Helical Antenna with Angle Reflector

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The "reflector plate" of a helical antenna cannot increase the antenna gain because it flips the sense of rotation of a circularly polarized wave. A double reflection avoids this disadvantage and increases the antenna gain. Performed measurements confirm these considerations.

1 Introduction

Effective transmission of electromagnetic waves requires matched antennas, usually wire antennas in the frequency range below 10 GHz. Helical antennas with a well-conducting wire are suitable for transmitting circularly polarized waves, which can be either left- or right-handed. Although invented about 70 years ago, research is still underway to find an optimal design. So far, it is unclear why no variant exceeds the maximum gain of 16 dB. Possibly, too little attention is paid to the reflector. Most often, a metal plate is suggested without precise information about shape, size and distance to the helix. May we conclude that the reflector is an embarrassment solution, a component to which one can screw the shield of the coaxial cable? A piece of metal without a defined electrical function?

2 Previous designs of helical antennas

Construction proposals on the Internet usually describe a single helix with at least four turns of copper wire, which is wound on a cylinder. Its circumference should be about one wavelength, the pitch of the helix about 25% of the wavelength. The terminal impedance of 130 ohms is matched by a $\lambda/4$ transformer to a common 50 ohm coaxial cable. More complicated proposals with multiple wires or variable winding diameters never gained acceptance for lack of convincing results. In contrast to linear dipole antennas, precise dimensions are nowhere given and the velocity factor strangely does not play a role.

3 Sense and effect of the reflector plate

When an electromagnetic wave is reflected from a flat, well-conducting metal surface, the result can be predicted using Maxwell's equations: the direction of rotation of the circular polarization is reversed, an RHCP becomes an LHCP and vice versa. If the reflecting plate is sufficiently large (many wavelengths in diameter), the law of reflection $angle\ of\ incidence = angle\ of\ reflection$ applies. This is no longer true for small dimensions of only a few wavelengths. Then the "reflector plate" scatters energy in arbitrary directions and its effect approaches an isotropic radiator, which redirects only a small part of the (backward) radiated energy.

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This is just as well, because if the "reflector plate" were to reflect the incident energy as effectively as a very large, very well-conducting flat metal surface, the helical antenna would generate a linearly polarized wave. The reason is simple to understand: If you radiate two circularly polarized waves of the same amplitude and the same frequency, but with different sense of rotation into the same direction, you get linear polarization. Its direction (horizontal or vertical or oblique) is determined by the phase difference of the two original waves. In other words, a linearly polarized wave can always be thought of as the sum of two equally strong circularly polarized waves with constant phase difference. In some areas of physics ($\lambda/4$-plates in optics) this idea is very useful, also in the reflection of short waves from the ionosphere.

In summary, the small "reflector plate" of a helical antenna is a scattering body, a metal object that partially uses the shield current of the coaxial cable to radiate something similar to a spherical wave of undefined polarization. This is the reason for the often peculiar directional patterns of helical antennas. It remains to be noted that the portion of energy radiated by the "reflector plate" in the helical antenna's target direction (forward) has the *wrong* circular polarization sense and is therefore ideally ignored by the receiving antenna. How can this be improved?

4 Improved helical antenna

We start with a Gedanken experiment and do without the "reflector plate". We build a symmetrical helical antenna: A wire is wound about twelve times around a tube (diameter $= \lambda/3$) with vertical axis. The distance between adjacent windings should be about $\lambda/4$. The transmit energy is fed into the center (similar to a $\lambda/2$ dipole) and the frequency is chosen so that the antenna radiates as much energy up and down as possible. The ratio of wire length or turn circumference to the wavelength of the injected energy is not of interest at first (This point contains another surprise, which will be discussed in more detail below). The only goal is to radiate circularly polarized waves into both axial directions.

If the wire was wound as a left-handed helix, a measurement confirms that the antenna radiates equally strong LHCP waves both upward and downward. A very large metal plate on the floor would reflect the downward wave but also turn it into an RHCP wave. This is undesirable. Only if the downward wave is reflected *twice* on metal surfaces, the direction of propagation is changed without reversing the direction of rotation of the circular polarization.

Figure 1 shows the principle: Two metal surfaces enclosing a right angle deflect the downward emerging wave upward. It makes sense to bend the lower half of the original symmetrical and very long helical antenna and to arrange both halves side by side. This shortens the overall length and simplifies the asymmetrical power supply through a coaxial cable.

Experiments have shown that the distance between the two halves of the helix is not critical; it allows fine tuning of the resonant frequency. This design ensures that the kinked reflector surface finally deserves its name: The amplitude of the LHCP wave radiated upwards increases. Ideally, no RHCP wave should be measurable.

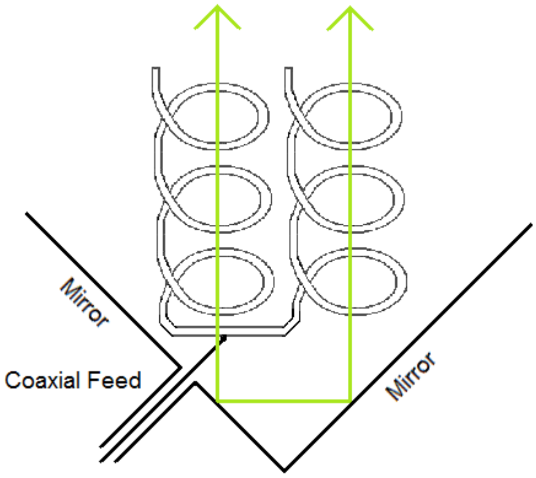

Figure 1: The angle mirror deflects every wave coming from above by exactly 180º. This also applies to waves arriving at an angle. Only on the short horizontal path below the helix the polarization sense is inverted.

