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Title: The W3KH Quadrifilar Helix Antenna
Author: Eugene F. Ruperto, W3KH

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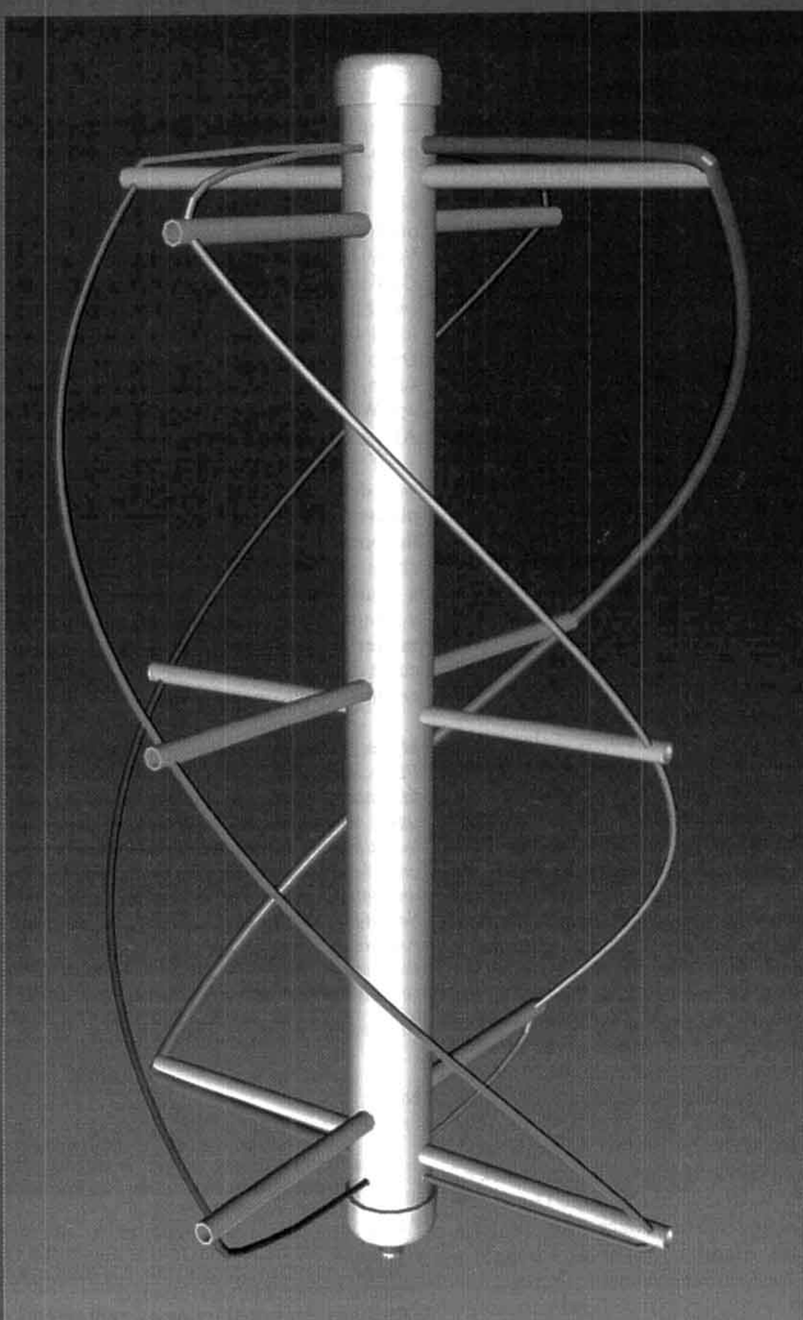
The W3KH Quadrifilar Helix Antenna



By Eugene F. Ruperto, W3KH

If your existing VHF omnidirectional antenna coverage is "just okay," this twisted 'tenna is probably just what you need!

I still remember that hollow, ghostly signal emanating from my receiver in 1957. The signal was noisy and it faded, but that was to be expected—it was coming from outer space. I couldn't help but marvel that mankind had placed this signal sender in space! They called it *Sputnik,* and it served to usher in the space race.

