TECHNICAL ARTICLE

The Basics of Quadrifilar Helix Antennas

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INTRODUCTION

From its almost accidental origins, the axial mode helix antenna has gone from a young professor's laboratory curiosity to one of the most widely used antennas for UHF and microwave communications. With the explosive growth of satellite-based services, the ability to receive or transmit a tight beam of circularly polarized radiation while minimizing unwanted radiation is imperative to maintaining good communication. The axial-mode helical antenna provides a high performance and robust antenna platform both in space as well as on the ground.

The term "axial-mode" refers to the tendency of the antenna to radiate in the direction of the ends (axially), instead of laterally, if the helix circumference is of the order of one wavelength. Moreover the axial mode helix also radiates a predominantly circularly polarized wave. Circular polarization is important in space communications as well as in terrestrial mobile applications, because the favorable relative orientation between linear polarized transmitting and receiving antennas is not guaranteed. Moreover, for space applications, Faraday rotation through the ionosphere is generally unpredictable. (Magnetized plasma in the ionosphere rotates the direction of linear polarization, but has no effect on circular polarization.) For these reasons, it is likely that linear polarized antennas would experience deep signal fades from these effects, making communication unreliable. Hence the utility of helical antennas in their many forms (for example: monofilar, quadrifilar, conical, resonant, spiral, etc.).

The simplest incarnation of the axial mode helix is the monofilar helical antenna. Consisting simply of a screw-wound single conductor over a ground plane (Figure 1), this antenna produces circular polarization that follows the winding sense of the helix and maintains a fairly constant feedpoint impedance over a wide bandwidth.

Using an antenna simulator, we explore several helical antenna examples. We first look at the monofilar helix antenna to establish a starting baseline for comparison with the quadrifilar antennas and to show a useful impedance matching method. We then study so-called long (i.e. more than a wavelength) traveling wave quadrifilar helix antennas to demonstrate the superior control one has over the antenna pattern by modifying the phase progression of each helical radiator. We end our brief story with the short resonant quadrifilar helix; the real star of our show. This antenna finds much use in portable applications, due to its compactness and ease of integration with mobile systems. We show some examples of our compact helix antenna designs for use in GPS, L-band satcom, as well as VHF/UHF ELT, PLB and EPIRB applications.

Keep in mind that a "traveling wave" antenna is a structure that is not a resonant antenna. A wave is "launched" from the feed and "leaks out" into space as it moves toward the end. By the time the launched wave has reached the end of the antenna, it has died down to a low level and power reflected back into the feed is very small, generally over a wide bandwidth. This behavior is the opposite of that of a small "resonant" antenna where a wave bounces back and forth from the feed end and open end of the antenna with little decay, as is the case with a dipole antenna or a short resonant helix. Power is efficiently radiated in this case only over a small bandwidth.

Three helix antenna types

The monofilar helix antenna was invented in 1946 by John Kraus. Few antennas are as easy to construct as Kraus' original monofilar helix. Some form of support, a "pie-pan" ground plane of any diameter between ½-1 wavelength, some simple impedance matching and a single conductor wound according to a few simple rules yields a circularly polarized antenna capable of 10-17 dBi gain over 60% fractional bandwidth. Feedpoint impedances, depending on the feed geometry, will be of the order 150-300 ohms (depending on antenna geometry), therefore some form of impedance matching will be needed for efficient operation in 50 ohm systems.

Helix windings and circular polarization are always described as "right-" or "left-handed." Keeping this straight is important, but not difficult using the "right-hand" and "left-hand" rules. If you point the thumb of your right hand along the helix axis away from the feed and your fingers coil around in the direction of the windings moving away from the feed, the helix is "right-handed." The helix is "left-handed" if it satisfies this rule with the left hand. For polarization, your thumb points in the direction of propagation away from the antenna (not necessarily along the helix axis, though) and your fingers correspond to the corresponding left- or right-hand circular movement of the electric field vector. Another possible visualization model is that of a screw. Most screw and bolt threads are "right-handed" spirals that can be easily verified using the right-hand rule pointing away from the screw head.

The antenna in Figure 1 consists of a single loosely wound coil of wire around a central axis. One can easily see that the sense of the winding is right-handed, indicating that this antenna radiates a right-handed circular polarized wave in the presence of the ground plane. Notice the central support needed to prevent drooping of the helical conductor. This can be metallic or non-metallic without affecting the radiation properties significantly.

Figure 1: *Monofilar axial-mode helical antenna.*[1]

The performance of the long helical antenna is improved by using the quadrifilar configuration seen in Figure 2. By adding the extra windings, the radiation pattern can be tightened up and sidelobes reduced with respect to the monofilar helix. Furthermore, the circular polarization characteristics can be improved without increasing the antenna footprint. Usually, each component helix is excited in a 90 degree progression going clockwise or counter clockwise, depending on polarization/lobe direction combination we want to radiate. For the quadrifilar helix wound in the right-hand sense, a clockwise (left-hand) phase progression of the feeds induces the “forward helix mode”, so called because the wave phase appears to propagate along the helix from the feed to the open end. The 0° phase point moves progressively to helices that sit physically above the others as time progresses. Likewise, a counter clockwise (right-hand) excitation of the individual helices causes a helix wave whose phase appears to move toward the feed in the so-called “backward helix mode” configuration. The 0° phase point now moves progressively to helices below the present one. Note that the forward mode will radiate as an endfire beam and the backward mode as a backfire beam and the circular polarization will be opposed to the sense of the helix winding sense, regardless of the feed phase progression.

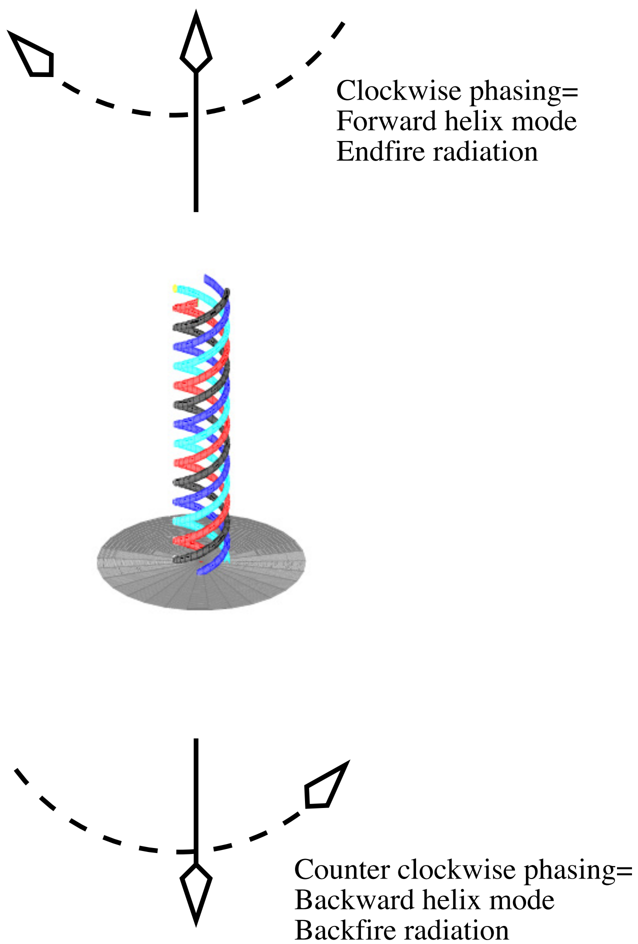


Figure 2: *Long quadrifilar axial-mode helical antenna wound in the right-hand sense. The disk at the bottom corresponds to the ground plane if it is present. The feed points of the helices are located at the bottom of the helices and the “clockwise” and “counterclockwise” feed sense is defined looking down from the top of the antenna.*

When a ground plane is present however, backfire radiation is then reflected forward and the circular polarization sense is reversed. Helical antennas that use ground planes typically use the backfire mode of operation, relying on the ground plane as a reflector for converting backfire to endfire radiation. Under certain circumstances we may desire to eliminate the ground plane and permit the backward mode to radiate in the direction of the feed, which we exploit for the compact resonant quadrifilar antennas.