Large area reflectors mean high capacitance and are able to absorb the shield current of the coaxial cable. The value of the energy radiated in the process was not investigated. Other, asymmetrical geometries may also be realized without loss of gain: In figure 2, the two wire screws made of silver-plated copper wire are arranged side by side and are therefore closer to the connecting edge of the two metal surfaces, increasing the antenna gain. Although the axes of the two screws do not point into the angle bisector of the metal plates, no gain losses were measured.

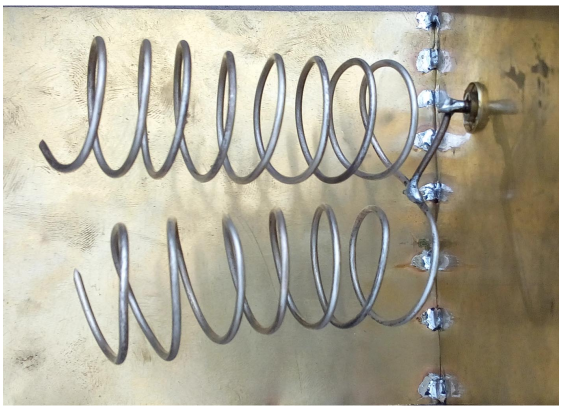

Figure 2: Double helix in front of the 90º reflector. On the right you can see the backside of the coax socket. The 20 mm short piece of wire to the helix simplifies the electrical matching (see text). For continuous operation a mechanical fixation of the helix is recommended to avoid a short circuit with the reflector.

The electrical parallel connection of two helical antennas brings a pleasant side effect: Near the resonant frequency the impedance 54 ohms is so close to the nominal value 50 ohms that the antenna reaches an acceptable SWR even without a transformer. Strangely, the approximately 2 cm short piece of wire between the inner conductor of the coax cable and the center of the two helix coils seems to be necessary, although it is too short for a $\lambda/4$ -transformer ($\lambda = 12.5$ cm). If you do without it, the adjustment will not be quite so simple.

Figure 3: Display of the VNA. At resonance (2401 MHz), the SWR is less than 1.3 (yellow U-curve). The green circle shows how much the reactance changes as a function of frequency.

Many construction descriptions claim a remarkably wide bandwidth of helical antennas. This does not apply to the arrangement described above: The measured values in figure 3 show that the antenna achieves an acceptable SWR only in the small frequency range 2400 MHz $\pm$ 3 MHz. The exact resonant frequency can be adjusted by bending the wires. To avoid incorrect measurements, it is important to repeat all measurements with coaxial cables of different lengths between the signal analyzer (Vector Network Analyzer) and the antenna. The cable length must not noticeably influence the resonant frequency or SWR.

5 Construction

Helical antenna-1: If one follows the usual construction instructions, one should wind the helix wire around a cylinder with diameter = $\lambda/3$, so that the circumference of the helix is about as long as the wavelength. However, the resonance of all model coils with dimensions D(inside) = 38 mm; D(outside)= 42 mm is not - as expected - at 2400 MHz but much lower near 1607 MHz. This experiment was repeated with different values of diameter, number and spacing of turns, wire length and wire thickness - always with similar results. Nevertheless, this antenna (with flat "reflector disk") was used as reference without further adjustment.

Helical antenna-2: If the winding diameter of the helical antenna is reduced to 23 mm, the resonant frequency increases to 2400 MHz. Obviously only the diameter of the helix is decisive. The pitch of the helically wound wire is about 10 mm. The optimization of the antenna for transmission is done with the help of a Vector Network Analyzer.

6 Results

Good transmitting antennas are also good receiving antennas. Therefore, the reception characteristics of several antennas were compared using a low-power miniature transmitter, consisting of few components: A 50 MHz quartz oscillator overrides a distortion circuit with a BF224, to whose collector a 20 mm long piece of wire is soldered as an antenna. The 48th harmonic of the quartz frequency can still be detected from a distance of several meters (d $\approx 20\lambda$) and allows comparative measurements. Various test antennas were connected one after the other to an ADALM Pluto, the signal strengths were determined with a Satsagen spectrum analyzer. (Thanks to Alberto Ferraris IU1KVL). The frequency range 2399 MHz to 2401 MHz is shown.

- The antenna is a 30 mm long piece of wire. The test signal is just detectable (max. 1 dB above noise).
- ADALM antenna (included in delivery): 1 dB
- adapter SMA-BNC screwed on, no load: 3 dB above noise
- helical antenna-1 of usual design: main lobe 22 dB; back lobe 2 dB
- double helix-2 with angle reflector: main lobe 29 dB; back lobe 12 dB

The striking increase in gain due to the angular reflector is physically well founded, but must be verified by further measurements. Apparently, the gain of this helical antenna design exceeds the magic limit of 15 dB. The main reason is probably the double reflection of the waves to avoid an undesired flip of the the rotation sense of the circularly polarized wave. Due to the lack of an anechoic measurement site, no directivity diagrams could be measured.