY Plane Vertical Polarization, Measured without SmartRF®04EB

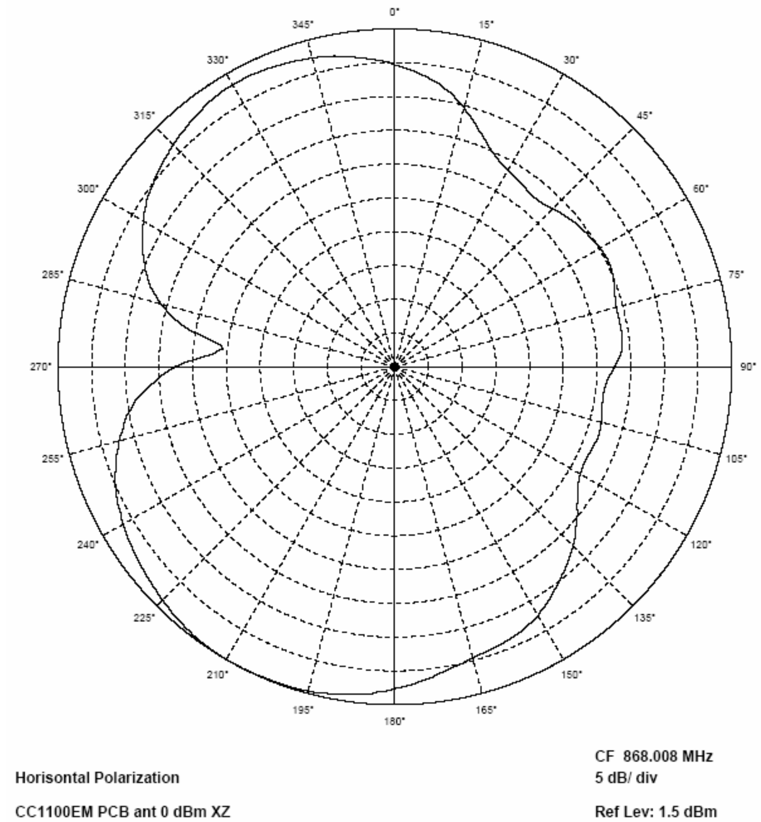

Figure 8. XZ Plane Horizontal Polarization, Measured with SmartRF®04EB

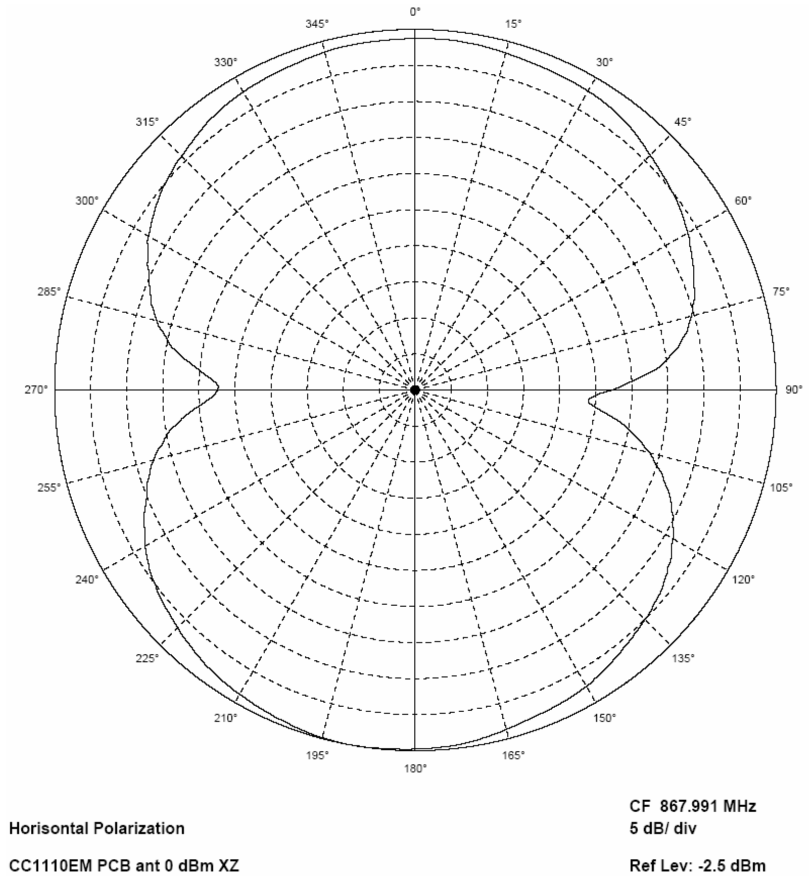

Figure 9. XZ Plane Horizontal Polarization, Measured without SmartRF®04EB

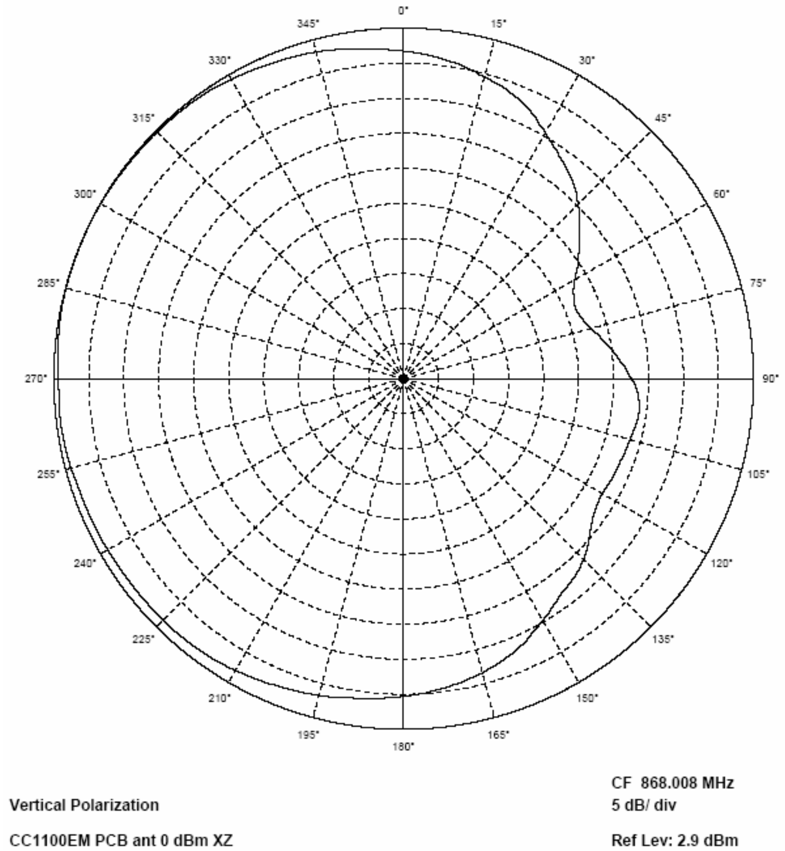