To summarize the salient points of the quadrifilar antenna:

- If feed phasing sense is the same as quadrifilar helix winding sense, the antenna will be backfire.
- If feed phasing sense is opposed to the helix winding sense, the antenna will be endfire.
- The circular polarization sense of the radiation will be opposed to the helix winding sense regardless of the feed phasing sense.
- If a backfire helix antenna is used with a reflector or ground plane at the feed, the sense of the circular polarization is reversed and the antenna becomes endfire. The polarization sense now corresponds to the winding sense of the helices.

The quadrifilar helix need not be a long traveling wave antenna, but can be shortened to sizes commensurate with ½ a wavelength and operated as a resonant antenna, much like the familiar resonant dipole or loop antenna. Whereas the wide-bandwidth long helices operate well despite some deviation from the ideal antenna dimensions, the operation of the resonant, narrow-bandwidth backfire quadrifilar helix antenna (Figure 3) requires a careful choice of antenna dimensions and attention to construction detail.

The feeds of each helix in the long quadrifilar antennas require some sort of quadrature feeding network to generate the 90° phase progressions. This can take the form of quadrature hybrids and power splitters. However, for the small resonant helix, it is advantageous to use two co-wound ½ helices of slightly different dimensions that induce quadrature excitation of each helix pair. This property is very similar to the "nearly square" method of generating circular polarization in a microstrip patch antenna.[2]

Consistent with the quadrifilar helix behavior in the absence of a ground plane, the helix winding sense is opposed to the desired circular polarization sense. That is to say a left-hand wound helix will generate right hand circular polarization. Keep in mind that if the winding sense is not correct, the polarization sense will be incorrect and communication will be severely impeded (if not completely prevented). The cross polarization suppression can be in excess of 20 to 30 dB!

This antenna produces a nearly hemispherical radiation pattern. Careful adjustment of the "bent eggbeater" loop dimensions will produce a 50 ohm feedpoint impedance as well as excellent quadrature excitation without the need for external quadrature generating circuits. Moreover, since no ground plane is needed, making this one of the most useful helix antennas for handheld and mobile UHF and microwave radios. Of course, for all this small antenna goodness, one must sacrifice the bandwidth and directivity of the large traveling wave helical antennas.

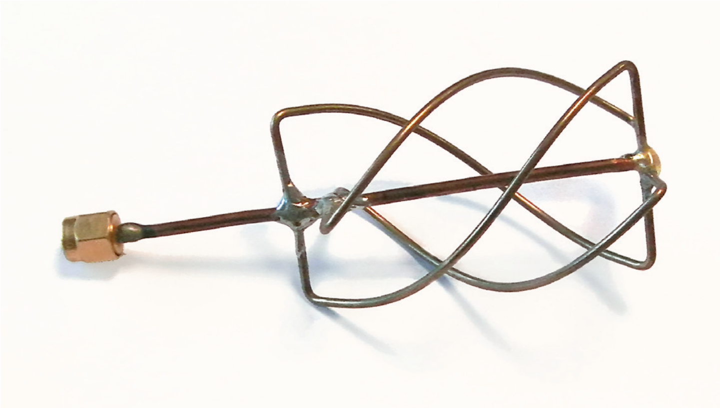


Figure 3: *Backfire resonant quadrifilar helix antenna popular for GNSS, communications and weather satellite receiving stations. This antenna is configured for right-hand circular polarization. Note left-hand winding sense and the feedpoint at the top of the antenna.*

Whereas we focus on three basic versions of the helical antenna, the reader needs to be aware that helical antennas include a large class of spirals and conical helices that take many forms and can be optimized for multi-octave bandwidths, variable polarization, steerable beams, etc. The goal of this brief article is to introduce three basic forms of the helical antenna in a qualitative manner; progressing from the monofilar helix to the compact quadrifilar helical antenna. The reader wishing a more in-depth exposition of helical antennas is directed to the list of references. The book by Kraus[3] is especially accessible and informative in this regard.

The monofilar helix as baseline

Before looking at the quadrifilar examples, we should get an idea of the expected performance of a typical helix antenna. The main design criteria are the helix diameter, the winding pitch angle (determined by the antenna height and number of turns) and the ground plane diameter, all shown in Figure 4. The electrical performance of the helix is not strongly affected by the diameter of the conductors and is generally dictated by mechanical constraints. Values of 0.001-0.01 wavelength will give good results. Increasing the spacing between the turns and the circumference of the helix and number of turns will increase the directivity of the antenna. The feedpoint impedance is also sensitive to the turn spacing and circumference, generally increasing as these dimensions increase.

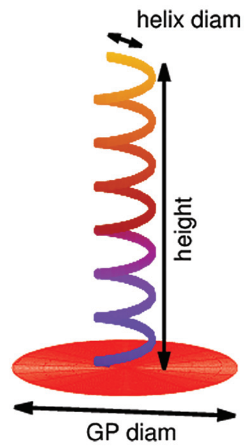


Figure 4: *Monofilar helix showing main design criteria. These dimensions scale to wavelengths.*

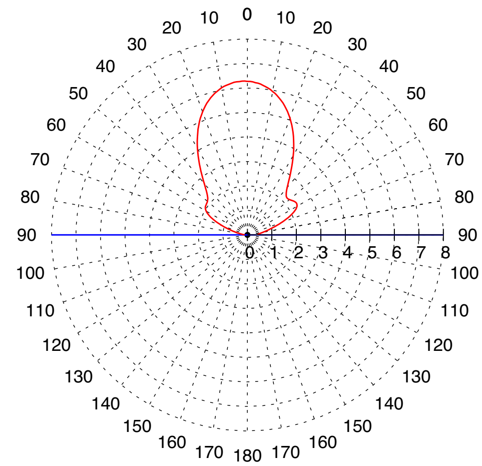


Figure 5: *Radiation pattern of 7 turn right-hand polarized helix at 300MHz. Radial scale in all plots is linear in power, helix axis is at 0°.*

Satisfying the requirements presented in Table 1, we choose a right-handed helix with seven turns and a winding pitch p of 0.25 wavelengths. Consequently, the helix height will be 1.75 wavelengths. If we choose the helix circumference to be one wavelength (near optimum), the helix diameter will be 1/π or 0.318 wavelengths. The winding pitch angle is 14.8°, which gives us the 0.25 wavelength turn separation. Let us start with the assumption that the ground plane is of infinite extent. If we assume a wavelength of 1 meter (frequency=300 MHz), we find that this antenna radiates a well-defined circularly polarized wave with a pattern found in Figure 5. As we move to lower elevations, the radiation becomes elliptically polarized (a degraded form of circular polarization). At the lowest elevations (near the ground plane) the radiation is nearly vertically polarized. The directivity of this antenna is about 8 dBi.