Little did I realize then that four decades later we would have satellites in orbit around Earth and other heavenly bodies performing all sorts of tasks. Now we tend to take satellites for granted. According to the latest information on the Amateur Radio birds, I count about 15 low-Earth-orbit (LEO) satellites for digital, experimental and communications work, and two in *Molniya*-type highly elliptical orbits (AO-10 and AO-13), with the probability of a third to be launched in early 1997.

The world has access to several VHF weather satellites in low Earth orbit. Unlike geostationary Earth-orbiting satellites (GOES), the ever-changing position of the LEOs presents a problem for the Earth station equipped with a fixed receiving antenna: signal fading caused by the orientation of the propagated wavefront. This antenna provides a solution to the problem. Although this antenna is designed primarily for use with the weather sats, it can also be used with any of the polar-orbiting satellites.

These days, technical advances and miniature solid-state devices make it relatively easy for an experimenter to acquire a weather-satellite receiver and a computer interface at an affordable price. So it was only a matter of time before I replaced my outdated weather-sat station with state-of-the-art equipment.

Yesterday

In the early '70s, I built a drum recorder that used a box with a light-tight lid. It was a clumsy affair. The box and photo equipment took up most of the 6×8-foot room in which it was housed. Next to the recorder, a 3×4-foot table supported a tube-type receiver, frequency converters, a reel-to-reel tape recorder (our data-storage medium), a

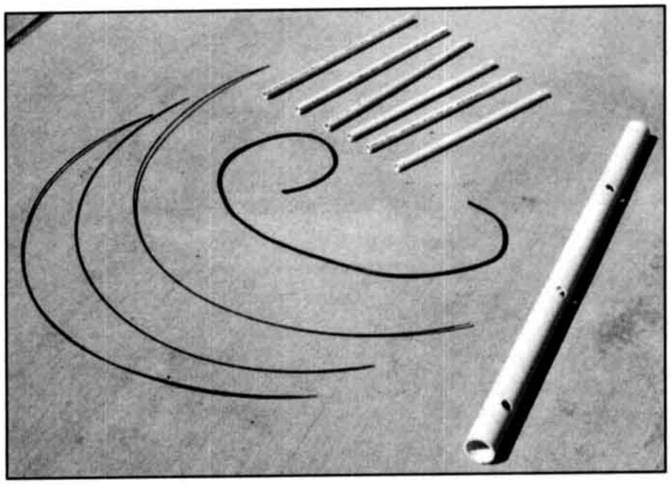


Figure 1—The humble beginnings of a terrific antenna.

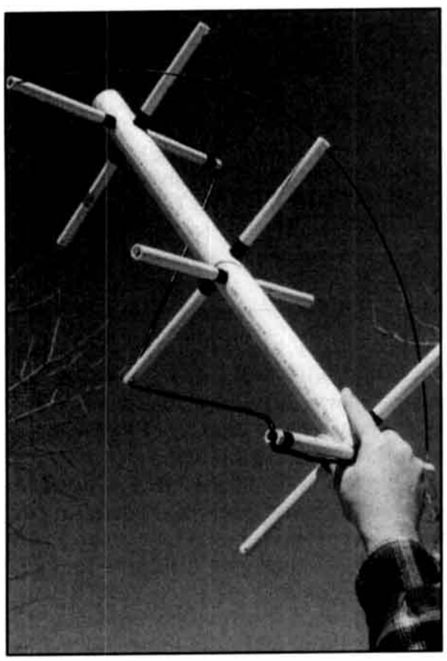


Figure 2—The quadrifilar helix antenna with two of the four legs (filars) of one loop attached.

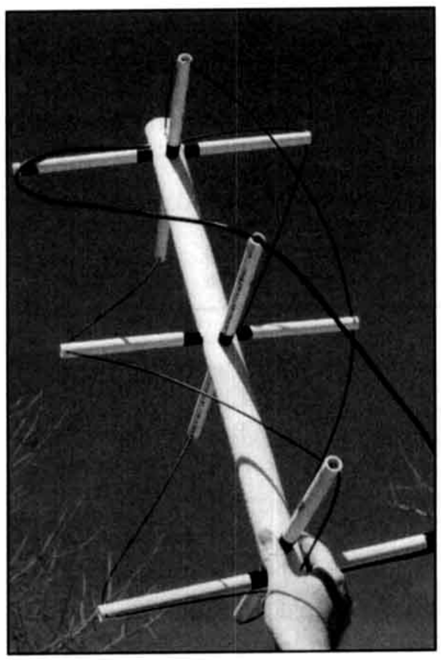


Figure 3—This view shows the QHA with all four legs in place. The ends of the PVC cross arms that hold the coaxial leg are notched; the wire elements pass through holes drilled in the ends of their supporting cross arms.

