Antenna Selection Guide

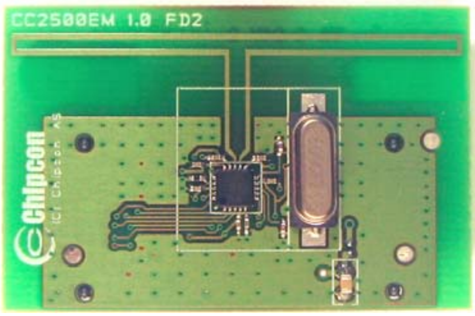
By Audun Andersen

Keywords

- *Antenna*
- *Radiation Pattern*
- *Bandwidth*
- *Reflection*
- *Anechoic Chamber*
- *Impedance*
- *Gain*
- *Directivity*
- *2.4 GHz*
- *868/915 MHz*

1 Introduction

This application note describes important parameters to consider when deciding what kind of antenna to use in a short range device (SRD) application. Radiation pattern, gain, impedance matching, bandwidth, size and cost are some of the parameters discussed in this document. In addition different antenna types are presented, with their pros and cons. All of the antenna reference designs available on www.ti.com/lpw are presented. The last section in this document contains references to additional antenna resources such as literature, applicable EM simulation tools and a list of antenna manufacturer and consultants.



PCB Antenna

Chip Antenna

Whip Antenna

Figure 1. Different Antenna Solutions

Table of Contents

2 Abbreviations

AN	Application Note
CW	Carrier Wave
DB	Demonstration Board
DN	Design Note
DUT	Device Under Test
EIRP	Effective Isotropic Radiated Power
EM	Electro Magnetic
EM	Evaluation Module
IFA	Inverted F Antenna
ISM	Industrial, Scientific, Medical
LOS	Line of Sight
MIFA	Meandered Inverted F Antenna
PCB	Printed Circuit Board
RF	Radio Frequency
SRD	Short Range Device
TI	Texas Instruments
VSWR	Voltage Standing Wave Ratio

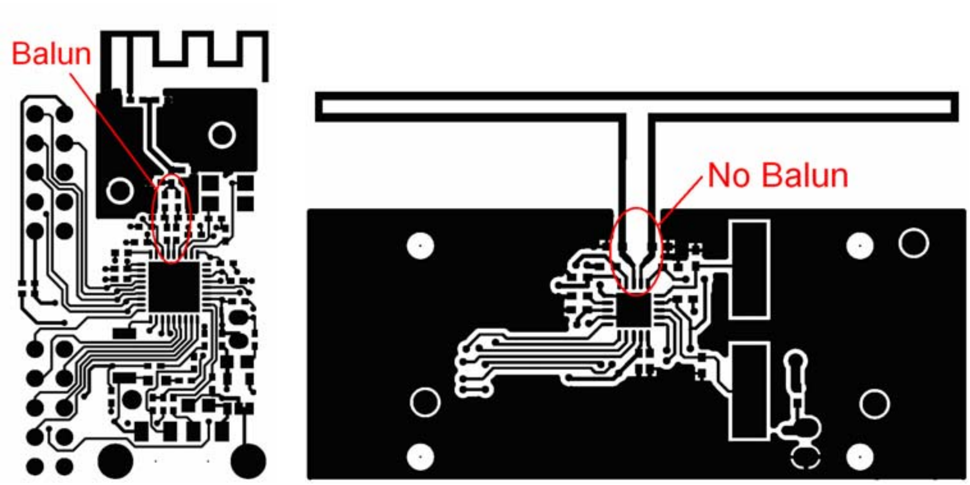
3 Antenna Types

There are several antenna types to choose from when deciding what kind of antenna to use in an RF product. Size, cost and performance are the most important factors when choosing an antenna. The three most commonly used antenna types for short range devices are PCB antennas, chip antennas and whip antennas with a connector. Table 1 shows the pros and cons for these antenna types.

Antenna types	Pros	Cons
PCB antenna	• Low cost • Good performance is possible • Small size is possible at high frequencies	• Difficult to design small and efficient PCB antennas • Potentially large size at low frequencies
Chip antenna	• Small size	• Medium performance • Medium cost
Whip antenna	• Good performance	• High cost • Difficult to fit in many applications

Table 1. Pros and Cons for Different Antenna Solutions

It is also common to divide antennas into single ended antennas and differential antennas. Single ended antennas are also called unbalanced antennas, while differential antennas are often called balanced antennas. Single ended antennas are fed by a signal which is referred to ground and the characteristic impedance for these antennas is usually 50 ohms. Most RF measurement equipments are also referenced to 50 ohms. Therefore, it is easy to measure the characteristic of a 50 ohm antenna with such equipment. However many RF IC's have differential RF ports and a transformation network is required to use a single ended antenna with these IC's. Such a network is called a balun since it transforms the signal from balanced to unbalanced configuration. Figure 2 shows a single ended antenna and a differential antenna. The figure shows the differential antenna connected directly to the RF pins and a balun needed by the single ended antenna.



Single Ended Antenna **Differential Antenna**

Figure 2. Single Ended and Differential Antenna

The antennas presented in this document are mainly intended for the license free 2.4-2.4835 GHz band, the 863-870 MHz band in Europe and the 902-928 MHz band in US. The European band is usually referred to as the “868 MHz band” and the US band is commonly designated the “915 MHz band”. It is often possible to achieve good performance with the same antenna for both the European 868 MHz and the US 915 MHz bands by tuning the antenna length or changing the values of the matching components. Such antennas are called “868/915 MHz antennas” in this document.

