

## 868 MHz, 915 MHz and 955 MHz Inverted F Antenna

By Fredrik Kervel

### Keywords

- CC10xx
- CC110x
- CC111x
- CC112x
- CC1150
- CC1175
- CC1100E
- CC11xL
- PCB Antenna
- 868 MHz
- 915 MHz
- 955 MHz
- Inverted F Antenna
- IFA

### 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  $-0.12$  dB and overall size requirements for this antenna are 43 x 20 mm. Thus this is

a medium size, low cost antenna solution. Figure 1 shows a picture of the board being used to develop and characterize this antenna. The board is pin compatible with CC1110 EM and is equipped with two LEDs, a push button, a 10-pin debug connector and a 2-pin power connector for test and characterization purpose.

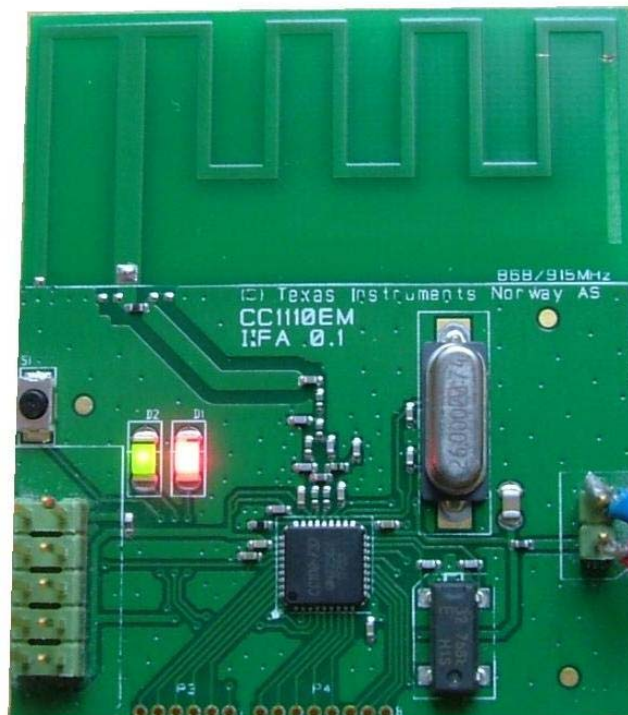


Figure 1. Prototype Board for 868 MHz, 915 MHz, and 955 MHz PCB Antenna

## Table of Contents

KEYWORDS.....	1
<b>1 INTRODUCTION.....</b>	<b>1</b>
<b>2 ABBREVIATIONS.....</b>	<b>2</b>
<b>3 DESCRIPTION OF THE PCB ANTENNA.....</b>	<b>3</b>
3.1 IMPLEMENTATION OF THE INVERTED F ANTENNA.....	3
<b>4 RESULTS.....</b>	<b>5</b>
4.1 RADIATION PATTERN.....	5
4.2 REFLECTION.....	9
4.3 BANDWIDTH.....	10
4.4 HARMONIC EMISSION.....	11
4.5 RANGE.....	12
<b>5 CONCLUSION.....</b>	<b>12</b>
<b>6 REFERENCES.....</b>	<b>13</b>
<b>7 GENERAL INFORMATION.....</b>	<b>13</b>
7.1 DOCUMENT HISTORY.....	13

## 2 Abbreviations

CAD	Computer Aided Design
CF	Correction Factor
dB	decibel
EB	Evaluation Board
EM	Evaluation Module
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FR-4	Flame Retardant 4
GHz	Giga Hertz
IFA	Inverted F Antenna
I/O	Input/Output
ISM	Industrial, Scientific, Medical
kBaud	kilo Baud
LED	Light Emitting Diode
MHz	Mega Hertz
mm	millimeter
PA	Power Amplifier
PCB	Printed Circuit Board
PER	Packet Error Rate
RF	Radio Frequency