50-pound monitor oscilloscope, az/el rotator controls for the helical antennas and a multitude of other devices including the drum-driver amplifiers and homemade demodulator. This station provided coverage of the polar-orbiting and geostationary satellites and furnished me with "tons" of data. Over time, my weather-satellite station evolved into a replica of mission control for the manned-spaceflight program! I had so much gear, it had to be housed in a shed separate from the house.

Today

Now, my entire weather-satellite station sits unobtrusively in one corner of the shack, occupying an area of less than one square foot—about the same size as my outboard DSP filter. My PC—now the display for weather-sat photos—is used for many applications, so an A/B switch allows me to toggle the PC between the printer and the weather-satellite interface.

What I needed next was a simple antenna system for unattended operation—something without rotators—something that would provide fairly good coverage, from about 20° above the horizon on an overhead pass. It was a simple request, but apparently one without a simple solution.

Background

Initially I used a VHF discone antenna with mixed results. The discone had a good low-elevation capture angle, but exhibited severe pattern nulls a few minutes after acquisition of signal and again when the satellite was nearly overhead. The fades and nulls repeated later as it approached the other horizon. About this time, Dave Bodnar, N3ENM (who got me reinterested in the antenna project), built a turnstile-reflector (T-R) array. The antenna worked fairly well but exhibited signal dropout caused by several nulls in the pattern. Dave built two more T-Rs, relocating them for comparison purposes. Unfortunately, the antennas retained their characteristic fades and nulls. Another experimenter and I built T-Rs and we experienced the same results. I suggested that we move on to the Lindenblad antenna. The Lindenblad proved to be a much better antenna for our needs than either the T-R or the discone, but still exhibited nulls and fades. Over a period of several months, I evaluated the antennas and found that by switching from one antenna to another on the downside of a fade, I could obtain a fade-free picture, but lost some data during the switching interval. Such an arrangement isn't conducive to unattended operation, so my quest for a fade-free antenna continued.

The Quadrifilar Helix Antenna

Several magazines have published articles on the construction of the quadrifilar helix antenna (QHA) originally developed by Dr. Kilgus,[1] but the articles themselves were generally reader unfriendly—some more than others. One exception is *Reflections* by Walt Maxwell, W2DU.[2] Walt had considerable experience evaluating and testing this antenna while employed as an engineer for RCA.

Part of the problem of replicating the antenna lies in its geometry. The QHA is difficult to describe and photograph. Some of the artist's renditions left me with more questions than answers, and some connections between elements as shown conflicted with previously published data. However, those who have successfully constructed the antenna say it is *the* single-antenna answer to satellite reception for the low-Earth-orbiting satellites. I agree.

Design Considerations

I had misgivings about the QHA construction because the experts implied that sophisticated equipment is necessary to adjust and test the antenna. I don't disagree with that assumption, but I *do know* that it's possible to construct a successfully performing QHA by following a cookbook approach using scaled figures from a successful QHA. These data—used as the design basis for our antennas—were published in an article describing the design of a pair of circularly polarized S-band communication-satellite antennas for the Air Force[3] and designed to be spacecraft mounted. Using this antenna as a model, we've constructed more than six QHAs,

[1]Notes appear on page 34.

mostly for the weather-satellite frequencies and some for the polar-orbiting 2-meter and 70-centimeter satellites with excellent results—*without the need for adjustments and tuning*. Precision construction is not my forte, but by following some prescribed universal calculations, a reproducible and satisfactory antenna can be built using simple tools. The proof is in the results.

