ANTENNA BASICS –
Basic Antenna Design Considerations for EnOcean based Products

Importance of Antenna Design

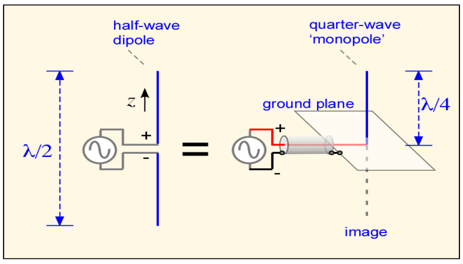
The purpose of this document is to give some knowledge as well as a guideline to the design with antennas. While the antenna is one of the most complicated aspects of RF design, it is also probably the most overlooked part of an RF design. The range and performance of an RF link are critically dependent upon the antenna. However, it is often neglected until the end of the design and expected to fit into whatever space is left, no matter how unfavorable to performance that location may be. Many of these designs will have to ultimately accept degraded performance or go through multiple redesigns.

The most popular and efficient small antenna types:

a) ¼ Wave Whip (Monopole):

A whip antenna provides exceptional overall performance and stability, has an isotropic pattern, a wide bandwidth, it is cheap and it is easily designed. Since a full-wave or even a half-wave dipole whip is generally quite long, most whips are ¼ wave.

Note: If one branch of the dipole antenna is replaced by an infinitely (enough) large ground plane, due to the effect of mirroring, the radiation pattern above the ground plane remains unaffected and delivers practically quite the same performance of a whole half-wave dipole.



This simple and most effective small antenna is the quarter-wave monopole and is the most common antenna on today's portable devices. Since most devices have a circuit board anyway, using it for half of the antenna can make a lot of sense. Generally, this half of the antenna is connected to ground and the transmitter or receiver will reference it accordingly, see Figure lefts.

b) Helical:

A helical element is a wire coil usually wound from copper, brass, steel, or even realized on PCB. Compared to the monopole, which is essentially a two-dimensional structure, the helical antenna is a 3-dimensional structure but is nothing else as a "shorter quarter-wave". Its radiation pattern is similar in nature to the monopole. This provides an optimum condition for portable communications. A small helical significantly reduces the needed physical size of the antenna and that is important at lower frequency (larger antennas); however this reduction is not without a price. Because a helical has a higher Q factor, its bandwidth is correspondingly narrower and its ideal gain is as a matter of principle lower than a "full size" quarter-wave whip. In many cases, the helical antenna will perform as well as the elongated ¼ wave antenna. The distributed capacity of the helical ¼ wave antenna acts as an impedance matching section that is not present in the full size ¼ wave antenna and minimizes the effect of the underground.

c) Chip (SMT): not further covered in this Appnote, see also table "short antenna comparison". For 868 MHz the Chip-Antenna WE-MCA (#7488910092) from Würth Elektronik could be an interesting alternative.

d) PCB antenna

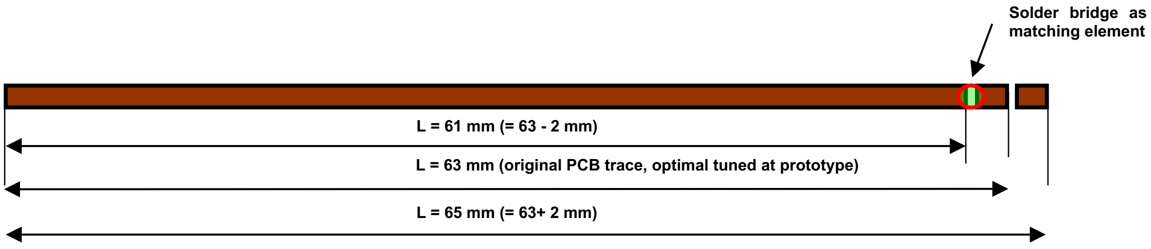
The below described PCB antenna is nothing else as a "special ¼ wave whip" antenna, where the whip is realized as copper trace on a PCB board. A PCB antenna is stable, reproducible, easy to manufacture and uses the existing board. This Appnote presents some specific basic guidelines on how to design such a PCB antenna for 868 MHz range. The described antenna is realized on standard 1.6 mm, low cost FR4 printed circuit board.

Determining the length of the printed monopole antenna

The antenna is printed on a standard 1.6 mm FR4 substrate material with a typical dielectric constant ε_r of 4.4 relative to air (1). The width of the monopole trace is w = 1.5 mm. For example the 868 MHz wavelength in air (ε_0) is λ_0 = 34.5 cm. It may be approximated that the guided wavelength on the effective resulting environment (PCB + air) is about $\lambda_E = 0.75 \cdot \lambda_0$. The antenna must have enough ground plane to be efficient and an ideal ground plane should spread out at least one quarter-wavelength around the feed-point. The physical length of a PCB quarter wave monopole antenna is then $L = ¼ \cdot \lambda_E$ or 6.3 cm, provided that the size of the available ground plane is close to the ideal and the antenna trace is uniformly surrounded by the FR4 substrate. (Often the antenna trace is implemented on one edge or/and corner of the PCB because of the space limitations). When implementing the monopole as a trace on the FR4 PCB, the initial roughly calculated length should be extended by the first prototype somewhat (starting with about +10%), to allow final fine-tuning of the antenna to resonance at 868 MHz (tuning procedure see below). When bending the antenna trace, be sure to keep the distance between the open end of the antenna trace and the ground plane as large as possible, preferably more than 20 mm. Reducing this distance will reduce the performance of the antenna. There shall be no ground plane on the PCB layer(s) beneath the antenna trace. No ground plane, PCB traces or components should be placed close to the antenna trace. The trace can also be e.g. L-shape bended if required.