3.1 PCB Antennas

Designing a PCB antenna is not straightforward and usually a simulation tool must be used to obtain an acceptable solution. In addition to deriving an optimum design, configuring such a tool to perform accurate simulations can also be difficult and time consuming. It is therefore recommended to make an exact copy of one of the reference designs available at www.ti.com/lpw, if the available board space permits such a solution. See section 5 for a description of the available reference designs. If the application requires a special type of antenna and none of the available reference designs fits the application, it could be advantageous to contact an antenna consultant or look for other commercial available solutions. Table 4 lists a few companies that can offer such services.

3.2 Chip Antennas

If the available board space for the antenna is limited a chip antenna could be a good solution. This antenna type allows for small size solutions even for frequencies below 1 GHz. The trade off compared to PCB antennas is that this solution will add BOM and mounting cost. The typical cost of a chip antenna is between $0.10 and $1.00. Even if manufacturers of chip antennas state that the antenna is matched to 50 ohms for a certain frequency band, it is often required to use additional matching components to obtain proper performance. The performance numbers and recommended matching given in data sheets are often based on measurements done with a test board. The dimensions of this test board are usually documented in the data sheet. It is important to be aware that the performance and required matching might change if the chip antenna is implemented on a PCB with different size and shape of the ground plane.

3.3 Whip Antennas

If good performance is the most important factor and size and cost are not critical, an external antenna with a connector could be a good solution. These antennas are often monopoles and have an omni-directional radiation pattern. This means that the antenna has approximately the same performance for all directions in one plane. The whip antenna should be mounted normally on the ground plane to obtain best performance. Whip antennas are typically more expensive than chip antennas, and will also require a connector on the board that also increases the cost. Notice that in some cases special types of connectors must be used to comply with SRD regulations. For more information about SRD regulations please see Application Note 001 [1] and Application Note 032 [2].

4 Antenna Parameters

There are several parameters that should be considered when choosing an antenna for a wireless device. Some of the most important things to consider are how the radiation varies in the different directions around the antenna, how efficient the antenna is, the bandwidth which the antenna has the desired performance and how much of the available power is delivered to the antenna. Sections 4.1 and 4.2 give an explanation on how these properties are defined and how they should be evaluated. Since all antennas require some space on the PCB, the choice of antenna is often a trade off between cost, size and performance. This will be discussed further in section 4.3.

4.1 Radiation Pattern and Gain

Figure 3 shows how the radiation from the PCB antenna in Figure 1 varies in different directions in the plane of the PCB. Several parameters are important to know when interpreting such a plot. Some of these parameters are stated in the lower left portion of Figure 3. In addition to the information shown on the plot in Figure 3, it is important to know how to relate the radiation pattern to the positioning of the antenna.

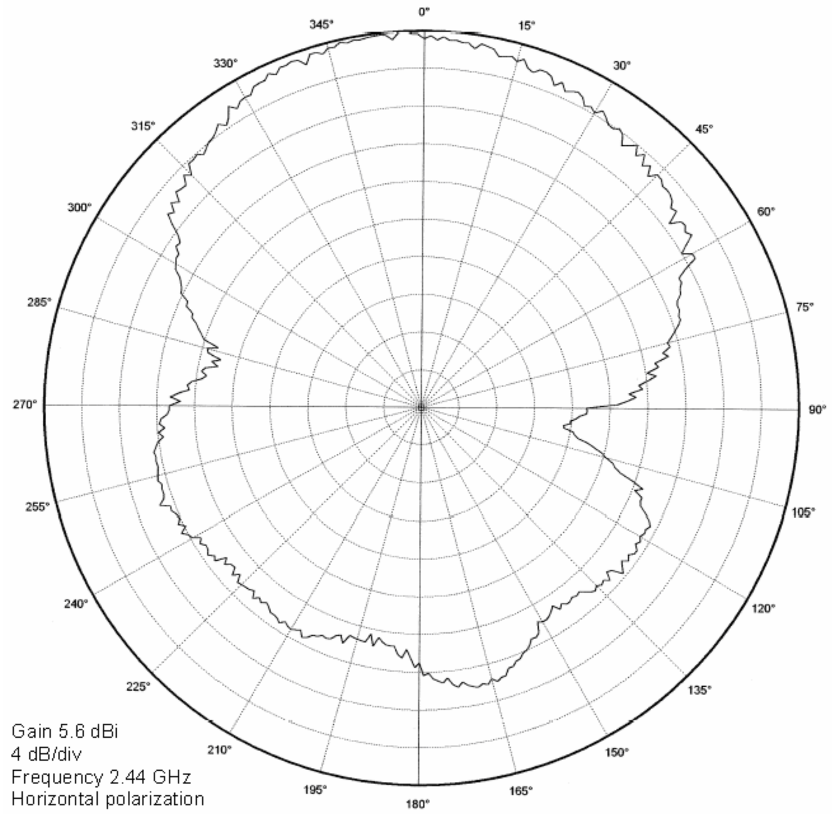


Figure 3. Radiation Pattern

The gain or the reference level is usually referred to an isotropic radiating antenna which is an ideal antenna that has the same level of radiation in all directions. When such an antenna is used as a reference, the gain is given in dBi or specified as the Effective Isotropic Radiated Power (EIRP). The outer circle in Figure 3 corresponds to 5.6 dBi. The “4 dB/div” notation in the lower left of Figure 3 means that for each of the inner circles the emission level is reduced by 4 dB. This means that compared to an isotropic antenna the PCB antenna in Figure 1 will have 5.6 dB higher radiation in the 0° direction and 6.4 dB lower radiation in the 180° direction.

$$G = e \cdot D = \frac{P_{rad}}{P_{in}} \cdot D = \frac{P_{rad}}{P_{in}} \cdot \frac{U_{\max}}{U_{avg}}$$

Equation 1. Definition of Gain

Gain (G) is defined as the ratio of maximum to average radiation intensity multiplied by the efficiency of the antenna, see Equation 1. Ohmic losses in the antenna element and reflections at the feed point of the antenna determine the efficiency. The ratio of the maximum and average radiation intensities is defined as directivity (D). High gain does not automatically mean that the antenna has good performance. Typically for a system with mobile units it is desirable to have an omnidirectional radiation pattern such that the performance will be approximately the same regardless of which direction the units are pointed relative to each other. For an application where both the receiver and the transmitter have fixed positions, high gain could be desirable. If the units could be placed such that the direction of maximum gain is pointed toward each other, this will result in optimum performance with that antenna.