The ultrahigh frequencies require a high degree of constructional precision because of the antenna's small size. For instance, the antenna used for the Air Force at 2.2 GHz has a diameter of 0.92 inch and a length of 1.39 inches! Nested inside this helix is a smaller helix, 0.837 inch in diameter and 1.27 inches in length. In my opinion, construction of an antenna *that* size requires the skill of a watchmaker! On the other hand, a QHA for 137.5 MHz is 22.4 inches long and almost 15 inches in diameter. The smaller, nested helix measures 20.5 by 13.5 inches; for 2 meters, the antenna is not much smaller. Antennas of this size are not difficult to duplicate even for those of us who are "constructionally challenged" (using pre-cut pieces, I can build a QHA in *less than an hour!*).

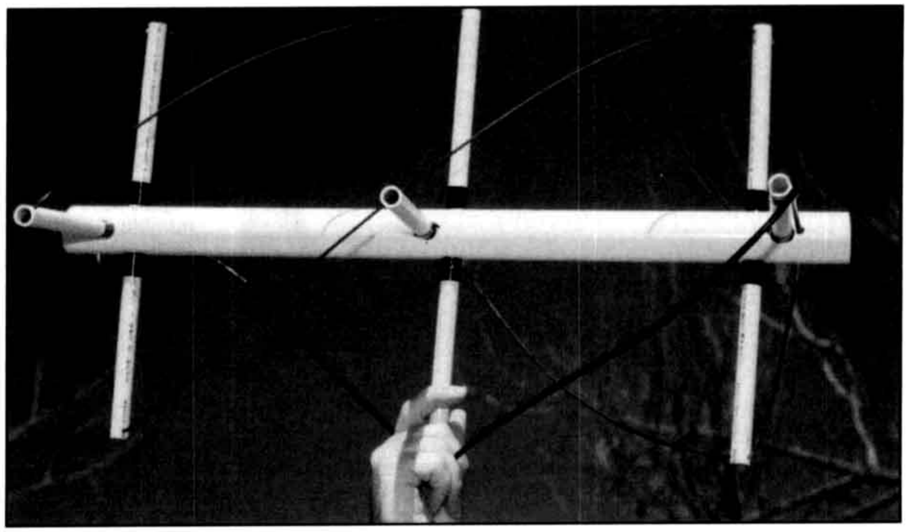


Figure 4—Another view of the QHA.

Table 1
Quadrifilar Helix Antenna Dimensions

Freq (MHz)	Wavelength λ (inches)	Leg Size (0.508 λ)	Small Loop Diameter (0.156 λ)	Small Loop Length (0.238 λ)	Big Loop Leg Size (0.560 λ)	Big Loop Diameter (0.173 λ)	Big Loop Length (0.26 λ)
137.5	85.9	43.64	13.4	20.44	48.10	14.86	22.33
146	80.9	41.09	12.6	19.25	45.30	14.0	21.03
436	27.09	13.76	4.22	6.44	15.17	4.68	7.04

Electrical Characteristics

A half-turn half-wavelength QHA has a theoretical gain of 5 dBi and a 3-dB beamwidth of about 115°, with a characteristic impedance of 40 Ω. The antenna consists basically of a four-element, half-turn helical antenna, with each pair of elements described as a *bifilar*, both of which are fed in phase quadrature. Several feed methods can be employed, all of which appeared to be too complicated for us with the exception of the infinite-balun design, which uses a length of coax as one of the four elements. To produce the necessary 90° phase difference between the bifilar elements, either of two methods can be used. One is to use the same size bifilars, which essentially consist of two twisted loops with their vertical axes centered and aligned, and the loops rotated so that they're 90° to each other (like an egg-beater), and using a quadrature hybrid feed. Such an antenna requires *two* feed lines, one for each of the filar pairs. The second and more practical method, in my estimation, is the self-phasing system, which uses *different-size loops:* a larger loop designed to resonate *below* the design frequency (providing an inductive reactance component) and a smaller loop to resonate *higher* than the design frequency (introducing a capacitive-reactance component), causing the current to lead in the smaller loop and lag in the larger loop. The element lengths are 0.560 λ for the larger loop, and 0.508 λ for the smaller loop. According to the range tests performed by W2DU, to achieve *optimum* circular polarization, the wire used in the construction of the bifilar elements should be 0.0088 λ in diameter. Walt indicates that in the quadrifilar mode, the fields from the individual bifilar helices combine in optimum phase to obtain unidirectional end-fire gain. The currents in the two bifilars must be in quadrature phase. This 90° relationship is obtained by making their respective terminal impedances R + *j*X and R – *j*X where X = R, so that the currents in the respective helices are –45° and +45°. The critical parameter in this relationship is the terminal reactance, X, where the distributed inductance of the helical element is the primary determining factor. This assures the ±45° current relationship necessary to obtain true circular polarization in the combined fields and to obtain maximum forward radiation and minimum back lobe. Failure to achieve the optimum element diameter of 0.0088 λ results in a form of elliptical, rather than true circular polarization, and the performance may be *a few tenths of a decibel* below optimum, according to Walt's calculations. For my antenna, using #10 wire translates roughly to an element diameter of 0.0012 λ at 137.5 MHz—not ideal, but good enough.

