Selecting antennas for low-power wireless applications

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Introduction

The antenna is a key component in an RF system and can have a major impact on performance. High performance, small size, and low cost are common requirements for many RF applications. To meet these requirements, it is important to implement a proper antenna and to characterize its performance. This article describes typical antenna types and covers important parameters to consider when choosing an antenna.

Antenna types

Antenna size, cost, and performance are the most important factors to consider when choosing an antenna. The three most common antenna types for short-range devices are PCB antennas, chip antennas, and whip antennas. Their pros and cons are shown in Table 1.

PCB antennas

Designing a PCB antenna is not straightforward and usually requires a simulation tool to obtain an acceptable solution. In addition to deriving an optimum design, configuring such a tool to perform accurate simulations can be difficult and time consuming.

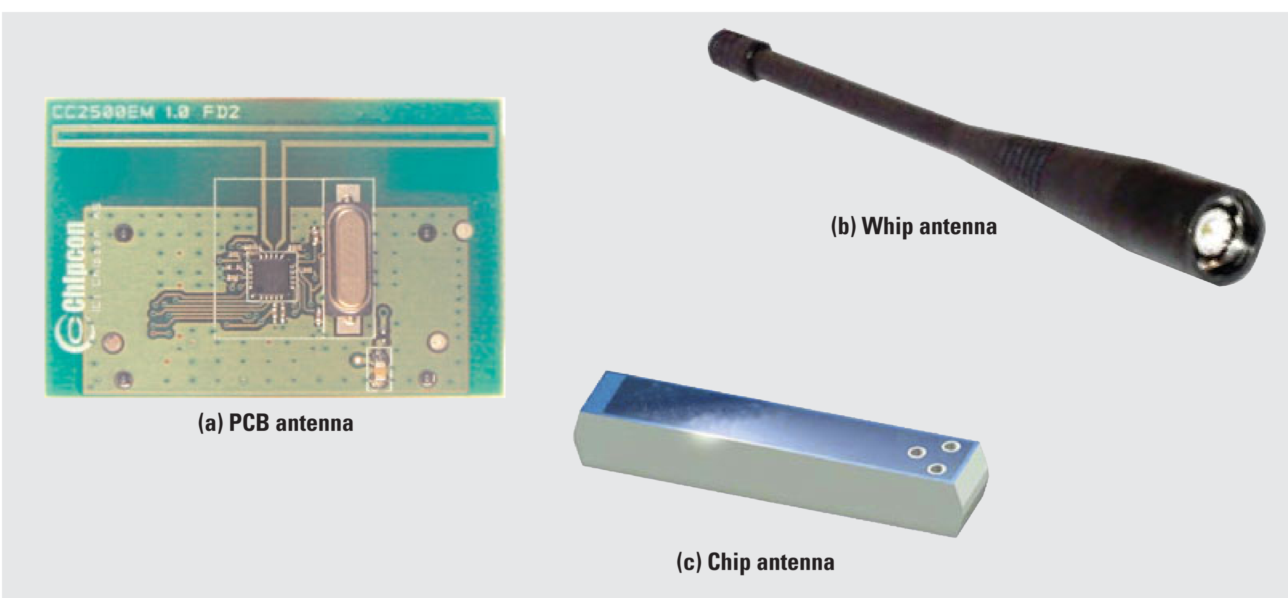
Table 1. Pros and cons for different antenna solutions

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 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

Chip antennas

If the board space for the antenna is limited, a chip antenna could be a good solution. This antenna type supports a small solution size even for frequencies below 1 GHz. The trade-off compared to PCB antennas is that this solution will add materials and mounting cost. The typical cost of a chip antenna is between $0.10 and $1.00. Even if chip-antenna manufacturers state that the antenna is matched to 50 Ω for a certain frequency band, additional matching components are often required to obtain proper performance.