Parameter	Value
Helix circumference C	$3\lambda/4<C<4\lambda/3$ (we choose 1λ)
Winding separation p	$0.19\lambda<p<0.25\lambda$ (we choose 0.25λ)
Winding pitch angle α	$11\lambda<\alpha<15\lambda$ (14.77° gives 0.25λ turn separation)
Number of windings N	$3<N<15$ (we use 7 turns)
Ground plane (GP) diameter D	$D>\lambda/2$ (we use infinite ground plane, unless stated otherwise)
Conductor thickness t	Low sensitivity to t, as long as mechanically feasible.
Feedpoint impedance Z	Sensitive to feed configuration. Typically 140-250 ohm

Table 1: *Set of parameters required for axial-mode operation.*

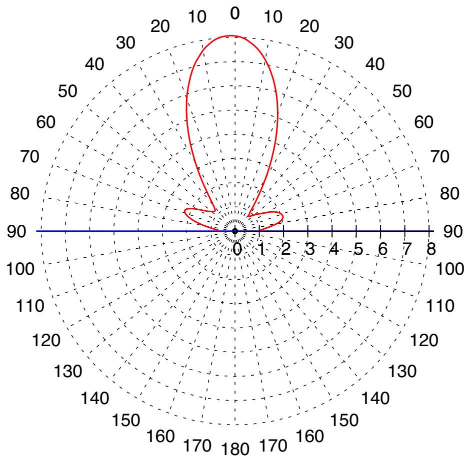


Figure 6: *Radiation pattern for 7 turn helix at 350 MHz. Notice that sidelobes are more evident and main lobe is narrower, exhibiting higher gain than at 300 MHz.*

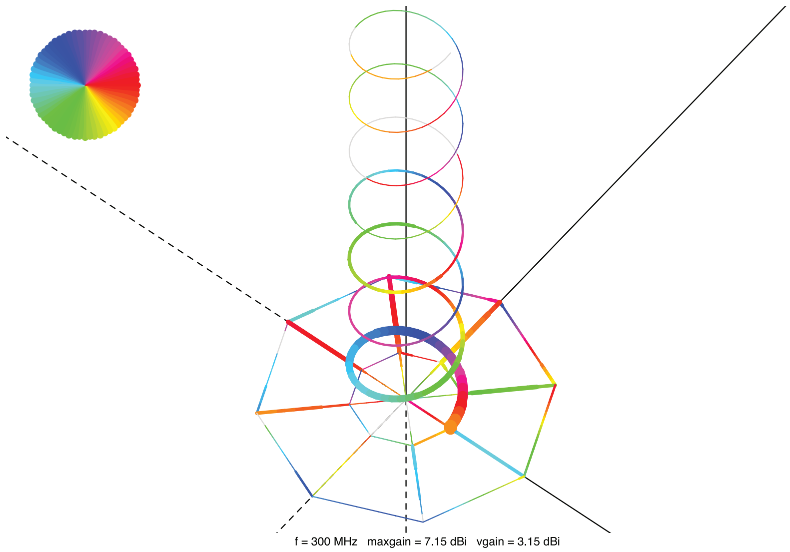


Figure 7: *Geometry of the wire mesh finite ground plane used in simulations. Ground plane diameter is 0.8 wavelength at 300 MHz.*

The 3 dB beamwidth in this case is about 70°. Notice the appearance of two sidelobes near 60° off the vertical axis. As a result of the feed geometry, we observe a slight asymmetry in the pattern, especially visible in the sidelobes. This asymmetry contributes to a slight “beam squint” in the main lobe (a slight off-axis deviation of the main lobe).

The sidelobes become more apparent as the frequency increases. This is because the helix antenna behaves exactly as an array antenna would, i.e. as phase delay between each array element increases (in this case, helix turns) sidelobes become more evident. The main lobe becomes narrower as well, as seen in Figure 6.

Additionally, the sidelobes become more linearly polarized at low elevation angles (near 90°). For all practical purposes, at low elevation angles around 70° off axis, the waves are nearly linearly (vertically) polarized at 350 MHz. The sidelobes become more pronounced and we now have a half-power beamwidth of about 50°, and a maximum directivity of 8 (9 dBi).

Effect of finite ground plane

One may also ask how a finite ground plane affects helix performance. To shed some light on this, we construct a model with a circular finite ground plane of 0.8 wavelength diameter instead of the infinite half-plane (Figure 7).

For the finite ground plane example, we should expect significant backfire radiation lobes as there will be some diffraction around the ground plane edges. However, we see that the main lobe beamwidth is perturbed only slightly from the infinite ground plane ideal (slightly reduced gain in Figure 8: 7.1 dBi versus 9 dB for the infinite ground plane at 300 MHz). There is a slightly increased beam squint over that of the infinite ground plane backed helix. The backfire sidelobes in the finite ground plane case are left-hand elliptically polarized, as a result of diffraction around the finite reflector. The extent of this effect will be strongly dependent on the antenna geometry. Therefore these results should not be taken as representative for all helical antennas with finite ground planes.

Feedpoint impedance and bandwidth

One of the remarkable things discovered by Kraus and his colleagues was the relative invariance of the feedpoint impedance of the helical antenna over a surprisingly wide bandwidth. Although the feedpoint impedance is very sensitive to the feed structure geometry, the impedance remains relatively constant over 60% or so bandwidth and is predominantly resistive. For our seven-turn example, Figure 9 shows the feedpoint impedance for the infinite ground plane and 0.8 wavelength diameter finite ground plane.

The finite ground plane increases the feedpoint impedance somewhat and introduces a bit more variation over the operating band, but the variation is not so much as to degrade an impedance match over a wide operating bandwidth.

Impedance matching

As we see in Figure 9, the feedpoint impedance of the helix is clearly too high for the 50 ohm antenna impedance expected by typical radio equipment. Narrowband matching can be readily carried out using lumped capacitors and inductors, but that would preclude the exploitation of the helical antenna's famously wide bandwidth. It turns out that the helix is easily matched over a wide bandwidth by modifying the feed with a wide strip that acts as a wideband impedance transformer, as seen in Figure 10. A ¼ wavelength metal strip is attached to the first ¼ turn of the helix. This forms a tapered transmission line transformer that provides the necessary (nearly) frequency independent match between the helix and the 50 ohm source.

The monofilar helix antenna with a 0.04λ wide strip attached to the first ¼ turn of the helix (using a wire segment approximation to a solid metal strip: Figure 11) yields a much more favorable feedpoint impedance (and hence VSWR), as is clear from Figure 12. In Figure 11, the currents on the wire segments are indicated by the color density on the segments. We see that

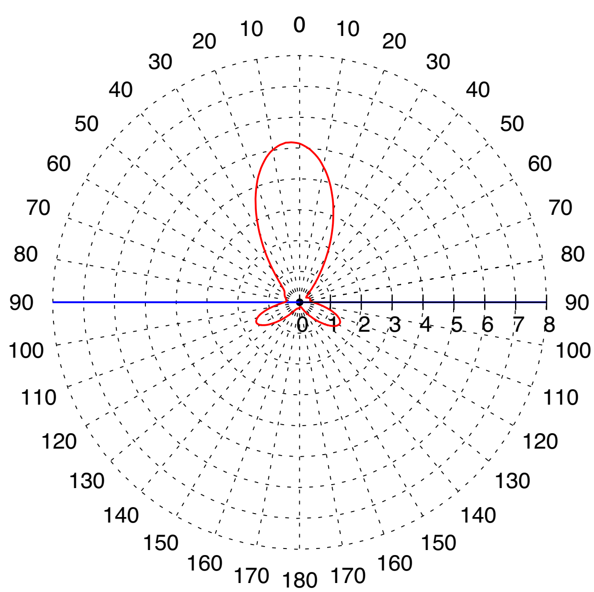


Figure 8: *Radiation pattern for 7 turn helix on 0.8 wavelength diameter ground plane at 300MHz.*

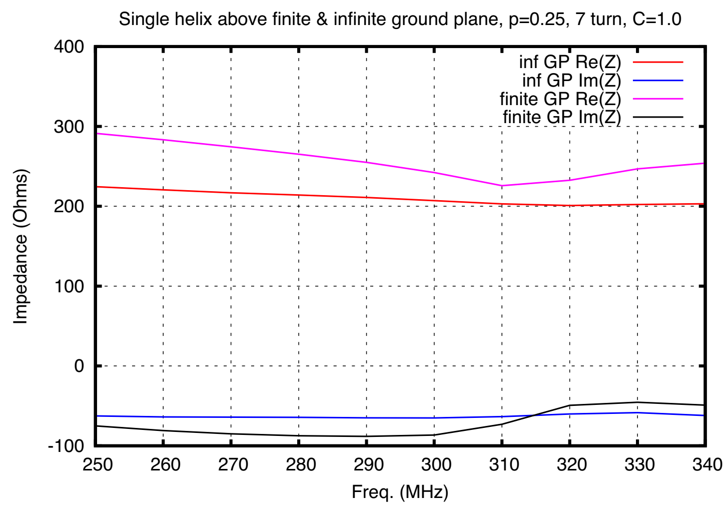


Figure 9: *Feedpoint impedance of 7 turn helix over infinite and finite ground planes. Note slightly higher impedance for finite ground plane case and the predominantly resistive nature of the impedance. The designation "inf GP" refers to infinite ground plane and "finite GP" refers to finite ground plane.*

the currents are large at the feed point and much lower at the start of the helix, indicative of the strip's transformer action. The best frequency of operation is near the middle of the operating band: 325 MHz, where the reactive component of the feedpoint impedance vanishes and the resistive component of the impedance lies near 45 ohms (a good match to a 50 ohm source impedance, VSWR=1.1).