Tuning of the antenna is done by simply cutting the initial starting length of the PCB antenna step by step trace until resonance at 868 MHz is reached (max. performance of DUT). The tuning has to be done on the equipped PCB, placed inside the intended application case/box, in typical environment. For applications where range performance is not very critical, the antenna can be tuned by measuring radiated power around the antenna with a spectrum analyzer. For more accurate tuning, a vector network analyzer is required for impedance and SWR (Standing Wave Ratio) measurements. Please note that the relative gain of such quarter wave PCB antennas compared with standard whip antennas (in the air) corresponds roughly with their dimension reduction factor, e.g. is also reduced with about the same factor 0.75.

For production, the optimum antenna length L found on the prototype should be used, two bridgeable (short, few mm optional soldering) in production fine tuning elements (e.g. L +/- 3%) to increase the tolerances for the later mass production (different PCB materials or suppliers, specific device mounting undergrounds) can also be implemented like in the example shown below:



Short Antenna Comparison

Antenna	Pros	Cons
¼ Whip antenna	Low cost solution, good efficiency, good radio performance, modular approval possible, simple to integrate	Large at lower frequency (whip length and ground plane), may need manuall shape fastening.
Helical	Good efficiency, small, good overall compromise (size vs. performance)	Higher costs as Whip. Matching network design needed.
Chip	Smallest solution for 900 MHz bands antenna.	High price. Matching network design needed. Recommended only in special cases (reduced range requirements and limited place availability, e.g. for key fob).
PCB	Lowest cost solution, reproducible, stable, use of existing PCB	

What does the Ground Plane have to do with all these antennas?

All antennas are resonant RLC networks and like any electronic component, have at least two connection points. IMPORTANT: Quarter wave, Helical, Chip or PCB antennas are, in opposite with dipole (½ wave) antennas all ground dependent, that is, they must have a ground plane (like a mirror) to work against. A quarter wave antenna and ground plane combine to form a complete resonant circuit at the operational frequency. Since this plane is the other half of the antenna, its size and proximity are essential. Often an antenna can appear smaller than its specified wavelength. This is due to internal mechanical tricks, such as helical windings or environmental (PCB) permeability that can dramatically reduce the antenna's physical size. This does not mean that the same size is appropriate for the ground plane. A compromised ground plane affects antenna stability, performance and operational frequency.

Please note that the performance of such antennas is critically dependant upon the counterpoise used as the other half of the antenna. This counterpoise can be a solid copper fill on a circuit board or even a metal enclosure. Since the RF stage is referenced to the circuit ground, this plane or the enclosure are also connected to ground. The size and shape of the ground plane counterpoise as well as its location with reference to the antenna will have a significant impact upon its performance figure.

Typically, antennas are designed on a counterpoise that is one wavelength in radius. At one wavelength, the counterpoise will act sufficiently like an infinite plane. This begs the question "what happens when the ground plane is reduced to something that is practical for a portable product?" Generally, if the radius of the counterpoise is longer than one wavelength, the performance is close to that of an infinite counterpoise. If the radius is shorter than one wavelength, the radiation pattern and input impedance are compromised. Significant performance reductions occur however when this radius is under a quarter-wave.

A common pitfall is also the implementation of the ground plane. As stated earlier, the ground plane is the other half of the antenna, so its size is critical to the final performance of the product. If the ground plane is either too small, cut up with traces and through-hole components, then it is not going to be able to work as an effective antenna counterpoise.

Another important practical aspect is, that since in the most practical applications it is not possible to integrate an straight 1/4 wave long whip ideal antenna with ground plane into a housing, the performance of an even correct selected and matched "standalone" antenna will be critically affected upon its later custom positioning, shape and housing.

Rules of Thumb for the Internal Antenna Design

- If the available space is sufficient, use a quarter-wave monopole antenna for best efficiency.
- Sometimes, conductive or dielectric materials in the reactive near field of the antenna are unavoidable. In these cases, measure the antenna impedance under real application conditions and match it correspondingly.
- In a small housing a well designed helical can achieve a better performance as a poor shaped whip while maintaining a very compact size. The helical is therefore very popular, since well designed it can provide excellent overall performance at small size.
- When using pre-manufactured antennas like e.g. helical or chip, keep in mind that their performance depends on the attached (ideal) ground plane. The manufacturer's specifications can be only achieved if the ground plane has the same size and shape as the manufacturer's reference board. In all other cases, you have to measure the impedance of the pre-manufactured antenna under application specific conditions and to match it to the required impedance.
- Take special care of the RF in/out tracking: as short as possible, and as good an approximation to a 50 Ohm strip-line as you can achieve (2.5 - 2.8 mm thick tracking on 1.6 mm epoxy board is a good starting point). If longer track is needed, then seriously consider using a 50-Ohm coax cable therefore.
- Size matters: Always keep in mind that Chu's and Wheeler's limit law defines the product between the bandwidth and efficiency as constant for a given antenna dimension. As consequence, an extremely small antenna cannot be efficient and tolerance-insensitive (broadband) at the same time. As a general physical rule, the antenna's efficiency is directly proportional to its volume, while its length correlates directly to the wavelength.
- Don't forget, the ground plane is part of the antenna
- A radio link has always TWO antennas (transmitter and receiver)

Finally just one remark: you can never make a "too good antenna" for receiving only, but maybe for transmission! Therefore, please make sure that the final device fulfils the specific, regional approval requirements with respect to maximum allowed transmitted power.