Polarization describes the direction of the electric field. All electromagnetic waves propagating in free space have electric and magnetic fields perpendicular to the direction of propagation. Usually, when considering polarization, the electric field vector is described and the magnetic field is ignored since it is perpendicular to the electric field and proportional to it. The receiving and transmitting antenna should have the same polarization to obtain optimum performance. Most antennas in SRD application will in practice produce a field with polarization in more than one direction. In addition reflections will change the polarization of an electric field. Polarization is therefore not as critical for indoor equipment, which experiences lots of reflections, as for equipment operating outside with Line of Sight (LOS). Some antennas produce an electrical field with a determined direction, it is therefore also important to know what kind of polarization that was used when measuring the radiation pattern. It is also important to state which frequency the measurement was done at. Generally the radiation pattern does not change rapidly across frequency. Thus it is usual to measure the radiation pattern in the middle of the frequency band in which the antenna is going to be used. For narrowband antennas the relative level could change slightly within the desired frequency band, but the shape of the radiation pattern would remain basically the same.

To make an accurate measurement of the radiation pattern, it is important to be able to measure only the direct wave from the DUT and avoid any reflecting waves affecting the result. It is therefore common to perform such measurements in an anechoic chamber. Another requirement is that the measured signal must be a plane wave in the far field of the antenna. The far field distance (R_f) is determined by the wavelength (λ) and the largest dimension (D) of the antenna, see Equation 2. Since the size of anechoic chambers is limited, it is common to measure large and low frequency antennas in outdoor ranges.

$$R_f = \frac{2\mathrm{D}^2}{\lambda}$$

Equation 2. Far Field Distance

It is also important to be able to relate the different directions on the radiation pattern plot to the antenna. Radiation pattern is typically measured in three orthogonal planes, XY, XZ and YZ. It is also possible to perform full 3D pattern measurements, but this is usually not done, since it is time consuming and requires expensive equipment. Another way of defining these three planes is by using a spherical coordinate system. The planes will then typically be defined by $\theta = 90°$, $\varphi = 0°$ and $\varphi = 90°$. Figure 4 shows how to relate the spherical notation to the three planes. If no information is given on how to relate the directions on the radiation pattern plot to the positioning of the antenna, 0° is the X direction and angles increase towards Y for the XY plane. For the XZ plane, 0° is in the Z direction and angles increase towards X, and for the YZ plane, 0° is in the Z direction and angles increase towards Y.

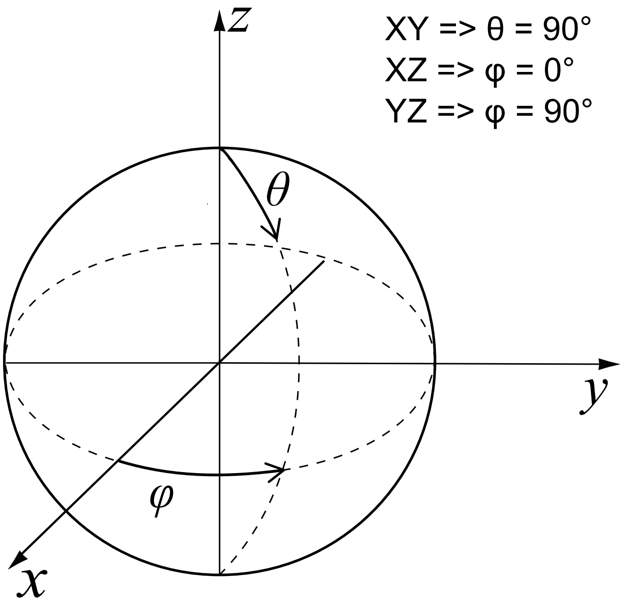


Figure 4. Spherical Coordinate System

The size and shape of the ground plane will affect the radiation pattern. Figure 5 shows an example of how the ground plane affects the radiation pattern. The radiation pattern in the upper left corner is measured with the small antenna board plugged in to the SmartRF04EB, while the pattern in the upper right corner of Figure 5 is measured with the antenna board only connected to a battery. SmartRF04EB has a solid ground plane. By plugging the antenna board into this, the effective ground plane seen by the antenna is increased. The change in size and shape of the ground plane changes the gain from -1.2 dBi to 4.6 dBi. Since many SRD applications are mobile, it is not always the peak gain that is most interesting. The average radiation for one plane gives more information about the total radiated energy and is commonly stated when antenna performance is presented.