Figure 10. XZ Plane Vertical Polarization, Measured with SmartRF®04EB

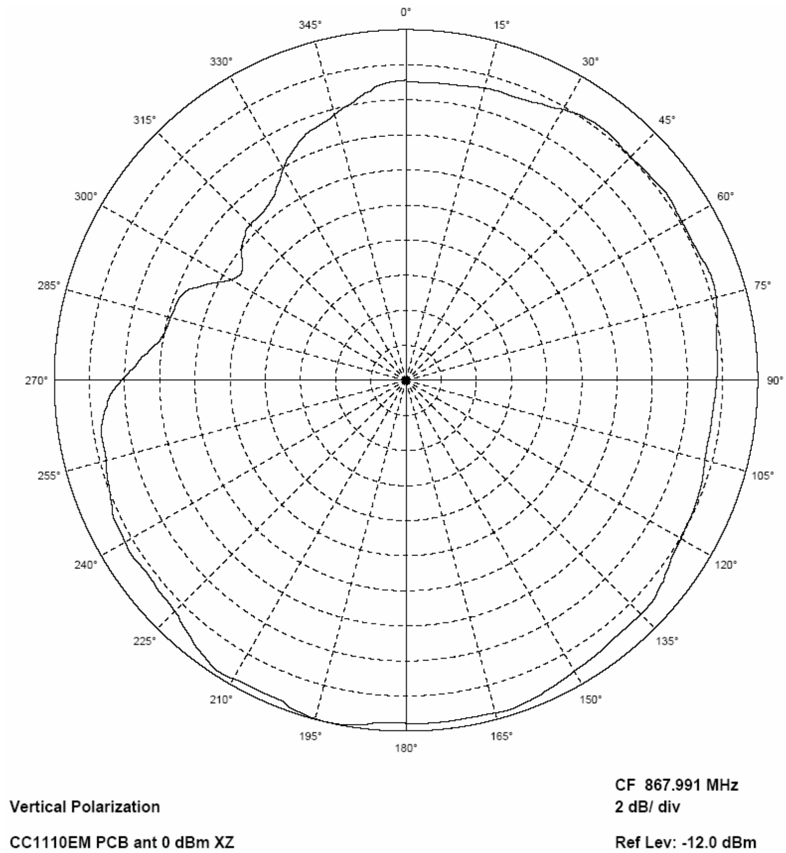

Figure 11. XZ Plane Vertical Polarization, Measured without SmartRF®04EB

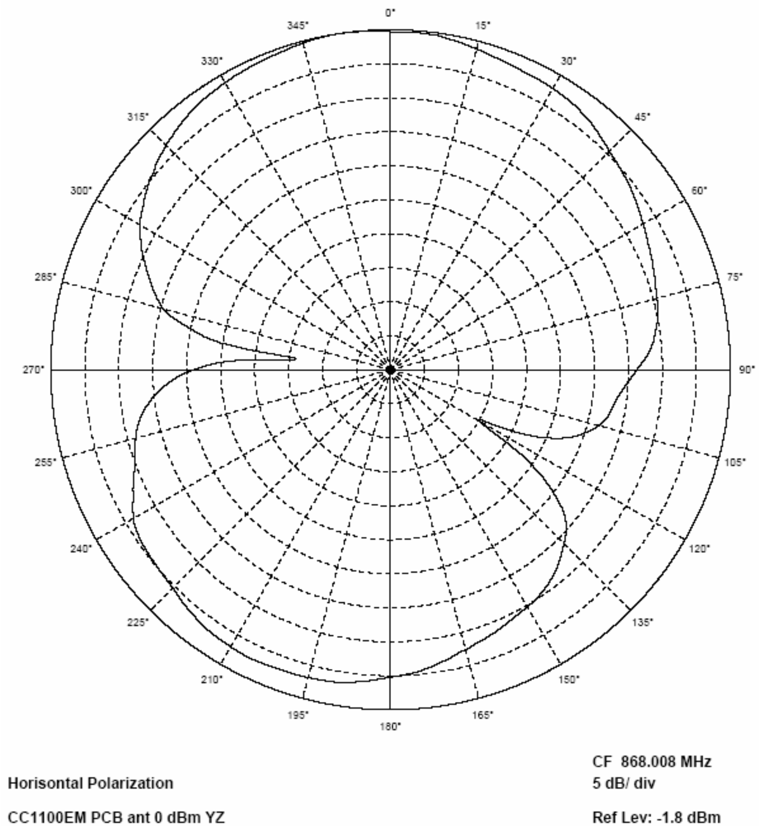

Figure 12. YZ Plane Horizontal Polarization, Measured with SmartRF®04EB

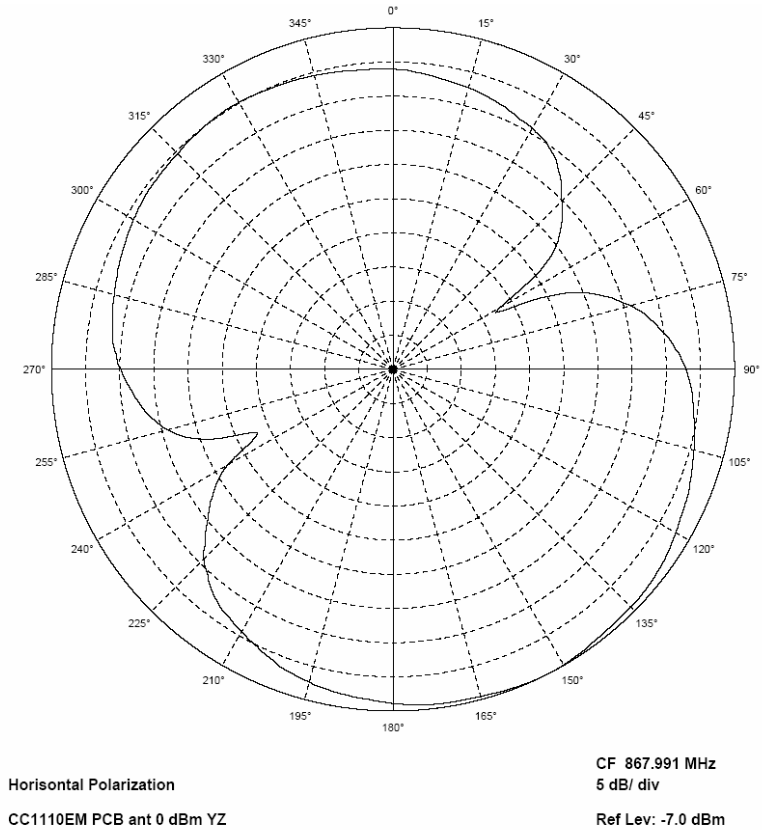

Figure 13. YZ Plane Horizontal Polarization, Measured without SmartRF®04EB

