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ANTENNA BASICS

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BASIC ANTENNA DESIGN CONSIDERATIONS FOR ENOCEAN BASED PRODUCTS

25 June 2026

Observe precautions! Electrostatic sensitive devices!

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WO98/36395, DE 100 25 561, DE 101 50 128,
WO 2004/051591, DE 103 01 678 A1, DE 10309334,
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The modules must not be used in any relation with equipment that supports, directly or indirectly, human health or life or with applications that can result in danger for people, animals or real value.
Components of the modules are considered and should be disposed of as hazardous waste. Local government regulations are to be observed.
Packing: Please use the recycling operators known to you.

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1 Introduction

The purpose of this document is to provide basic knowledge and practical guidance for antenna design. The range and performance of an RF link depend strongly on the antenna. However, it is often considered only at the final stage of the design and expected to fit into the remaining space, even if this negatively affects performance. As a result, many designs either suffer from reduced performance or require multiple redesigns.

2 Most Popular and Efficient Small Antenna Types

2.1 ¼-wave whip (Monopole)

A whip antenna offers very good overall performance and stable operation. It has an almost isotropic, nearly omnidirectional radiation pattern, wide bandwidth, low cost, and a simple design. Because a full-wave or even a half-wave whip is usually too long for practical use, most whip antennas are designed as quarter-wave antennas.
If one arm of a dipole antenna is replaced by a sufficiently large ground plane, the ground plane acts as a mirror. As a result, the radiation pattern above the ground plane remains nearly the same as that of a half-wave dipole, and the antenna can provide very similar performance. This simple and effective antenna is called a quarter-wave monopole. It is one of the most common antennas used in portable devices today. Since most devices already contain a circuit board, using it as part of the antenna structure is often practical. In most cases, this part is connected to ground, and the transmitter or receiver is referenced to it accordingly, as shown in Figure 1.

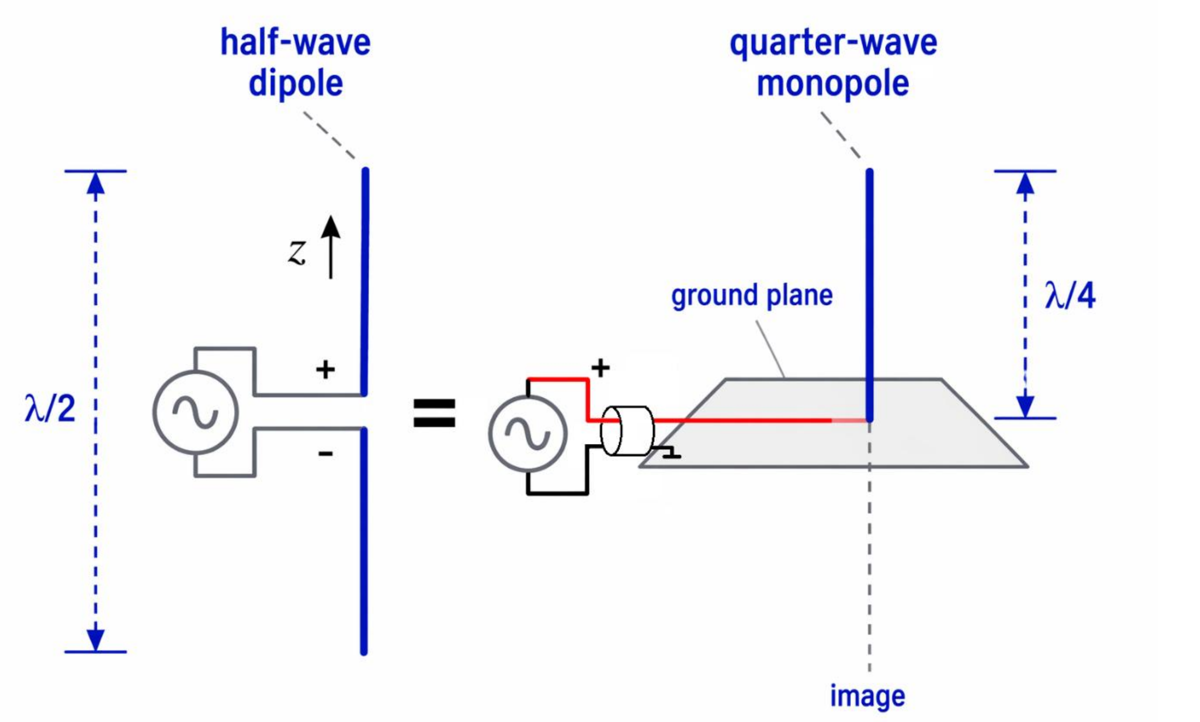

Figure 1 Half-Wave Dipole and Quarter-Wave Monopole Equivalence

2.2 Helical Antenna (Compact Quarter-Wave Design)

A helical antenna is a wire coil, usually made from copper, brass, or steel, and it can also be implemented on a PCB. Compared to a monopole, which is essentially a two-dimensional structure, a helical antenna is three-dimensional. It can be considered a shortened version of a quarter-wave antenna. Its radiation pattern is similar to that of a monopole, which makes it suitable for portable communication applications. A key advantage of the helical antenna is its compact size, especially at lower frequencies where antennas are normally larger. However, this size reduction comes with some trade-offs. Due to its higher Q factor, a helical antenna has a narrower bandwidth and typically lower gain than a full-size quarter-wave whip. In many practical cases, a helical antenna can still provide performance comparable to a quarter-wave antenna. The distributed capacitance of the helical structure also helps with impedance matching, which is not present in a straight quarter-wave antenna. This effect reduces the influence of the ground and simplifies integration.