It is remarkable that such a simple impedance matching structure can retain almost the entire bandwidth of the unmatched antenna. From 300 MHz to 370 MHz, the VSWR lies around 1.2 and over the band 240 MHz to 390 MHz, the VSWR is less than 2 (when connected to a 50 ohm system). Whereas an elaborate inductor-capacitor (LC) network may be able to achieve this result, the losses incurred in a wideband LC matching network would render such a network impractical. (A narrowband LC matching network might still find practical use, depending on the application.)

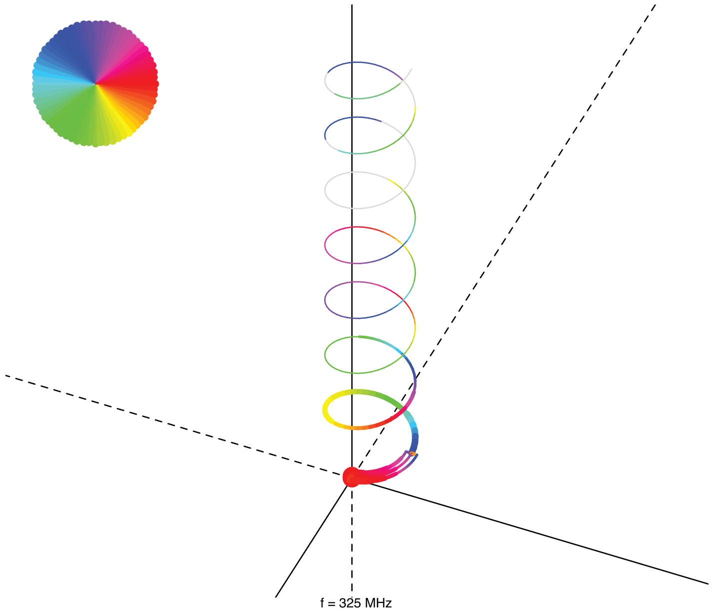


Figure 11: Helix geometry showing wire segment approximation to impedance matching strip at base of helix.

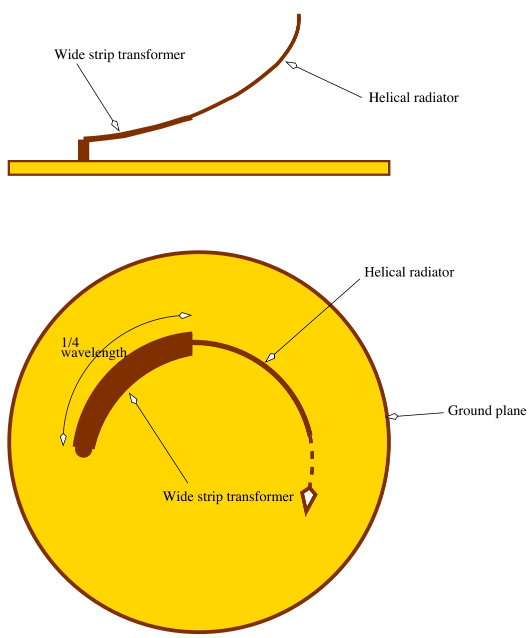


Figure 10: *Wideband matching feed for helical antenna consisting of a 1/4 wavelength strip attached to the start of the helix.*

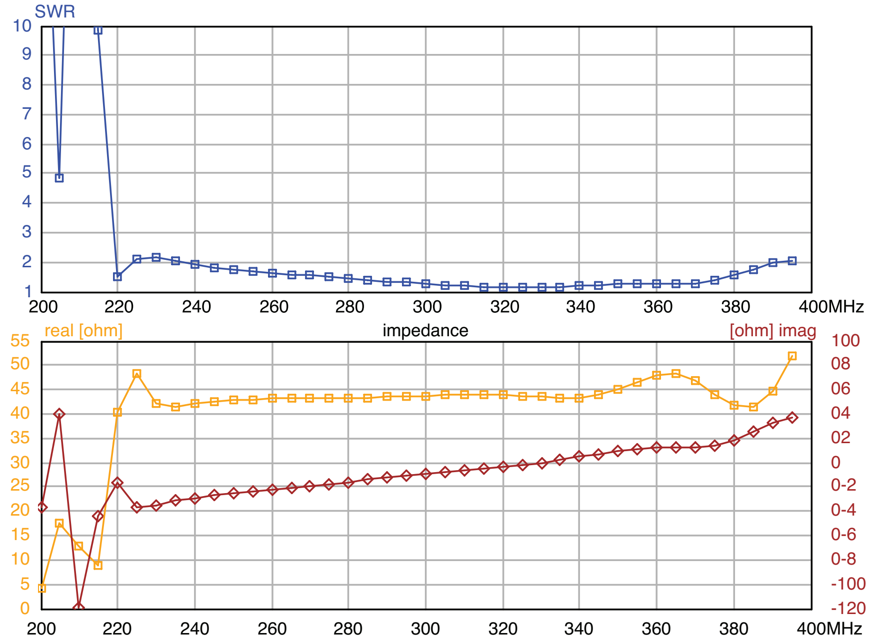


Figure 12: *Impedance and VSWR plots for strip-matched helical antenna. Note VSWR less than 2 over 50% fractional bandwidth.*

The long quadrifilar helix

We now turn to a more complex manifestation of the helical antenna: the long quadrifilar helix with a ground plane. This antenna has the same dimensions (number of turns, diameter, winding pitch) as the monofilar helix, but now we have four right-handed co-wound helices whose starting points on the ground plane are located at 90 degree intervals (Figure 13).

If each helix is driven in a 90 degree progression with the same amplitude, as shown in Figure 14, we radiate a right-hand circular polarized wave with a tighter radiation pattern than the monofilar helical antenna described in Table 1.

If we compare the gain and axial ratio performance (higher axial ratio=worse circular polarization) of the quadrifilar antenna with the monofilar helix, we see that the quadrifilar antenna has 2.5 times higher gain (4dB) and superior on-axis axial ratio (Figure 16). The axial ratio performance of the quadrifilar helix at low elevations degrades faster than that for the monofilar, but it should be kept in mind that the gain rolloff is much sharper for the quadrifilar (see Figure 17), so the degraded circularly (i.e. elliptically) polarized radiated power at low elevations contributes little to overall antenna performance. The circular polarization performance of the quadrifilar antenna is actually superior over its main lobe. The beam squint is also no longer present. The main beam is perfectly on-axis.

The versatility of the quadrifilar helix can justify the extra complexity, especially if we wish to operate the helix in a different mode.

For example, by reversing the phase progression (rotation sense of the feed), we excite the forward wave mode, which is the true endfire mode of the quadrifilar helix. Since it comes out of the open end of the antenna, it does not interact significantly with the ground plane and exhibits the left-hand polarization of a right-hand wound helix. The ground plane serves to reflect the side lobes into the forward direction.