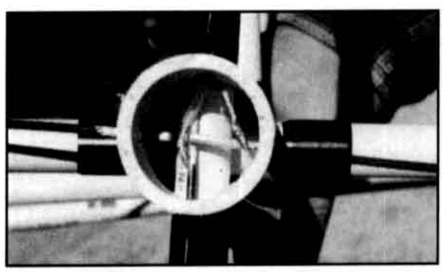


Figure 5—An end-on view of the top of the QHA prior to soldering the loops and installing the PVC cap.

To get a grasp of the QHA's topography, visualize the antenna as consisting of two concentric cylinders over which the helices are wound (see Figures 1 through 5). In two-dimensional space, the cylinders can be represented by two nested rectangles depicting the height and width of the cylinders. The width of the larger cylinder (or rectangle) can be represented by 0.173 λ, and the width of the smaller cylinder represented by 0.156 λ. The length of the larger cylinder or rectangle can be represented by 0.260 λ, and the length of the smaller rectangle or cylinder can be represented by 0.238 λ. Using these figures, you should be able to scale the QHA to virtually any frequency. Table 1 shows some representative antenna sizes for various frequencies, along with the universal parameters needed to arrive at these figures.

Physical Construction

After several false starts using plywood circles and plastic-bucket forms to hold the helices, I opted for a simple PVC solution that not only is the simplest from a constructional standpoint, but also the best for wind loading. I use a 25-inch-long piece of schedule 40, 2-inch-diameter PVC pipe for the vertical member. The cross arms that support the helices are six pieces of 1/2-inch-diameter PVC tubing: three the

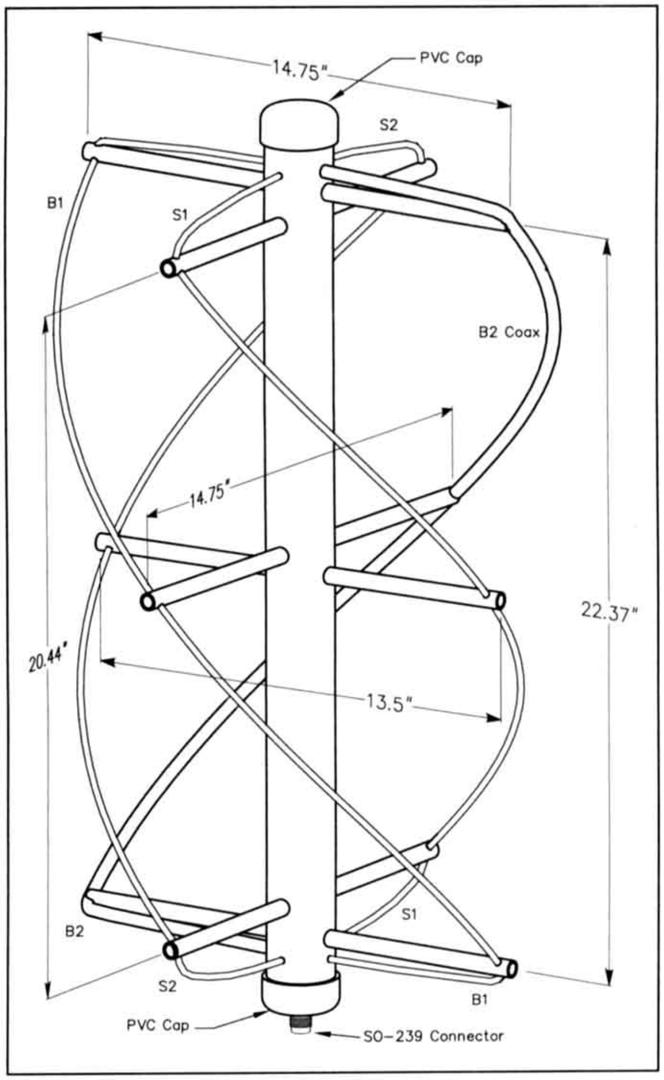


Figure 6—Drawing of the QHA identifying the individual legs; see text for an explanation.