2.3 Chip Antenna (SMT, Compact Solution)

Chip antennas (SMT) are not covered in detail in this document. For comparison, please refer to the table “Short Antenna Comparison”. For the 868 MHz band, the chip antenna WE-MCA (#7488910092) from Würth Elektronik can be considered as a suitable alternative.

2.4 PCB Antenna (Printed Quarter-Wave Design)

The PCB antenna described here can be seen as a special type of quarter-wave whip, where the radiating element is implemented as a copper trace on a printed circuit board. A PCB antenna is stable, reproducible, easy to manufacture, and makes use of the existing circuit board, which reduces cost and complexity. This application note provides basic guidelines for designing such a PCB antenna in the 868 MHz frequency range. The antenna is implemented on a standard, low-cost 1.6 mm FR4 printed circuit board.

2.5 Designing the Length of a PCB Monopole Antenna

The antenna is implemented on a standard 1.6 mm FR4 substrate with a typical dielectric constant of $\varepsilon r = 4.4$. The width of the monopole trace is $w = 1.5$ mm. At 868 MHz, the wavelength in air is $\lambda 0 = 34.5$ cm. As an approximation, the guided wavelength in the effective environment of PCB material and air can be taken as $\lambda E = 0.75 \times \lambda 0$. The antenna should have a sufficiently large ground plane for good efficiency. Ideally, the ground plane should extend at least a quarter wavelength around the feed point. The approximate physical length of a printed quarter-wave monopole antenna is therefore: $L = \lambda E / 4 \approx 6.2$ cm.
This value applies if the available ground plane is close to the ideal size and if the antenna trace is surrounded uniformly by the FR4 material. In practice, the antenna trace is often placed at the edge or in the corner of the PCB because of limited space. When implementing the monopole as a PCB trace, the initial trace length should be made somewhat longer in the first prototype, typically by about 25%. This extra length allows final tuning to resonance at 868 MHz. If the antenna trace must be bent, keep the distance between the open end of the trace and the ground plane as large as possible, preferably more than 20 mm. A smaller distance will reduce antenna performance. There should be no ground plane on the PCB layer or layers directly below the antenna trace. In addition, no ground plane, PCB traces, or

components should be placed close to the antenna trace. If needed, the antenna trace may also be bent into an L-shape.