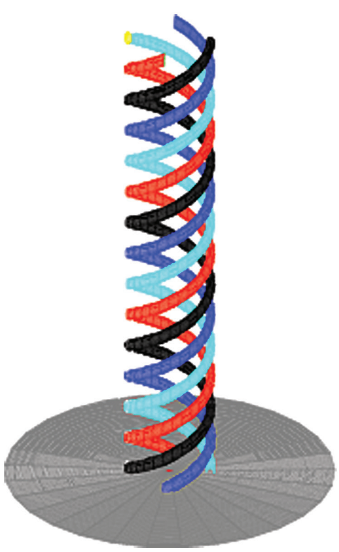


Figure 13: *Long quadrifilar helical antenna geometry over an infinite ground plane. Dimensions are equivalent to the monofilar helix, but now we have 4 co-wound helices.*

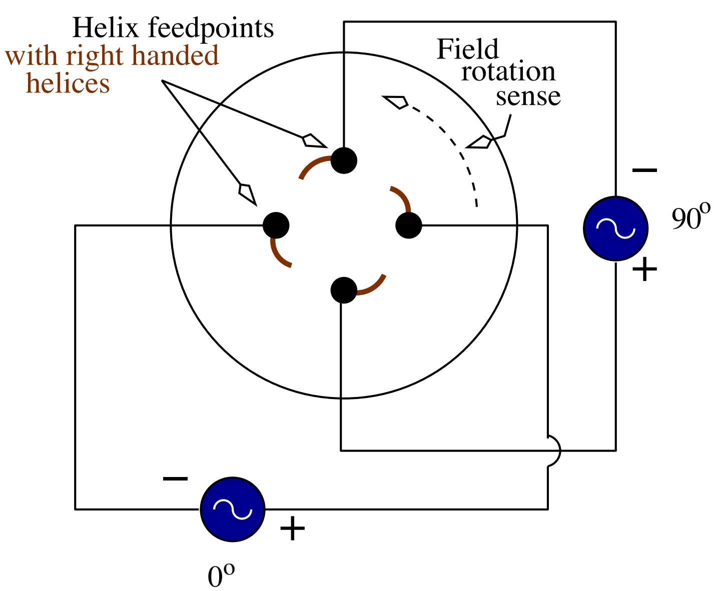
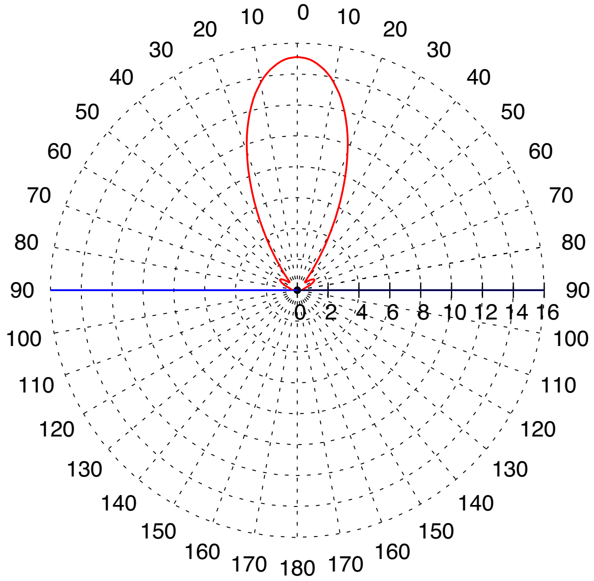


Figure 14: *Depiction of the driving signals for right-hand circular polarization applied to each co-wound helix in the quadrifilar antenna with a ground plane. The axis of the helix is directed out of the page and phase progression sense is always defined by looking down on the antenna.*



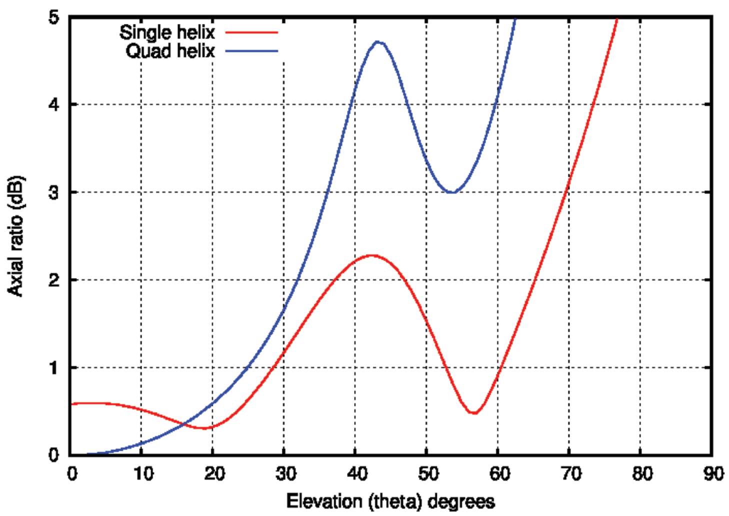
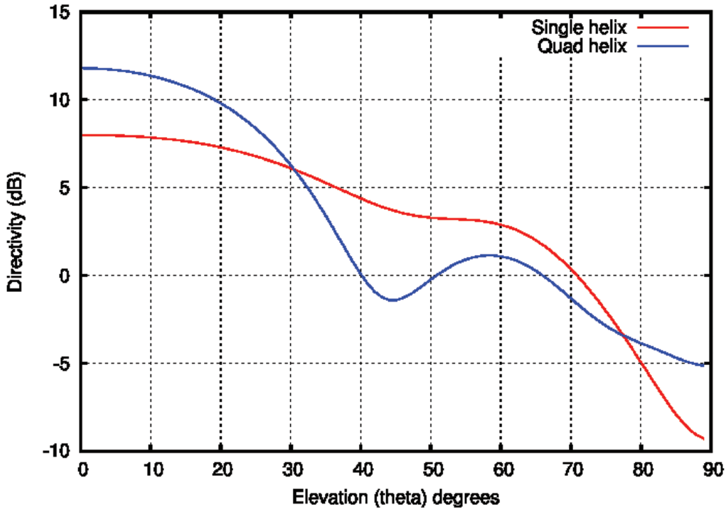


Figure 15: *Antenna pattern of long quadrifilar helix radiating in forward mode at 300 MHz with ground plane. Note the lack of substantial sidelobes and smaller beamwidth when compared to Figure 5. Directivity of 15 corresponds to 11.7 dBi.*

Figure 16: *Comparison of the axial ratio performance of the monofilar and quadrifilar helical antennas. Elevation angle is defined such that 0° lies along the axis of the helix.*



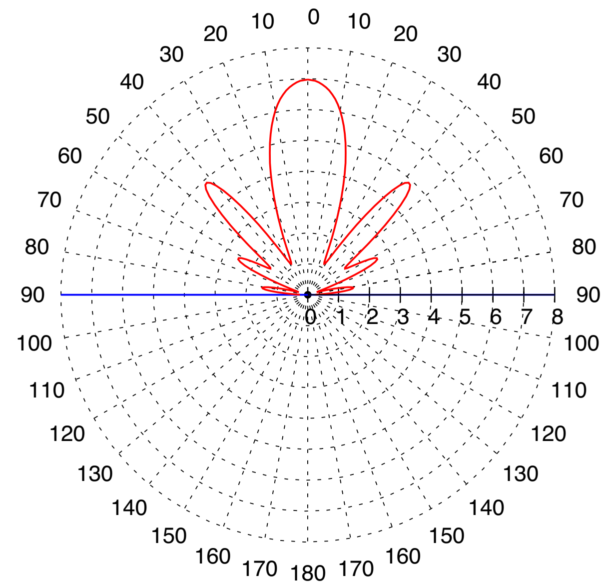


Figure 17: *Directivity profiles for monofilar and quadrifilar antennas at 300 MHz. Quad antenna has approximately 4 dB more gain along the endfire direction and rolls of more quickly than the monofilar case. Elevation angle is defined such that 0° lies along the axis of the helix.*

Figure 18: *Right-handed quadrifilar helix with left-handed feedpoint phase progression over an infinite ground plane*

The quadrifilar helix antenna without a ground plane

Since we can operate the helices as balanced pairs (i.e. one helix in a pair with current +1 and the other with -1), it turns out that it is useful to eliminate the ground plane all together! Doing this, however, causes some interesting changes to the quadrifilar helix operation. Most strikingly, removing the ground plane reverses the relationship between the winding sense of the helices and the polarization sense of the radiated wave for the backward helix mode. That is to say, the right-handed helical antenna radiates a left-hand polarized wave and vice versa. Another useful difference is the capability to radiate backfire beams (lobes in the direction of the antenna feed). Furthermore, the ratio of endfire to backfire radiated power can be controlled by changing the phasing and amplitude of the excitation of each individual helix.