The prototype worked better than expected and duplicates required no significant changes.

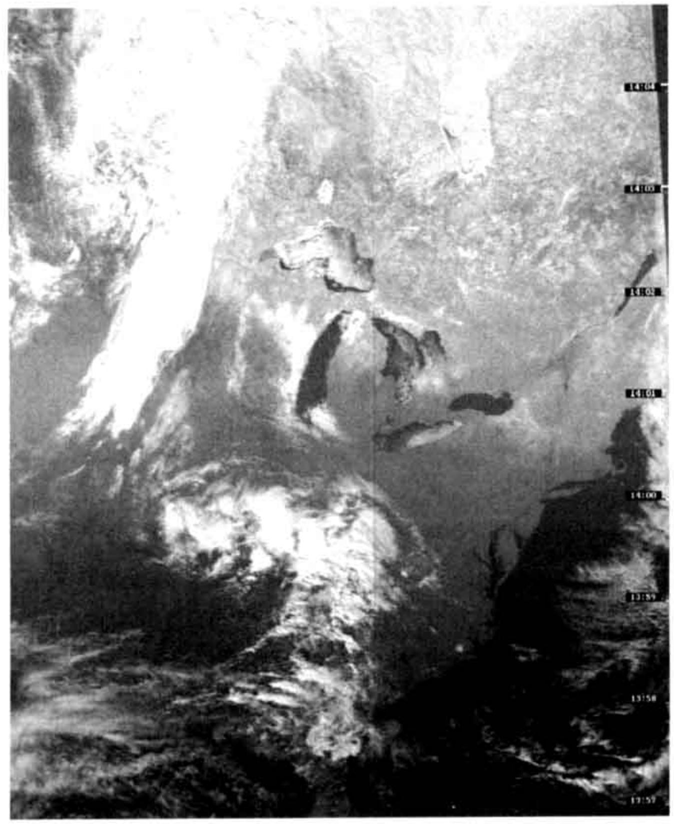


Figure 8—It's said that "The proof of the pudding is in the eating." To a weather-satellite tracker, clear, no-fade, no-noise pictures such as this one—compliments of W3KH's quadrifilar helix antenna—are delicious fare!

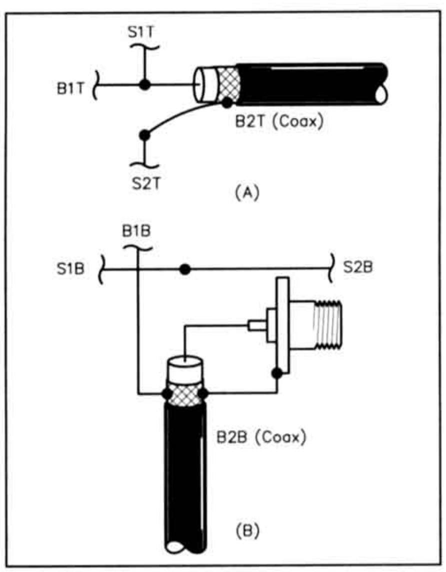


Figure 7—At A, element connections at the top of the antenna. B shows the connections at the bottom of the antenna. The identifiers are those shown in Figure 6 and explained in the text.

width of the large rectangle or cylinder, and three the width of the smaller cylinder. Two cross arms are needed for the top and bottom of each cylinder. The cross arms are oriented perpendicularly to the vertical member and parallel to each other. A third cross arm is placed midway between the two at a 90° angle. This process is repeated for the smaller cylindrical dimensions using the three smaller cross arms with the top and bottom pieces oriented 90° to the large pieces. Using $^5/_8$-inch-diameter holes in the 2-inch pipe ensures a reasonably snug fit for the $^1/_2$-inch-diameter cross pieces. Each cross arm is drilled (or notched) at its ends to accept the lengths of wire and coax used for the elements. Then the cross arms are centered and cemented in place with PVC cement. For the weather-satellite antennas, I use #10 copperclad antenna wire for three of the helices and a length of RG-8 for the balun, which is also the fourth helix. (I do not consider the velocity factor of the coax leg for length calculation.) For the UHF antennas, I use #10 soft-drawn copper wire and RG-58 coax. Copperclad wire is difficult to work with, but holds its shape well. Smaller antennas can be built without the cross arms because the wire is sufficiently self-supporting.