## 3 Description of the PCB Antenna

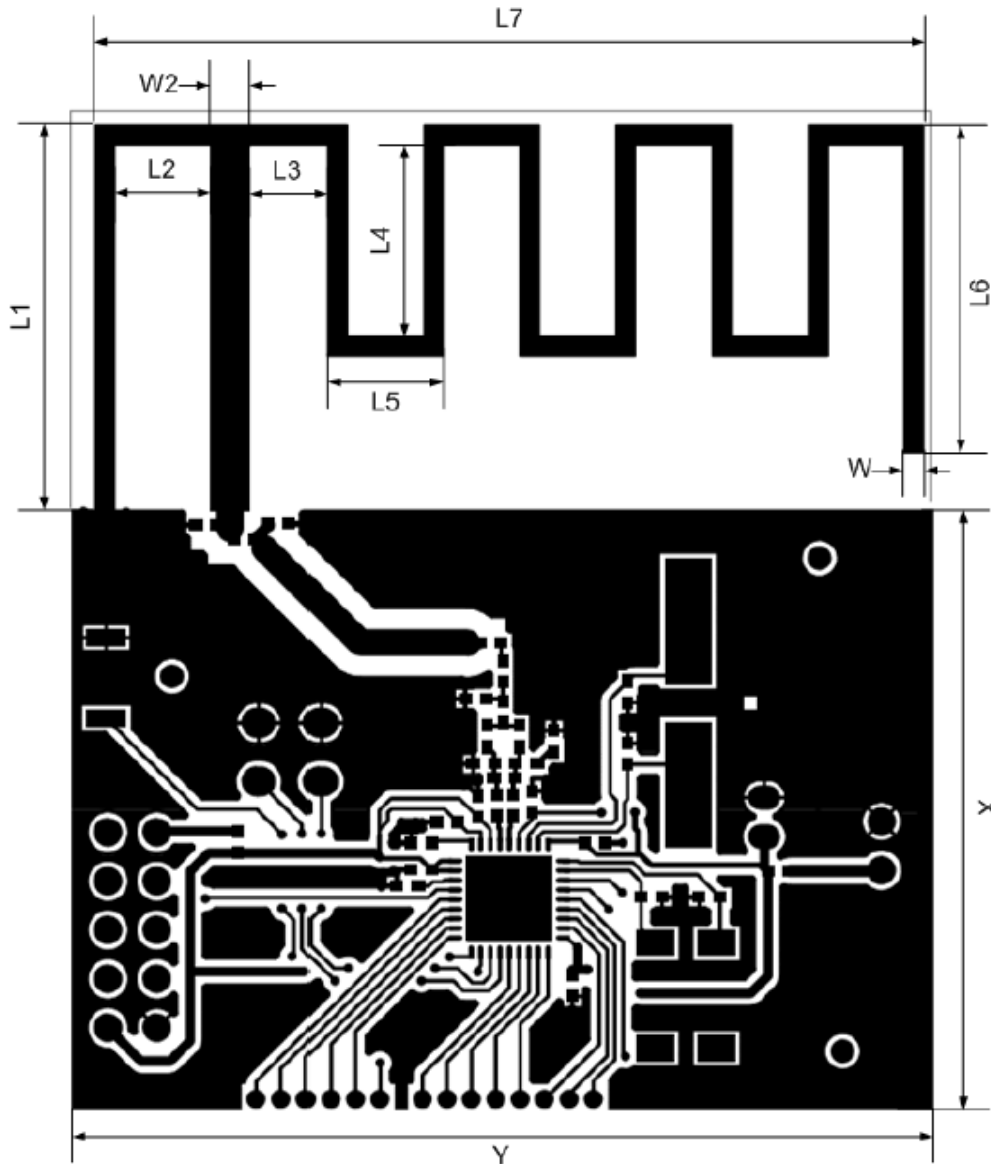
The antenna described in this document is an inverted F antenna. Since the impedance of this antenna is approximately matched to 50 ohm, no external matching components are needed. The size of the ground plane affects the impedance of the antenna. This PCB antenna reference design has included the option for one series and two shunt components 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 AN058 Antenna Selection Guide [1].

For test purpose the antenna has been implemented on an evaluation module equipped with two LEDs and a push button for running small test programs. The evaluation module can be connected to SmartRF04EB via a 10-pin debug cable for programming. The module is also equipped with a two pin power connector (3 volt) and soldering points for the chip's I/O-ports. The external power must be disconnected when the module is connected to SmartRF04EB.

### 3.1 Implementation of the Inverted F Antenna

To obtain optimum performance it is important to make an exact copy of the antenna dimensions. The antenna was implemented on a 0.8 mm thick FR-4 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.

One approach to implement the antenna in a PCB CAD tool is to import the antenna layout from a Gerber file. Such a file is included in the CC1110EM IIFA Reference Design [2], and is called "antenna.spl". If the antenna is implemented on a PCB that is wider than the antenna, it is important to avoid placing components or having a ground plane close (minimum 5 mm) to each side of the antenna. If the CAD tool being used does not support import of Gerber files, Figure 2 and Table 1 can be used.



**Figure 2. Antenna Dimensions**

L1	20.0 mm	L7	43.0 mm
L2	5.0 mm	X	31.0 mm
L3	4.0 mm	Y	45.0 mm
L4	10.0 mm	W	1.0 mm
L5	6.0 mm	W2	2.0 mm
L6	17.0 mm		

**Table 1. Antenna Dimensions**

Optimum length for L6 is dependent on the geometry and size of the ground plane. With the ground plane shown Figure 2 (31 x 45 mm) L6 should be approx. 9 mm for 868 MHz and 1 mm for 915 MHz. 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. Bigger ground planes might require additional tuning.

## 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  $0^\circ$  corresponds to the direction out of the picture and. The radiation patterns were measured with 10 dBm output power.

Notice that the size of the ground plane will affect the radiation pattern, hence implementing this antenna on a board with a different size and shape of the ground plane will most likely affect the radiation pattern. These measurements were performed with the small ground plane shown in Figure 2.

The values in the plots of the antenna patterns are in dBm and represents gain relative to 10 dBm and 5 dBm in the plot equals a gain of  $-5$  dB, etc.