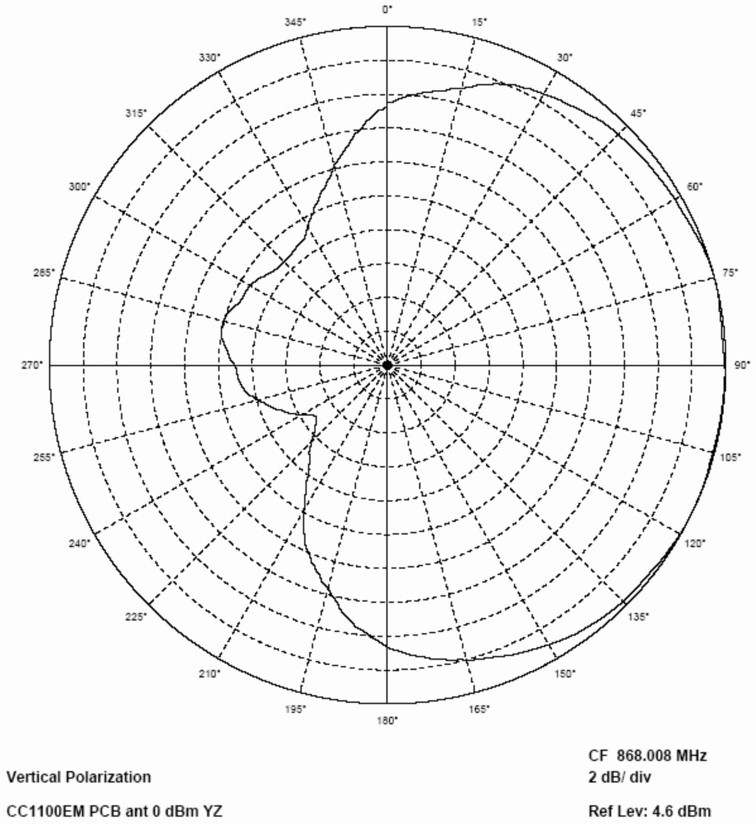

Figure 14. YZ Plane Vertical Polarization, Measured with SmartRF®04EB

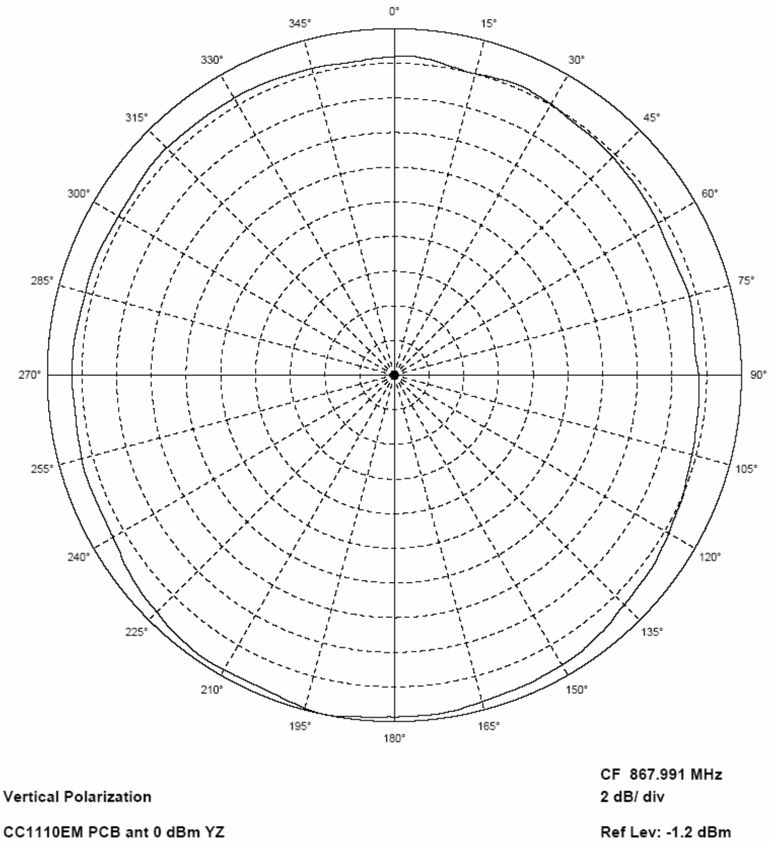

Figure 15. YZ Plane Vertical Polarization, Measured without SmartRF®04EB

4.2 Bandwidth

To measure the bandwidth of the antenna a small test program, stepping a 0 dBm carrier from 780 MHz to 950 MHz, was used. By using the “Max Hold” option on the spectrum analyzer it is possible to see how the output power varies across frequency when using this test program. Figure 16 show that the antenna described in this document has an approximately constant performance across both the 868 MHz and 915 MHz ISM bands. The antenna can also be used for 955 MHz but then the total length of the antenna has to be reduced more than the length specified for 915 MHz. Notice that the bandwidth characteristic is dependent on direction and polarization. The result shown in Figure 16 is based on a measurement performed with the PCB vertically oriented and the antenna pointing towards a horizontal polarized receiving antenna.