To minimize confusion regarding the connections and to indicate the individual legs of the helices, I label each loop or cylinder as B (for big) and S (for small); T and B indicate top and bottom. See Figures 6 and 7. I split each loop using leg designators as B1T and B1B, B2T and B2B, S1T and S1B and S2T and S2B, with B2 being the length of coax and the other three legs as wires. For right-hand circular polarization (RHCP) I wind the helices *counterclockwise* as viewed from the top. This is contrary to conventional axial-mode helix construction. (For LHCP, the turns rotate *clockwise* as viewed from the top.) See Figure 7 for the proper connections for the top view. When the antenna is completed, the view shows that there are two connections made to the center conductor of the coax (B2) top. These are B1T and S1T, for a total of three wires on one connection. S2T connects to B2T braid. The bottom of the antenna has S1B and S2B soldered together to complete the smaller loop. B1B and the braid of B2B are soldered together. I attach an SO-239 connector to the bottom by soldering the center conductor of B2B to the center of the connector and the braid of B2B to the connector's shell. The bottom now has two connections to the braid: one to leg B1B, the other to the shell of the connector. There's only one connection to the center conductor of B2B that goes to the SO-239 center pin.

Insulator Quality

A question arose concerning the dielectric quality of the tubing and pipe used for the insulating material. Antennas—being reciprocal devices—exhibit losses on a percentage basis, the percentage ratio being the same for transmit and receive. Although signal loss may not be as apparent on receive with a 2-µV signal as with a transmitted signal of 100 W (ie, it would be apparent if dielectric losses caused the PVC cross arms to melt!), signal loss could be a significant factor depending on the quality of the insulating material used in construction. As a test, I popped the pipe into the microwave and "nuked" it for one minute. The white PVC pipe and the tan CPVC tubing showed no significant heating, so I concluded that they're okay for use as insulating materials at 137.5 MHz or thereabouts.

The antennas cost me nothing because the scrap pieces of PVC pipe, tubing and connectors were on hand. Total price for all new materials—including the price of a suitable connector—should be in the neighborhood of $8 or less.

Results

I use a 70-foot section of RG-9 between the receiver and antenna, which is mounted about 12 feet above ground. As with the earlier antennas, I use a preamp in the shack. With AOS (acquisition of signal) on the first scheduled pass of NOAA-14, I was pleasantly surprised to receive the first of many fade-free passes from the weather satellites, including some spectacular pictures from the Russian Meteors! Although the design indicates a 3-dB beamwidth of 140°, an overhead pass provides useful data down to 10° above the horizon. (My location has a poor horizon, being located in a valley with hills in all directions but south.) I've also received almost-full-frame pictures of the West Coast and northern Mexico at a maximum elevation angle of only 12° at my location. (The 70-cm antenna works fine for PACSATs, although Doppler effect makes manual tracking difficult.) The weather-satellite antenna prototype worked better than expected and a number of copies built by others required no significant changes. The quadrifilar helix antenna is *definitely* a winner! And believe me, *it's easy to build!*

Acknowledgments

Thanks to Chris Van Lint, and Tom Loebl, WA1VTA, for supplying me with the necessary technical data to complete this project. A special thanks to Walt Maxwell, W2DU, for his review and technical evaluation and for sharing his technical expertise with the amateur satellite community.

Notes

[1] C. C. Kilgus, "Resonant Quadrafilar Helix," *IEEE Transactions on Antennas and Propagation,* Vol AP-17, May 1969, pp 349 to 351.

[2] M. Walter Maxwell, W2DU, "Reflections, Transmission Lines and Antennas," (Newington: ARRL, 1990). [This book is now out of print.—*Ed.*]

[3] Randolph W. Brickner Jr and Herbert H. Rickert, "An S-Band Resonant Quadrifilar Antenna for Satellite Communication," RCA Corp, Astro-Electronics Division, Princeton, NJ 08540.