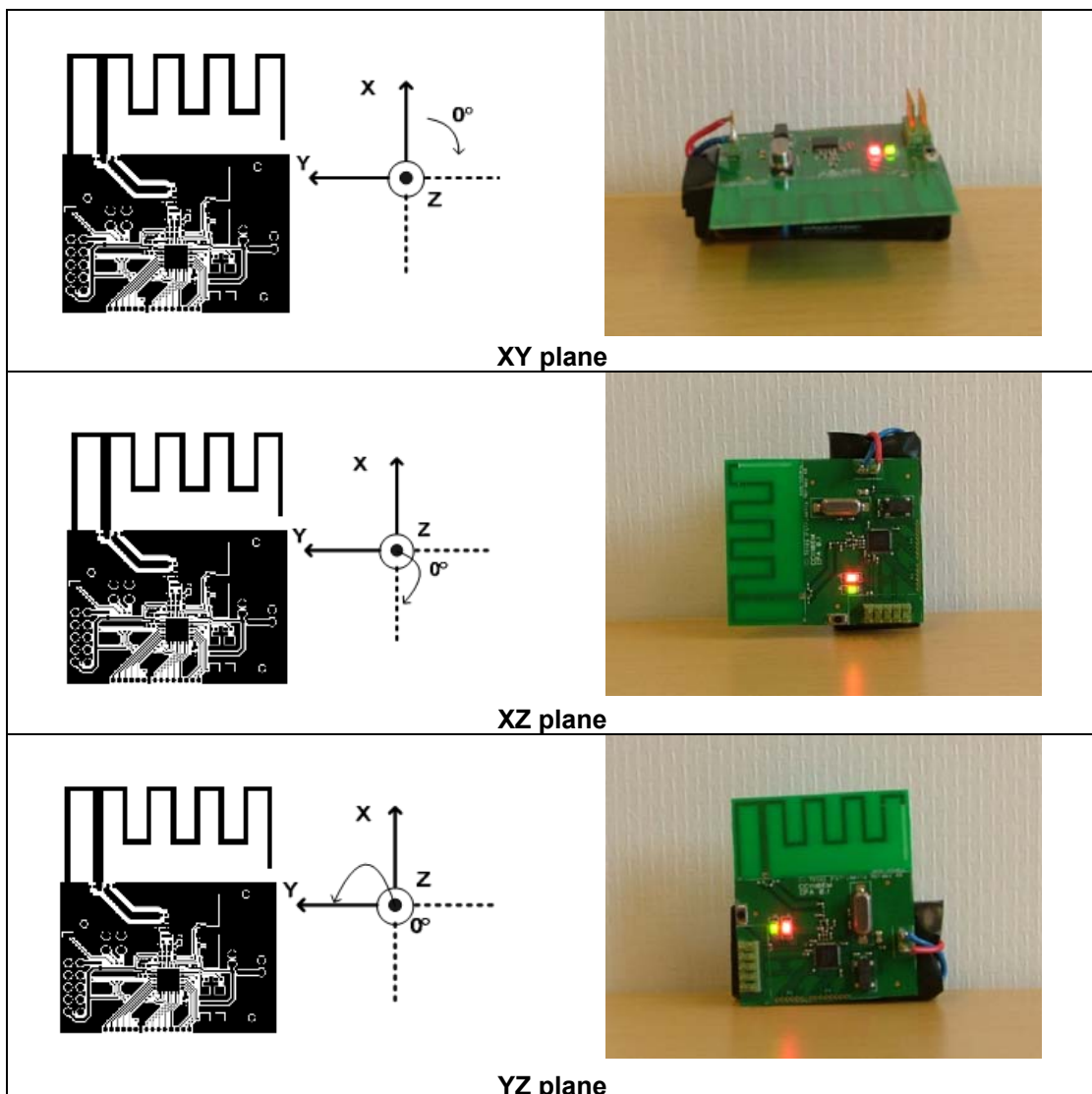


Figure 3. How to Relate the Antenna to the Radiation Patterns

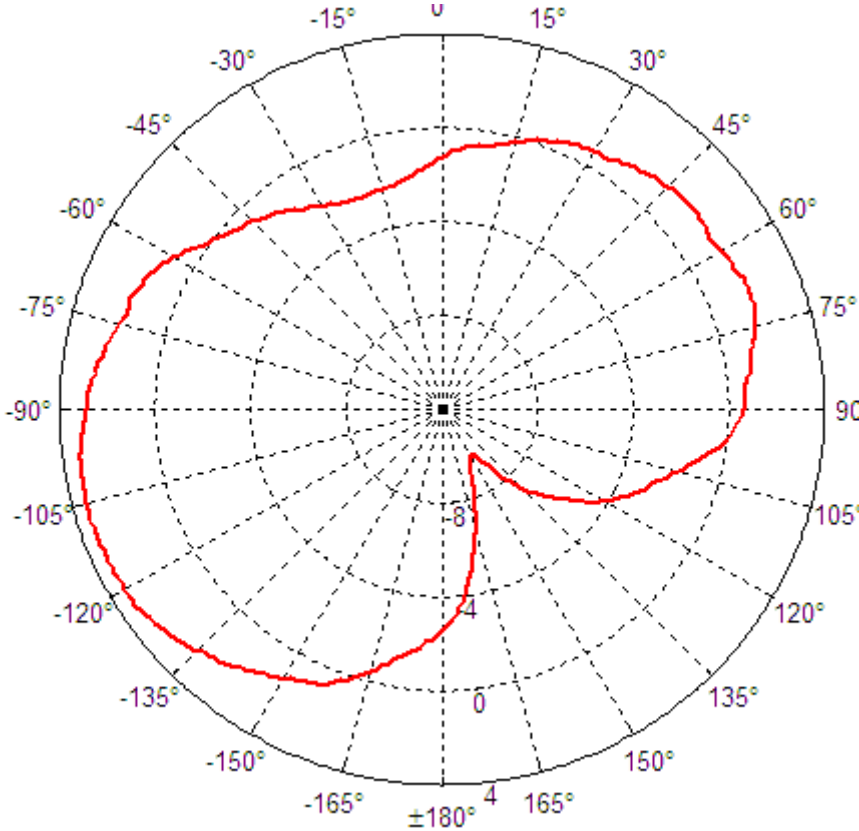


Figure 4. XY Plane Horizontal Polarization

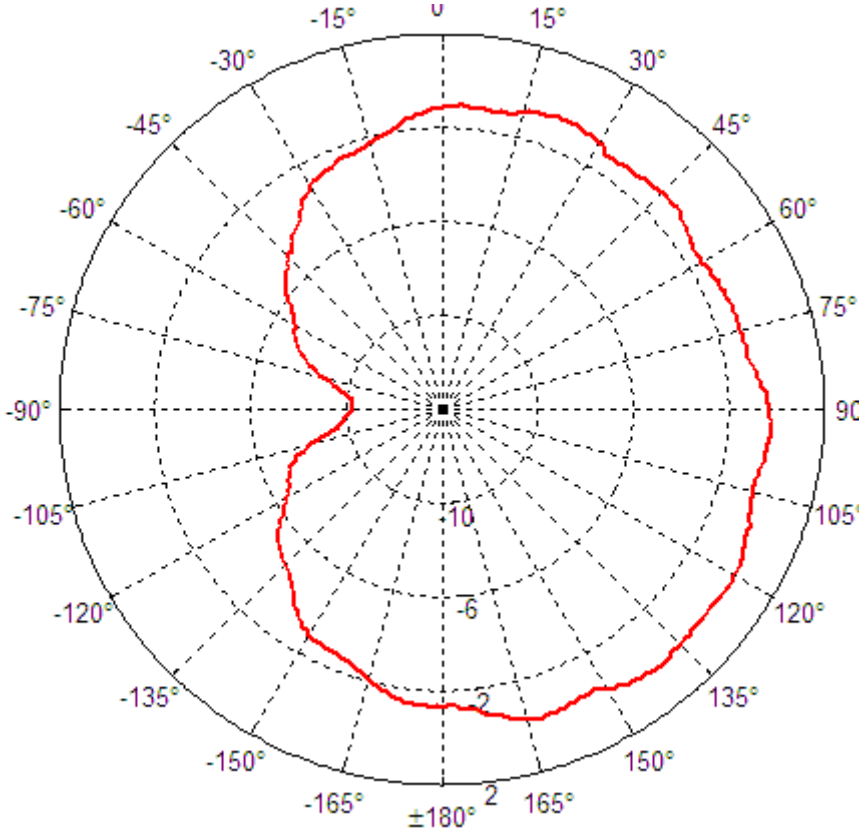


Figure 5. XY Plane Vertical Polarization