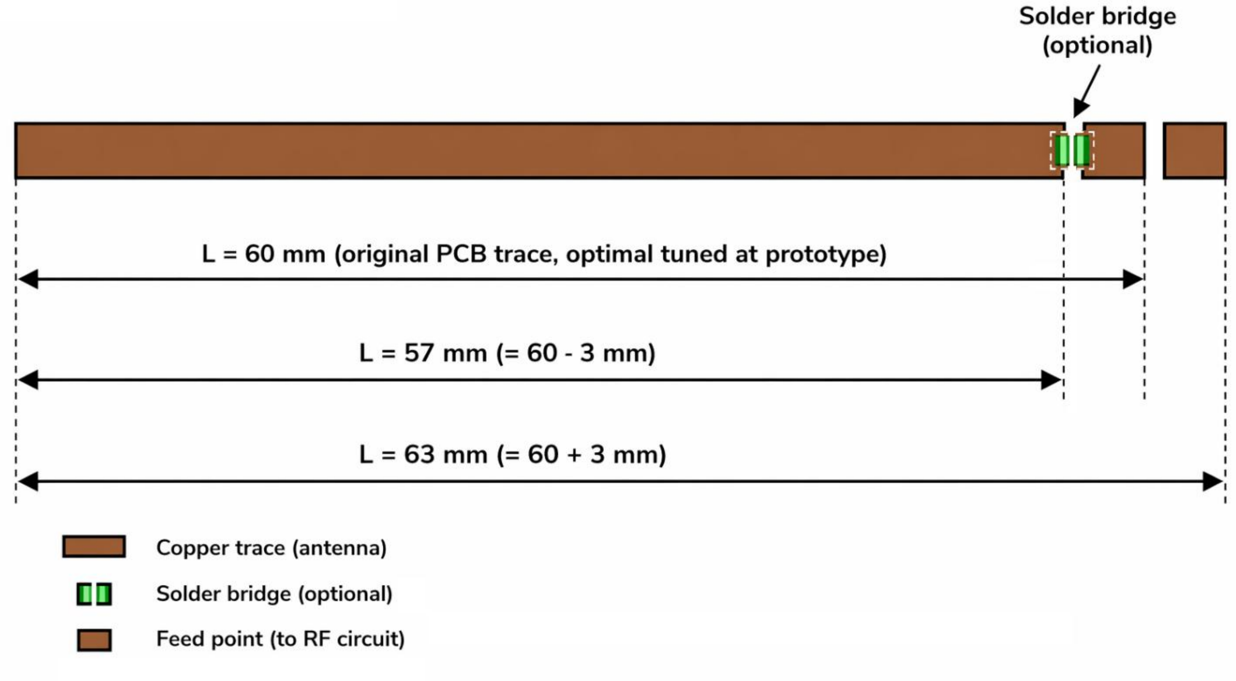

Figure 2 Example of PCB Antenna Length Fine Tuning Using Solder Bridges

Table 1 Comparison of Antenna Types

Antenna Type	Pros	Cons
¼-wave whip antenna	Low cost, good efficiency, good radio performance, easy to integrate, modular approval possible	Large at lower frequencies (long whip and ground plane), may require mechanical support
Helical antenna	Good efficiency, compact size, good compromise between size and performance	Higher cost than whip antenna, matching network required
Chip antenna	Very compact solution, especially at 868 MHz	High cost, matching network required; efficient chip antennas are limited; suitable only for special cases (e.g. key fobs)
PCB antenna	Lowest cost, reproducible, stable, uses existing PCB	Suitable only if PCB is large enough (including spacing)

3 Ground Plane Requirements and Practical Considerations

All antennas can be seen as resonant RLC circuits and, like other components, require at least two connection points. Important: Quarter-wave, helical, chip, and PCB antennas depend on a ground plane to operate correctly. Unlike a dipole (half-wave) antenna, these antennas require a ground plane as the second half of the radiating structure. A quarter-wave antenna and its ground plane together form a complete resonant system at the operating frequency. Therefore, the size, shape, and position of the ground plane are critical for proper antenna performance. Some antennas may appear physically shorter than their wavelength due to design techniques such as helical structures or the influence of PCB materials. However, this size reduction does not apply to the ground plane. A small or poor ground plane will negatively affect stability, performance, and operating frequency. The ground plane, also called a counterpoise, can be a solid copper area on the PCB or a metal enclosure. Since the RF circuitry is referenced to ground, this structure is directly connected to the antenna system. Its size, shape, and position relative to the antenna strongly influence overall performance. Ideally, antennas are designed with a ground plane that extends to about one wavelength. At this size, the ground plane behaves similarly to an infinite reference plane. If the ground plane is smaller, antenna characteristics such as radiation pattern and input impedance will degrade. Performance reduction becomes significant when the size is below a quarter wavelength. A common mistake is using a ground plane that is too small or fragmented by traces and components. In such cases, it cannot function effectively as the counterpoise of the antenna. In practical applications, it is often not possible to use an ideal straight quarter-wave antenna with a perfect ground plane inside a device enclosure. Therefore, even a well-designed and properly matched antenna can show reduced performance after integration, depending on its position, shape, and the surrounding housing.

4 Practical Guidelines for Antenna Design

This chapter presents practical guidelines for antenna design, focusing on efficient implementation and reliable performance.

- If enough space is available, use a quarter-wave monopole antenna for the best efficiency.
- Conductive or dielectric materials near the antenna are sometimes unavoidable. In such cases, measure the antenna impedance under real application conditions and match it accordingly.
- In small housings, a well-designed helical antenna can perform better than a poorly shaped whip antenna while keeping a compact size. For this reason, helical antennas are widely used and can provide very good overall performance when properly designed.
- When using pre-manufactured antennas (such as helical or chip antennas), keep in mind that their performance depends on the ground plane. The specified performance is only achieved if the ground plane has the same size and shape as the manufacturer’s evaluation board. Otherwise, measure the antenna impedance in the real application and match it to the required impedance.
- Keep the RF input/output trace as short as possible and design it close to a 50 Ω transmission line. As a starting point, a trace width of about 2.5–2.8 mm on a 1.6 mm FR4 board can be used. If the trace length exceeds 1 cm, consider using a 50 Ω coaxial cable.

- Size matters: According to fundamental physical limits (Chu and Wheeler limits), there is a trade-off between antenna size, bandwidth, and efficiency. A very small antenna cannot be both highly efficient and insensitive to tolerances. In general, antenna efficiency increases with volume, and antenna length is related to the wavelength.
- Do not forget that the ground plane is part of the antenna.
- A radio link always includes two antennas: one at the transmitter and one at the receiver.

5 Regulatory Note and Antenna Supplier References

For a receiver-only system, antenna performance can hardly be too good. However, for a transmitter or transceiver, a very efficient antenna may increase the radiated power. Therefore, make sure that the final device still complies with regulatory requirements such as CE or FCC/IC, especially with respect to radiated power limits.

Example antenna manufacturers (products and documentation):

- TE Connectivity (formerly Linx Technologies):
  https://www.te.com/en/products/antennas.html

- Würth Elektronik:
  https://www.we-online.com/en/components/products/pbs/signal_and_communications/antennas

- Taoglas:
  https://www.taoglas.com/products/embedded-antennas

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