Eugene "Buck" Ruperto, W3KH, was first licensed as W3QYG in 1950, then upgraded to Extra Class in 1957. Buck worked for American Airlines as a radio operator and retired from the Federal Aviation Administration, where he worked for 15 years as a data systems specialist, systems analyst and technical writer. Buck was the manager of automation for the ARTS III system (the automated radar terminal system for tracking aircraft) several years before retirement. Still flying, Buck holds a commercial pilot's license and is a certified flight instructor, with ratings for aircraft, instruments and gliders. Flying, he says, accounts for his interest in the weather. Buck's Amateur Radio interests include working the OSCAR satellites, especially those with Molniya orbits like AO-10 and 13. He's an avid island and DX chaser, at the Top of the Honor Roll and holds a W6OWP 40-wpm CW certificate. Buck's a long-time member of MENSA. You can reach Buck at 1035 McGuffey Rd, West Alexander, PA 15376, e-mail ***w3kh@pulsenet.com.***

Photos by the author

New Books

THE LOW AND MEDIUM FREQUENCY RADIO SCRAP BOOK

By Ken Cornell, W2IMB

Published by Ken Cornell, 225 Baltimore Ave, Point Pleasant Beach, NJ 08742. Telephone 908-899-1664. 10th Edition, 1996. 8½×11 inches, stapled, B&W figures, 99 pp. $17.50 including shipping at book rate, $18.75 shipped first-class mail, $21.00 Europe Air Mail (US funds) and $22.00 Air Mail (US funds) to other parts of the world.

Reviewed by Paul Danzer, N1II
Assistant Technical Editor

Want a real challenge? Pick a set of frequencies where you are limited to low power, antenna length is regulated to a tiny fraction of a wavelength, the noise level is usually very high, and propagation is primarily ground wave. In addition, you will have occasional competition from commercial stations, incessant power line conducted noise, and only a handful of fellow enthusiasts close enough to talk to. Sounds like no one would really want to do this? Well, Ken Cornell, W2IMB, believes that many people would want to try it, and if you notice his most recent book is the 10th edition, it appears he is correct.

Of course, the popularity of the book may be due to it its content—it is really a mini-manual on circuits and home construction projects. It contains helpful hints for the first-time builder and the details of a dozen one-night projects. Many of the hints and tips are very practical—related by someone who has been homebrewing for many years. As an example, suppose you want to modify a circuit you built a few years ago, or perhaps build another one? Do you remember how many turns you wound for the inductor? W2IMB suggests using white typewriter correction fluid to form a smooth surface on the coil, and then marking it with a felt marker. Worried about connecting a low current drain circuit backwards to its power supply and blowing the circuit? Just put a diode in series with the positive lead. If you now connect it backwards, no current will flow.[1]

Many of the circuits, although printed with the values for the LF and MF bands, are equally applicable to most of the HF ham bands. A number of simple converting mixers are shown for converting LF to HF, but they can also be used to convert HF ham or SWBC to broadcast-band receivers.

Noise is a problem at low frequencies, so the book naturally includes audio filters, and even one regenerative filter—shades of the old National *Select-O-Ject.* Circuits such as small audio amplifiers, wave traps and power supplies are scattered through the book. A number of loop and ferrite core antennas are shown. It is difficult to know how well they work, but they sure look like they would be fun to build!

As in previous editions, simple exciters for the 160 to 190-kHz unlicensed (LOWFER) band are shown. They meet the FCC requirements of 1 W maximum final output, and a maximum combined antenna and transmission line length of 15 meters. Other designs for the 510 to 1705 (MEDFER) band—100 mW maximum input to the final with a combined transmission line and antenna length of 3 meters maximum—also are included.

If you want to try something different while our friendly sunspots are in hiding, Ken Cornell's latest book is certainly one interesting place to start.

[1] Some manufacturers use the opposite technique on high-current equipment. They connect a heavy power diode backwards, *across* the power supply leads. Then, if you reverse the supply leads, the fuse presumably will blow before the equipment does—and, under normal conditions, the supply voltage to the equipment is not reduced by the drop in a series diode. But notice the word *presumably.*