Let us consider an example: a simulation of a 7 turn left-handed quadrifilar helix with element excitation for the forward helix mode produces the radiation pattern in Figure 19.

The gain of this antenna is considerably lower at 3 (5 dBi) than the quadrifilar helix antenna with the ground plane (with directivity 15 or 11.7 dBi).

Reversing the phase progression of the sources driving the helices excites the backward helix mode, producing a backfire main radiation lobe (Figure 20).

By carefully choosing the excitation, we can excite both modes simultaneously, producing both endfire and backfire radiation (Figure 21)!

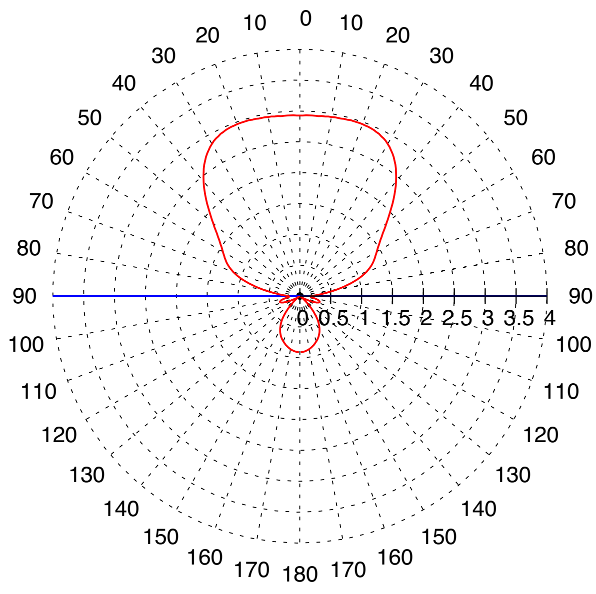


Figure 19: *Endfire mode of left-handed quadrifilar with excitation that produces an endfire main lobe. Here, left-handed helices now produce right-handed circular polarization.*

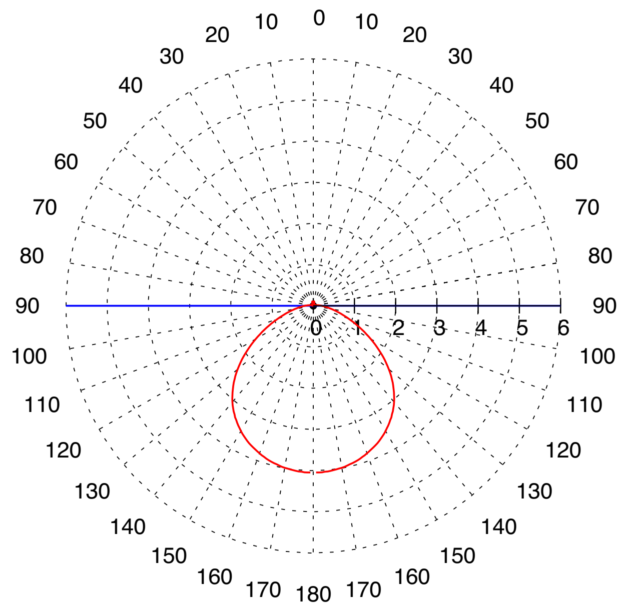


Figure 20: *Reversing the phase progression of the excitation produces backfire radiation. The polarization of the radiation is still predominantly right-hand circular. Notice that the quality of the backfire main lobe is better than the endfire lobe (i.e. sidelobes are smaller, directivity higher).*

Reviewing the three previous patterns, we see that the forward (endfire) radiation mode for our chosen antenna geometry produces a somewhat "squashed" wide radiation lobe. The backward (backfire) radiation mode gives us a pleasing-looking cardioid pattern. Calculations indicate that current is very small toward the end of the antenna, indicating that the final turns do not affect the antenna performance much. The antenna could be shortened without affecting performance much.

To summarize the differences between the ground-plane backed quadrifilar helical antennas and the antennas not backed with a ground plane, we have:

- Typically, the usual desired mode is when helix winding sense and polarization sense correspond for ground plane backed antennas (with some exceptions).
- For quadrifilars without ground plane, helix winding sense is the opposite of the expected polarization sense.
- For quadrifilars without a ground plane, backfire radiation is possible (and, as we will see with the small quadrifilars, desirable).
- For quadrifilars without the ground plane, the backfire mode usually yields a better radiation pattern than the endfire mode, i.e. higher directivity, lower sidelobes.

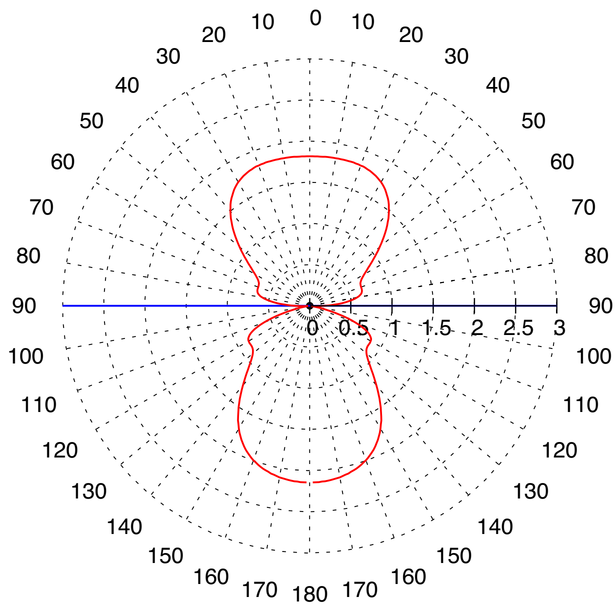


Figure 21: *Quadrifilar helix operating in endfire and backfire mode simultaneously. Radiation in the backfire lobe has a linearly polarized component. However, we have predominantly circular polarization and it is always right-handed.*

Small quadrifilars: the backfire resonant quadrifilar helical antenna

Up to now, we considered large helical antennas that exhibited large bandwidths and directivities. These antennas are useful for mounting on fixed stations or satellites, where highly directional beams and/or wide bandwidth are demanded, but compactness is not a design constraint. The monofilar antenna requires a ground plane to function properly, which adds to its bulk. The quadrifilar antenna, because it can be fed with a pair of balanced sources, can be designed without a ground plane. We can exploit this property of the quadrifilar helix in compact helical designs as well. This is the starting point for the discussion of the compact backfire resonant quadrifilar antenna.

Mobile and hand-held applications put tight constraints on antenna size. Maintaining circular polarization and giving nearly hemispherical coverage (since antenna orientation during operation is often unknown) are useful characteristics. The small resonant quadrifilar helix is an ideal antenna for these applications.

Usually, this antenna consists of four helices of ¼ or ½ turn and phased in a 90 degree progression, as in the long quadrifilar helix described above. The form is somewhat like a “twisted eggbeater” as shown in Figure 22. The feedpoint is at the top of the antenna and the sense of the twist is opposite to the desired polarization (as in our “free space” long quadrifilars discussed above). The feed phase progression is defined opposite to the twist sense to excite the backward wave mode of the helix, which gives rise to the backfire radiation. This phasing can be generated in an external network, but it is possible to eliminate external phasing networks by careful dimensioning of the loops.

It turns out by making one pair of helices slightly larger than the other, and connecting the feed as in the lower depiction in Figure 22, we can auto-generate the quadrature excitation. Using a technique reminiscent of the “nearly square” method of quadrature generation in circularly polarized patch antennas, one loop is above resonance and the other below such that the current phase difference is exactly 90°. Judicious choice of dimensions will also place the feedpoint impedance near 50 ohms, and ensure equal power splitting between the large and small loops.