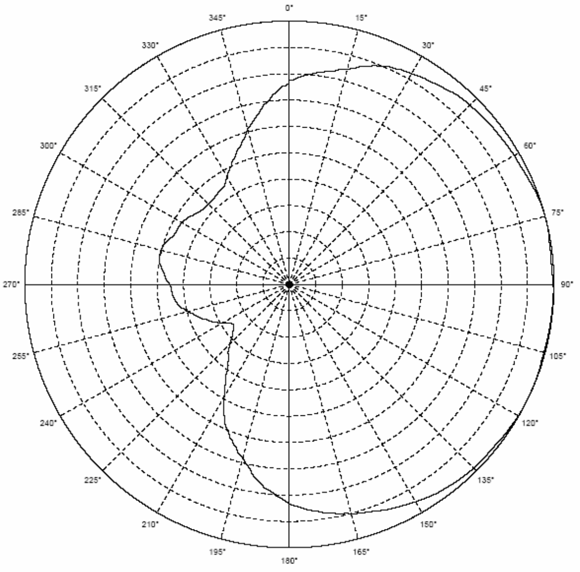
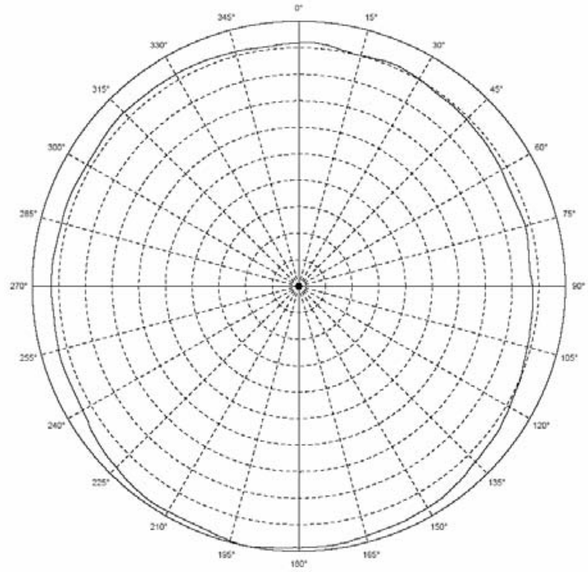
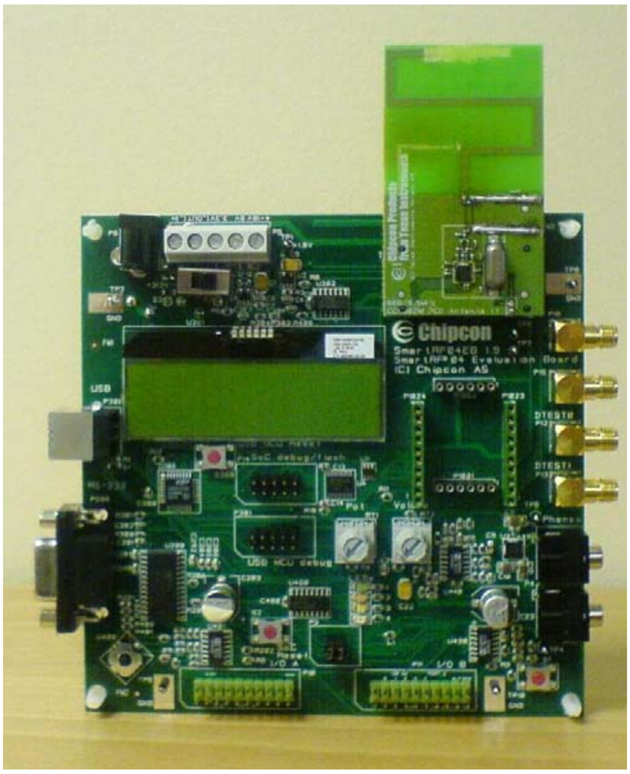
CC1100EM PCB Antenna in SmartRF04EB	CC1100EM PCB Antenna without SmartRF04EB
	
Vertical Polarization, YZ plane 2 dB/div 0 dBm, 868 MHz Ref Lev: 4.6 dB	Vertical Polarization, YZ plane 2 dB/div 0 dBm, 868 MHz Ref Lev: -1.2 dB
	

Figure 5. Influence on Shape and Size of the Ground Plane on Radiation Pattern

4.2 Bandwidth and Impedance Matching

There are two main ways of measuring the bandwidth of the antenna. Measuring the radiated power when stepping a carrier across the frequency band of interest and measuring the reflection at the feed point of the antenna with a network analyzer. Figure 6 shows a measurement of the radiated power from a 2.4 GHz antenna. The result show that the antenna has approximately 2 dB variation in output power across the 2.4 GHz frequency band and max radiation at the center of this band. This measurement was done with the radio stepping a continuous wave (CW) from 2.3 GHz to 2.8 GHz. Such measurements should be performed in an anechoic chamber to obtain a correct absolute level. This kind of measurement can however also be very useful even if an anechoic chamber is not available. Performing such a measurement in an ordinary lab environment will give a relative result, which shows whether the antenna has optimum performance in the middle of the desired frequency band. The performance of the antenna connected to the spectrum analyzer will affect the result. Thus it is important that this antenna has approximately the same performance across the frequency band being used. This will ensure that the result gives a correct view of the relative change in performance across the measured frequency band.

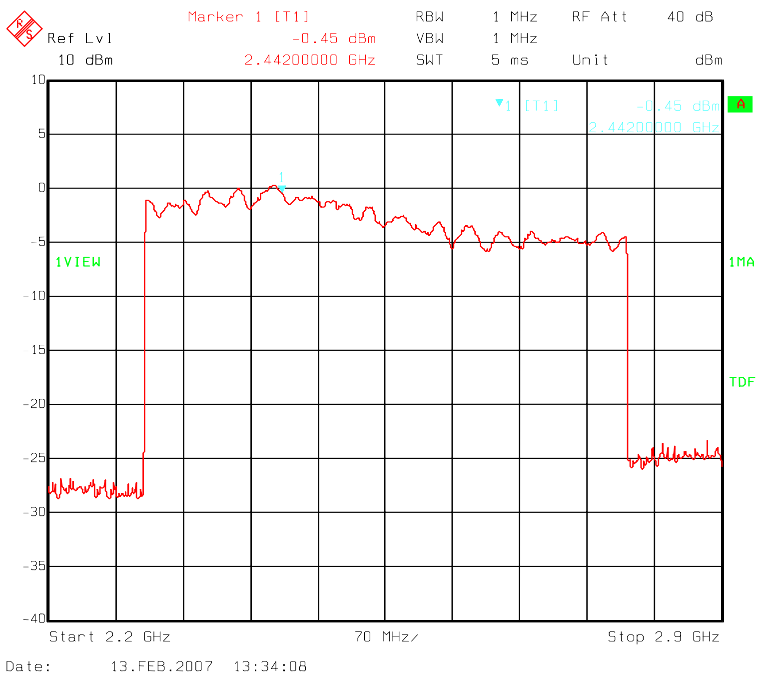


Figure 6. Bandwidth of a 2.4 GHz Antenna.