Figure 1. Typical antenna solutions



(a) PCB antenna

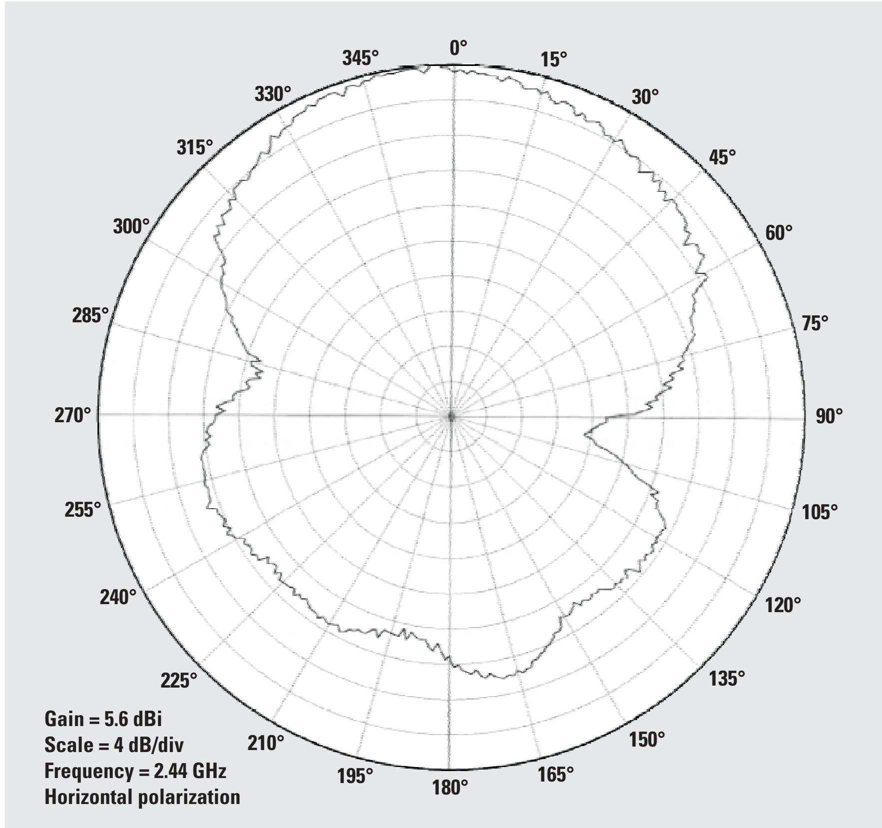
(b) Whip antenna

(c) Chip antenna

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. For maximum economy, a quarter-wavelength piece of wire can provide an effective solution.

Figure 2. Radiation pattern



Antenna parameters

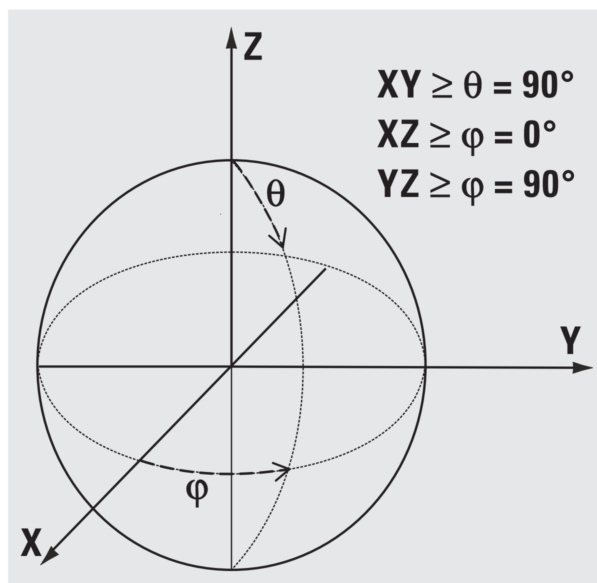
Some of the most important things to consider when choosing an antenna are: the radiation pattern, antenna efficiency, and antenna bandwidth.

Radiation pattern and gain

Figure 2 shows how the radiation pattern from a PCB antenna 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 2.

In addition to the plot information, it is important to relate the radiation pattern to the positioning of the antenna. Radiation pattern is typically measured in three orthogonal planes, XY, XZ and YZ. It is possible to perform full 3D pattern measurements, but it is usually not done because 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 3 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. For the YZ plane, 0° is in the Z direction and angles increase towards Y.

Figure 3. Spherical coordinate system



The gain, or reference level, usually refers to an isotropic radiating antenna, which is an ideal antenna with uniform radiation in all directions. When an isotropic 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 2 corresponds to 5.6 dBi and the 4-dB/div label in the lower left means that for each progressively smaller circle, the emission level is reduced by 4 dB. Compared to an isotropic antenna, the PCB antenna will have a 5.6-dB higher level of radiation in the 0° direction.

As shown by Equation 1, antenna gain, G, is defined as the ratio of maximum-to-average radiation intensity multiplied by the efficiency of the antenna.

$$G = e \times D = \frac{P_{rad}}{P_{in}} \times D = \frac{P_{rad}}{P_{in}} \times \frac{U_{max}}{U_{avg}}, \qquad (1)$$

where U_{max} is the maximum radiation intensity, U_{avg} is the average intensity, and the ratio of these two values is known as directivity, D. Ohmic losses in the antenna element and reflections at the antenna feed point determine the efficiency, e, which is simply the radiated power, P_{rad}, divided by the input power, P_{in}. High gain does not automatically mean that the antenna has good performance. Typically, mobile systems require an omnidirectional radiation pattern so the performance will be about the same for any antenna orientation. For an application where both the receiver and the transmitter have fixed positions, higher performance can be achieved when the antennas are positioned to direct their high-gain lobes toward each other.