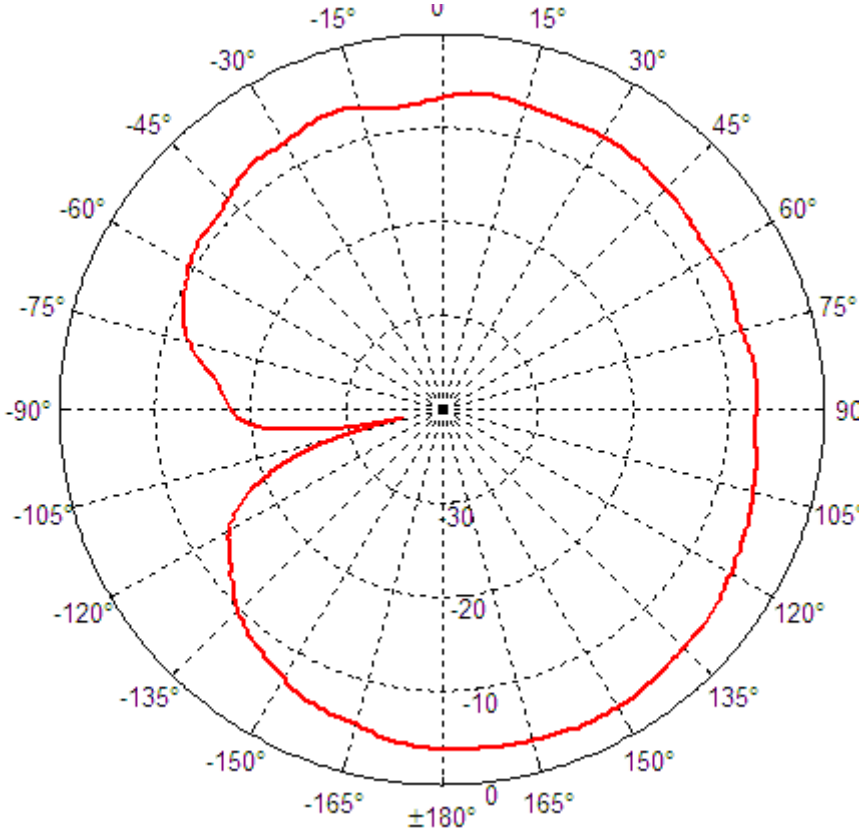


Figure 6. YZ Plane Horizontal Polarization

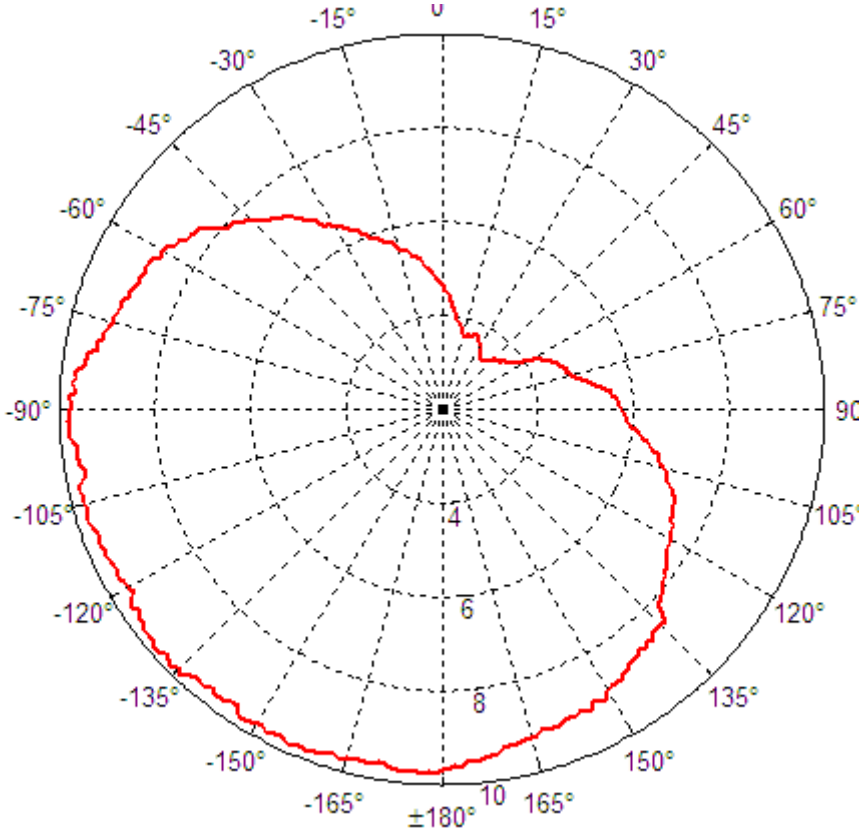


Figure 7. YZ Plane Vertical Polarization

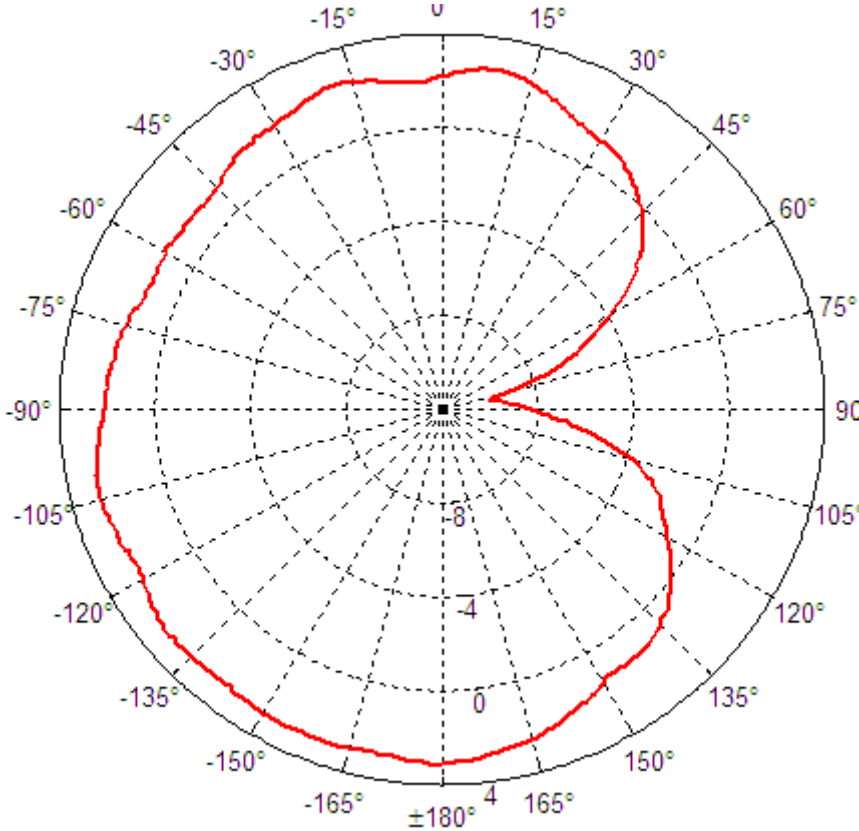


Figure 8. XZ Plane Horizontal Polarization