Another method to characterize the bandwidth is to measure the reflected power at the feed point of the antenna. By disconnecting the antenna and connecting a coax cable at the feed point of the antenna, such measurements could be performed with a network analyzer. The bandwidth of an antenna is typically defined as the frequency range for which the reflection is lower than -10 dB or the VSWR of less than 2. This is equal to the frequency range where less than 10 % of the available power is reflected by the antenna. More information about reflection measurements can be found in Design Note 001 [10].

Figure 7 shows plots from three reflection measurements performed on an antenna intended for a 2.4 GHz remote control. The red plot shows the reflection when the antenna is positioned in free space with no objects in its vicinity. Encapsulating the antenna in plastic affects the performance by lowering the resonance frequency. This is shown by the blue graph. By holding the encapsulated antenna in one's hand, the performance is affected even more. This shows why it is important to do characterization and tuning when the antenna is placed in the position and environment it is going to be used during normal operation.

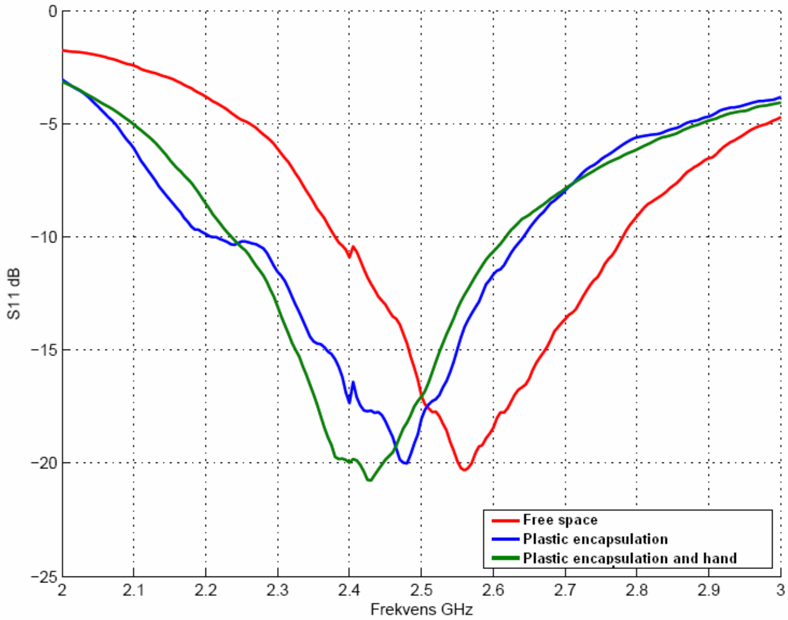


Figure 7. Reflection Influenced by the Vicinity of the Antenna

4.3 Size, Cost and Performance

The ideal antenna is infinitely small, has zero cost and has excellent performance. In real life this is not possible. Therefore a compromise between these parameters needs to be found. Reducing the operating frequency by a factor of two doubles the range. Thus one of the reasons for choosing to operate at a low frequency when designing an RF application is often the need for long range. However, most antennas need to be larger at low frequencies in order to achieve good performance. Thus in some cases where the available board space is limited, a small and efficient high frequency antenna could give the same or better range than a small an inefficient low frequency antenna. A chip antenna is good alternative when seeking a small antenna solution. Especially for frequencies below 1 GHz a chip antenna will give a much smaller solution compared to a traditional PCB antenna. The main draw backs with chip antennas are the increased cost and often narrow band performance.

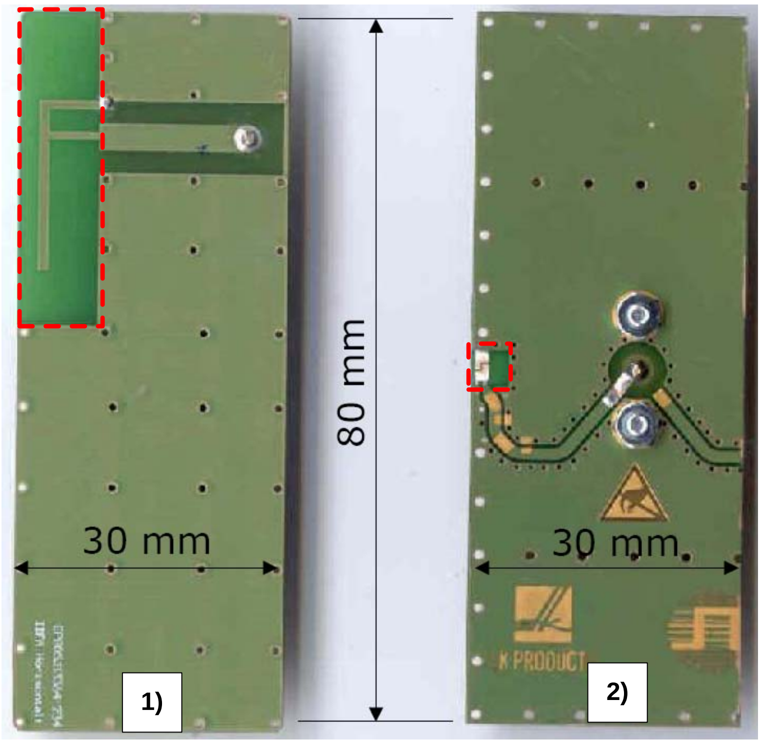


Figure 8. Layout Comparison of 1) PCB Antenna and 2) Chip Antenna

Figure 8 shows the layout of a 2.4 GHz PCB antenna and a 2.4 GHz chip antenna. The required space for the two antenna solutions are indicated with red squares. As can be seen from the picture, the chip antenna consumes much less board space than the PCB antenna. The radiation efficiency of these two antenna solutions is shown in Figure 9. The graph clearly shows that the chip antenna has a narrower bandwidth than the PCB antenna, even though both antennas have the same efficiency in the middle of the 2.4 GHz band.