To accurately measure an antenna radiation pattern, it is important to measure only the direct wave from the device under test and avoid reflecting waves that could affect the result. To minimize picking up reflected energy, measurements are often performed in an anechoic chamber or at an antenna range. 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 antenna dimension, DIM, as shown by Equation 2. Since the size of anechoic chambers is limited, it is common to test large, low-frequency antennas in outdoor ranges.

$$R_f = \frac{2 \times DIM^2}{\lambda} \qquad (2)$$

Polarization

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. When considering polarization, the electric-field vector is usually described and the magnetic field is ignored because it is perpendicular and proportional to the electric field. To obtain optimum performance, the receiving and transmitting antenna should have the same polarization. In practice, most antennas in short-range applications will produce a field with polarization in more than one direction. Reflections change the polarization of en electromagnetic wave. Since indoor equipment experiences a lot of reflections, polarization is not as critical as it is with equipment operating outside with line-of-sight limitations.

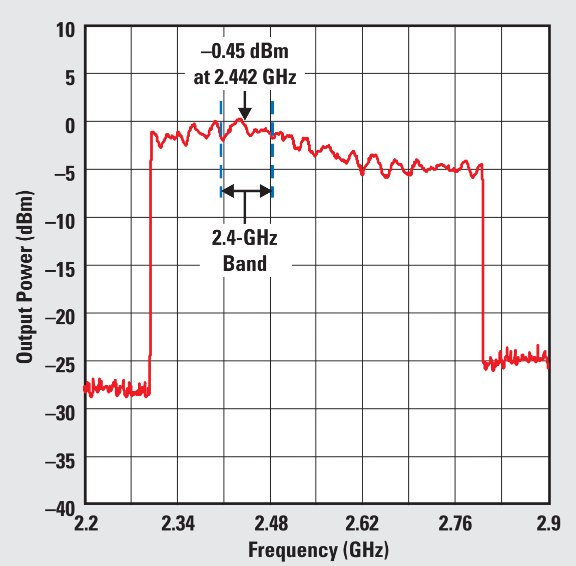
Bandwidth and impedance matching

Two common methods to determine antenna bandwidth are: 1) measuring the radiated power while stepping a carrier across the frequency band of interest, and 2) measuring the reflection at the antenna feed point with a network analyzer. Figure 4 shows the first method which is measurement of radiated power from a 2.4-GHz antenna that has approximately 2-dB variation in output power across the 2.4-GHz frequency band and has maximum radiation near the center of this band. This measurement was done by stepping a continuous-wave signal from 2.3 GHz to 2.8 GHz. Such measurements should be performed in an anechoic chamber to obtain a correct absolute level. However, this measurement can be very useful even if an anechoic chamber is not available.

Measurement in an ordinary lab environment can give a relative result that shows if the antenna has optimum performance in the middle of the desired frequency band. The performance characteristics of the receiving antenna being used to conduct the measurement will affect results. Therefore, it is important that this antenna has approximately the same performance across the measured frequency band. This precaution will help ensure that the observed relative change in performance across the measured frequency band is valid.

The second method to characterize antenna bandwidth is to measure the reflected power at the antenna feed

Figure 4. Bandwidth of a 2.4-GHz antenna



point. Disconnecting the antenna and connecting a network analyzer with a coax cable to the antenna allows such a measurement. The bandwidth of an antenna is typically defined as the frequency range for which the reflection is lower than –10 dB or the VSWR is less than 2. This is equivalent 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 Reference 1.

Size, cost and performance

The ideal antenna is infinitely small, has zero cost and has excellent performance. In real life, however, a compromise between parameters is necessary. For example, decreasing the operating frequency by a factor of two can double the RF range. Thus, one of the reasons to operate at a lower frequency is often to achieve longer range. The down side is that most antennas need to be larger at lower frequencies to achieve good performance. In some cases where the board space is limited, a small, efficient high-frequency antenna may provide equal or greater range performance than a small, inefficient low-frequency antenna. A chip antenna is good alternative when seeking a small antenna solution. This is particulary true with frequencies below 1 GHz because the chip antenna will allow a much smaller solution than the traditional PCB antenna. The main drawbacks with chip antennas are the increased cost and typically narrow-band performance.

Antenna reference designs

Texas Instruments (TI) offers a wide range of RF products that are design to operate in license-free frequency bands. The newest products consist of the CC11xx, CC24xx, and CC25xx families. TI also offers several antenna reference designs. Each reference design includes documentation of the antenna dimensions and the measured performance. Since the size and shape of the ground plane affects antenna performance, implementing the reference designs on a PCB with different ground-plane shapes and sizes may produce slightly different results. It is important to carefully copy the exact dimensions of the antenna to obtain optimum performance. No ground plane or traces should be placed beneath the antenna. Reference 2 gives an overview of available antenna reference designs and provides links to the relevant documentation.

References

For more information related to this article, you can download an Acrobat Reader file at www.ti.com/litv/pdf/*litnumber* and replace *"litnumber"* with the **TI Lit. #** for the materials listed below.

Document Title **TI Lit. #**

1. DN001, "Antenna measurement with network analyzer" swra096
2. AN058, "Antenna Selection Guide" swra161

Related Web sites

RF/IF and ZigBee® Solutions: **www.ti.com/lpw**
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