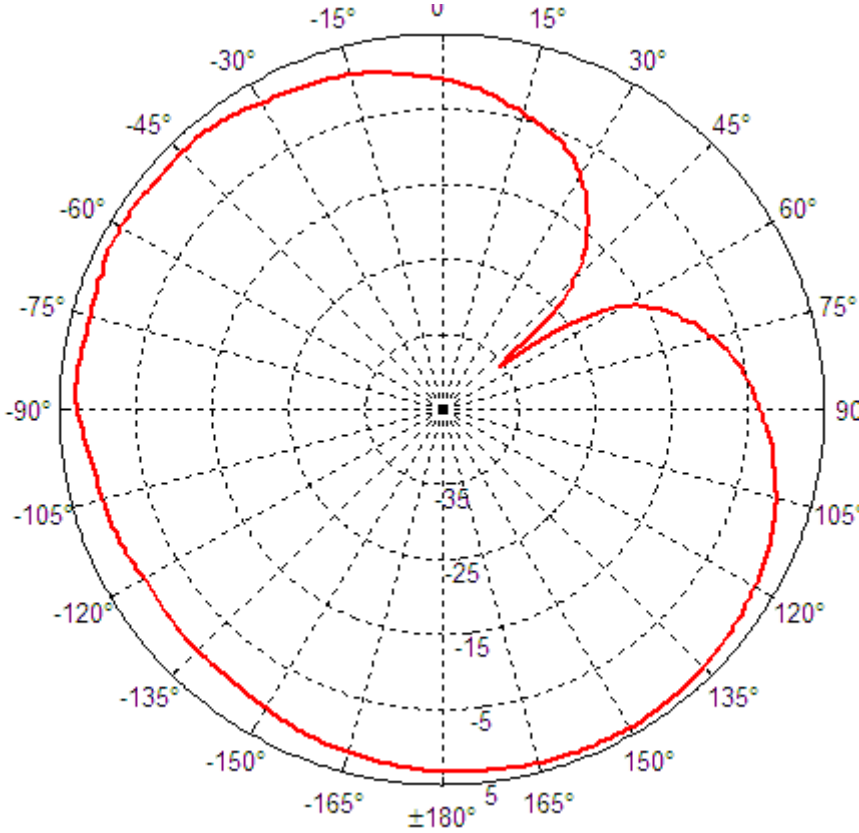


Figure 9. XZ Plane Vertical Polarization



4.2 Reflection

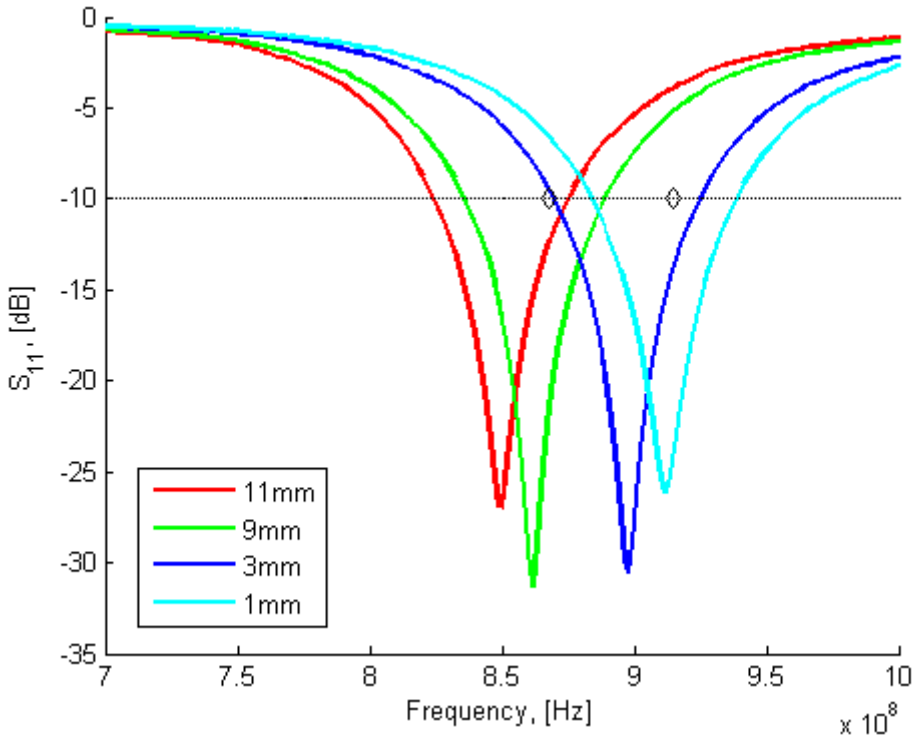


Figure 10. Measured Reflection at the End of a 15 mm long, 50 Ω, Line Feeding the Antenna. (The