After optimizing the dimensions a bit, we arrive at the specifications shown in Table 2:

Parameter	Value
Large loop height	39.3 cm
Small loop height	33.0 cm
Diameter	12.5 cm
Conductor diameter	1.0 mm
Operating frequency	300 MHz

Table 2: *Specifications of a small quadrifilar antenna.*

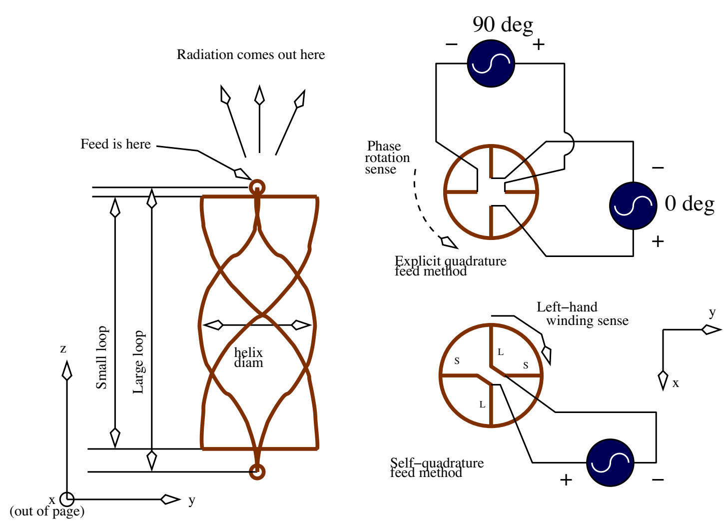


Figure 22: *Geometry of the small resonant quadrifilar helix antenna. Top feeding method is that used in the discussion of long quadrifilar antennas. The lower feeding method is the “self-quadrature” method. L=long loop, S=short loop.*

The resulting feedpoint impedance indicates essentially a perfect match at 300 MHz in Figure 23. A VSWR of 2 or less is achieved between 292 MHz and 308 MHz; approximately 5% fractional bandwidth (half that amount, if we want to keep the VSWR below 1.5). The narrow bandwidth of this structure indicates that the radiation properties depend very strongly on small variations of the antenna geometry. Constructing this antenna requires good attention to detail if one expects to get good performance.

The radiation pattern in Figure 24 shows the good hemispherical coverage achieved with this antenna. The attentive reader will notice how the cardioid shape is similar to the radiation pattern generated by the backfire long quadrifilar helix in the previous section.

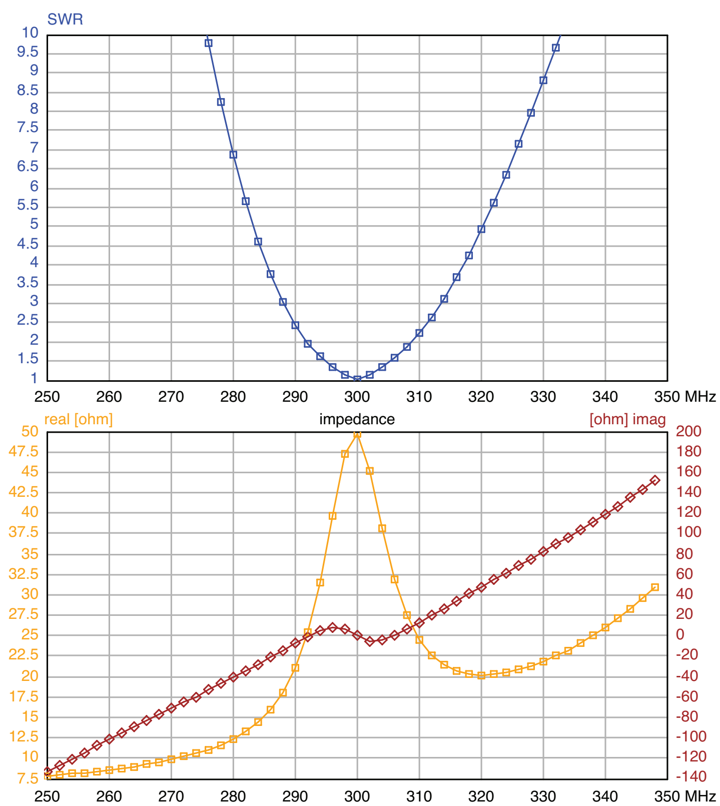


Figure 23: *Feedpoint impedance versus frequency. This is clearly a narrowband antenna in comparison to the long helices covered in the previous sections. The match at the design frequency is good.*

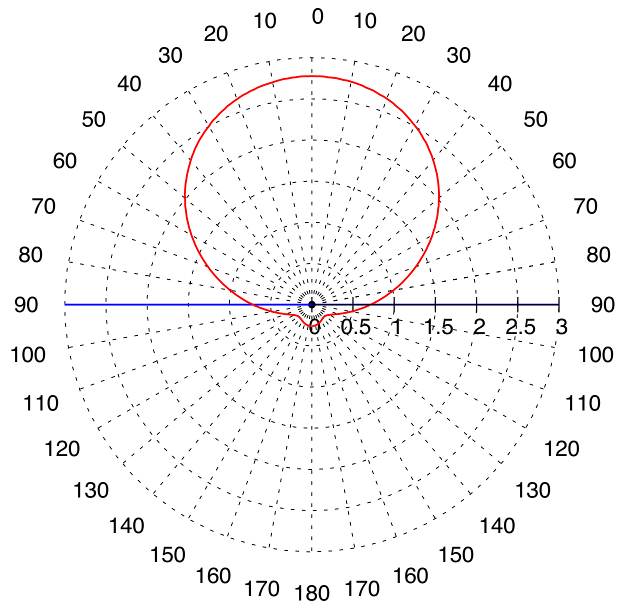


Figure 24: *Circularly polarized hemispherical pattern for resonant quadrifilar helix based on self-quadrature. Note that we have turned the antenna around so that the backfire direction is now at 0°.*

The circular polarization is of a reasonable quality. The axial ratio over the main lobe is below 2 dB (i.e. from 0-110° from the vertical).

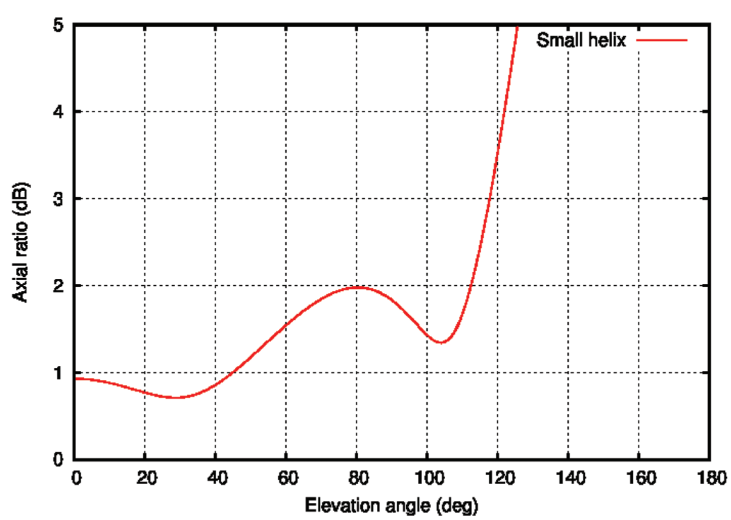


Figure 25: *Axial ratio for compact resonant helix versus elevation angle.*

Despite the lack of a physical ground plane, the front-to-back ratio is surprisingly good in the (better than 10 dB).

SUMMARY

This concludes our brief survey of three important axial-mode helical antennas. The discussion of the monofilar helix provides a baseline for operation as well as a historical link to the early work by Kraus in helical antennas. Important topics, such as wideband impedance matching, are also briefly covered. Moving on to quadrifilar helical antennas, we study some of the versatile ways in which these antennas behave as we alter the excitation of the individual helical elements.