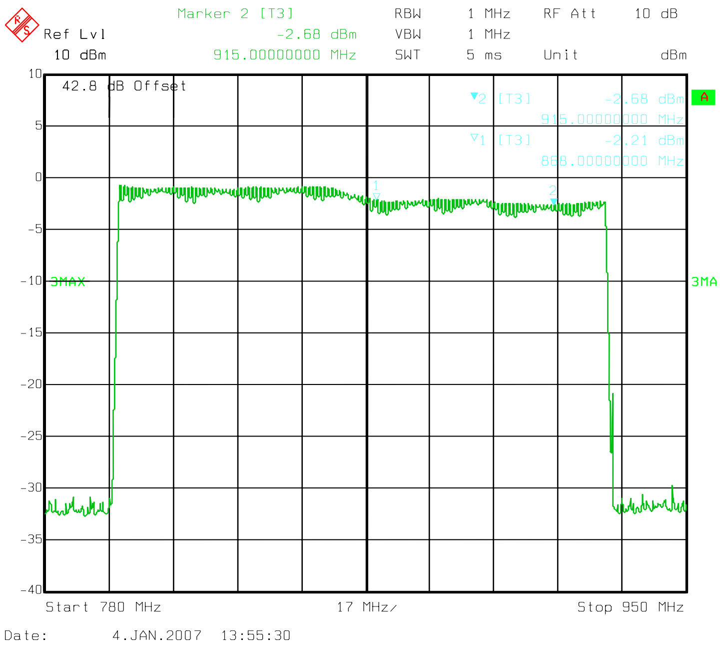

Figure 16. Bandwidth of Antenna

4.3 Harmonic Emission

Measurement of harmonic emission was done according to FCC requirements and performed with 10 dBm output power. All measurements of harmonic emission were conducted with the CC1100 PCB antenna board mounted on SmartRF®04EB. Table 2 shows the measurement results and FCC limits. Above 1 GHz, FCC allows the radiation to be up to 20 dB above the limits given in Table 2, if duty cycling is being used. The harmonic frequencies that would require duty cycling to be used are shaded with gray in Table 2. The second harmonic would only be an issue when qualifying under FCC part 15.249 since 15.247 only requires 20 dBc. Notice that programmed output power and size of the ground plane will affect the level of the harmonics and thus determine the necessary duty cycling.

	2. harm	3. harm	4. harm	5. harm	6. harm	7. harm	8. harm	9. harm
Limit: FCC 249	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m
Limit: FCC 247	20 dBc	54 dBµV/m	54 dBµV/m	54 dBµV/m	20 dBc	20 dBc	54 dBµV/m	54 dBµV/m
Measured	61.3 dBuV/m	61.5 dBµV/m	35.0 dBµV/m	50.4 dBµV/m	59.9 dBµV/m	58.2 dBµV/m	62.5 dBµV/m	48.0 dBµV/m

Table 2. Measured Harmonic Emission According to FCC Requirement

The allowed additional emission, or correction factor, is calculated based on maximum transmission time during 100 ms. Equation 1 can be used to calculate the correction factor, where t is equal to maximum transmission time during 100 ms. Using Equation 1 it can be calculated that a maximum transmission time of 50 ms, during 100 ms, will permit all radiation above 1 GHz to be 6 dB above the given limits.

$$CF = -20 \bullet \log\left(\frac{t}{100ms}\right)$$

Equation 1: FCC Correction Factor.

The dBm results in Table 3 are converted from dBμV/m by subtracting 95. Since the measurement setup for ETSI and FCC is different this conversion will not give an exact result, but typically it will give a result that are within 1-2 dB of a correct ETSI measurement.

	2. harm	**3. harm**	**4. harm**	**5. harm**	**6. harm**	**7. harm**	**8. harm**	**9. harm**
Limit: ETSI	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm
Measured	-33.7 dBm	-33.5 dBm	-60.0 dBm	-44.6 dBm	-35.1 dBm	-36.8 dBm	-32.5 dBm	-47.0 dBm

Table 3. FCC Results, Converted to dBm

5 Conclusion

The antenna proposed in this design note can be used for both 868 MHz and 915 MHz operation. The antenna can also be used for 955 MHz but then the total length of the antenna has to be reduced more than the length specified for 915 MHz. Measurement results show that it is possible to comply with both ETSI and FCC limits by using this design. If CC1100 is used at full output power duty cycling must be used for FCC compliance. Required board size for this antenna is 39 x 37 mm and maximum gain is between 2.9 dB and 4.6 dB, dependent on direction. Measurements of radiation pattern show that the gain is influenced by the size and shape of the ground plane. A large and asymmetrical ground plane results in higher gain and higher directivity than a small and symmetrical ground plane.

Antenna Size	39 x 37 mm	
	With SmartRF®04EB	Without SmartRF®04EB
Max Gain in XY Plane	3.3 dB	-2.4 dB
Max Gain in XZ Plane	2.9 dB	-2.5 dB
Max Gain in YZ Plane	4.6 dB	-1.2 dB

Figure 17. Key Parameters

6 References

[1] DN001 Antenna Measurement with Network Analyzer (swra096.pdf)

[2] ISM-Band and Short Range Device Antennas (swra046.pdf)

[3] CC1100EM PCB Antenna Reference Design (swru122.zip)

7 General Information

7.1 Document History

Revision	Date	Description/Changes
SWRU121B	2009.08.20	Added CC430 to list of devices
SWRU121A	2009.03.17	Removed logo from header. Updated with 955 MHz.
SWRU121	2007.04.16	Initial release.