values in the box represent different lengths of L6.)

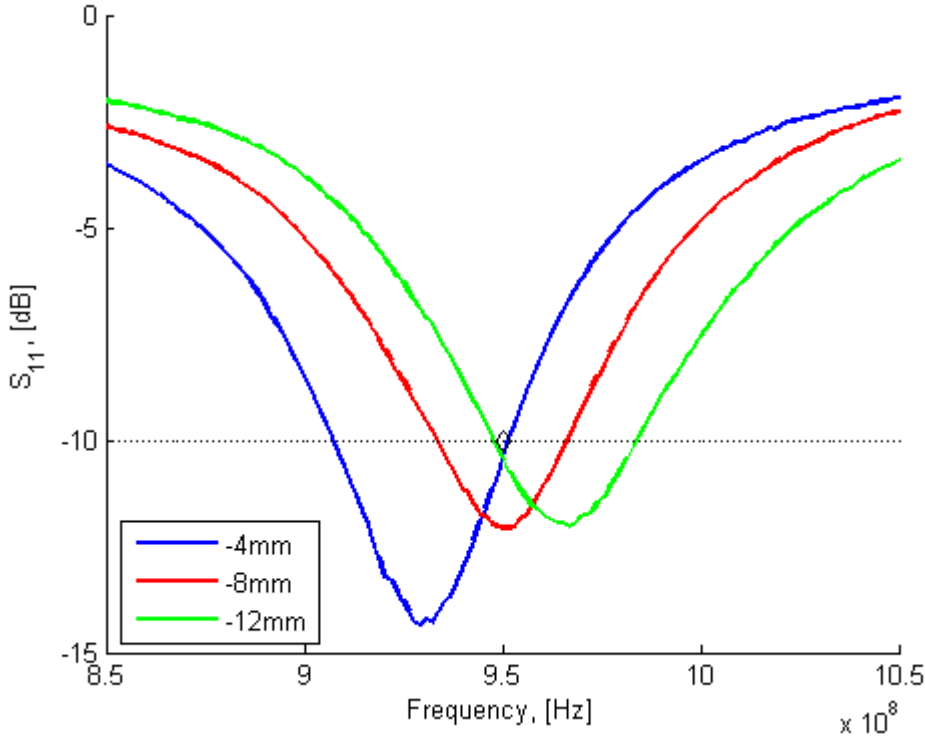


Figure 11. Measured Reflection at the Feed Point of the Antenna. (The values represent subtracted length of the antenna in addition to removing L6 completely.)

# Design Note DN023

Figure 10 shows that the antenna reflects less than 10% of the available power for a bandwidth of approximately 50 MHz. It is also clear from Figure 10 that the antenna is easily tuned to the desired center frequency simply by adjusting the length of the antenna.

As shown in Figure 11, this antenna could also be used in the frequency band around 950 MHz. The bandwidth for this frequency is not great, ~25 MHz, thus requiring precise tuning.

Measurements performed on the antenna with bigger ground planes show that further trimming of the antenna length might be required. However, the ground plane size will not result in any big changes in reflection or bandwidth.

Measurements also show that it is possible to place ground planes on the side of the antenna. Minimum recommended distance from the antenna to the ground plane is in this case 15 mm. Ground plane on the side(s) of the antenna will not have much effect on the impedance, but will result in changes in the distribution of the radiated power.

### 4.3 Bandwidth

To measure the bandwidth of the antenna a small test program, stepping a 10 dBm carrier from 782 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.

Notice that the bandwidth characteristic is dependent on direction and polarization. The result shown in Figure 12 and Figure 13 is based on a measurement performed with the PCB horizontally oriented (XY-plane,  $\phi = 0^\circ$ ) and the antenna pointing towards a vertical polarized receiving antenna. The measurement is uncompensated so 38.19 dB has to be added to the received power.

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

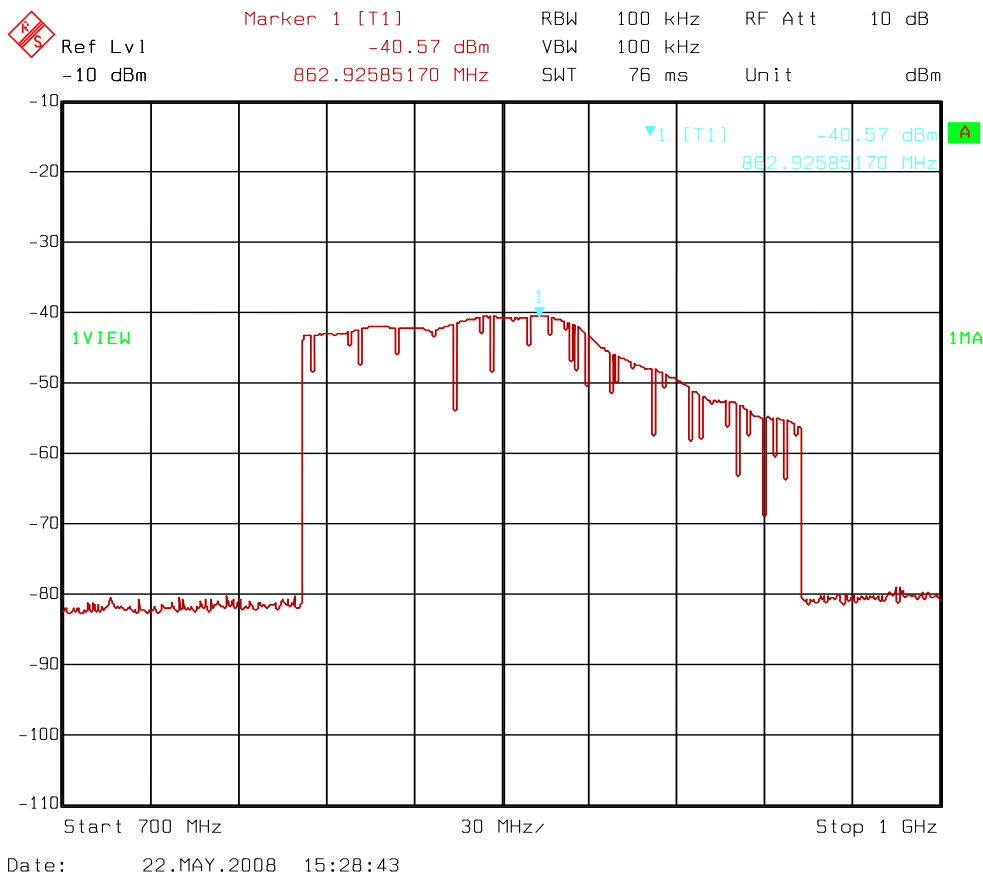
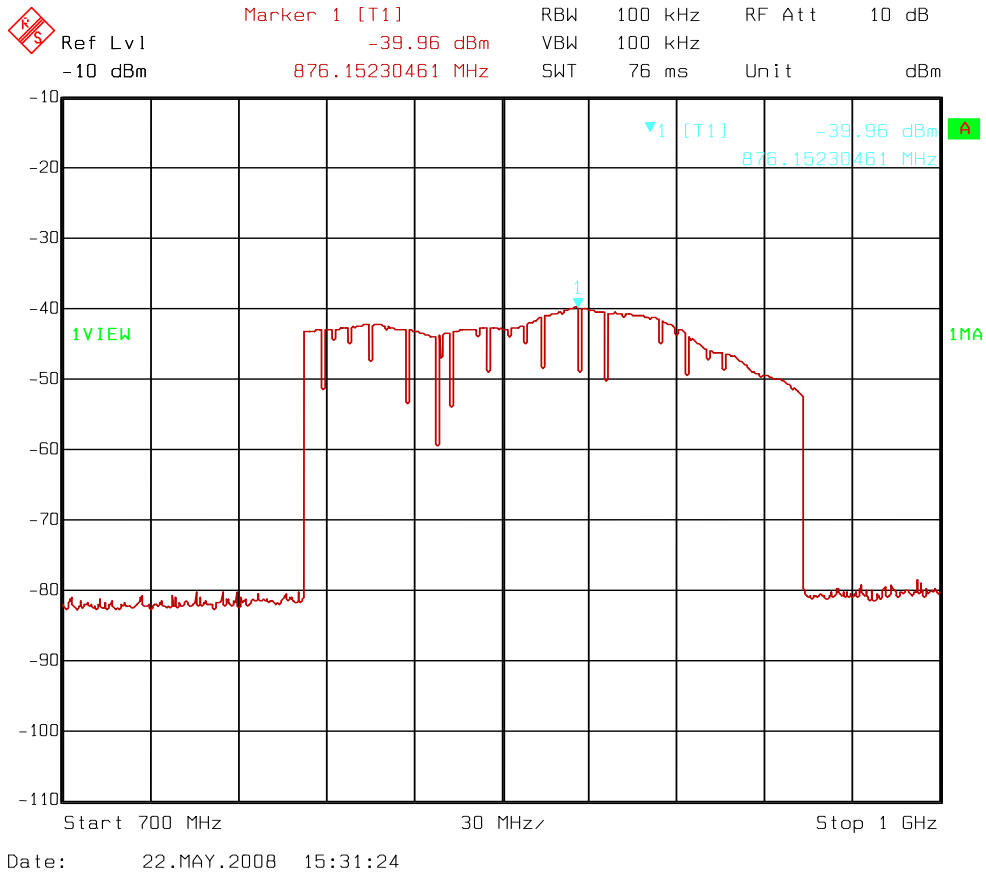


Figure 12. Bandwidth of Antenna Tuned for 868 MHz (L6 = 11 mm)

# Design Note DN023



**Figure 13. Bandwidth of Antenna Tuned for 915 MHz (L6 = 3 mm)**

Notice that the measurements were performed with two different settings for the PA-register. In Figure 12 the PA was optimized for 868 MHz (PA\_TABLE = 0xC2) and in Figure 13 the PA was optimized for 915 MHz (PA\_TABLE = 0xC0).

## 4.4 Harmonic Emission

Measurement of harmonic emission has not been done for this antenna. Harmonic emission will be dependent on ground plane geometry, encapsulation etc. Thus this measurement should be performed on a complete prototype. Table 2 shows the FCC- and ETSI 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 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
<b>Limit: FCC 249</b>	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m
<b>Limit: FCC 247</b>	20 dBc	54 dB $\mu$ V/m	54 dB $\mu$ V/m	54 dB $\mu$ V/m	20 dBc	20 dBc	54 dB $\mu$ V/m	54 dB $\mu$ V/m
<b>Limit ETSI</b>	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm

**Table 2. ETSI and FCC Limits for Harmonic Radiation**

# Design Note DN023

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**

## 4.5 Range

Measurements of the antenna range have been performed outdoors, in line of sight with two equal antennas as sender and receiver. The measurements were done with both antennas aligned with the YZ-plane horizontally ( $\phi = 0^\circ$ ). At a data rate of 38.4 kBaud a range of over 1300 meters was achieved (PER = 1 %). The measurements were performed with the prototype boards connected to a SmartRF04EB by cable, so the effective ground plane was only 31 x 45 mm.

## 5 Conclusion

The antenna proposed in this design note can be used for 868 MHz, 915 MHz and 955 MHz operation. Required board size for this antenna is 43 x 20 mm and maximum gain is approximately 0 dB dependent on direction. Measurements of reflection show that the center frequency is easily adjusted by trimming the antenna length. The radiation patterns show wide distribution of the radiated power.

<b>Antenna Size</b>	43 x 20 mm
<b>Range</b>	~1300 m (line-of-sight)
<b>Max Gain in XY Plane</b>	-6.54 dB
<b>Max Gain in XZ Plane</b>	-5.95 dB
<b>Max Gain in YZ Plane</b>	-0.12 dB
<b>Reflection</b>	< -25 dB

**Table 3. Key Parameters**

## 6 References

- [1] AN058 Antenna Selection Guide (swra161.pdf)
- [2] CC1110EM IIFA Reference Design (swrr058.zip)

## 7 General Information

### 7.1 Document History

Revision	Date	Description/Changes
SWRA228C	2011.09.30	Updated values in Table 1.
SWRA228B	2009.07.28	Added abbreviations. Cosmetic changes
SWRA228A	2009.03.17	Updated with 955 MHz. Removed logo from header
SWRA228	2007.04.16	Initial release

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Mobile Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Transportation and Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2011, Texas Instruments Incorporated