Figure 9. Comparison of a PCB Antenna and a Chip Antenna

5 Antenna Reference Designs Available on www.ti.com\lpw

Texas Instruments offers several antenna reference designs. For each reference design TI provides design files and documentation that show what kind of board the antenna was tested on and the measured performance. Common to all these designs is that the size and shape of the ground plane affects the performance of the antenna. Thus implementing the antennas on a PCB with different shape and size of the ground plane might result in slightly different results. It is important to make an exact copy of the dimensions of the antenna to obtain optimum performance. No ground plane or traces should be placed beneath the antenna. All the reference designs presented in chapter 5 and additional documentation can be downloaded from www.ti.com\lpw. Table 5 in chapter 7 gives an overview of the properties and documentation for all the presented antenna designs.

5.1 Reference Designs for 2.4 GHz 50 ohm Single Ended Antennas

For 2.4 GHz solutions, TI provides five different antenna reference designs. Three of these are single ended antennas matched to 50 ohms. These can be used with all 2.4 GHz products as long as a 50 ohm balun is implemented. TI provides reference designs with a balun matched to 50 ohm for all 2.4 GHz products.

The smallest antenna solution for 2.4 GHz is a Meandered Inverted F Antenna (MIFA) shown in
Figure 10. This antenna is optimum for USB dongles and other implementations with limited board space. The antenna and its performance are described in Application Note 043 [3] and design files showing the layout is included in CC2511 USB Dongle Reference Design [16].

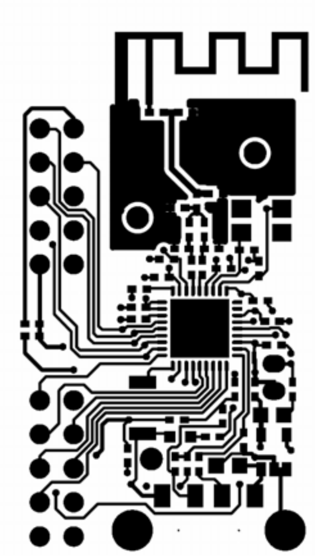


Figure 10. Meandered Inverted F Antenna

The Inverted F Antenna (IFA) shown in Figure 11 requires more board space than the MIFA, but provides a more omni-directional radiation pattern than the MIFA. This antenna can be found in the CC2400DB, CC2420DB and CC2430DB reference designs and the performance is documented in Design Note 007 [4]. The length of the IFA differs slightly between the various DB boards. The reason is that the length is tuned to compensate for the different sizes of the ground plane on the different boards.

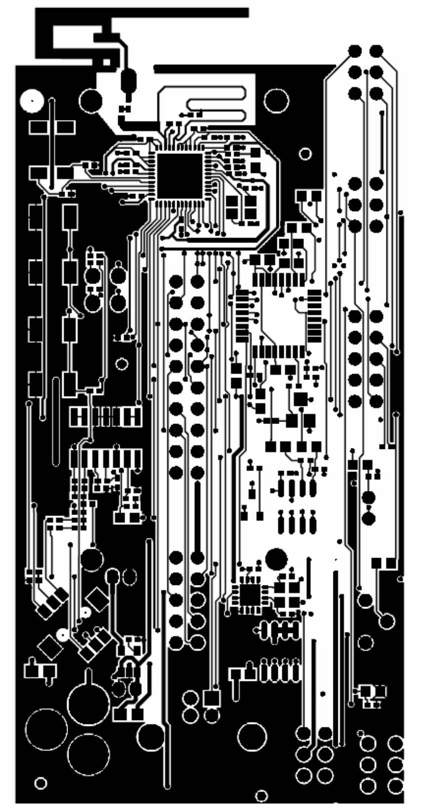
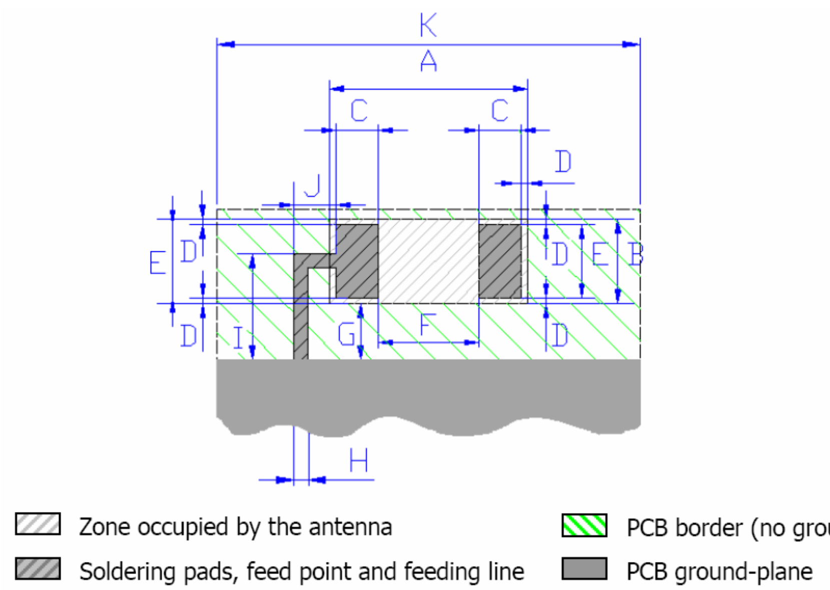


Figure 11. Inverted F Antenna

Together with Fractus [11], Texas Instruments provides an application note describing how to implement a 2.4 GHz chip antenna with 2.4 GHz radios. Application Note 048 [7] contains implementation recommendations and measurement results for a chip antenna implemented on a PCB with the size of a USB dongle. Figure 12 shows the required board space for this solution.