Whereas the monofilar axial mode helix antenna is limited to a single polarization defined by its winding geometry and must use a ground plane, quadrifilar helices can be operated in a combination of modes that provide control over the radiation pattern and polarization mix. Ground planes are not needed if the quadrifilar antenna is operated as a pair of balanced helices. This turns out to be very useful for designing compact resonant helical antennas for portable applications.

Designers need to be aware of how the presence or absence of the ground plane changes the radiation behavior of the antenna. Notably, the helix winding sense usually corresponds to the polarization sense when a ground plane is present. When the ground plane is absent, the winding sense and polarization sense are usually opposed. Furthermore, care must be taken to ensure that the feedpoint excitation yields the desired radiation direction (endfire or backfire) depending on the application.

We described the most basic form of the compact resonant helix in this article. In recent years, many variations of this antenna have been developed for use in commercial devices. For example, the antenna can be further miniaturized by using a dielectric core inside the helix. Other modifications include integrating baluns and dielectric core versions of the compact helix that improve the radiation and feedpoint impedance characteristics.

From modest beginnings as a research curiosity, the helical antenna has become one of the most important circularly polarized antennas for high frequency communications. It is indispensable in space applications, due to its simplicity, high gain, wide bandwidth and low mass. Low power terrestrial radio links and hand-held navigation and communication terminals continue to provide a market for millions of small and large helical antennas as well.

References

1. Photo: Licensed under Public domain via Wikimedia Commons – http://commons.wikimedia.org/wiki/File:Hammer_Ace_SATCOM_Antenna.jpg#mediaviewer/File:Hammer_Ace_SATCOM_Antenna.jpg.

2. D. Orban and G Moernaut, “Basics of patch antennas, updated” RF Globalnet, Sept. 2009.

3. J. D. Kraus and R. J. Marhefka, Antennas for all Applications, Third edition, McGraw-Hill, 2002.

Some Design Examples

Below are some descriptions of quadrifilar antennas we have developed for GPS, L-Band satellite segment, VHF and UHF emergency locator transponder (ELT) and personal locator beacon (PLB) applications. All of these applications require hemispherical or sectoral coverage and good circular polarization all the way down to the horizon.

The electrical requirements for all these antennas are quite similar:

- Hemispherical radiation pattern
- Right hand circular polarization
- Gain from 5 dBi at 5˚ off axis elevation to -3 dBi in broadside
- VSWR: 1.5:1 or better
- Gain variation versus azimuth less than 3 dB (i.e. good azimuthal pattern symmetry)
- The L-Band and the ELT antennas are able to handle 10 watts of transmitter power.
- The PLB antenna is able to handle approximately 2 watts of transmitter power.
- The GPS antenna is receive only.

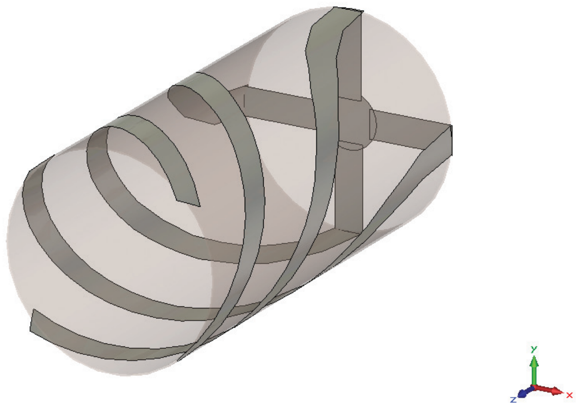


Figure 26: *Air-core L-band helix antenna.*

The mechanical requirements for GPS and the L-Band satellite segment versions of this antenna are similar. The diameter of this antenna is 18 mm and the height is 30 mm and uses an air dielectric (Figure 26).

The plot in Figure 27 shows the performance of the antenna that operates at GPS L1. The performance for versions of this antenna operating at the 1.545 and 1.645 GHz satcom bands is similar.

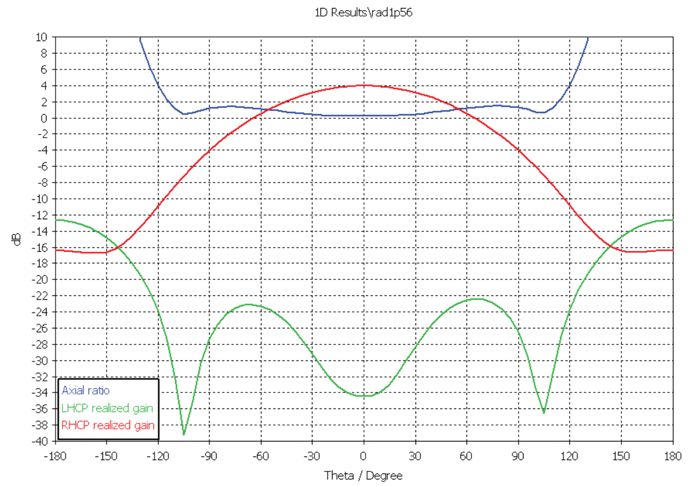


Figure 27: *Radiation characteristics of GPS L1 helix antenna*

The size of this antenna can be further reduced by using a dielectric core.

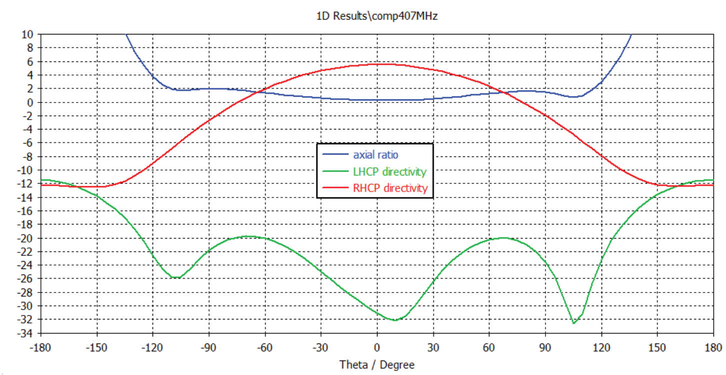


Figure 28: *Radiation characteristics of air-core ELT antenna.*

By using a dielectric core, we have developed an electrically small helical antenna for operation at the UHF ELT band. For comparison, we first developed a version that uses an air dielectric and has a diameter of 67 mm and a height of 120 mm. The resultant radiation patterns is seen in Figure 28.

The version with a dielectric measures 32 mm diameter and is 57 mm high, occupying approximately 1/8 the volume of the air-core helix. The radiation pattern is seen in Figure 29.

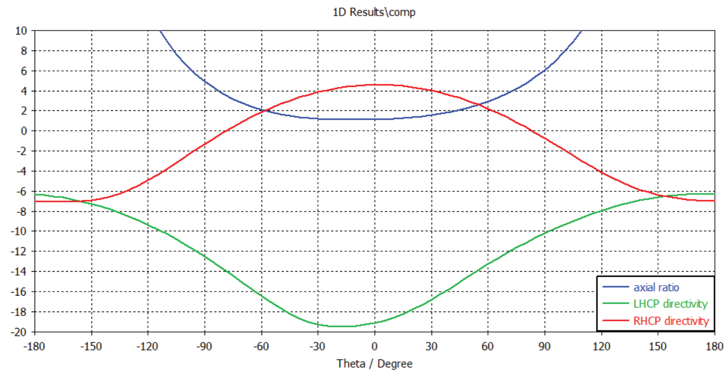


Figure 29: *Radiation characteristics of dielectric core helix antenna.*

Our portfolio also includes quadrifilars for VHF (121.5 and 162 MHz) and dual band VHF/UHF versions.

Please contact us if you need more information.

Orban Microwave

Orban Microwave was established in 1996 as an independent RF and Microwave Design organization. In 1998, Antenna Design was added to our capabilities further enhancing our portfolio. Today, the company designs and manufactures RF & Microwave Subsystems and Antennas in the 0.1 to 25 GHz frequency range. Our two product lines RF & Microwave Subsystems and Antennas cover VHF through Ka-Band.

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A more in-depth version of this article will be presented at the Del Mar Electronics & Design Show in May of 2015, www.mfgshow.com

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