All dimensions listed in millimetres.

Letter	Meas.
A	7.00
B	3.00
C	1.50
D	0.20
E	2.60
F	3.60
G	2.00
H	0.50
I	3.75
J	1.50
K	15.00

Figure 12. 2.4 GHz Chip Antenna from Fractus

5.2 Reference Designs for 2.4 GHz Differential Antennas

To reduce the number of external components required by a balun, it is possible to design a differential antenna that is matched directly to the impedance of the RF port of the radio. In some cases a few external components are required to obtain proper impedance matching or filtering.

CC2500, CC2510, CC2511 and CC2550 have all the same impedance. This makes it possible to use the antenna shown in Figure 13 with all these products. This antenna design and the measured performance are presented in Design Note 004 [5]. The only external components needed are two capacitors to ensure compliance with ETSI regulations. Thus for FCC compliance no external components are required if the proper output power and duty cycling are used.

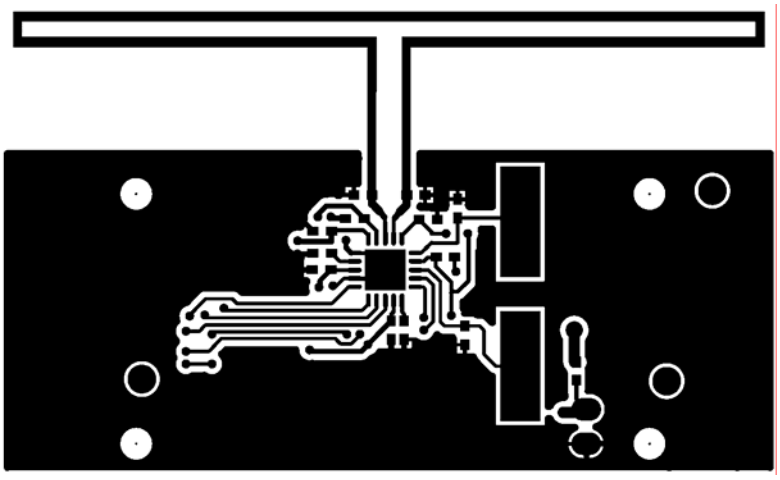


Figure 13. CC 25xx Folded Dipole

CC2400, CC2420 and CC243x have all slightly different impedances. It is therefore necessary to use external components to tune the impedance so the same antenna structure can be used for all these products. The antenna presented in Application Note 040 [6] can be used with CC2400, CC2420 and CC243x if the inductor sitting between the RF pins is tuned accordingly. In addition to the tuning inductor it is recommended to use an inductor in series with the TXRX switch pin. This inductor works as a RF choke at 2.4 GHz.

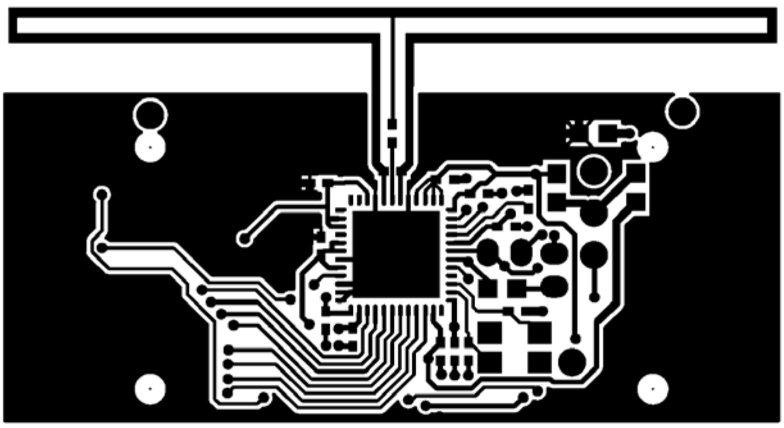


Figure 14. CC24xx Folded Dipole

5.3 Reference Designs for 868/ 915 MHz Antennas

For 868/915 MHz operation, TI offers two reference designs that can be used with all RF products capable of operating at these frequencies. One design is a pure PCB antenna and the other is a chip antenna in conjunction with a special PCB trace. Both designs are matched to 50 ohms. Thus a balun is needed for all products with differential output.

The pure PCB antenna consists of a bent monopole and is a medium-size, low-cost solution. Figure 15 shows the layout of the bent monopole PCB antenna for 868/915 MHz. More information about this design can be found in Design Note 008 [9] and CC1100EM PCB Antenna Reference Design [23].

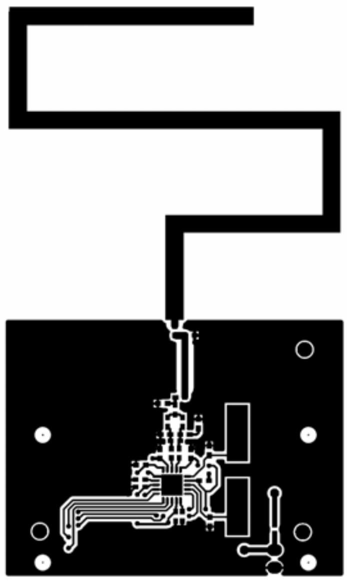


Figure 15. Bent Monopole 868/915 MHz

The smallest antenna solution provided by TI for 868/915 MHz is shown in Figure 16. It consists of a chip antenna from Johanson Technology [12] in conjunction with a special PCB trace. Design recommendations and measurement results are presented in Design Note 016 [8].

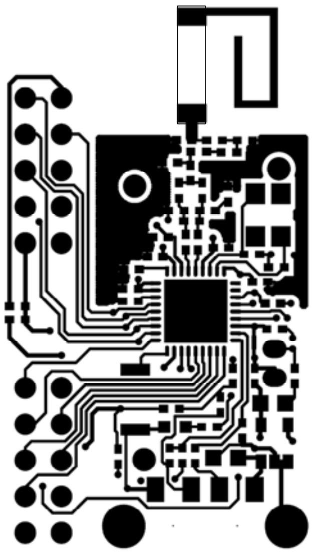


Figure 16. 868/915 MHz Chip Antenna from Johanson Technology

6 Additional Antenna Resources

There exists a lot of literature discussing antenna types and antenna theory. Several companies offer EM simulation tools applicable for antenna simulation. There are also many companies that manufacture antennas and also companies offering consultant services to do custom antenna design. This section lists different antenna resources.

6.1 Antenna Literature

There exist a large number of publications covering antennas. Table 2 lists some relevant literature dealing with this topic.

Title	Author
Antenna Theory and Design	Warren L. Stutzman & Garry A. Thiele
Antenna Handbook	Y. T. Lo & S. W Lee
Microwave and RF Design of Wireless Systems	David M. Pozar

Table 2. Antenna Literature

6.2 EM Simulation Tools

Table 3 lists EM simulation tools that can be used to do antenna simulations. The list is given as a reference only as TI has not evaluated all these programs.

Tool	Company
IE3D	Zeland [13]
Momentum	Agilent [14]
HFSS	Ansoft [15]

Table 3. EM Simulation Tools

6.3 Antenna Suppliers and Consultants

It is difficult to design small and effective antennas and even if a chip antenna is chosen it is often necessary to perform impedance matching to obtain optimum performance. Therefore it could be wise to contact a consultant if a special antenna solution is required. Below is a list of companies that sell different antenna solutions and offer consultant services.

Company	Web page	Expertise
Fractus	http://www.fractus.com/	Chip antennas
Johanson Technologies	http://www.johansontechnology.com/	Chip antennas
Pulse	http://www.lkproducts.com/	Chip antennas
Antenova	http://www.antenova.com/	Chip antennas Whip antennas
Badland	http://www.badland.co.uk/	Whip antennas
Linx Technologies	http://www.linxtechnologies.com/	Whip antennas
Antennasys	http://www.antennasys.com	Antenna consultant
LS Research	http://www.lsr.com/	Antenna consultant

Table 4. Antenna Suppliers and Consultants

7 Summary

The first section of this application note gives an overview of different types of antennas and which parameters to consider when implementing an antenna. The second part gives an overview of the different antenna reference designs available at www.ti.com/lpw and also a list of additional antenna resources.

Table 5 lists all the antenna reference designs available at www.ti.com/lpw. This table lists which products the different antennas can be used with, the required PCB size to implement the antenna and main properties. It does also lists where to find more information on the different designs.

Reference design	Applicable products	Required Size, in mm	Properties	Documentation
CC2511 USB Dongle [16]	All 2.4 GHz products	15.2 x 5.7	Small size Easy to tune	AN043 [3]
CC2430DB [17] CC2420DB [18] CC2400DB [19]	All 2.4 GHz products	25.7 x 7.5	Medium size Omnidirectional Easy to tune	DN007 [4]
CC2500 Folded Dipole [20]	CC2500 CC2550 CC2510 CC2511	46.0 x 9.0	Large size High gain Hard to tune	DN004 [5]
CC2400 Folded Dipole [6]	CC2400 CC2420 CC2430 CC2431	48.2 x 7.5	Large size High gain Hard to tune	AN040 [6]
2.4 GHz chip antenna	All 2.4 GHz products	15.0 x 5.5	Small size Medium performance	AN048 [7]
CC1111 USB Dongle [22]	All 868/915 MHz products	8.5 x 7.8	Small size Omnidirectional Easy to tune	DN016 [8]
CC1100EM PCB Antenna [23]	All 868/915 MHz products	39.0 x 37.0	Medium size Omnidirectional Easy to tune	DN008 [9]

Table 5. Reference designs available on www.ti.com/lpw.

References

[1] AN001 SRD Regulations for License Free Transceiver Operation (swra090.pdf)

[2] AN032 2.4 GHz Regulations (swra060.pdf)

[3] AN043 Small Size 2.4 GHz PCB antenna (swra117.pdf)

[4] DN007 2.4 GHz Inverted F Antenna (swru120.pdf)

[5] DN004 Folded Dipole Antenna for CC25xx (swra118.pdf)

[6] AN040 Folded dipole antenna for CC2400, CC2420 and CC2430/31 (swra093.pdf)

[7] AN048 2.4GHz Chip Antenna (swra092.pdf)

[8] DN016 Compact 868/915 MHz Antenna Design (swra160.pdf)

[9] DN008 868 and 915 MHz PCB antenna (swru121.pdf)

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

[11] Fractus: http://www.fractus.com

[12] Johanson Technology: http://www.johansontechnology.com

[13] Zeland: http://www.zeland.com/

[14] Agilent: http://eesof.tm.agilent.com/products/momentum_main.html

[15] Ansoft: http://www.ansoft.com/products/hf/hfss/

[16] CC2511 USB-Dongle Reference Design (swrc062.zip)

[17] CC2430DB Reference Design (swrr034.zip)

[18] CC2420DB Reference Design (swrr019.zip)

[19] CC2400DB Reference Design (swrr020.zip)

[20] CC25xxEM Folded Dipole Reference Design (swrc065.zip)

[21] CC2400EM Folded Dipole Reference Design (swra093a.zip)

[22] CC1111 USB Dongle Reference Design (swrr049.zip)

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

8 General Information

8.1 Document History

Revision	Date	Description/Changes
SWRA161	2007.11.26	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		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Telephony	www.ti.com/telephony
Low Power Wireless	www.ti.com/lpw	Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless