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17.7 Bibliography

Chapter 17 — CD-ROM Content

Supplemental Articles

- “A 12-Foot Stressed Parabolic Dish” by Richard Knadle, K2RIW
- “A Parasitic Lindenblad Antenna for 70 cm” by Anthony Monteiro, AA2TX
- “A Portable Helix for 435 MHz” by Jim McKim, WØCY
- “A Simple Fixed Antenna for VHF/UHF Satellite Work” by L.B. Cebik, W4RNL
- “An EZ-Lindenblad Antenna for 2 Meters” by Anthony Monteiro, AA2TX
- Converted C-Band TVRO Dishes
- “Double-Cross Antenna – A NOAA Satellite Downlink Antenna” by Gerald Martes, KD6JDJ
- “EME with Adaptive Polarization at 432 MHz” by Joe Taylor, K1JT, and Justin Johnson, GØKSC
- “Inexpensive Broadband Preamp for Satellite Work” by Mark Spencer, WA8SME
- “L Band Helix Antenna Array” by Clare Fowler, VE3NPC
- “Quadrifilar Helix As a 2 Meter Base Station Antenna” by John Portune, W6NBC
- Space Communications Antenna Examples
- “The W3KH Quadrifilar Helix” by Eugene Ruperto, W3KH (plus two Feedback items)
- “Two-Meter Eggbeater” by Les Kramer, WA2PTS and Dave Thornburg, WA2KZV
- “Work OSCAR 40 With Cardboard-Box Antennas” by Anthony Monteiro, AA2TX
- “WRAPS: A Portable Satellite Antenna Positioning System” by Mark Spencer, WA8SME
- “WRAPS Rotator Enhancements Add a Second Beam and Circular Polarization” by Mark Spencer, WA8SME

Chapter 17

Antennas for Space Communications

When we consider amateur space communications, we usually think about two basic modes: satellite and Earth-Moon-Earth (EME — also referred to as *moonbounce*). At their essence, both modes communicate using one of the Earth's satellites — our natural satellite (the Moon) or one of a variety of man-made satellites. (Antennas for meteor scatter modes are covered in the **VHF and UHF Antenna Systems** chapter.) The distances involved and the motion of the targets place special requirements on antennas for both types of communications as discussed in this chapter.

Because of technological advances, particularly regarding new digital modes that allow communications with extremely weak signals, the traditional distinction between antenna systems for satellite communications and for EME communications has become blurred. Thus, this chapter has been rearranged by antenna type and then specific requirements for each type of operation are discussed.

Material in this chapter has been contributed by several authors. Dick Jansson, KD1K, developed satellite-related topics while the EME material is largely the work of Dave Hallidy, K2DH and Joe Taylor, K1JT. References to KD1K also include material contributed with the call sign WD4FAB, Jansson's previous call sign. Wherever possible, designs referenced or illustrated in the text are also listed in the Bibliography. For additional information on constructing antennas, feeds and equipment techniques for use at microwave frequencies, see the ARRL and RSGB books listed in the Bibliography. All of these books provide a wealth of information for the experimenter.

17.1 SPACE COMMUNICATION ANTENNA SYSTEMS

There are two main differences between the Moon and man-made satellites in orbits closer to the Earth. The first is one of distance. The Moon is about 250,000 miles from Earth, while man-made satellites in highly elliptical orbits can be as far as 52,000 miles away. This 5:1 difference in distance makes a huge difference in the signals that arrive at the satellite, since transmission loss varies as the square of the distance. In other words, the signal arriving at the Moon is 20 dB weaker than that arriving at a geosynchronous satellite 25,000 miles high, due to distance alone.

The second difference between the Moon and a man-made satellite is that the Moon is a *passive reflector* — and not a very good one at that, since it has a craggy and rather irregular surface, at least when compared to a flat mirror-like surface that would make an ideal reflector. Signals scattered by the Moon's irregular surface are thus weaker than those for better reflecting surfaces. By comparison, a man-made satellite is an *active* system, where the satellite receives the signal coming from Earth, amplifies it and then retransmits the signal (usually at a different frequency) using a high-gain antenna. Think of a satellite as an ideal reflector, with gain.

The net result of these differences between a man-made satellite and the Earth's natural satellite is that moonbounce (EME) operation challenges the station builder considerably more than satellite operation, particularly in the area of antennas. Successful EME requires higher transmitting power and receiver sensitivity, along with sophisticated computer software for digital modes or an excellent operator capable of pulling weak analog signals out of the noise.

There are areas of commonality between satellite and EME antenna requirements, of course. Both require consideration of the effects of polarization and elevation angle, along with the azimuth directions of transmitted and received signals. High-performance Yagi arrays or helical antenna systems designed for satellite operation will likely suffice to make EME contacts using digital modes such as those of the *WSJT* software suite (**www.physics.princeton.edu/pulsar/K1JT**). Dish antennas, such as those converted from commercial C-band (4-8 GHz range) TVRO (television, receive only) service will certainly suffice for both types of communication.

This chapter will first explore antennas suitable for satellite operations and then describe the antennas needed for EME work.

17.1.1 ANTENNA SYSTEMS FOR SATELLITES

Amateur satellites provide links from 2 meters and up and these provide opportunities to use antennas of many types — from the very simple to the pretty complex. Antenna design and construction requirements for use with amateur satellites vary from low-gain antennas for low-Earth-orbit (LEO) satellites to higher-gain antennas for the high-altitude elliptical-orbit satellites (HEO). The AMSAT website (**www.amsat.org**) is a good general resource for antenna and transceiver design, operating information and satellite parameters. See the AMSAT website's Station and Operating Hints page for antenna designs for satellite operations and other useful accessories and station components.

Contacts can be made via FM LEO satellites with a basic dual-band VHF/UHF FM transceiver. Some amateurs manage to work the FM birds with hand-held radios and a multielement directional antenna such as the popular Arrow Antenna shown in **Figure 17.1A**. Of course, this means they must aim their antennas at the satellites, even as they cross overhead. Other operators have even had success using an FM hand-held radio with the stock flexible antenna, although the extended flexible antenna as shown in Figure 17.1B provides for a better signal. If you wish to use a preamp for 70 cm downlink signals, an inexpensive design is described in the article "Inexpensive Broadband Preamp for Satellite Work" by Mark Spencer, WA8SME, included on this book's CD-ROM.

High-quality omnidirectional antennas for LEO service come in quite a number of forms and shapes. M^2 Enterprises EB-144 and EB-432 Eggbeater antennas have proven to be very useful and do not require any rotators for control. See **Figure 17.2**. The turnstile-over-reflector antenna has been around for a long time, as shown in **Figure 17.3**. L.B. Cebik, W4RNL, described a fixed satellite antenna system that uses crossed-Moxon antennas to produce a circularly polarized, hemispherical pattern requiring no rotators. This system is described in the article "A Simple Fixed Antenna for VHF/UHF Satellite Work" on the CD-ROM provided with this book and is shown in **Figure 17.4**.

For even better performance, at the modest cost of a single, simple TV antenna rotator, check out the fixed-elevation *Texas Potato Masher* antenna by Gerald Brown, K5OE, shown in **Figure 17.5.** This antenna provides a dual-band solution for medium-gain directional antennas for LEO satellites. This is a considerable improvement over omnidirectional antennas and does not require an elevation rotator for

(A)

(B)

Figure 17.1 — At A, Keith Baker, KB1SF/VA3KSF, uses a Kenwood TH-78A dual-band handheld and a lightweight Arrow Antenna to make a contact through AO-51 from the shores of Lake Huron in Michigan. When used with a full-duplex handheld in an open location free of foliage, such as a beach or field, the antenna provides enough uplink and downlink gain to successfully work the FM birds, even on passes close to the horizon. (KB1OGF/VA3OGF photo) At B, Kate Baker, KB1OGF/VA3OGF, makes a contact through AO-51 satellite on the shores of Lake Huron in Michigan with her Kenwood TH-78A dual-band HT. The extended flexible antenna (MFJ Model 1717 from MFJ Enterprises) and about 5 W of uplink power provides just enough gain on the uplink and downlink to briefly work the satellite on near overhead passes. (KB1SF/VA3KSF photo)

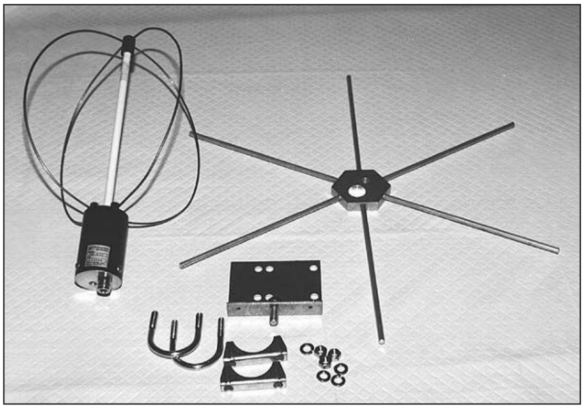


Figure 17.2 — Eggbeater antennas are popular for base station LEO satellite operations. This M2 EB-432 eggbeater antenna for 70 cm is small enough to put in an attic. Antenna gain pattern is helped with the radials placed below the antenna.

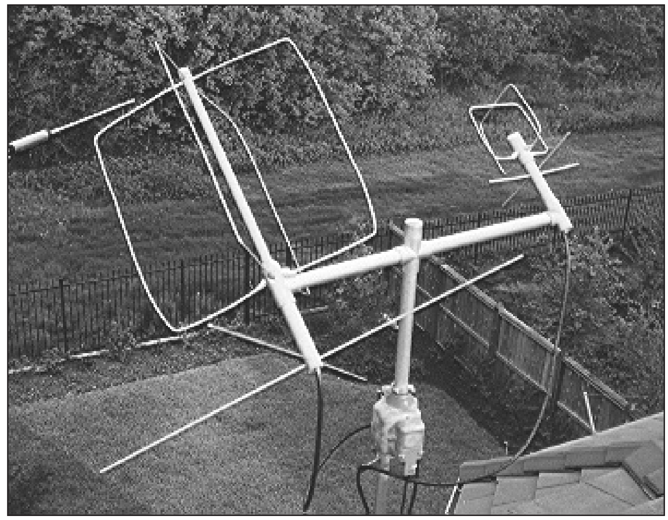


Figure 17.5 — Jerry Brown, K5OE, uses his Texas Potato Masher antennas to work LEO satellites.

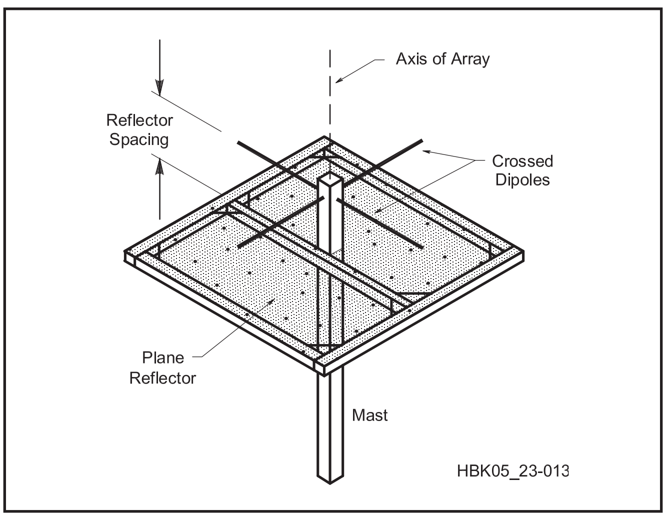


Figure 17.3 — The Turnstile Over Reflector antenna has served well for LEO satellite service for a number of years.

good performance. If an az-el rotator is available (see also the WRAPS az-el rotator project at the end of this chapter) reflecting screens can be added to the Moxon-pair antennas of W4RNL for even better performance.

There was still one early LEO satellite operating on the 10 meter band as of early 2015. The 1974 AO-7 spontaneously recovered from a battery failure and can be used whenever its solar panels are illuminated. Its 10 meter downlink covers 29.3 to 29.5 MHz. Low-gain antennas for 10 meters, such as dipoles or long-wire antennas, are used to receive the signal from this satellite.

High-altitude Phase 3 satellites such as the now defunct AO-10 and AO-13 were deployed in the 1980s. Ultimately there may be geostationary satellites for amateur use and the same requirements would apply as well to them. The greater distances to these satellites mean that more transmitted power is needed to access them and weaker signals are received on the ground. Successful stations usually require ground-station antennas with significant gain (12 dBi or more), such as a set of high-gain Yagi antennas. (See the Yagi Arrays section of this chapter.) Inexpensive Yagi designs for satellite operation have been published by Kent Britain, WA5VJB, and are available at **www.wa5vjb.com/references/Cheap%20Antennas-LEOs.pdf**.

Satellite S-band (2.4 GHz) downlinks have become very popular for HEO operations for a variety of reasons:

- Good performance with physically small downlink antennas.
- Availability of good quality downconverters.
- Availability of preamps at reasonable prices.

A number of people advocate

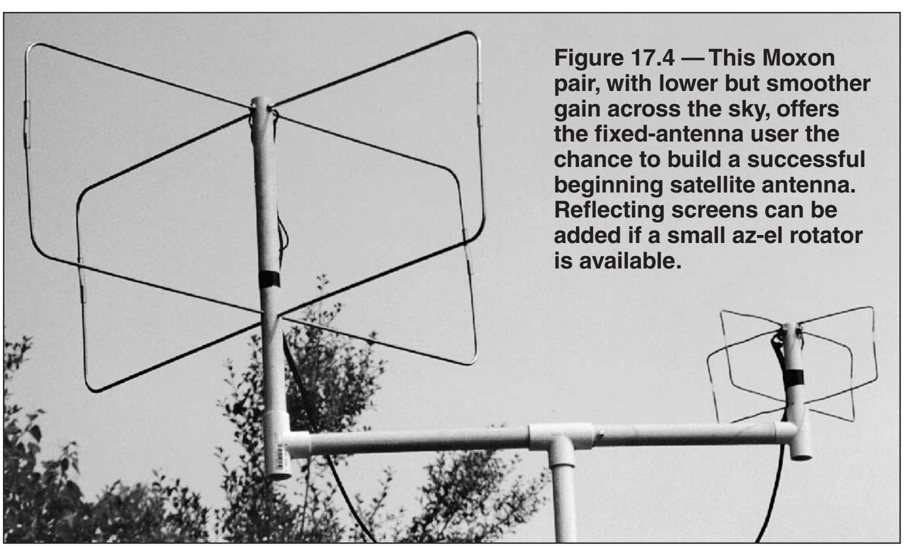


Figure 17.4 — This Moxon pair, with lower but smoother gain across the sky, offers the fixed-antenna user the chance to build a successful beginning satellite antenna. Reflecting screens can be added if a small az-el rotator is available.

Receiving NOAA Satellite Signals

US National Oceanographic and Atmospheric Administration (NOAA) polar orbiting weather satellites (POES) transmit data for production of gray-scale images of the ground below them. Data is transmitted at 137 MHz frequency used by the NOAA satellites and can be received twice a day. There are many free programs available to decode the data and produce images. The article "Double-Cross — A NOAA Satellite Downlink Antenna" on this book's CD-ROM describes a fixed antenna shown in the photo designed for the 137 MHz frequency and can receive signals from any other satellite in that band.

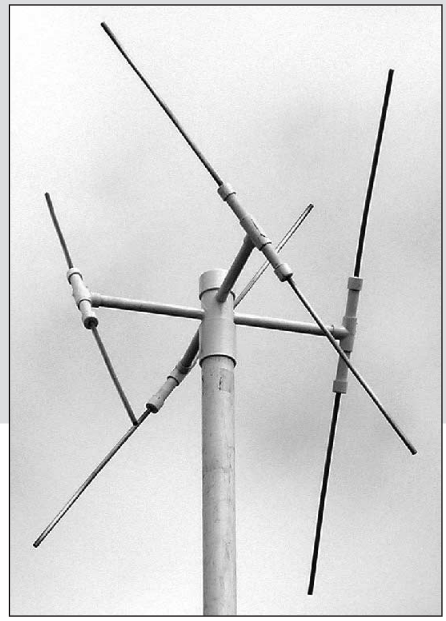


Figure 17.A — The Double Cross antenna is made from four dipoles. [Gerald Martes, KD6JDJ]

Table 17.1
Amateur Satellite Band Designations

10 meters (29 MHz):	H
2 meters (145 MHz):	V
70 cm (435 MHz):	U
23 cm (1260 MHz):	L
13 cm (2.4 GHz):	S
5 cm (5.6 GHz):	C
3 cm (10 GHz):	X

S-band operation, including Bill McCaa, KØRZ, who led the team that designed and built the AO-13 S-band transponder and James Miller, G3RUH, who operated one of the AO-40 command stations. Ed Krome, K9EK, and James Miller have published a number of articles detailing construction of preamps, downconverters and antennas for S band. (See **Table 17.1** for a list of the satellite band designations used throughout this chapter.)

17.1.2 ANTENNA SYSTEMS FOR EARTH-MOON-EARTH (EME)

The antenna is arguably the most important element in determining an EME station's capability. It is not accidental that the baseline station requirements outlined in **Table 17.2** use Yagi arrays on the VHF bands and parabolic dishes at 1296 MHz and above. One of these two antenna types is almost always the best choice for EME.

Table 17.2
Typical Antenna and Power Requirements for CW EME

For use with JT65 or other encoded digital modes, subtract approximately 10 dB of gain or power.

Freq (MHz)	*Ant Type[1]*	*G (dBi)*	*HPBW (deg)*	*TxPwr (W)*
50	4×12 m	19.7	18.8	1200
144	4×6 m	21.0	15.4	500
432	4×6 m	25.0	10.5	250
1296	3 m	29.5	5.5	160
2304	3 m	34.5	3.1	60
3456	2 m	34.8	3.0	120
5760	2 m	39.2	1.8	60
10368	2 m	44.3	1.0	25

[1]Example antennas for 50, 144 and 432 MHz are Yagi arrays with stated lengths; those for 1296 MHz and higher are parabolic dishes of specified diameter.

The gains of some nominal antennas of each type are illustrated graphically in **Figure 17.6**, which helps to show why Yagis are nearly always the best choice for EME on the VHF bands. They are light, easy to build and have relatively low wind resistance. Stacks of four Yagis are small enough that they can be mounted on towers for sky coverage free of nearby obstructions. Larger arrays of 8, 16 or even more Yagis are possible, although the complexity and losses in phasing lines and power dividers then become important considerations, especially at higher frequencies. Long Yagis are narrowband antennas, usable on just a single band.

We usually think of the linear polarization of a transmitted signal as being "horizontal" or "vertical." Of course, on the spherical Earth these concepts have meaning only locally. As seen from the Moon, widely separated horizontal antennas may have very different orientations (see **Figure 17.7**). Therefore, in the absence of Faraday rotation an EME signal transmitted with horizontal polarization by station A will have its linear polarization misaligned at stations B and C by angles known as the spatial polarization offset. (Faraday rotation is a rotation of the polarization of radio waves when the waves travel through the ionosphere, in the presence of the Earth's magnetic field.) In Figure 17.7 the signal from A arrives with vertical polarization at B and at 45° to the horizon at C. Suppose C is trying to work A and $\theta_s = 45°$ is the spatial polarization offset from A to C. The return signal from C to A will be offset in the opposite direction, that is, by an amount $-\theta_s = -45°$. The Faraday rotation angle θ_F, on the other hand, has the same sign for transmission in both directions. Thus the net polarization shift from A to C is $\theta_F + \theta_s$, while that from C to A is $\theta_F - \theta_s$. If θ_F is close to any of the values ±45°, ±135°, ±225°, …, then one of the net polarization shifts is nearly 90° while the other is close to 0°. The result for stations with fixed linear polarization will be apparent one-way propagation: for example, A can copy C, but C cannot copy A.

Obviously no two-way contact can be made under these conditions, so the operators must wait for more favorable circumstances or else implement some form of polarization control or polarization diversity. One cost-effective solution is to mount two full sets of Yagi elements at right angles on the same boom. Arrays of such cross-polarized or "Xpol" Yagis make especially attractive EME antennas on the VHF and lower UHF bands because they offer a flexible solution to the linear polarization misalignment problem. As an example, **Figure 17.8** shows the 4 × 10 element, dual-polarization EME array at KL7UW. This antenna and a 160-W solid-state amplifier have accounted for hundreds of EME contacts with the state of Alaska on 2 meters.

At 1296 MHz and above, gains of 30 dBi and more can be achieved with parabolic dishes of modest size. As a result, these antennas are almost always the best choice on these bands. Their structure does not depend on any radio frequency resonances, so in many ways dishes are less critical to build than Yagis. Element lengths in high-gain Yagis must be accurate to better than 0.005 λ, while the reflecting surface of a dish need be accurate only to about 0.1 λ.

A parabolic antenna has a single feed point, so there are no losses in phasing lines or power splitters. You can use

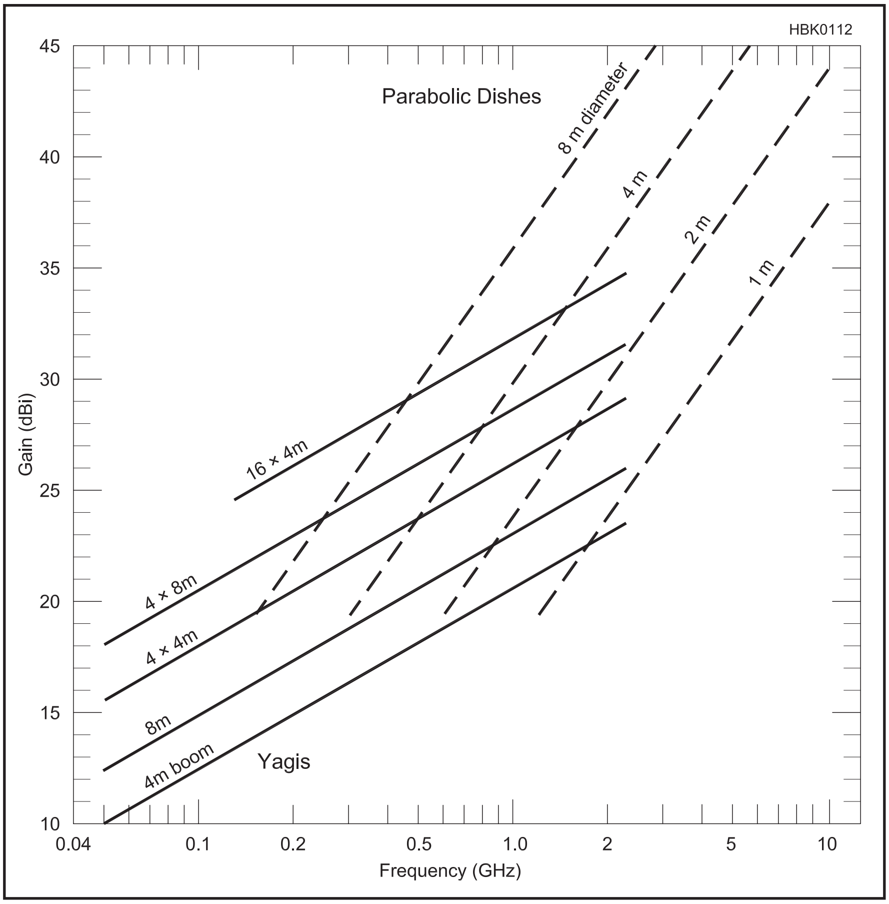


Figure 17.6 — Representative gains of practical Yagi antennas, arrays of Yagis and parabolic dishes as a function of frequency. Yagi arrays make the most cost-effective and convenient antennas for EME on the VHF bands, while parabolic dishes are generally the best choice above 1 GHz.

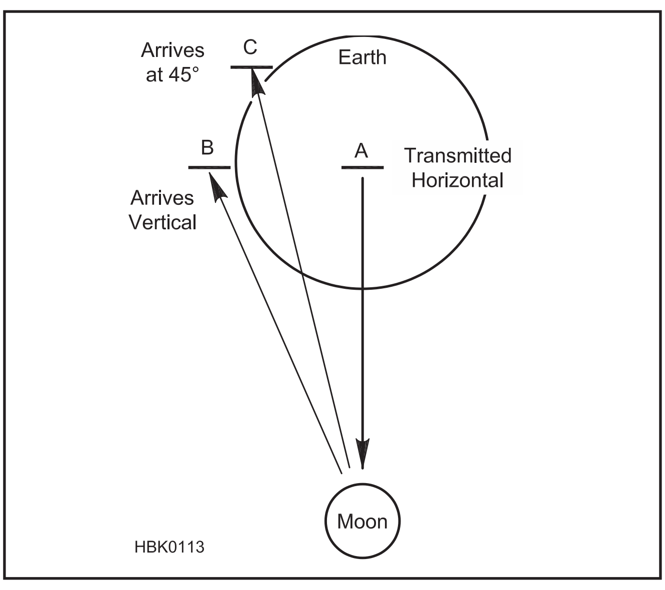


Figure 17.7 — The spherical Earth creates spatial polarization offsets for well-separated stations with horizon-oriented linear polarization. Here, a signal transmitted horizontally at A arrived with vertical polarization at B and midway between horizontal and vertical at C. When combined with Faraday rotation, offsets close to 45° can lead to apparent one-way propagation. See text for details.

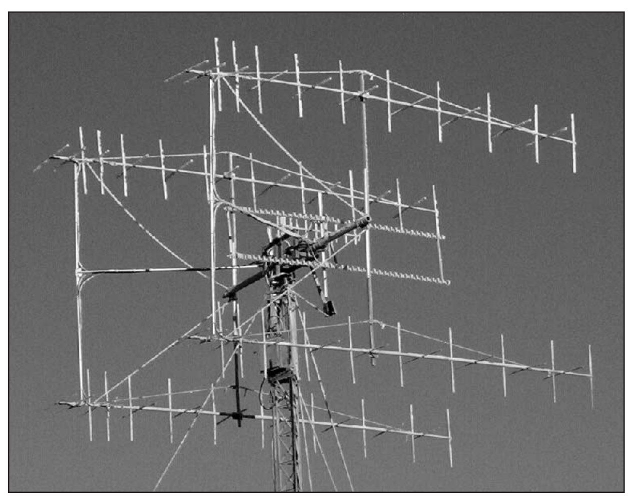


Figure 17.8 — Array of four 10-element, dual-polarization 144-MHz Yagis at KL7UW. Alaskan frost makes the horizontal and vertical elements stand out clearly. A pair of loop Yagis for 1296 MHz can be seen inside the 2 meter array.

a dish on several bands by swapping feeds, and with suitable feed designs you can produce either linear or circular polarization, including dual polarizations. A very attractive and convenient option is to transmit in one sense of circular polarization and receive in the opposite sense. Transmitting in right-hand circular and receiving in left-hand circular has become the standard for EME at 1296 and 2304 MHz, and will probably become the standard on higher bands as well. More information about circular polarization is presented later in this chapter.

As made clear in Figure 17.6, the 432 MHz band lies in a transition region where both Yagis and parabolic dishes have attractive features. Either four long Yagis or a 6 meter dish can produce enough gain (about 25 dBi) to let you work many other EME stations on this band. Many linear-polarization systems are already in use — for good reason, since most amateur use of this band is for terrestrial communication — so converting everyone to circular polarization is impractical. Therefore, schemes have been devised to physically rotate dish feeds and even whole Yagi arrays to cope with the resulting polarization alignment problems. Another scheme is to use a dual-polarization dish feed or dual-polarization Yagis, as described above and increasingly used on 144 MHz. This approach has not yet gained wide popularity on 432 MHz, however.

Antenna Pattern

A clean pattern withgood suppression of side and rear lobes is important for all EME antennas — especially at 432 MHz and above, where excessive noise pickup through sidelobes can significantly increase the system noise temperature, T_S. For Yagi arrays you should use modern, computer optimized designs that maximize G/T_S, the ratio of forward gain to system noise temperature. Be sure to pay attention to maintaining a clean pattern when stacking multiple antennas. First sidelobes within 10-15° of the main beam may not be a major problem, because their solid angle is small and they will look mostly at cold sky when EME conditions are favorable. Side and rear lobes farther from the main beam should be suppressed as much as possible, however. Remember that even close-in sidelobes will degrade your receiving performance at low elevations.

For parabolic dishes, G/T_S is optimized by using a feed with somewhat larger taper in illumination at the edge of the dish than would yield the highest forward gain. Best forward gain is generally obtained with edge taper around −10 dB, while best G/T_S occurs around −15 dB. Edge taper of −12 dB is usually a good compromise. Some good reproducible designs for dish feeds are described or referenced later in this chapter.

17.2 CIRCULARLY POLARIZED ANTENNAS

Linearly polarized antennas are horizontal or vertical in terms of the antenna's position relative to the surface of the Earth, a reference that loses its meaning in space. If spacecraft antennas used linear polarization, ground stations would not be able to maintain polarization alignment with the spacecraft because of its changing orientation. Thus the ideal antenna for random satellite signal polarization is one with *circular polarization* or *CP*.

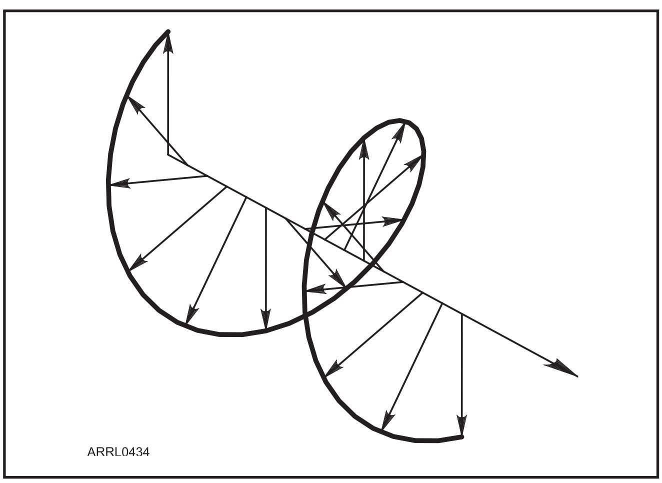


Figure 17.9 — The polarization of a circularly polarized wavefront rotates around its central axis, either clockwise (right-hand or RHCP) or counterclockwise (left-hand or LHCP).

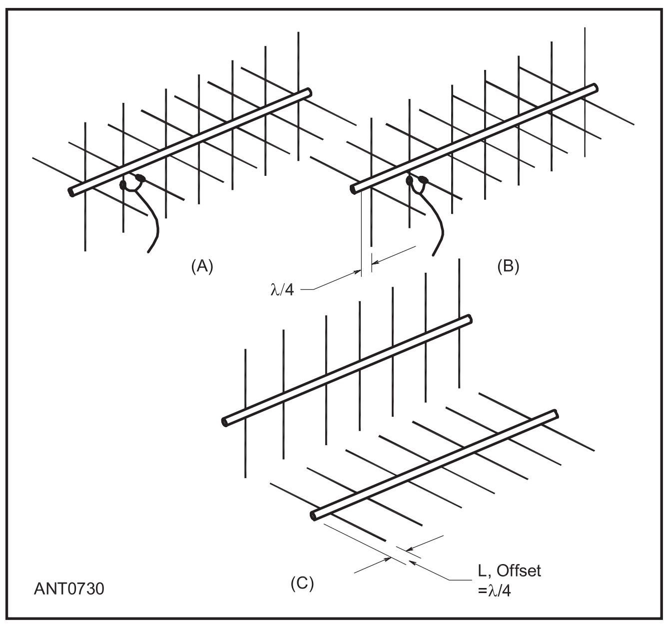


Figure 17.10 — Evolution of the circularly polarized Yagi. The simplest form of crossed Yagi, A, is made to radiate circularly by feeding the two driven elements 90° out of phase. Antenna B has the driven elements fed in phase, but has the elements of one bay mounted ¼ λ forward from those of the other. Antenna C offers elliptical (circular) polarization using separate booms. The elements in one set are perpendicular to those of the other and are ¼ λ forward from those of the other.

Circular polarization is simply linear polarization with a direction that continually rotates as it travels through space as in **Figure 17.9**. The direction of polarization can be imagined as the second hand of a watch that is moving forward with the wave such that the second hand makes one complete revolution per wavelength traveled. The second hand represents the *instantaneous polarization* of the signal.

Figure 17.5 shows a pair of Yagi antennas mounted on each boom to provide circular polarization. (See the **Antenna Fundamentals** chapter for additional background on polarization.) There are several commonly used antennas with circular polarization described in the following sections.

Polarization Sense

Polarization *sense* is a critical factor, especially in EME and satellite work. The IEEE standard uses the term "clockwise circular polarization" for a *receding* wave (one traveling away from the observer). Amateur technology follows the IEEE standard, calling clockwise polarization for a receding wave as *right-hand circular polarization* or *RHCP*. This means that the second hand of the watch traveling with the receding wave is revolving clockwise. A wave for which polarization rotates in the opposition direction is *left-hand circular polarization* or *LHCP*.

When making satellite contacts using a circularly polarized antenna, it is often convenient to have the capability of switching polarization sense. This is because the sense of the received signal from some of the LEO satellites reverses when the satellite passes its nearest point to you. If the received signal has right-hand circular polarization as the satellite approaches, it may have left-hand circular polarization as the satellite recedes. A sense reversal occurs in EME communications as well, because of the phase reversal of the signal as it is reflected from the lunar surface. A signal transmitted with RHCP will be returned to the Earth with LHCP. Similarly, the polarization is reversed as it is reflected from a dish antenna so that to transmit an RHCP signal, the feed antenna for the dish needs to be LHCP.

17.2.1 CROSSED LINEAR ELEMENTS

Dipoles radiate linearly polarized signals and the polarization direction depends on the orientation of the antenna. If two dipoles are arranged as horizontal and vertical dipoles, and the two outputs are combined with the correct phase difference (90°), a circularly polarized wave results. Because the electric fields are identical in magnitude, the power from the transmitter will be divided equally between the two fields. Another way of looking at this is to consider the power as being divided between the two antennas — hence the gain of each is decreased by 3 dB when taken alone in the plane of its orientation.

A 90° phase shift must exist between the two antennas and the simplest way to obtain this shift is to use two feed lines to a *coplanar pair* of crossed-Yagi antennas in which the elements lie approximately in the same plane, as shown in **Figure 17.10A**. One feed line section is ¼ λ longer than the other, as shown in Figure 17.10. These separate feed lines are then connected in parallel with a common transmission line to the transmitter or receiver. An example is shown in **Figure 17.11** and **Figure 17.12**. Assuming negligible coupling between the crossed antennas, the impedance presented to the common transmission line by the parallel combination is one half that of either section alone. (This is not true when there is mutual coupling between the antennas, as in phased arrays.)

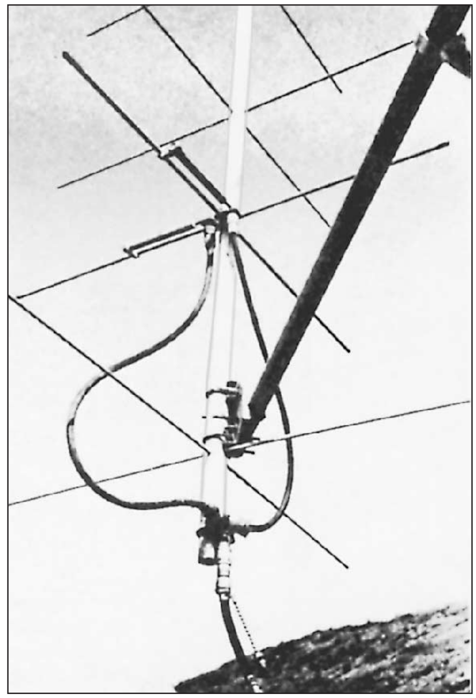


Figure 17.11 — This VHF crossed Yagi design by KH6IJ (Jan 1973 *QST*) illustrates the co-planar, fixed-circularity Yagi.

This creates some difficulties for the antenna builder. With this phasing-line method, any mismatch at one antenna will be magnified by the extra ¼ λ of transmission line. This upsets the current balance between the two antennas, resulting in a loss of polarization circularity. Another factor to consider is the attenuation of the cables used in the harness, along with the connectors. Good low-loss coaxial line should be used with Type N or BNC connectors. A practical construction method for implementing a RHCP/LHCP coplanar switched system is shown in **Figure 17.13**.

Another method to obtain circular polarization is to use equal-length feed lines and place one antenna ¼ λ ahead of the other. This offset pair of Yagi-crossed antennas is shown in Figure 17.10B. The advantage of equal-length feed lines is that identical load impedances will be presented to the common feeder, as shown in **Figure 17.14**, which shows a fixed circularity-sense feed. To obtain a switchable-sense feed with the offset Yagi pair, you can use a configuration as in **Figure 17.15**, although you must compensate for the extra phase shift added by the relay and connectors.

Figure 17.10C diagrams a popular method of mounting two separate off-the-shelf Yagis at right angles to each other.

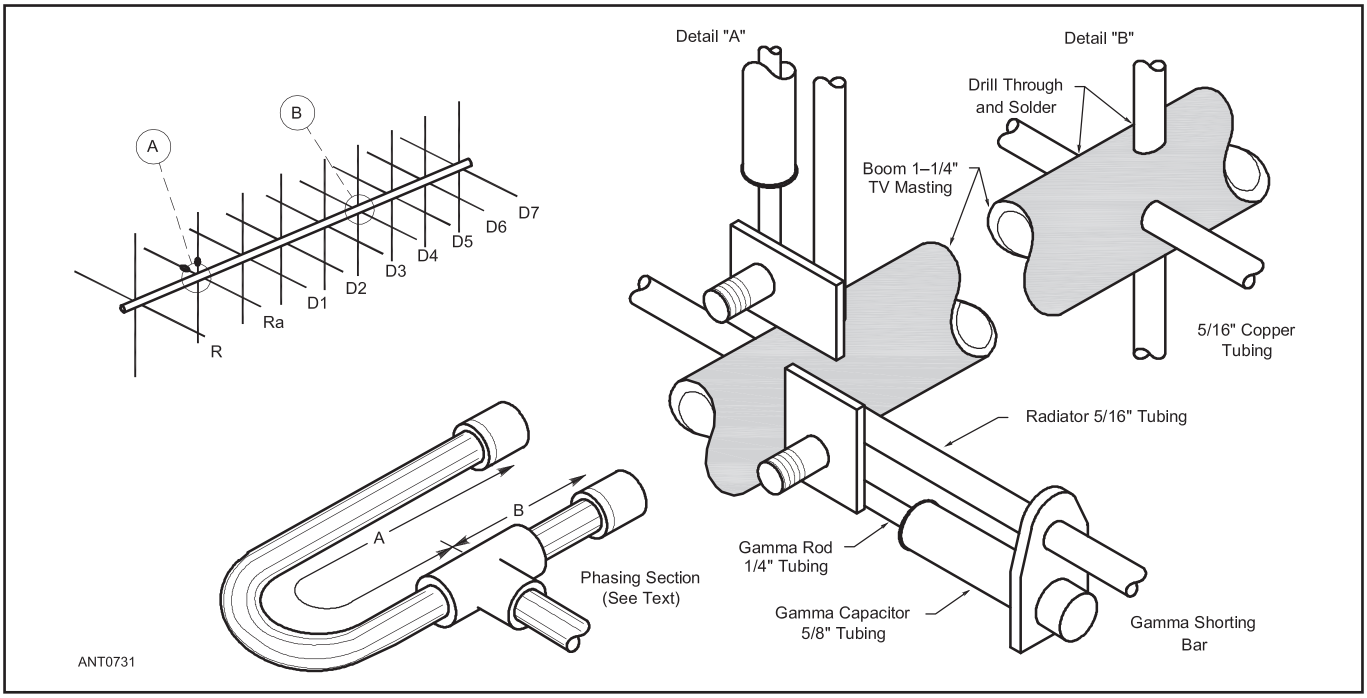


Figure 17.12 — Construction details of a co-planar crossed-Yagi antenna.

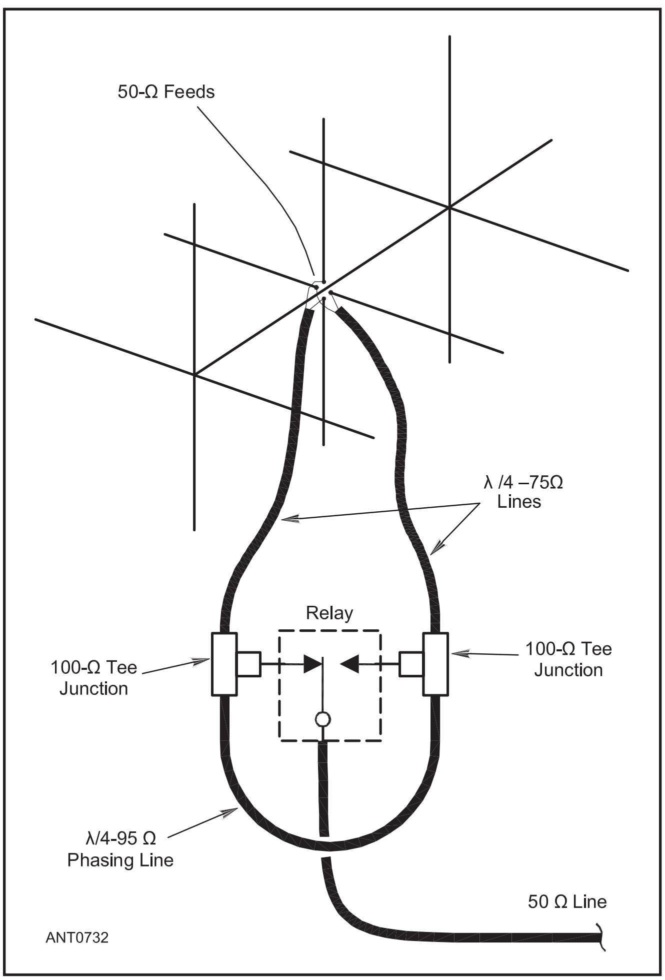


Figure 17.13 — Co-planar crossed Yagi, circularly polarized antenna with switchable polarization phasing harness.

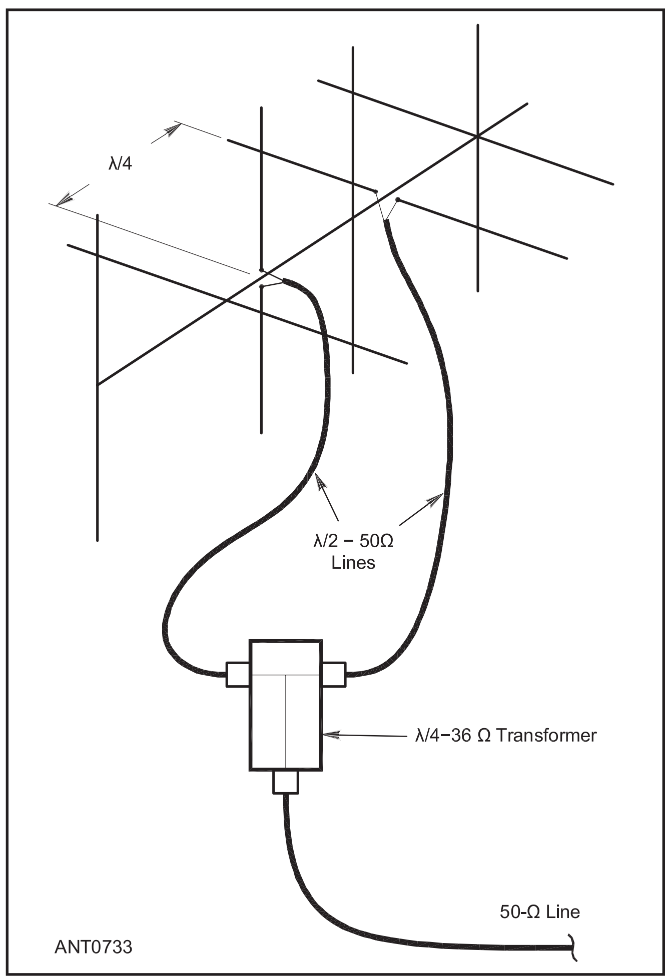


Figure 17.14 — Offset crossed-Yagi circularly polarized antenna-phasing harness with fixed polarization.

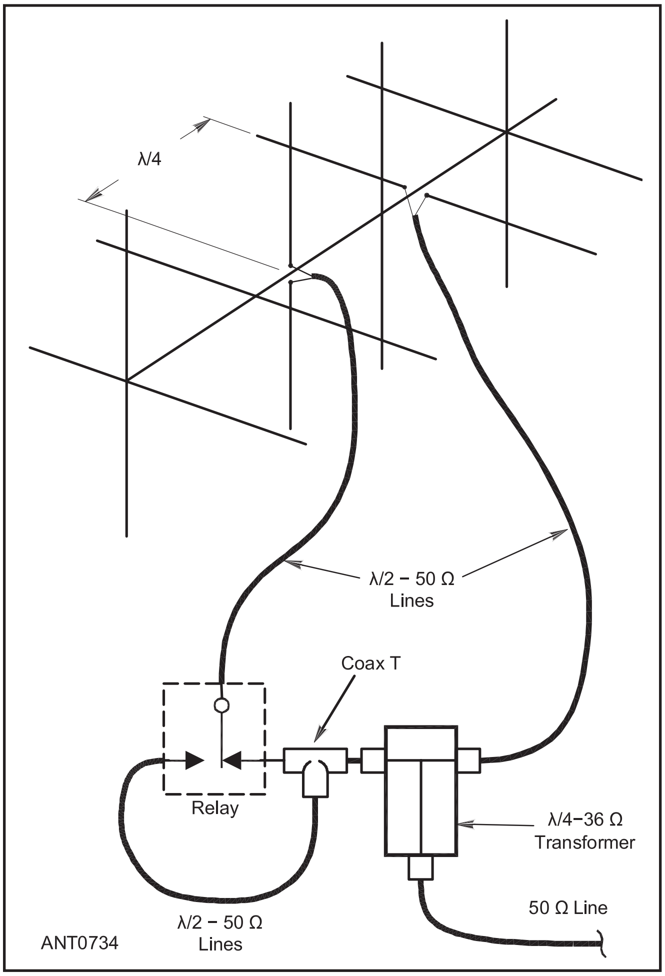


Figure 17.15 — Offset crossed-Yagi circularly polarized antenna-phasing harness with switchable polarization.

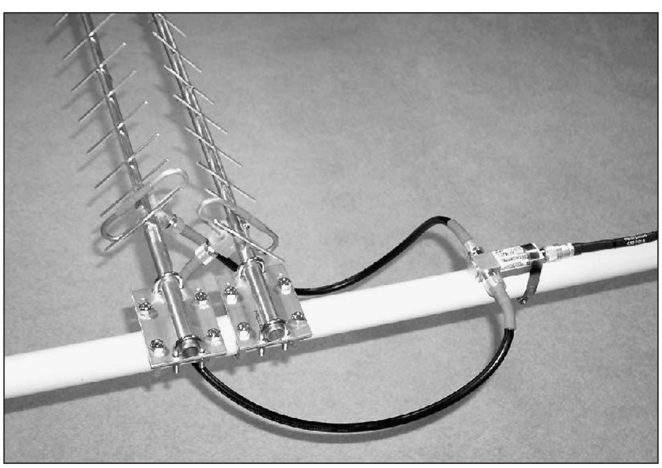


Figure 17.16 — An example of offset crossed-Yagi circularly polarized antennas with fixed polarization. This example is a pair of M2 23CMM22EZA antennas for 1296 MHz, mounted on an elevation boom.

The two Yagis may be physically offset by ¼ λ and fed in parallel, as shown in Figure 17.10C, or they may be mounted with no offset and fed 90° out of phase. Neither of these arrangements on two separate booms produces true circular polarization. Instead, *elliptical* polarization results from such a system, an example of which is shown in **Figure 17.16**.

17.2.2 THE EGGBEATER ANTENNA

The eggbeater antenna shown in Figure 17.2 is a popular design named after the old-fashioned kitchen utensil it resembles. The antenna is composed of two full-wave loops of rigid wire or metal tubing. Each of the two loops has an impedance of 100 Ω, and when coupled in parallel they offer an ideal 50-Ω impedance for coaxial feed lines. The loops are fed 90° out of phase with each other and this creates a circularly polarized pattern.

An eggbeater may also use one or more parasitic reflector elements beneath the loops to focus more of the radiation pattern upward. This effect makes it a "gain" antenna, but that gain is at the expense of low-elevation reception. Toward the horizon an eggbeater is actually horizontally polarized. As the pattern rises in elevation, it becomes more and more right-hand circularly polarized. Experience has shown that eggbeaters seem to perform best when reflector elements are installed just below the loops.

Eggbeaters can be built relatively easily, but commercial models such as the one shown in Figure 17.2 are available. The spherical shape of the eggbeater creates a fairly compact antenna when space is an issue, which is another reason why it is an attractive design. (See this book's CD-ROM.)

17.2.3 THE TURNSTILE ANTENNA

The basic turnstile antenna in Figure 17.3 consists of two horizontal half-wave dipoles mounted at right angles to each other (arranged like the letter "X") in the same horizontal plane with a reflector screen beneath. When these two antennas are excited with equal currents 90° out of phase, their typical figure-eight patterns merge to produce a nearly circular pattern. (See this book's CD-ROM.)

To get the radiation pattern in the upward direction for space communications, the turnstile antenna needs a reflector underneath. For a broad pattern it is best to maintain a distance of ⅜ λ at the operating frequency between the reflector and the turnstile. Homemade turnstile reflectors often use metal window-screen material that you can pick up at many hardware stores. (Make sure it is a metal, not plastic, screen material.)

Like their cousins the eggbeaters, turnstiles are relatively easy to build. In fact, building one may be your only choice since turnstiles are rarely available off the shelf.

17.2.4 THE LINDENBLAD ANTENNA

The Lindenblad antenna shown in **Figure 17.17A** is constructed from linear elements, is circularly polarized, and has an omnidirectional radiation pattern. With most of its gain at low elevation angles as shown in Figure 17.17B, it is ideal for accessing Low-Earth-Orbit (LEO) satellites.

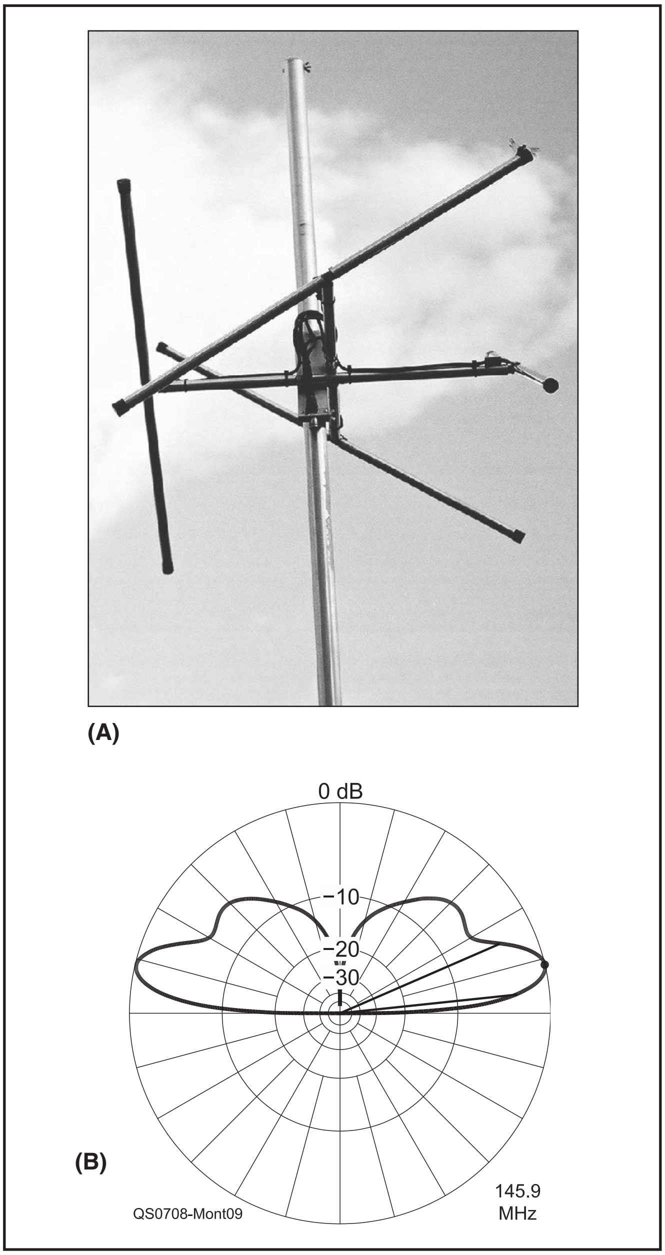


Figure 17.17 — The Lindenblad antenna in A has circular polarization and an omnidirectional azimuthal pattern as shown in B. (AA2TX photo)

Because it is omnidirectional, it does not need to be pointed at a satellite, eliminating the need for an azimuth/elevation (az/el) rotator system. This makes the Lindenblad especially useful for portable or temporary satellite operations. It is also a good general purpose antenna for a home station because its circular polarization is compatible with the linearly polarized antennas used for FM/repeater and SSB/CW operation. Two complete construction articles for Lindenblad antennas are included on this book's CD-ROM.

17.2.5 THE QUADRIFILAR HELIX (QFH)

Designed for spacecraft use in the early days of space exploration, the *quadrifilar helix* (QFH) antenna (also called the quadrifilar helicoidal antenna) has not gained much popularity on the ham bands. Yet, as a general-purpose base-station antenna, such as the 2 meter version in **Figure 17.18**, it's hard to beat. The pattern is almost omnidirectional in both planes, like the mythical *isotropic* radiator, receiving nearly to the horizon. No matter what direction signals come from, or whether the polarization is vertical or horizontal, the QFH receives them. It's good for overhead satellites, such as the International Space Station, for horizontally polarized 2 meter SSB simplex stations on the horizon, and also for vertically polarized mobile and repeater stations. It isn't a gain antenna — no true omni can be. The primary benefit of a QFH is the coverage afforded by its pattern.

The QFH is often used by hams for receiving weather satellite pictures from the 137 MHz NOAA automatic picture

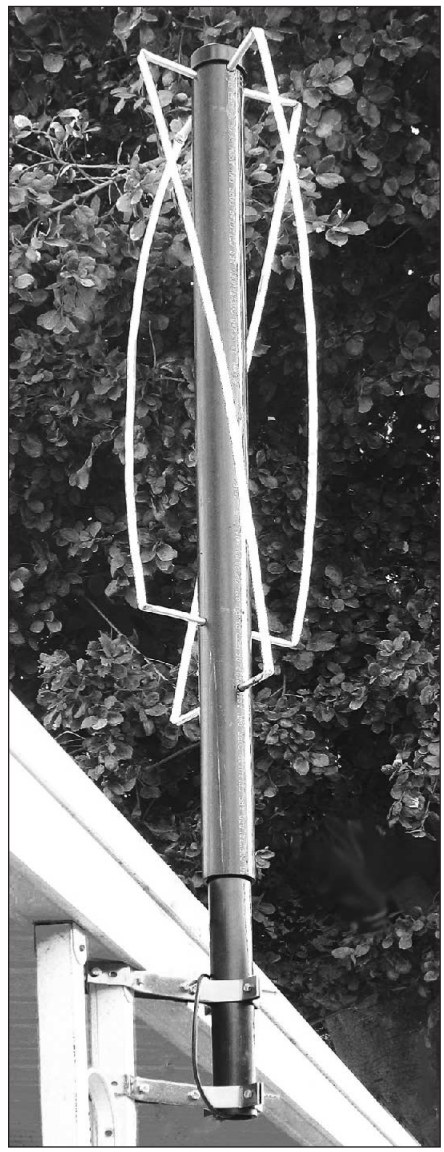


Figure 17.18 — W6NBC's Quadrifilar Helix base station antenna (W6NBC photo)

transmitting (APT) satellites in low polar orbit. Its omnidirectional and circular polarization characteristics accommodate the constantly changing direction and polarization of the APT satellite signals. Several have been built for this service. Three of these weather birds still fly by every day — NOAA 15, 17, 18 and 19. (Pictures of these satellites are available at **w6nbc.com**.)

The QFH can be envisioned as follows: Take two vertical full wavelength rectangular loops with open feed points *at the top*. Now place them on the same vertical axis, but with one loop rotated 90° horizontally so that they are in quadrature. Also, you need to make one loop slightly larger than the other. This creates a phase shift at the feed point to compensate for the physical rotation of the loops. Next, twist both loops horizontally a quarter turn into helices. Finally connect the feed points in parallel to create a quadrifilar helix antenna.

The curious eggbeater-like configuration of the QFH has useful characteristics — an almost perfectly spherical radiation pattern as well as circular polarization throughout the pattern. This version is right-handed. For left, twist the loops in the opposite direction. For the general purpose 2 meter base station antenna, the twist direction does not matter. And yes, there is a small loss working linear polarized signals (vertical or horizontal) with a circularly polarized antenna, but it is quite acceptable. Commercial broadcast antennas often use this very technique to accommodate both mobile (vertical) as well as home antennas (horizontal).

After experimenting ham style with square loops and tall versus thin rectangular ones, and the small size difference between the two loops as well as the amount of twist, it has been concluded that the QFH is a dimensionally tolerant design. The performance changed little with all these variations.

The antenna shown in Figure 17.18 is described in the complete construction article by John Portune, W6NBC, included on this book's CD-ROM along with another QFH construction article by Eugene Ruperto, W3KH.

17.2.6 HELICAL ANTENNAS

The axial-mode helical antenna was introduced by Dr John Kraus, W8JK (SK), in the 1940s. **Figure 17.19** shows examples of S-band (2400-MHz), V-band (145-MHz), and U-band (435-MHz) helical antennas, all constructed by KD1K for satellite service.

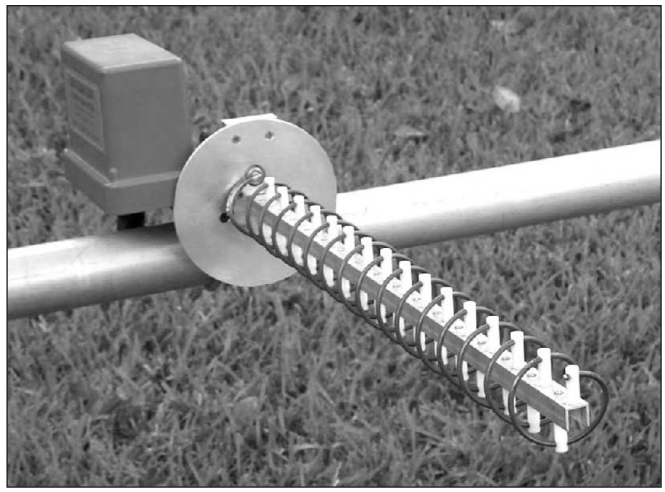
This antenna has two characteristics that make it especially interesting and useful in many applications. First, the helix is circularly polarized with a fixed polarization sense determined by its configuration. The polarization rotates about the axis of the antenna.

The second interesting property of the helical antenna is its predictable pattern, gain and impedance characteristics over a wide frequency range. This is one of the few antennas with both broad bandwidth and high gain. The benefit of this property is that, when used for narrowband applications, the helical antenna is very forgiving of mechanical inaccuracies.

Probably the most common amateur use of the helical antenna is in satellite communications, where the spinning of the satellite antenna system (relative to the Earth) and the effects of *Faraday rotation* cause the polarization of the satellite signal to be unpredictable. Using a linearly polarized antenna in this situation can result in deep fading, but with the helical antenna (which responds equally to linearly polarized signals), fading is essentially eliminated.

This same characteristic makes helical antennas useful in polarization-diversity systems. The advantages of circular polarization have been demonstrated on VHF voice schedules over non-optical paths, in cases where linearly polarized beams did not perform satisfactorily.

Another use for the helical antenna is the transmission of color ATV signals. Many beam antennas (when adjusted



(A)

(B)

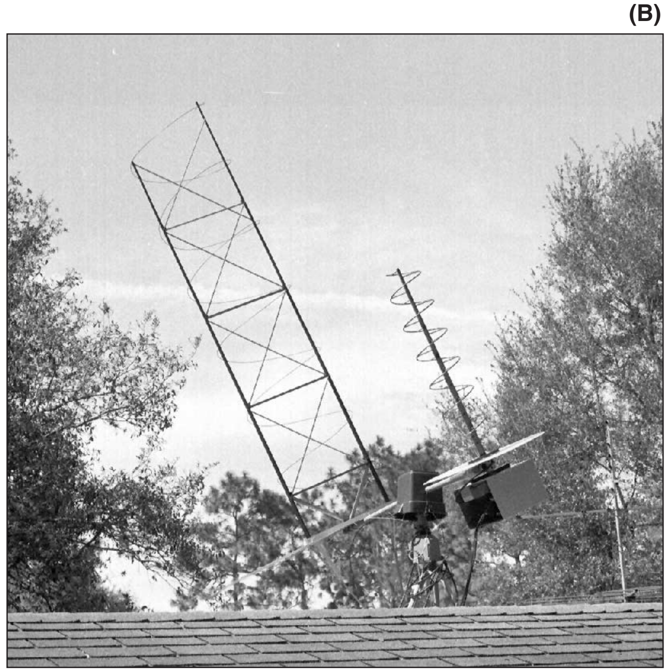


Figure 17.19 — At top, a 16-turn S-band helical antenna. This is about the maximum length of any practical helix. Note the SSB UEK2000 downconverter mounted behind the reflector of the antenna. At bottom, a pair of helical antennas for service on 2 meters and 70 cm. The 2 meter helical antenna is not small! (KD1K photos.)

for maximum gain) have far less bandwidth than the required 6 MHz, or lack uniform gain over this frequency range. The result is significant distortion of the transmitted and received signals, affecting color reproduction and other features. This problem becomes more aggravated over non-optical paths. The helix exhibits maximum gain (within 1 dB) across a range of more than 20 MHz anywhere above 420 MHz.

The helical antenna can be used to advantage with multimode rigs, especially above 420 MHz. Not only does the helix give high gain over an entire amateur band, but it also allows operation on FM, SSB and CW without the need for separate vertically and horizontally polarized antennas.

Helical Antenna Basics

The helical antenna is an unusual specimen in the antenna world, in that its physical configuration gives a hint to its electrical performance. A helix looks like a large air-wound coil with one of its ends fed against a ground plane, as shown in **Figure 17.20**. The ground plane is a screen of 0.8 to 1.1 λ diameter (or on a side for a square ground plane). The circumference (C_λ) of the coil form must be between 0.75 and 1.33 λ for the antenna to radiate in the axial mode. The coil should have at least three turns to radiate in this mode. The ratio of the spacing between turns (in wavelengths), S_λ to C_λ, should be in the range of 0.2126 to 0.2867. This ratio range results from the requirement that the pitch angle, α, of the helix be between 12° and 16°, where:

$$\alpha = \arctan \frac{S_\lambda}{C_\lambda} \qquad \text{(Eq 1)}$$

These constraints result in a single main lobe along the axis of the coil. This is easily visualized from Figure 17.19. The winding of the helix comes away from the reflector with a clockwise winding direction for RHCP. (The winding can also be counterclockwise — this results in a LHCP polarization sense.)

A helix with a C_λ of 1 λ has a wave propagating from

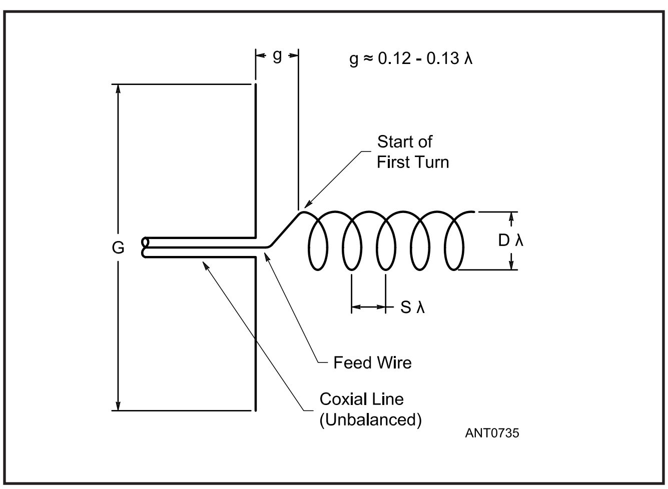


Figure 17.20 — The basic helical antenna and design parameters.

one end of the coil (at the ground plane), corresponding to an instantaneous dipole "across" the helix. The electrical rotation of this dipole produces circularly polarized radiation. Because the wave is moving along the helix conductor at nearly the speed of light, the rotation of the electrical dipole is at a very high rate, and true circular polarization results.

The IEEE definition, in simple terms, is that when viewing the antenna from the feed point end, a clockwise wind results in right-hand circular polarization (RHCP), and a counterclockwise wind results in left-hand circular polarization (LHCP). This is important, because when two stations use helical antennas over a nonreflective path, both must use antennas with the same polarization sense. If antennas of opposite sense are used, a signal loss of at least 20 dB results from the cross-polarization alone.

As mentioned previously, circularly polarized antennas can be used in communication with any linearly polarized antenna (horizontal or vertical), because circularly polarized antennas respond equally to all linearly polarized signals. The gain of a helix appears 3 dB less than the theoretical gain in this case, because the linearly polarized antenna does not respond to linearly polarized signal components orthogonal to it.

The response of a helix to all polarizations is indicated by a term called *axial ratio*, also known as *circularity*. Axial ratio is the ratio of amplitude of the polarization that gives maximum response to the amplitude of the polarization that gives minimum response. An ideal circularly polarized antenna has an axial ratio of 1.0. A well-designed practical helix exhibits an axial ratio of 1.0 to 1.1. The axial ratio of a helix is:

$$AR = \frac{2n+1}{2n} \qquad \text{(Eq 2)}$$

where
AR = axial ratio
n = the number of turns in the helix

Axial ratio can be measured in two ways. The first is to excite the helix and use a linearly polarized antenna with an amplitude detector to measure the axial ratio directly. This is done by rotating the linearly polarized antenna in a plane perpendicular to the axis of the helix and comparing the maximum and minimum amplitude values. The ratio of maximum to minimum is the axial ratio.

The impedance of the helix is easily predicted. The terminal impedance of a helix is unbalanced, and is defined by:

$$Z = 140 \times C_\lambda \qquad \text{(Eq 3)}$$

where Z is the impedance of the helix in ohms.

The gain of a helical antenna is determined by its physical characteristics. Gain can be calculated from:

$$\text{Gain (dBi)} = 11.8 + 10 \log (C_\lambda^2 n S_\lambda) \qquad \text{(Eq 4)}$$

In practice, helical antennas do not deliver the gain in Eq 4 for antennas with turns count greater than about twelve. This will be discussed further regarding practical antennas.

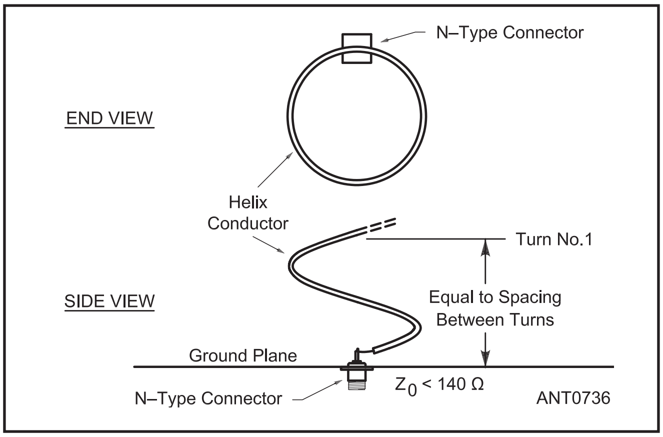


Figure 17.21 — End view and side view of peripherally fed helix.

The beamwidth of the helical antenna (in degrees) at the half-power points is:

$$BW = \frac{52}{C_\lambda \sqrt{nS_\lambda}} \quad \text{(Eq 5)}$$

The diameter of the helical antenna conductor should be between 0.006 and 0.05 λ but smaller diameters have been used successfully at 144 MHz. The previously noted diameter of the ground plane (0.8 to 1.1 λ) should not be exceeded if you desire a clean radiation pattern. As the ground plane size is increased, the sidelobe levels also increase. The ground plane need not be solid; it can be in the form of a spoked wheel or a frame covered with hardware cloth or screen. Cupped ground planes have also been used according to Kraus. (See the Bibliography.)

50-Ω Helix Feed

Joe Cadwallader, K6ZMW, presented this feed method in June 1981 *QST*. Terminate the helix in an N connector mounted on the ground screen at the periphery of the helix. See **Figure 17.21**. Connect the helix conductor to the N connector as close to the ground screen as possible (**Figure 17.22**). Then adjust the first quarter turn of the helix to a close spacing from the reflector.

This modification goes a long way toward curing a deficiency of the helix — the 140-Ω nominal feed point impedance. The traditional λ/4 matching section has proved difficult to fabricate and maintain. But if the helix is fed at the periphery, the first quarter turn of the helix conductor (leaving the N connector) acts much like a transmission line — a single conductor over a perfectly conducting ground plane. The impedance of such a transmission line is:

$$Z_0 = 138 \log \frac{4h}{d} \quad \text{(Eq 6)}$$

where

Z_0 = line impedance in ohms

h = height of the center of the conductor above the ground plane

d = conductor diameter (in the same units as h).

The impedance of the helix is 140 Ω a turn or two away from the feed point. But as the helix conductor curves down toward the feed connector (and the ground plane), h gets smaller, so the impedance decreases. The 140-Ω nominal impedance of the helix is transformed to a lower value. For any particular conductor diameter, an optimum height can be found that will produce a feed point impedance equal to 50 Ω. The height should be kept very small, and the diameter should be large. Apply power to the helix and measure the SWR at the operating frequency. Adjust the height for an optimum match.

Typically, the conductor diameter may not be large enough to yield a 50-Ω match at practical (small) values of h. In this case, a strip of thin brass shim stock or flashing copper can be soldered to the first quarter turn of the helix conductor (**Figure 17.23**). This effectively increases the conductor diameter, causing the impedance to decrease further yet. The edges of this strip can be slit every ½ inch or so, and the strip bent up or down (toward or away from the ground plane) to tune the line for an optimum match.

This approach yields a perfect match to nearly any coax. The usually wide bandwidth of the helix (70% for less than 2:1 SWR) will be reduced slightly (to about 40%) for the same conditions. This reduction is not enough to be of any consequence for most amateur work. The improvements in performance, ease of assembly and adjustment are well worth the effort in making the helix more practical to build and tune.

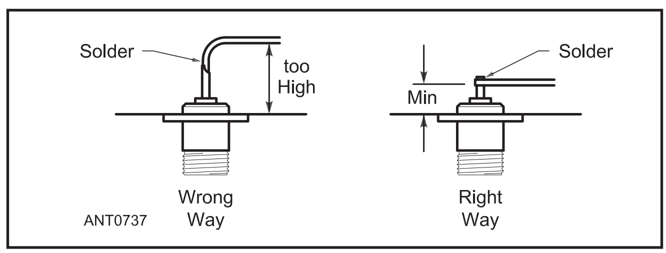


Figure 17.22 — Wrong and right ways to attach a helix to a type N connector for 50-Ω feed.

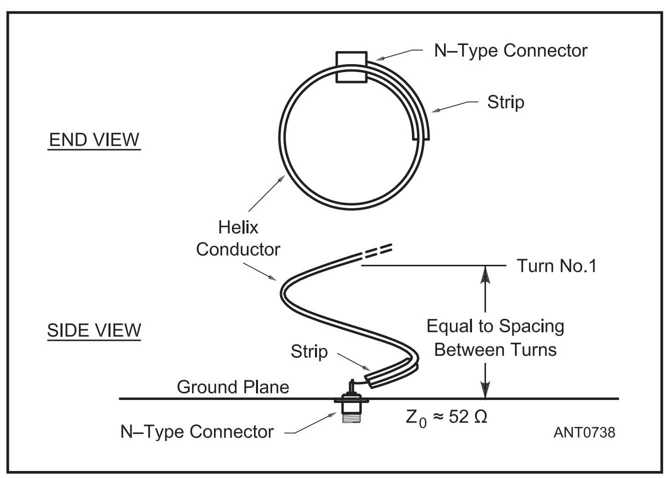


Figure 17.23 — End view and side view of peripherally fed helix with metal strip added to improve transformer action.

Portable Helix for 435 MHz

Helical antennas for 435 MHz are excellent uplinks for U-band satellite communications. The true circular polarization afforded by the helix minimizes signal *spin fading* that is so common in these applications. The antenna shown in **Figure 17.24** fills the need for an effective portable uplink antenna for OSCAR operation. Speedy assembly and disassembly and light weight are among the benefits of this array. This antenna was designed by Jim McKim, WØCY.

Although the helix is about the most tolerant of any antenna in terms of dimensions, the dimensions given here should be followed as closely as possible. Most of the materials specified are available in any well supplied do-it-yourself hardware or building supply store.

The portable helix consists of eight turns of ¼-inch soft-copper tubing spaced around a 1-inch fiberglass tube or maple dowel rod 4 feet, 7 inches long. Surplus solid aluminum shield hardline can be used instead of the copper tubing if necessary. The turns of the helix are supported by 5-inch lengths of ¼-inch maple dowel mounted through the 1-inch rod in the center of the antenna. For further details, a complete parts list and construction information see the CD-ROM included with this book.

Figure 17.24 — The portable 435-MHz helix assembled and ready for operation. (WØCY photo)

Helix Array for L Band (23 cm)

A four-element array of 27-turn helixes is described in the presentation "L Band Helix Antenna Array" by Clare Fowler, VE3NPC, provided on the CD-ROM accompanying this book. While designed for use with HEO satellites, the array is also suitable for EME operation, particularly using digital modes. Each antenna has a calculated gain of 19 dBi and the array has an estimated actual gain of 23 dB.

17.3 YAGI ARRAYS

The Yagis in this section are typical of the high-performance designs used for terrestrial communications. For satellite or EME operation, they are often combined into arrays of 2, 4, 8 or even more antennas with both azimuth and elevation position control. Designs of such Yagis can be found in the **VHF and UHF Antenna Systems** chapter or commercial models are available.

17.3.1 ARRAYS FOR SATELLITES

It is not necessary to use a high-gain Yagi array to access an LEO satellite except possibly when it is very near the horizon. Reliable operation via the HEO satellites, however, requires more gain and Yagi arrays are very popular from VHF through 1.2 and 2.4 GHz.

Figure 17.25 shows the satellite antennas at KD1K. The Yagi antennas are used for the U- and L-band uplinks and the V-band downlink, while the S-band dish antenna is for downlink. These satellite antennas are tower mounted at 63 feet (19 meters) to avoid pointing into the many nearby trees and suffering from the resulting "green attenuation." Of course, satellite antennas do not always need to be mounted high on a tower if dense foliage is not a problem. If satellite antennas are mounted lower, feed line length and losses can reduced.

Another benefit, however, to tower mounting of satellite antennas is that they can be used for terrestrial ham communications and contests. The fact that the antennas are set

Figure 17.25 — Details of KD1K's tower cluster of satellite antennas including a home-brew elevation rotator. Top to bottom: M2 436-CP30, a CP U-band antenna; two M2 23CM22EZA antennas in a CP array for L band; "FABStar" dish antenna with helix feed for S band; M2 2M-CP22, a CP V-band antenna (only partially shown.) To left of dish antenna is a NEMA 4 weatherproof equipment box with an internal 40-W L-band amplifier, and also hosts externally mounted preamplifiers. (KD1K photo)

up for circular polarization (CP) does not really degrade these other operating activities.

Experience has clearly shown the advantages of using RHCP antennas for both the uplink and downlink communications. The antennas shown in Figure 17.25 are a single-boom RHCP Yagi antenna for U band, a pair of closely spaced Yagi antennas phased for RHCP for L band (see Figure 17.16), and a helix-fed offset dish antenna for S band described below. The antenna gain requirements for U band can easily be met with the gain of a 30-element crossed Yagi. Antennas of this size have boom lengths of 4 to 4.5 wavelengths. The enterprising amateur can build a Yagi antenna from one of several references but most of us prefer to purchase well-tested antennas from commercial sources. In the past, KLM (now out of business) had offered a 40-element CP Yagi for U-band satellite service, and many of these are still in satisfactory use today.

U-band uplink requirements have clearly demonstrated the need for gain of 16 to 17 dBic RHCP, with an RF power of less than 50 W PEP at the antenna (≈ 2500 WPEP EIRP with a RHCP antenna) depending upon the *squint angle*. (The squint angle is the angle at which the main axis of the satellite is pointed away from your antenna on the ground. If the squint angle is less than half of the half-power beamwidth, the ground station will be within the spacecraft antenna's nominal beamwidth. dBic means the gain of a circularly polarized antenna with respect to that of an isotropic antenna with the same polarization characteristic.)

A gain of 16 to 17 (dB isotropic-circular) RHCP can be obtained from a 30-element crossed Yagi — good news, considering that the satellite may be over 60,000 km (37,000 miles) from your station. Success on U-band uplinks is easier than those for L band at squint angles wider than 20°. At squint angles less than 10°, U-band uplink operation can even be done with 1-5 W power outputs to a RHCP antenna (≈ 200 W PEP EIRP with RHCP). These lower levels mean that smaller antennas can be used. In practice, these uplinks will produce downlink signals that are 10 to 15 dB above the noise floor, or S7 signals over an S3 noise floor. The beacon will give a downlink S9 signal for these same conditions.

Experience with L-band uplinks has demonstrated that 40 W PEP delivered to an antenna with a gain of ≈ 19 dBic (3000 W PEP EIRP with RHCP) is needed for operations at the highest altitudes and with squint angles ≈ 15°. The compact L-band antenna arrangement with two 22-element antennas in a RHCP array shown in Figure 17.16 is an example of such an antenna system.

Using the L-band uplink for HEO operations instead of the U-band uplink allows the use of Yagi antennas that are more manageable since their size for a given gain is only one third of those for U-band. With L band there is a narrower difference between using a dish antenna and a Yagi, since a 21- to 22-dBic dish antenna would be only about 1.2 meters (4 feet) in diameter. However, some of us may not have such "real estate" available on our towers and may seek the lower wind-loading solution offered by Yagis. Long-boom rod-element Yagi, or loop-Yagi antennas are commercially offered

Figure 17.26 — Domenico, I8CVS, has this cluster of satellite antennas. Left to right: array of 4 × 23-element Yagi horizontally polarized for L band; 1.2-meter dish with 3-turn helix feed for S band; 15-turn RHCP helical antenna for U band; 60-cm dish for X band. All microwave preamplifiers and power amplifiers are homebrew and are mounted on this antenna cluster. (I8CVS photo)

by M^2 and DEM, although this band is about the highest for practical Yagis. The example shown in Figure 17.16 is a pair of rod-element Yagi antennas from M^2 in a CP arrangement with a gain of 18 to 19 dBic.

Other amateurs have successful HEO experience with different arrangements. **Figure 17.26** shows I8CVS's 4 × 23 element linear array for a 1270 MHz, a 1.2 meter solid dish for 2400 MHz, a 15 turn helical antenna for 435 MHz, and a 60 cm dish for 10,451 MHz This arrangement clearly shows the advantage and accessibility of having a roof-mounted antenna.

17.3.2 ARRAYS FOR EME

Several types of antennas for 2 meters and 70 cm are popular among EME enthusiasts. Perhaps the most popular antenna for 144-MHz operation is an array of either 4 or 8 long-boom (14 to 15 dBi gain) Yagis. The 4-Yagi array provides approximately 20 dB gain, and an 8-Yagi array gives an approximate 3 dB increase over the 4-antenna array. **Figure 17.27** shows the computed response at a 30° tilt above the horizon for a stack of four 14-element 2-meter Yagis, each

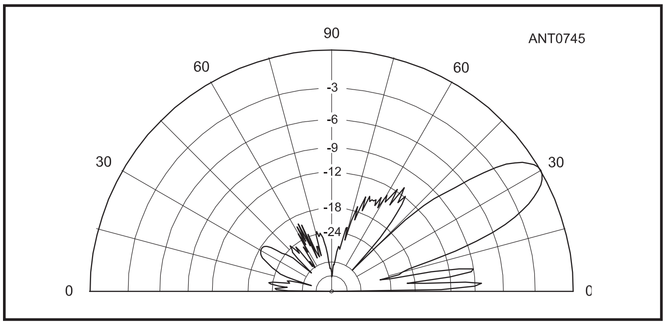


Figure 17.27 — *EZNEC Pro* elevation pattern for four 14-element 2 meter Yagis (3.6-λ boom lengths) at an elevation angle of 30° above the horizon. The computed system gain is 21.5 dBi, suitable for 2 meter EME. This assumes that the phasing system is made of open-wire transmission lines so that feed line losses can be kept below 0.25 dB.

Figure 17.28 — Four-Yagi dual-polarization 432 MHz array at the Princeton University station, W2PU. The Yagis are rear-mounted; boom length is 3.5 meters, and stacking distance is 1.2 meters in each direction. (Photo courtesy Joe Taylor, K1JT)

with a boom length of 3.1 λ (22 feet). At 432 MHz, EME enthusiasts often use 8 or 16 long-boom Yagis in an array as seen in Figure 17.8 previously. However, recent advances in Yagi design as described in the **VHF and UHF Antenna Systems** chapter make smaller arrays of high-performance antennas a satisfactory alternative.

The main disadvantage of Yagi arrays is that the polarization plane of the individual Yagis cannot be conveniently changed. One way around this is to use cross-polarized Yagis and a relay switching system to select the desired polarization, as described in the previous section. This represents a considerable increase in system complexity to select the desired polarization. Some amateurs have gone so far as to build complicated mechanical systems to allow constant polarization adjustment of all the Yagis in a large array.

Polarization shift of EME signals at 144 MHz is fairly rapid, and the added complexity of a relay-controlled cross-polarized antenna system or a mechanical polarization adjustment scheme is probably not worth the effort. At 432 MHz, however, where the polarization shifts at a much slower rate, an adjustable polarization system does offer a definite advantage over a fixed one. An example of a 70 cm Yagi array with switchable-polarization is shown in **Figure 17.28** and described in the article "EME with Adaptive Polarization at 432 MHz" by Joe Taylor, K1JT, and Justin Johnson, GØKSC (available on this book's CD-ROM).

Although not as popular as Yagis, *Quagi* antennas (made from both quad and Yagi elements) are sometimes used for EME work. Slightly more gain per unit boom length is possible as compared to the conventional Yagi, at the expense of some robustness. Additional information on the Quagi is presented in the **VHF and UHF Antenna Systems** chapter.

The collinear array is an older type of antenna for EME work. A 40-element collinear array has approximately the same frontal area as an array of four Yagis, but produces approximately 1 to 2 dB less gain. One attraction to a collinear array is that the depth dimension is considerably less than the long-boom Yagis. An 80-element collinear is marginal for EME communications, providing approximately 19 dB gain. As with Yagi and Quagi antennas, the collinear cannot be adjusted easily for polarity changes. From a construction standpoint, there is little difference in complexity and material costs between the collinear and Yagi arrays.

17.4 PARABOLIC REFLECTOR (DISH) ANTENNAS

Very few antennas evoke as much interest among UHF amateurs as the parabolic dish, and for good reason. First, the parabola and its cousins — Cassegrain, hog horn and Gregorian — are probably the ultimate in high-gain antennas. One of the highest-gain antennas in the world (148 dB) is a parabola. This is the 200-inch Mt. Palomar telescope. (The very short wavelength of light rays causes such a high gain to be realizable.)

Second, the efficiency of the parabola does not change as size increases. With Yagis and collinear arrays, the losses in the phasing harness increase as the array size increases. The corresponding component of the parabola is lossless air between the feed horn and the reflecting surface. If there are a few surface errors, the efficiency of the system stays constant regardless of antenna size.

The major problems associated with parabolic dish antennas are mechanical ones. For example, a dish of about 16 feet in diameter is the minimum size required for successful analog EME operation on 432 MHz. With wind and ice loading, structures of this size place a real strain on the mounting and positioning system. Extremely rugged mounts are required for large dish antennas, especially when used in windy locations. **Figure 17.29** shows the impressive 7-meter diameter dish built by David Wardley, ZL1BJQ. A smaller dish used for 1296 MHz operation is shown in **Figure 17.30**.

Several aspects of parabolic dish antennas make the extra mechanical problems worth the trouble, however. For example, the dish antenna is inherently broadband, and may be used on several different amateur bands by simply changing the feed. An antenna that is suitable for 432 MHz work will most likely be usable on several of the higher amateur bands too. Increased gain is available as the frequency of operation is increased.

Another advantage of a dish is the flexibility of the feed system. The polarization of the feed, and therefore the polarization of the antenna, can be changed with little difficulty. It is a relatively easy matter to devise a system to rotate the feed remotely from the shack to change polarization. Because polarization changes can account for as much as 30 dB of signal attenuation, the rotatable feed can make the difference between consistent communications and no communications at all.

A great deal of useful information on microwave antennas, particularly dishes, is online at *The W1GHZ Online Microwave Antenna Book* at **www.w1ghz.org/antbook/contents.htm**. There are several chapters that are of particular interest to satellite and EME operators.

17.4.1 DISH ANTENNA BASICS

The *parabolic reflector* or dish antenna must have a feed source looking into the surface of the dish. Some dishes are designed so that the feed source is mounted directly in front of the dish. This is referred to as a *center-fed dish*. Other dishes are designed so that the feed source is off to one side, referred to as an *off-center-fed dish*, or just offset-fed dish, as shown in **Figure 17.31**. The offset-fed dish may be considered a side section of a center-fed dish. The center-fed dish experiences some signal degradation due to blockage of the feed system, but this is usually an insignificantly small amount. The offset-fed dish is initially more difficult to aim, since the direction of reception is not the center axis, as it is for center-fed dishes but signal blockage caused by the feed system is essentially eliminated.

The dish's parabola can be designed so the focus point

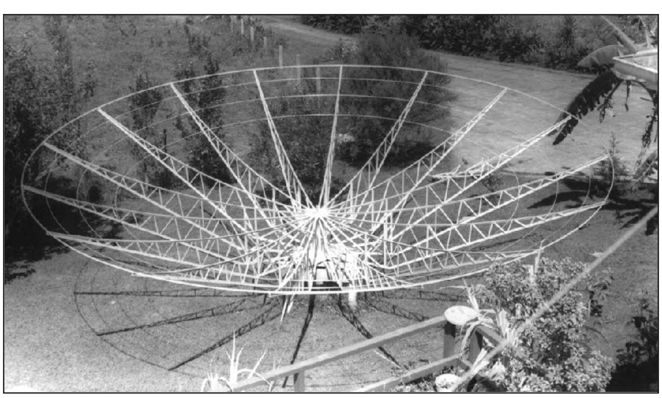


Figure 17.29 — ZL1BJQ's homemade 7-meter (23-foot) parabolic dish, just prior to adding ½-inch wire mesh. (Photo courtesy ZL1BJQ)

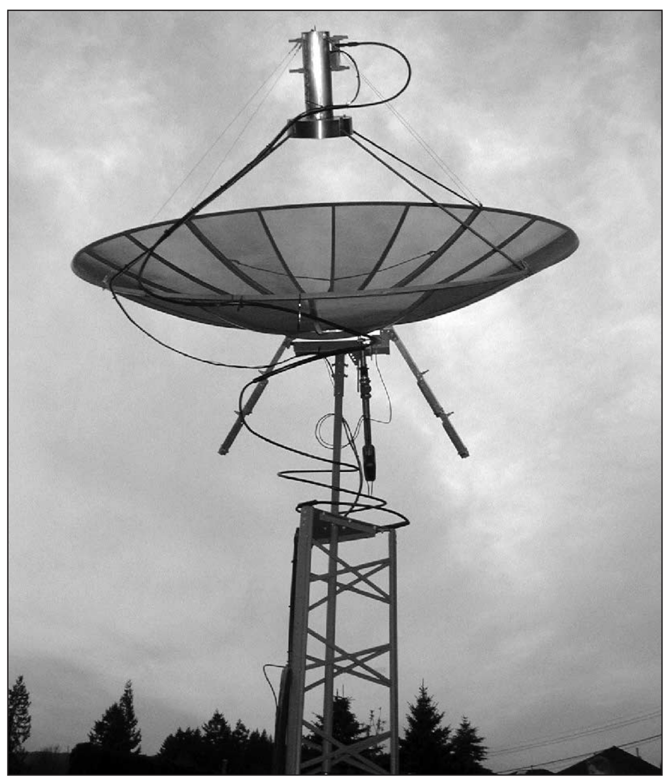


Figure 17.30 — This 3-meter TVRO dish with aluminum frame and mesh surface was outfitted for 1296 MHz EME as a joint effort by VA7MM and VE7CNF. The dual circular polarization feed is a VE4MA/W2IMU design.

Figure 17.31 — PrimeStar offset-fed dish with KD1K's helix-feed antenna. NØNSV was so pleased with the modification that he renamed the dish "FABStar," and made a new label! (NØNSV photo)

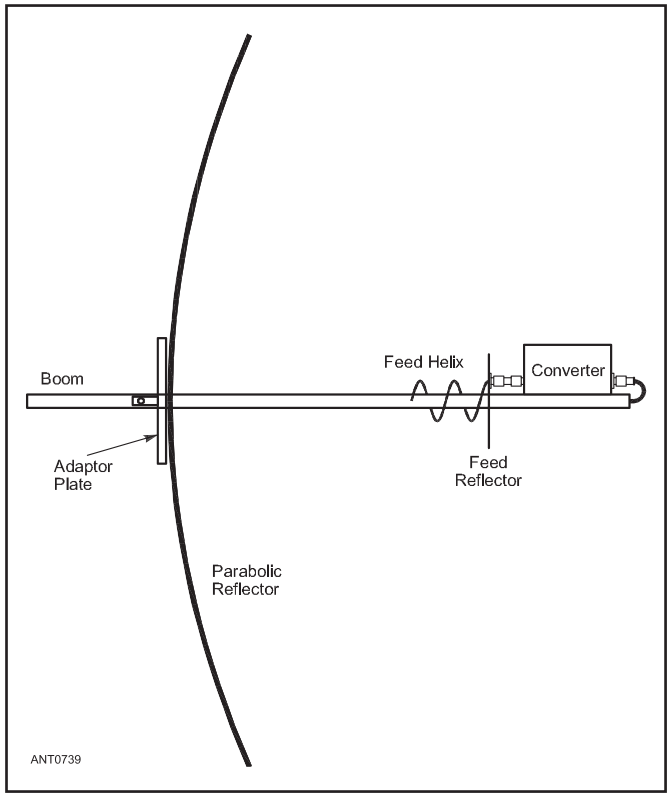


Figure 17.32 — Detail of 60-cm S-band dish antenna with feed.

is closer to the surface of the dish, referred to a *short-focal-length* dish, or further away from the dish's surface, referred to as a *long-focal-length* dish. To determine the exact focal length, measure the diameter of the dish and the depth of the dish.

$$f = \frac{D^2}{16d} \qquad \text{(Eq 7)}$$

The focal length divided by the diameter of the dish gives the *focal ratio*, commonly shown as f/D. Center-fed dishes usually have short focal ratios in the range of f/D = 0.3 to 0.45. Offset-fed dishes usually have longer focal lengths, with f/D = 0.45 to 0.80. If you attach two small mirrors to the outer front surface of a dish and then point the dish at the Sun, you can easily find the focus point of the dish. Put the reflector of the patch or helix feed just beyond this point of focus.

An alternate method for finding a dish's focal length is suggested by W1GHZ (ex-N1BWT), who provides a computer program called *HDL_ANT*, available at **www.w1ghz.org/10g/10g_home.htm**. The method literally measures a solid-surface dish by the dimensions of the bowl of water that it will form when properly positioned. (See **www.w1ghz.org/antbook/chap5.pdf**.) KD1K used this method on the dish of Figure 17.31, carefully leveling the bowl, plugging bolt holes, and filling it with water to measure the data needed by the W1GHZ calculation.

17.4.2 DISH ANTENNA CONSTRUCTION

There are three parts to the dish antenna — the parabolic reflector, the boom and the feed. There are as many ways to construct this as there are builders so this is an excellent opportunity for experimentation and adaptation of existing designs.

As an example, **Figure 17.32** is a detail drawing of TJ Moss, G3RUH's S-band dish antenna. (See the Bibliography for the complete article.) You need not slavishly replicate every nuance of the design. The only critical dimensions occur in the feed system. After construction, you will have a 60-cm diameter S-band RHCP dish antenna with a gain of about 20 dBi and a 3-dB beamwidth of 18°. Coupled with the proper downconverter, performance will be more than adequate for S-band downlink reception.

The parabolic reflector used for the original antenna was intended to be a lampshade. Several of these aluminum reflectors were located in department store surplus. The dish is 585 mm in diameter and 110 mm deep, corresponding to an f/D ratio of 585/110/16 = 0.33 and a focal length of 0.33 × 585 = 194 mm. The f/D of 0.33 is a bit too concave for a simple feed to give optimal performance but the price was right, and the under-illumination keeps ground noise pickup to a minimum. The reflector already had a 40-mm hole in the center with three 4-mm holes around it in a 25-mm radius circle.

A small helix is used for the S-band antenna feed as shown in **Figure 17.33**. The reflector for the helix is made from a 125-mm square piece of 1.6-mm thick aluminum. The center of the reflector has a 13-mm hole to accommodate the square center boom described above. The type-N connector is mounted to the reflector about 21.25 mm from the middle. This distance from the middle is, of course, the radius of a helical antenna for S-band. Mount the N connector with spacers so that the back of the connector is flush with the reflector surface.

Surfacing Materials

The choice of surface materials is a compromise between RF reflecting properties and wind loading. Aluminum screening, with its very fine mesh (and weight of 4.3 pounds per 100 square feet) is useful beyond 10 GHz because of its very close spacing. This screening is easy to roll up and is

Build a Dish Kit

You can also build a dish antenna from a kit, available in 1.2-meter and 1.8-meter diameters. One ingenious design by KG6IAL is available from **www.teksharp.com**. Figure 17.43 shows one of KG6IAL's cleverly designed 1.2-meter dishes with an f/D of 0.30 as constructed by KD1K. The 1.2-meter dish is fed with a dual-band patch feed for L and S bands. The 1.8-meter dish is designed for up to three bands using a tri-band patch feed for the U, L and S bands. This dish will permit U-band operation. A Central States VHF Society (**www.csvhfs.org**) measurement on a similarly sized dish (by WØLMD) with a patch feed showed a gain of about 17.1 dBic (actual measurement was 12.0 dBd linearly fed). This performance along with a small V-band (145 MHz) Yagi would permit a very modest satellite antenna assembly for all of the VHF/UHF LEO and HEO satellites.

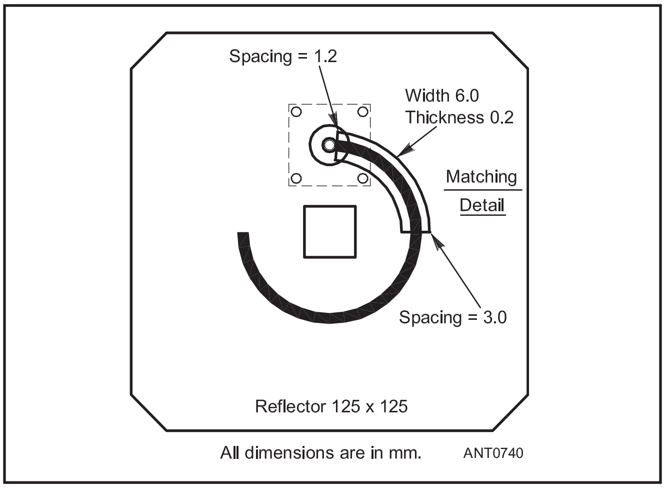


Figure 17.33 — Details of helix feed for S-band dish antennas. The type-N connector is fixed with three screws and is mounted on a 1.6-mm spacer to bring the Teflon molding flush with the reflector. An easier mounting can be using a smaller TNC connector. Reflectors should be 95 to 100 mm in diameter.

Using Surplus Grill Dishes

While many of us enjoy building our own antennas, surplus-market availability of these small dish antennas makes their construction unproductive. Many HEO operators have followed the practices of earlier operators using a surplus MMDS linear-screen parabolic reflector antenna as in Figure 17.45 and Figure 17.46. These grid-dish antennas are often called *barbeque-grill dishes*. K5OE and K5GNA have shown how to greatly improve these linearly polarized reflectors by adapting them for the CP service desired (see **wb5rmg.somenet.net/k5oe**). Simple methods can be used to circularize a linear dish and to further add to its gain using simple methods to increase the dish area and feed efficiency.

therefore ideal for a portable dish. This close spacing causes the screen to be a 34% filled aperture, bringing the wind force at 60 mph to more than 400 *pounds* on this 12-foot dish. Those considering a permanent installation of this dish should investigate other surfacing materials.

Mesh surfaces are attractive at frequencies up to at least 5 GHz, because of their light weight and lower wind resistance. Openings in the mesh can be as large as 0.05 λ without allowing much ground noise to feed through the surface.

Hexagonal 1-inch poultry netting (chicken wire), which is an 8% filled aperture, is nearly ideal for 432-MHz operation. It weighs 10 pounds per 100 square feet, and exhibits only 81 pounds of force with 60 mph winds. Measurement on a large piece reveals 6 dB of feedthrough at 1296 MHz, however. Therefore, on 1296 MHz, one fourth of the power will feed through the surface material. This will cause a loss of only 1.3 dB of forward gain. Since the low-wind loading material will provide a 30-dBi gain potential, it is still a very good tradeoff.

Poultry netting is very poor material for 2300 MHz and above, because the hole dimensions approach ½ λ. As with all surfacing materials, minimum feedthrough occurs when the E-field polarization is parallel to the longest dimension of the surfacing holes.

Hardware cloth with ½-inch mesh weighs 20 pounds per 100 square feet and has a wind loading characteristic of 162 pounds with 60 mph winds. The filled aperture is 16%, and this material is useful to 2300 MHz.

There are some general considerations to be made in selecting surface materials:

1) Joints of screening do not have to make electrical contact. The horizontal wires reflect the horizontal wave. Skew polarizations are merely a combination of horizontal and vertical components which are thus reflected by the corresponding wires of the screening. To a horizontally polarized wave, the spacing and diameter of only the horizontal wires determine the reflection coefficient (see **Figure 17.34**). Many amateurs have the mistaken impression that screening materials that do not make electrical contact at their junctions are poor reflectors.

2) By measuring wire diameter and spacings between the wires, a calculation of percentage of aperture that is filled can be made. This will be one of the major determining factors of wind pressure when the surfacing material is dry.

Effects of Surface Errors

How accurate must a parabolic surface be? This is a frequently asked question. According to the Rayleigh limit for telescopes, little gain increase is realized by making the mirror accuracy greater than ±⅛ λ peak error. John Ruze of the MIT Lincoln Laboratory, among others, has derived an equation for parabolic antennas and built models to verify it. The tests show that the tolerance loss can be predicted within a fraction of a decibel, and less than 1 dB of gain is sacrificed with a surface error of ±⅛ λ. (⅛ λ is 3.4 inches at 432 MHz, 1.1 inches at 1296 MHz and 0.64 inch at 2300 MHz.)

Some confusion about requirements of greater than ⅛-λ

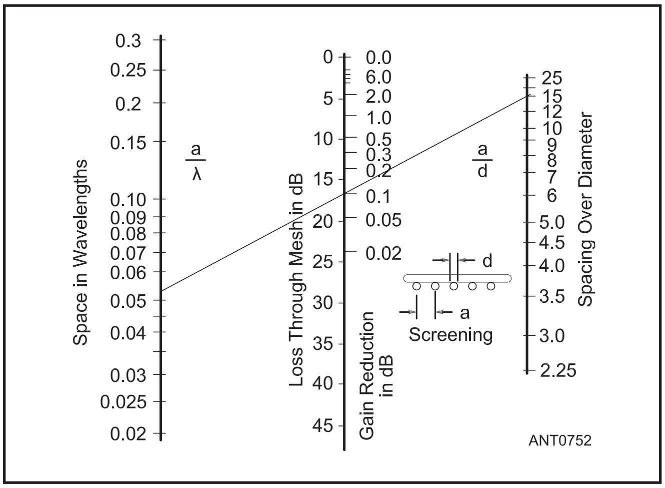


Figure 17.34 — Surfacing material quality.

accuracy may be the result of technical literature describing highly accurate surfaces. Low sidelobe levels are the primary interest in such designs. Forward gain is a much greater concern than low sidelobe levels in amateur work; therefore, these stringent requirements do not apply.

When a template is held up against a surface, positive and negative (±) peak errors can be measured. The graphs of dish accuracy requirements are frequently plotted in terms of RMS error, which is a mathematically derived function much smaller than ± peak error (typically ⅓). These small RMS accuracy requirements have discouraged many builders who confuse them with ± peak errors.

Figure 17.35 may be used to predict the resultant gain of various dish sizes with typical errors. There are a couple of surprises, as shown in **Figure 17.36**. As the frequency is increased for a given dish, the gain increases 6 dB per octave until the tolerance errors become significant. Gain deterioration then increases rapidly. Maximum gain is realized at the frequency where the tolerance loss is 4.3 dB. Notice that at 2304 MHz, a 24-foot dish with ±2-inch peak errors has the same gain as a 6-foot dish with ±1-inch peak errors. This is quite startling, when it is realized that a 24-foot dish has 16 times the area of a 6-foot dish. Each time the diameter or frequency is doubled or halved, the gain changes by 6 dB. Each time all the errors are halved, the frequency of maximum gain is doubled. With this information, the gain of other dish sizes with other tolerances can be predicted.

These curves are adequate for predicting gain, assuming a high-efficiency feed horn is used (as described earlier), which realizes 60% aperture efficiency. At frequencies below 1296 MHz where the horn is large and causes considerable blockage, the curves are somewhat optimistic. A properly

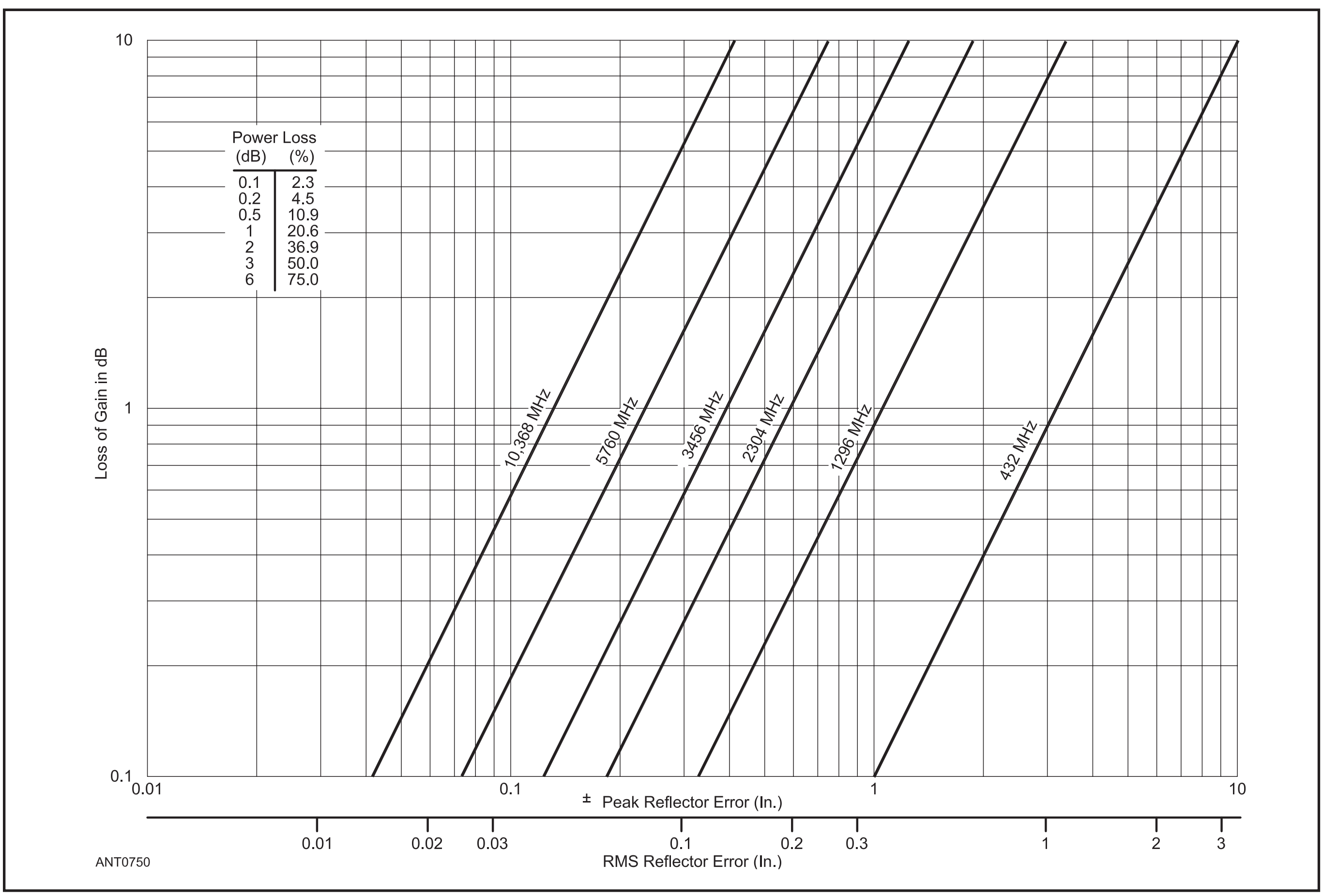


Figure 17.35 — Gain deterioration versus reflector error. By Richard Knadle, K2RIW.

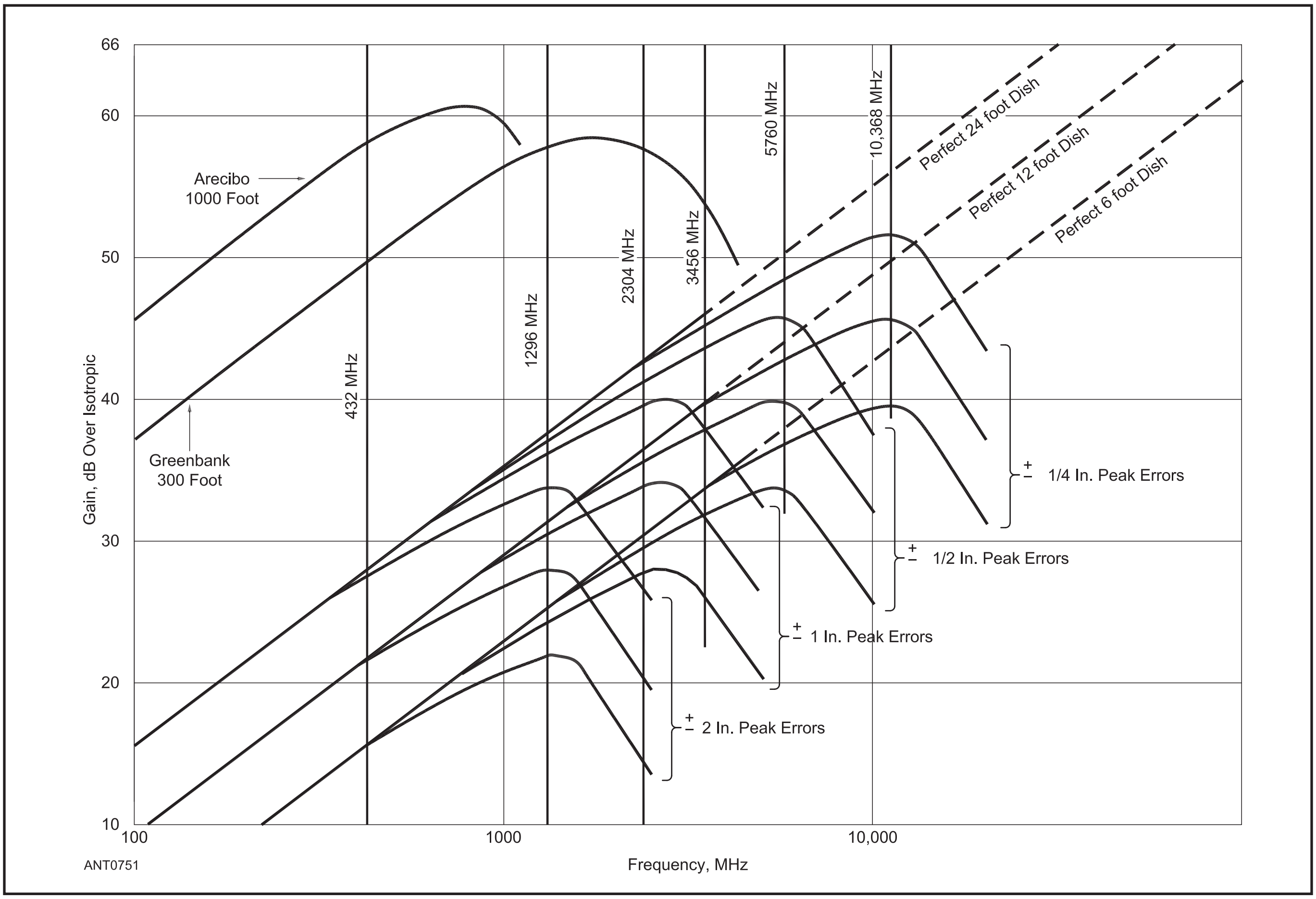


Figure 17.36 — Parabolic-antenna gain versus size, frequency and surface errors. All curves assume 60% aperture efficiency and 10-dB power taper. Graph by K2RIW for amateur bands, using display technique of J. Ruze, British IEE.

built dipole and "splashplate" feed (a round disc reflector) will have about 1.5 dB less gain when used with a 0.6 f/D dish than the dual-mode feed system described.

The worst kind of surface distortion is where the surface curve in the radial direction is not parabolic but gradually departs in a smooth manner from a perfect parabola. The decrease in gain can be severe, because a large area is involved. If the surface is checked with a template, and if reasonable construction techniques are employed, deviations are controlled and the curves represent an upper limit to the gain that can be realized.

If a 24-foot dish with ±2-inch peak errors is being used with 432 and 1296-MHz multiple feed horns, the constructor might be discouraged from trying a 2300-MHz feed because there is 15 dB of gain degradation. The dish will still have 29 dBi of gain on 2300 MHz, however, making it worthy of consideration.

The near-field range of a 12-foot stressed dish is 703 feet at 2300 MHz. By using the Sun as a noise source and observing receiver noise power, it was found that the antenna had two main lobes about 4° apart. The template showed a surface error (insufficient spoke bending at ¾ radius), and a correction was made. A re-check showed one main lobe, and the solar noise was almost 3 dB stronger.

SHF EME Challenges for Dishes

The challenges met when successfully building a station for EME at 900 MHz to 5.7 GHz only become more significant on the SHF bands at 10 GHz and above. Absolute attention to detail is the primary requirement, and this extends to every aspect of the EME antenna system. The dish surface is probably the most difficult problem to solve. As was discussed earlier, shape and accuracy of the reflector contribute directly to the overall gain of the antenna.

But where slight errors in construction can be tolerated at the lower frequencies, the same cannot be said at millimeter wavelengths. Those who have attempted EME on 10 and 24 GHz have discovered that the weight of the dish reflector itself will distort its shape enough to lower the gain to the point where echoes are degraded. Stiffening structures at the back of such dishes are often found necessary.

Pointing accuracy is also paramount. A 16-foot dish at 10 GHz has a beamwidth about equal to the diameter of the Moon — 0.5°. This means that the echo degradation due to the Moon's movement away from where the dish is pointed is almost immediate, and autotracking systems become more of a necessity than a luxury. At these frequencies, most amateurs actually peak their antennas on Moon noise — the black-body radiation from the Moon that becomes the dominant source of noise in space.

At these frequencies, the elevation of the Moon above the horizon also plays a role in the ability to communicate since tropospheric absorption due to water vapor is greatest at low elevation angles (the signal must pass through a greater portion of the troposphere than when the Moon is highly elevated). It is beyond the abilities of most amateurs to construct their own dishes for these frequencies, so surplus dishes for Ku-band (12 GHz) satellite TV (typically 3 meters in diameter) are usually employed, as are high-performance dishes designed for millimeter-wave radar and point-to-point communications at 23 and 38 GHz.

17.4.3 DISH FEEDS

Dr Robert Suding, WØLMD, has described the two major factors of feeding a dish that determine the efficiency: the feed source should evenly illuminate the entire dish and none of the feed energy should spill over outside the dish's reflecting surface. No feed system is perfect in illuminating a dish. Losses affect the gain from either under-illuminating or over-illuminating the dish (spillover losses). Typical dish efficiency is 50%. That's 3 dB of lost gain. A great feed system for one dish can be a real lemon on another. A patch feed system is very wide angle, but a helix feed system is narrow angle.

WØLMD has also experimented with helical feeds for low f/D antennas ("deep" dishes) and has shown that circularly polarized (CP) patch antennas are the preferred feed system. When used with high f/D offset-fed dishes, a patch-type feed system will result in a considerable spillover, or over-illumination loss, with an increased sensitivity to off-axis QRM, due to the f/D of this dish. Offset-fed dishes do much better when fed with a helix antenna, as shown in **Figure 17.37**.

A Helix Feed for an Offset-Dish Antenna

This section describes KD1K's surplus PrimeStar offset-fed dish antenna with a 7-turn helical feed antenna shown in Figure 17.31. This S-band antenna can receive Sun noise

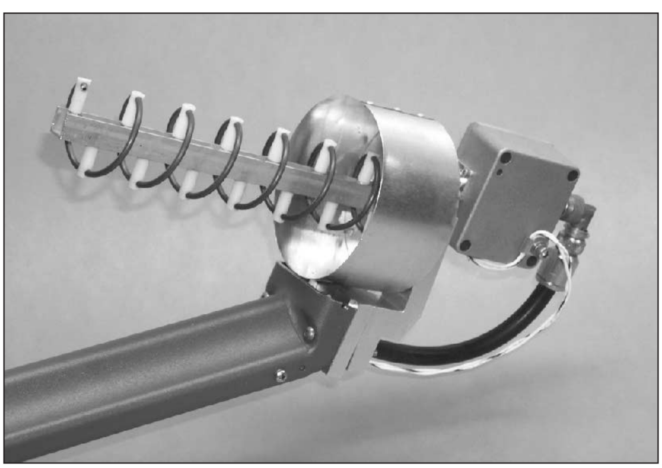


Figure 17.37 — A seven-turn LHCP S-band dish feed for a long f/D offset dish antenna. This helical antenna uses a cupped reflector and has a preamplifier mounted directly to the antenna feed point. (KD1K photo)

5 dB above sky noise. (Don't try to receive Sun noise with the antenna looking near the horizon, since terrestrial noise will likely be greater than 5 dB in most urban and suburban environments.)

The dish's reflector is a bit out of the ordinary, with the shape of a horizontal ellipse. It is still a single paraboloid, illuminated with an unusual feed horn. At 2401 MHz (S band) we can choose to under-illuminate the sides of the dish while properly feeding the central section, or over-illuminate the center while properly feeding the sides. KD1K chose to under-illuminate. The W1GHZ water-bowl measurements showed this to be a dish with a focal point of 500.6 mm and requiring a feed for an f/D = 0.79. The total illumination angle of the feed is 69.8°. At 50% efficiency this antenna was calculated to provide a gain of 21.9 dBi. A 7-turn helical feed antenna was estimated to provide the needed characteristics for this dish and is shown in Figure 17.33.

The helix is basically constructed as described previously for the G3RUH parabolic dish. A matching section for the first ¼ turn of the helix is spaced from the reflector at 2 mm at the start and 8 mm at the end of that fractional turn. Modifications of the G3RUH design include the addition of a cup reflector, a design feature used by the originator of the helical antenna, John Kraus, W8JK (SK). For the reflector, a 2-mm thick circular plate is cut for a 94 mm (0.75 λ) diameter with a thin aluminum sheet metal cup, formed with a depth of 47 mm. Employment of the cup enhances the performance of the reflector for a dish feed, as shown by K5OE. (See the K5OE material on the CD-ROM accompanying this book.)

The important information for this 7-turn helical antenna is:

- Boom: 12.7-mm square tube or "C" channel.
- Element: ⅛-inch diameter copper wire or tubing.

Close wind the element on a circular 1.50-inch tube or rod; the finished winding is 40 mm in diameter and spaced to a helical angle of 12.3°, or 28 mm spacing. These dimensions work out for an element circumference of 1.0 λ about the center of the wire.

KD1K chose to use PTFE (Teflon) support posts every ½ turn. This closer spacing of posts permitted a careful control of the helix-winding diameter and spacing and also made the antenna very robust. He set up a fixture on the drill press to uniformly pre-drill the holes for the element spacers and boom. Attachment of the reflector is through three very small aluminum angle brackets on the element side of the boom.

The W1GHZ data for this focal point is 500.6 mm from the bottom edge of the dish and 744.4 mm from the top edge. A two-string measurement of this point can confirm the focal point, as shown by W1GHZ in his writings. When mounting this feed antenna the builder must be cautious to aim the feed at the beam-center of the dish. Taking the illumination angle information noted above, the helical feed antenna should be aimed 5.5° down from the geometric center of the dish.

As illustrated in Figure 17.37, a preamp was directly mounted to the feed helix, using a TNC female connector on the helix, chosen for this case since N connectors are quite large for this antenna. A male chassis connector should be mounted on the preamp so that the preamp can be directly connected to the antenna without any adaptors.

Exposed connectors must be protected from precipitation. KD1K chose to make a rain cover instead from a 2-liter soft-drink bottle. (See **Figure 17.38**) Cutting off the top of the bottle allows it to be slid over the helix reflector cup and secured with a large hose clamp. You must provide UV protection for the plastic bottle and that was done with a wrapping of aluminum foil pressure-sensitive adhesive tape.

Patch Feeds for Dish Antennas

Feeds made from patch antennas are almost as simple as helix feeds. (See the V**HF and UHF Antenna Systems** chapter for a discussion of patch and Vivaldi antennas.) A patch can be practically summarized as building a shape that resonates at the desired frequency, compensated in size by the capacitive inductance between itself and the reflector. A patch can be practically any shape since it basically acts like a parallel-plate transmission line. Current in the patch flows from the feed point to the outer edge(s), where all the radiation occurs. (See the Bibliography for a tutorial on patch antennas provided by Orban Microwave.)

A patch antenna typically is constructed as an N connector on a flat reflector plate with a tuned flat-metal plate soldered to the center terminal. Sometimes the flat plate is square; sometimes it is rectangular; sometimes it is round. It could have two feed points, 90° out of phase for circular polarization. Some patches are rectangular with truncated corners to create a circular radiation pattern.

On 2401 MHz, the radiator plate is 57 mm square and spaced 3 mm away from the reflector. The RF feed point is about halfway between the center and the edge. A round patch for 2401 MHz is about 66 mm in diameter. These patches work well on the shorter focal length center-fed MMDS and TVRO dishes. (MMDS means Multichannel Multipoint Distribution Service, also known as wireless cable TV.)

WØLMD has done a considerable amount of experimenting with patch feeds for his larger TVRO dish antennas. One tri-band feed is shown in **Figure 17.39**. These are circular patches that have CP properties through the arrangement of the feed point and a small piston-variable capacitor that is offset from the feed point.

Some recent satellites have L-band (23-cm) receivers on 1268-1269 MHz. The reasons for using L band can be varied, but there is no arguing the benefits in reduced antenna size and AGC suppression. The types of L-band antennas are varied as well. Many use helices. Others use beams and arrays of beams. Still others use dishes, small and large.

K5OE has done a lot of experimenting with dishes in the range of 1.2 to 1.5 meters as to what feed schemes work for both S-band and L-band. This led him to experiment for months with different configurations, leading ultimately to a design with:

- Good performance on both S-band receive and L-band uplink.
- An easy-to-produce model using common hardware and simple hand tools.

Patch antennas turn out to be better than helices as dish feeds as illustrated by the radiation pattern for the G3RUH patch feed (see **www.jrmiller.demon.co.uk/products/patch.html**). When K5OE modeled that pattern and entered it into the W1GHZ feed pattern program, it produced an amazing 72% efficiency. The best helix he ever modeled has about 60% efficiency. I8CVS recently ran his own antenna range tests of a design similar to the G3RUH patch and produced a similarly impressive pattern.

The *truncated corners* square patch design popularized by K3TZ is attributed to 7N1JVW, JF6BCC and JG1IIK. There are references in the literature going back over a decade for this now-common commercial design. The first model K5OE built outperformed his best helix-in-cup design by a full S unit of signal-to-noise ratio. Compared to a helix, the patch simply has better illumination efficiency with less spillover from sidelobes.

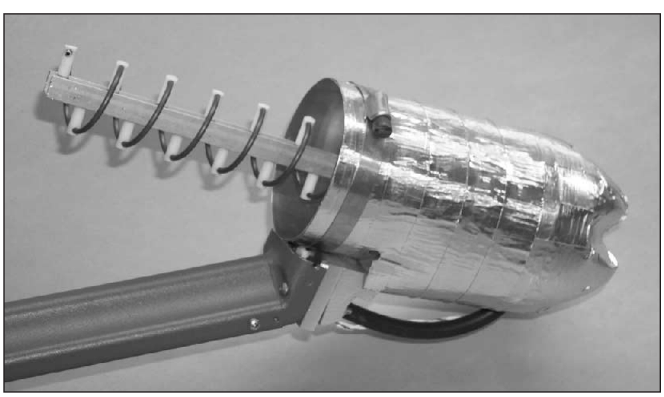


Figure 17.38 — Rain cover for preamp using a two-liter soft-drink bottle with aluminum foil tape for protection from Sun damage. (KD1K photo)

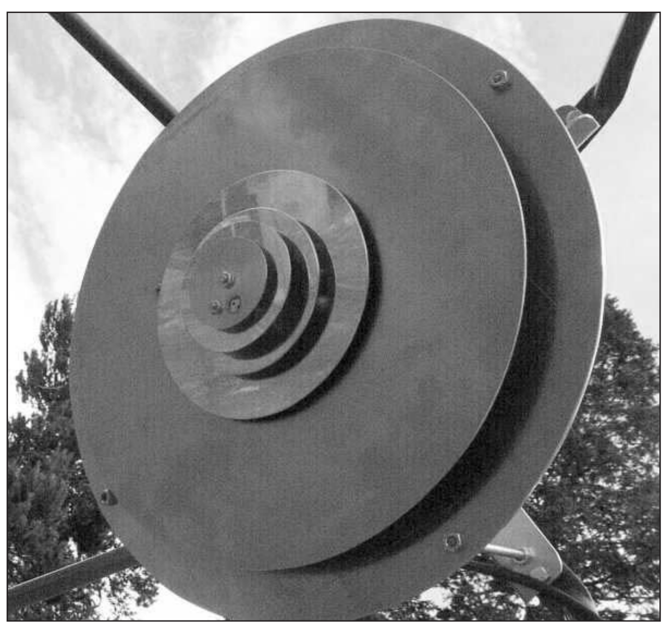


Figure 17.39 — A triband (U, L and S bands) patch-CP feed for large dish antennas for HEO service. (WØLMD photo)

The reputed, but often disputed, circularity of the truncated corner patch is accomplished by effectively designing two antennas into the patch element (of two different diagonal lengths) and feeding them 90° out of phase.

Figure 17.40 shows KD1K's version of K5OE's dual-band patch antenna while **Figure 17.41** shows the mounting of the K5GNA S-band converter and **Figure 17.42** shows the weatherproofing of the feed assembly.

One final design issue deals with the first harmonic of the L-band antenna. You must significantly reduce the potentially destructive effect from the 1269-MHz signal's second harmonic. Severe desense could result and potentially even overload and damage the first active device in your receive system. Sensitive preamps and downconverters without a pre-RF-amplifier filter will need an external filter. K5OE has used a G3WDG stub filter rated at 100-dB rejection with good success ahead of his preamp. His current setup, however, uses the K5GNA supplied AIDC-3731AA downconverter with its internal comb-line filter providing adequate filtering. Using the downconverter directly at the feed point has a noise figure (NF) of 1.0 dB, compared to the cumulative NF of 1.6 dB using a filter and a preamp.

Construction of the feed begins with selection of material for both the electrical parts (the antennas) and the mechanical parts (the support structure). The L-band antenna is constructed using a 6×6-inch double-sided circuit board for the reflector and a piece of 26-gauge copper sheet for the driven element (patch). A flanged female type-N connector is used for the feed connection. The S-band antenna is constructed of two pieces of 26-gauge copper sheeting and the feed connection is made with a short piece of UT-141 (0.141-inch copper-clad semi-rigid coax) terminated in a male SMA fitting. Figure 17.37 illustrates the assembly of the L-band reflector with the nylon-center support bolt, the L-band N connector, and the S-band semi-rigid coax terminated onto an SMA-to-N adapter through the circuit board. (See the Bibliography for more on patch feeds.)

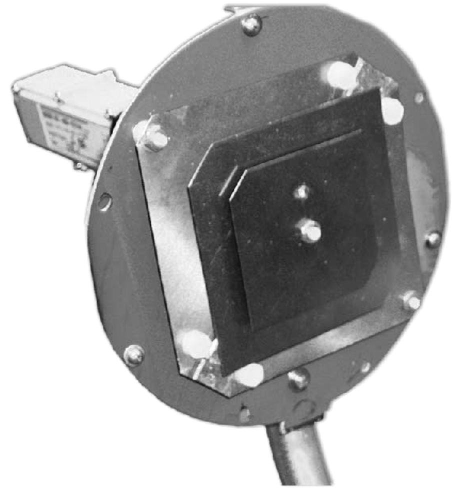


Figure 17.40 — Dual L-band and S-band patch feed assembly. (KD1K photo)

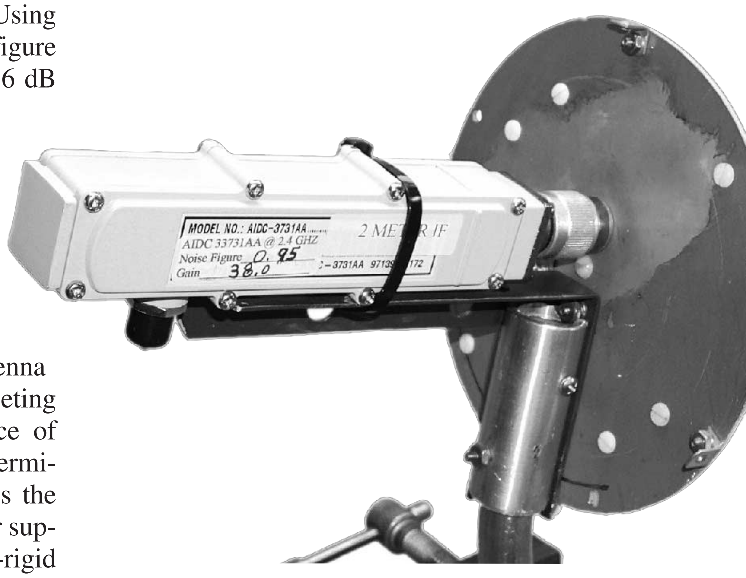


Figure 17.41 — The K5GNA S-band downconverter assembled to the rear of the patch feed assembly. The L-band connector is hidden in this view. (KD1K photo)

17.4.4 DISH ANTENNAS FOR SATELLITES

Dish antennas are not required for satellite operation except in the case of HEO satellites operating with microwave up or down-links. At lower frequencies, Yagi arrays are the more practical choice.

A 1.2-meter L-band dish antenna and 40 W of RF power (6100 W PEP EIRP with RHCP) can also provide a superb uplink for squint angles even up to 25°. A dish antenna can have a practical gain of about 21 to 22 dBic. These uplinks will provide the user a downlink that is 10 to 18 dB above the transponder noise floor. In more practical terms, these are S7 to 8 signals over an S3 transponder noise floor, making for very comfortable "armchair" copy.

KD1K shows in **Figure 17.43** what can be done with a 1.2 meter dish antenna kit for HEO operations. **Figure 17.44** shows a WØLMD 8-foot TVRO dish with patch feed, az/el mount, a U-band Yagi, and an L-band helical antenna.

Other hams have also taken advantage of surplus dishes.

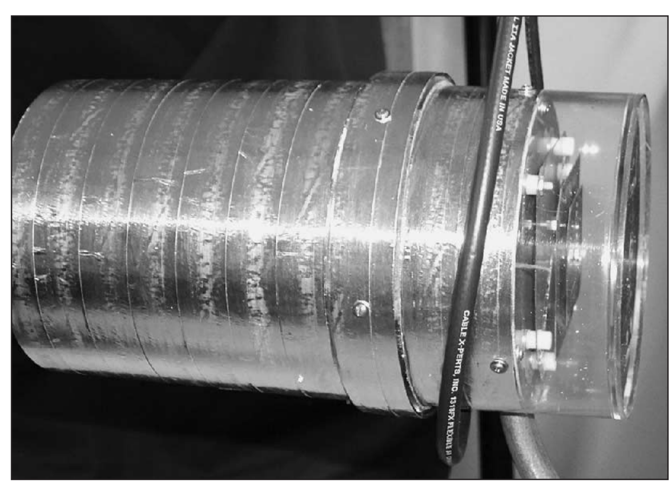


Figure 17.42 — The dual-band feed radome cover from the Martha Stewart Collection! (KD1K photo)

Figure 17.45 shows modified MMDS dishes, by K5GNA, and **Figure 17.46**, by K5OE, both using helix feeds.

One very popular spun-aluminum dish antenna in HEO use has been the G3RUH-ON6UG 60-cm unit with its S-band patch feed shown in **Figure 17.47**. With a gain of 21 dBic it provides a 2.5 dB Sun noise signal. Surplus dishes have not been the only source of antennas for HEO operations — even cardboard boxes lined with aluminum foil will work as shown in **Figure 17.48**! (This interesting antenna was the subject of the March 2003 *QST* article "Work OSCAR 40 with Cardboard-Box Antennas!" by AA2TX which is included on this book's CD-ROM.)

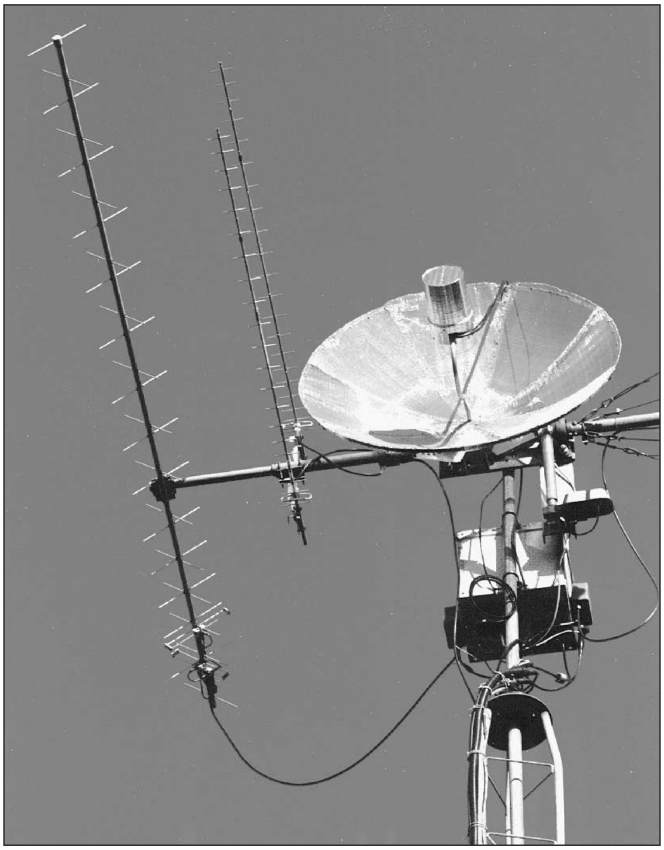


Figure 17.43 — KD1K's completed HEO antenna system mounted to the tower and ready to go. The 40 W, 23 cm amplifier is in the box below the KG6IAL 1.2 meter dish. (KD1K photo)

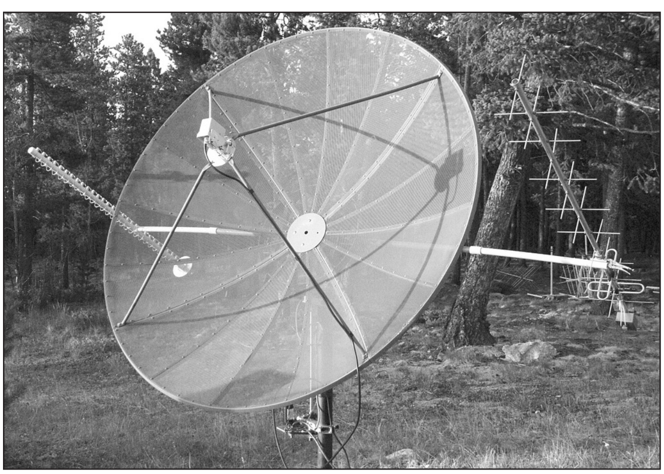


Figure 17.44 — WØLMD created this 8-foot dish with patch feed for S band for working HEO satellites. On the left is a helical antenna for L band and on the right is a 2 × 9-element offset-feed Yagi for U band. A homebrew az/el mount is provided. (WØLMD photo)

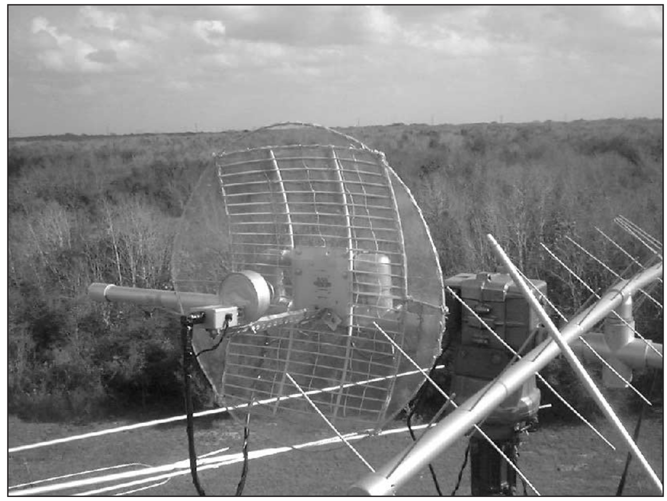


Figure 17.45 — K5GNA's "circularized" mesh modification of an MMDS dish antenna with a helix-CP feed and preamp. The dish modification reduces the spillover loss by making the antenna fully circular. (K5OE photo)

Figure 17.46 — Mesh modification of an MMDS dish antenna by K5OE, with a helix-CP feed and preamplifier by Down-East Microwave mounted directly to the helix feed point. (K5OE photo)

Figure 17.47 — G3RUH's 60-cm spun-aluminum dish with CP-patch feed is available as a kit. This antenna has been popular with HEO operators all over the world.

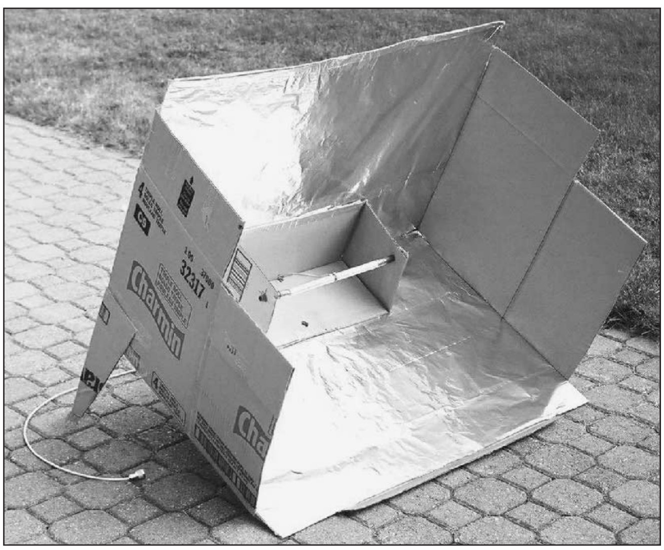


Figure 17.48 — The completed high-performance corner-reflector uplink antenna for U band. Note how the box corners hold the reflectors and dipole feed in place. The rear legs set the antenna elevation to 20° — this gives good coverage at the design latitude but will need modification for other stations.

17.4.5 C-BAND TVRO DISHES

Since the 1990s, there has been a significant change in the systems people use to watch satellite TV broadcasts. Formerly, C band satellite receivers were used, along with parabolic dish antennas in the 3- to 5-meter diameter range. Now, Ku-band (12 GHz) receivers are the norm, with their associated small (usually 18-inch) dish antennas. This has provided a large body of surplus C-band dishes, which can be used for EME — certainly on the bands at 33 cm and above, and for the larger dishes (5 meters), even at 70 cm. Many times, these dishes and their mounts can be had for the asking so they truly become an inexpensive way to build a multiband EME antenna.

As an example of how these dishes can be converted to amateur use, the following sections summarize an article first presented by David Hallidy, K2DH (ex-KD5RO) in the *ARRL UHF/Microwave Projects Manual* describing the use of a 3-meter (10-foot) TVRO antenna for EME. Additional photos of other TVRO dish installations are available on this book's CD-ROM.

Background

Calculations show that a 3-meter dish will have about 30 dBi gain at 1296 MHz. With a state-of-the-art LNA (Low-Noise Amplifier or preamp) at the feed, an efficient feed horn illuminating the dish surface, and 200 W at 1296 MHz, lunar echoes should be easily detected and many stations can be worked. The biggest challenges to such a system are assembling the dish to its mount and steering it to track the Moon. As much as possible, the KISS ("Keep It Simple, Stupid") principle was used to accomplish this task.

In 1987, WA5TNY, KD5RO, KA5JPD and W7CNK proved that such an EME system could work, even as high as 3.4 and 5.7 GHz, to provide the first EME contacts on those bands. An additional advantage to this (or any) small dish is its ability to be mounted to a trailer and taken out on EME expeditions. It can also be easily disassembled and stored, if necessary.

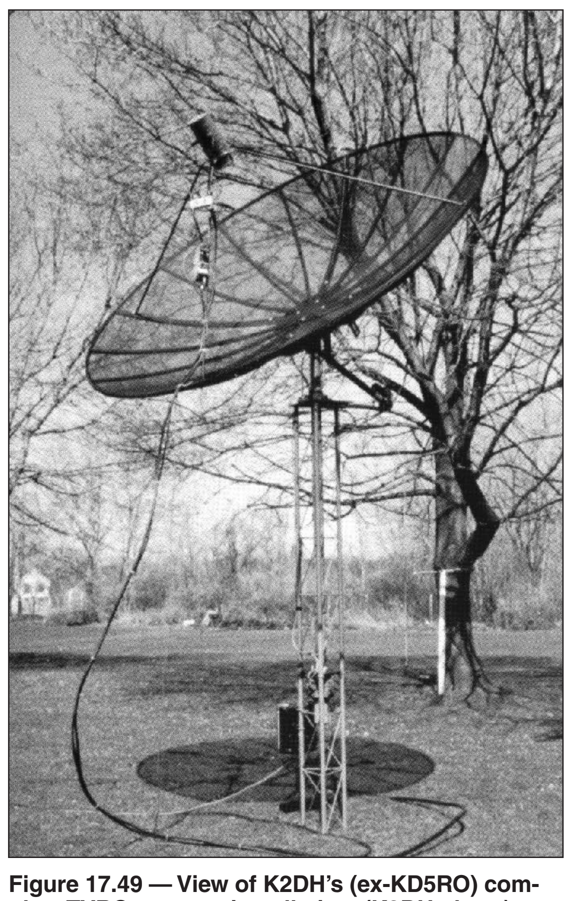


Figure 17.49 — View of K2DH's (ex-KD5RO) complete TVRO antenna installation. (K2DH photo)

As can be seen from **Figure 17.49**, the entire setup is very simple, using a standard amateur tower as the main support for the dish.

Azimuth Drive

In azimuth, direct drive of the main rotating shaft was selected, and a small prop-pitch motor was used. These motors, while not as plentiful as they were some years ago, still turn up with some regularity at flea markets for very little money. The beauty of the prop-pitch motor is that it turns slowly, is reversible, provides very high torque, and requires no braking system (the gear reduction, on the order of 4000:1, provides the necessary braking). Prop-pitch motors are dc motors, and were designed to vary the pitch of propeller blades of older large airplanes at start-up, take-off and landing. Thus, they can be run at different speeds merely by varying the dc voltage to the motor, and can be reversed by reversing the polarity of the dc voltage. By mounting a thrust bearing of the appropriate size at the top of the tower, and mounting the motor directly below it at the end of the rotating shaft that turns the antenna, a simple direct-drive system can be constructed.

The dc power supply and control relays are located in a weatherproof box on the side of the tower, next to the motor. This system requires only 9 V dc at about 5 A to adequately start, turn and stop the prop-pitch motor, and this voltage turns the antenna through 360° of rotation in about 2½ minutes.

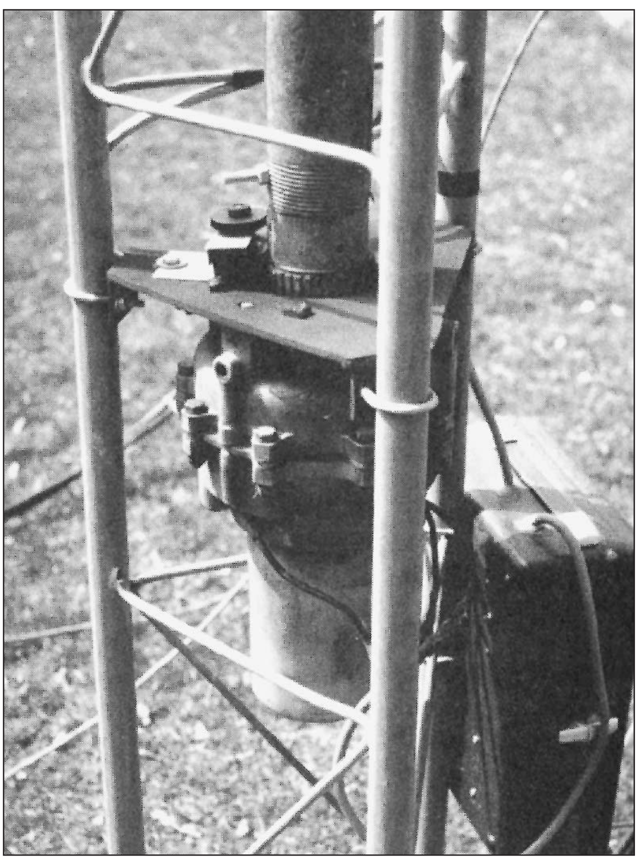


Figure 17.50 — Azimuth rotation systems, showing prop-pitch motor and position sensor.

Azimuth position sensing is also a simple task. See **Figure 17.50**. A linear multiturn potentiometer is driven by the rotating shaft, using a simple friction drive. A strip of rubber is attached to the rotating shaft and a wheel is connected to the shaft of the pot. The pot is then mounted so that it presses against the rubber strip, and as the shaft turns so does the pot. If a 10-turn pot is used, and the system is aligned such that the pot is at the center of its rotation when the antenna is pointed approximately south, the pot will not rotate past the end at either extreme of the antenna's rotation (clockwise/counter-clockwise north), and absolute alignment is a simple task of calibrating the change in resistance (change in voltage, when the pot is fed from a constant voltage source) with degrees of rotation (see the discussion on Position Display for details).

Elevation Drive

The elevation drive is also very simple. Most (nearly all) TVRO setups have a means of moving the dish across the sky to align it with various satellites. To do this, most companies use a device called a *linear actuator*. This is a dc motor to which is attached a long lead screw that pulls (or pushes) the outer shell of the actuator in or out to make it longer or shorter. The movable end of the actuator is attached to the dish and the motor end is fixed to the mount. The dish rests on pivots, which allow it to move as the actuator extends/retracts. To convert this type of mount (called a *polar mount*) to an az/el mount is usually very simple.

Figure 17.51 shows how this can be done. Simply breaking the welds that held the mount in a polar fashion allows the mount to be turned on its side and used to pivot the dish vertically with the linear actuator. Another feature of linear actuators is that they also have some means of feeding their relative position to the satellite receiver. This is usually just a multiturn potentiometer geared to the lead screw. All we have to do is connect this pot to a readout system, and we can calibrate the lift of the actuator in degrees. We thus have a simple means of rotating the dish and elevating it — but how do we know that it's pointed at the Moon?

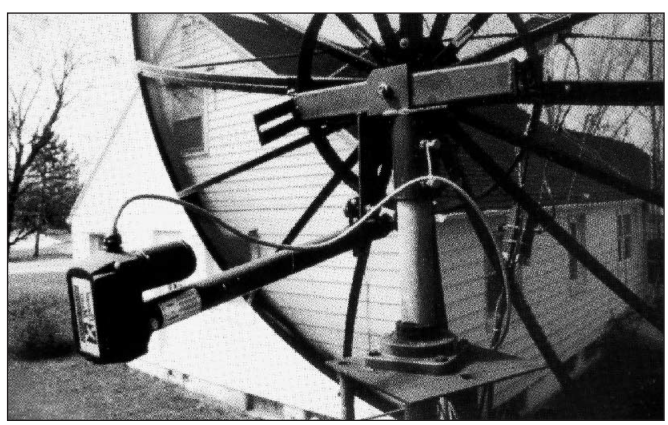


Figure 17.51 — Elevation system, showing modified TVRO mount.

Position Display

Displaying the position of the antenna, in both azimuth and elevation is also a relatively simple task. On the surplus market there are available digital voltmeters (DVMs) using LED or LCD displays that can do this job nicely, and that have more precision than is probably necessary for a dish (or Yagi array) of small size. As mentioned earlier, a multiturn potentiometer on the elevation-drive mechanism can be used to readout elevation, and the same technique can be used for azimuth readout — a potentiometer coupled to the main rotating shaft that turns the antenna.

When using a pot for readout, the most important thing to know is how many degrees of antenna position change occur (in azimuth or elevation) for each turn of the pot. This then can be used to calibrate a voltmeter to read volts directly as degrees — for example, 3.60 V could correspond to 360° azimuth (Clockwise North), and 9.0 V could correspond to 90° elevation (straight up).

A resistance bridge circuit is best used in this application, since it is less sensitive to changes in the supply voltage. The only thing to be careful about is that the DVM must have both the positive (high) and negative (low) inputs isolated from ground (assuming the power supply used to power the DVM is grounded). You could also use a pair of small, inexpensive digital multimeters (DMMs). Because they are battery powered, the isolation issue just discussed is eliminated.

Figure 17.52 is a complete schematic of the azimuth, elevation and readout electronics for this antenna-drive system. Also note that while this discussion is geared toward the

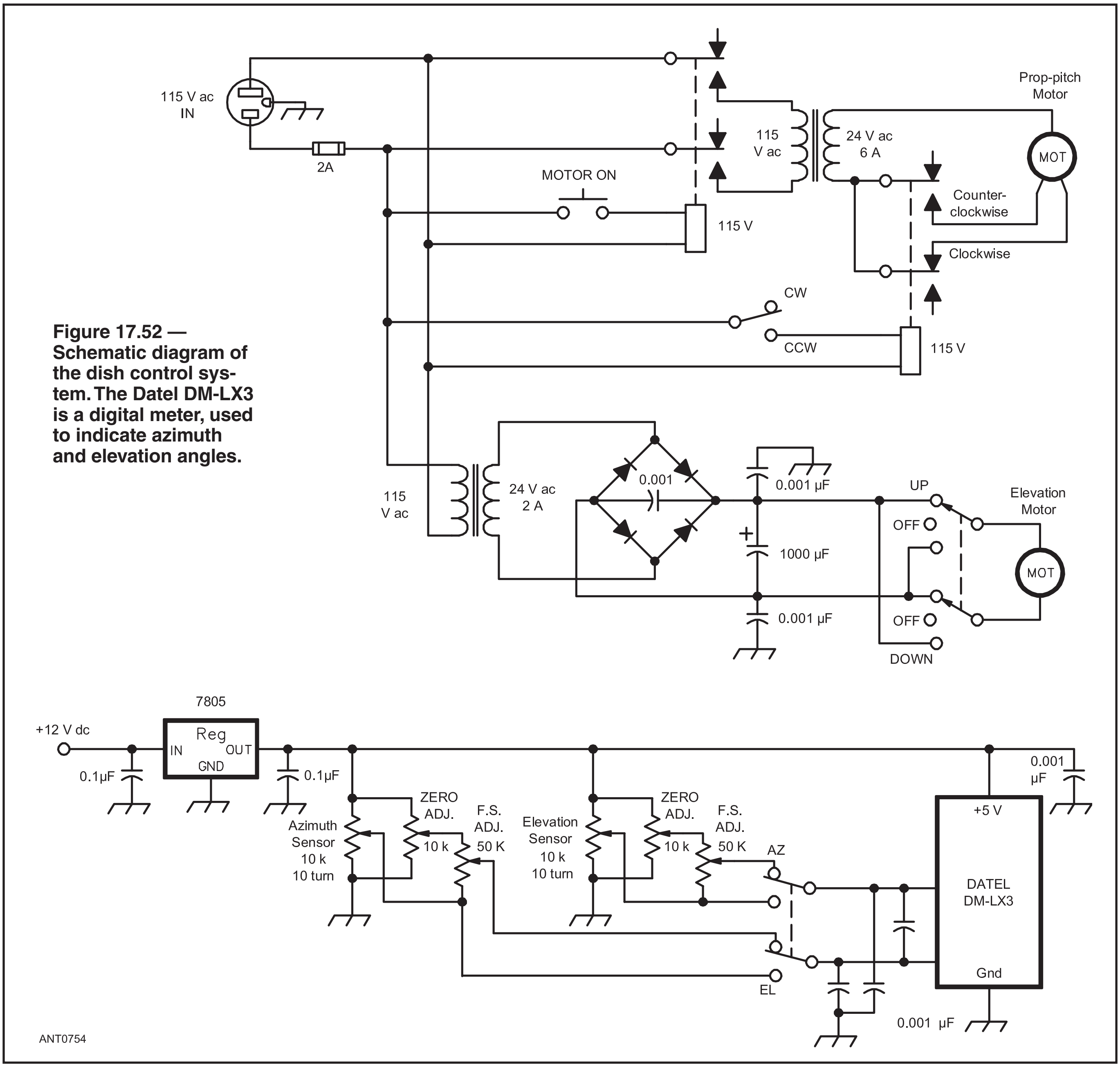


Figure 17.52 — Schematic diagram of the dish control system. The Datel DM-LX3 is a digital meter, used to indicate azimuth and elevation angles.

use of a small dish, the same positioning and readout systems could be used in a Yagi array for 2 meters or 70 cm.

Now that we know where the dish is pointed, how do we know where the Moon is? There are several software programs available to the Amateur for tracking celestial bodies such as the Moon, the Sun, certain stars (usable as noise sources), and even amateur satellites. Programs by W2MRO (ex W9IP), VK3UM, F1EHN and others can be obtained very reasonably and these work well to provide highly accurate position information for tracking.

Feeding the Surplus TVRO Dish

An area that needs particular attention when attempting EME with a small dish is an efficient feed system. An efficient feed system can be a real challenge with TVRO dishes, because many are "deep" — that is, their f/D (focal length to diameter ratio) is small.

The satellite TV industry used deep dishes because they tend to be quieter, picking up less Earth noise due to spillover effects. A deep dish has a short focal length, and therefore, the feed is relatively close to the surface of the dish. To properly illuminate the reflector out to its edges, a feed horn of relatively wide beamwidth must be used. The feeds designed several years ago by Barry Malowanchuk, VE4MA, are intended for use with just such dishes, and have the advantage of being adjustable to optimize their pattern to the dish in use.

The feed that was used with this dish was modeled after VE4MA's 1296-MHz feed, and a version was even scaled for use at 2304 MHz that worked as well as the original. See **Figure 17.53** and the Bibliography at the end of this chapter. (Also see the earlier section of this chapter describing patch feeds for dishes.)

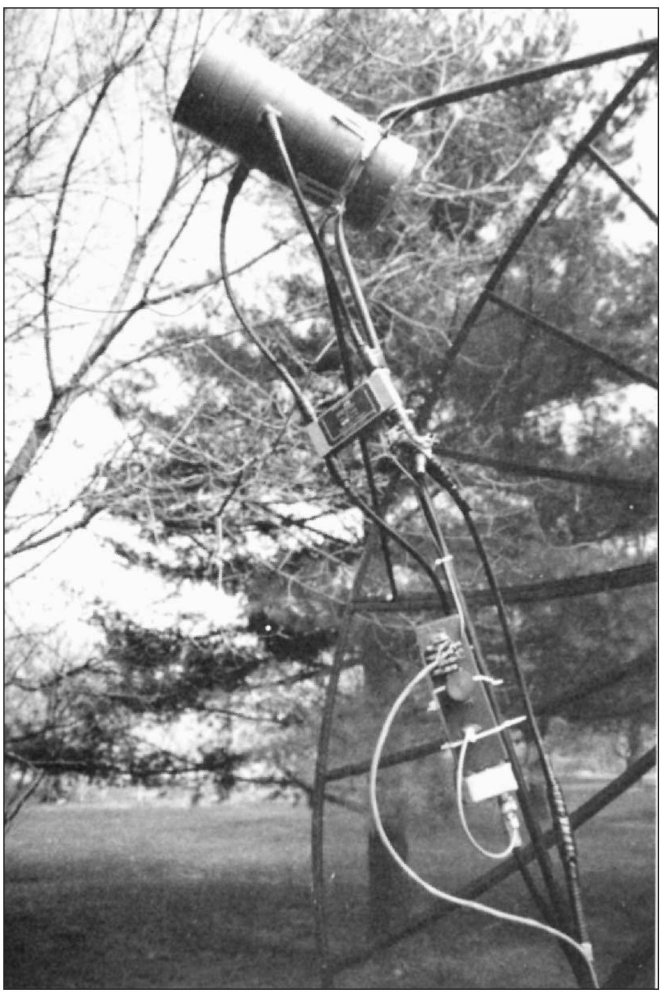


Figure 17.53 — View of feed, showing coffee-can feed horn and hybrid coupler.

17.4.6 A 12-FOOT STRESSED PARABOLIC DISH

This project was originally presented by Richard Knadle, K2RIW, in August 1972 *QST* and the full article, including parts and materials lists, and construction details is included on this book's CD-ROM.

Some amateurs reject parabolic antennas because of the belief that they are all heavy, hard-to-construct, have large wind-loading surfaces and require precise surface accuracy. However, with modern construction techniques, a prudent choice of materials and an understanding of accuracy requirements, these disadvantages can be largely overcome. A parabola may be constructed with a 0.6 f/D (focal length/diameter) ratio, producing a rather flat dish, which makes it easy to surface and allows the use of recent advances in high-efficiency feed horns. This results in greater gain for a given dish size over conventional designs.

Such an antenna is shown in **Figure 17.54**. This parabolic dish is lightweight, portable, easy to build, and can be used for 432 and 1296 MHz mountaintopping, as well as on 2304, 3456 and 5760 MHz. Disassembled, it fits into the

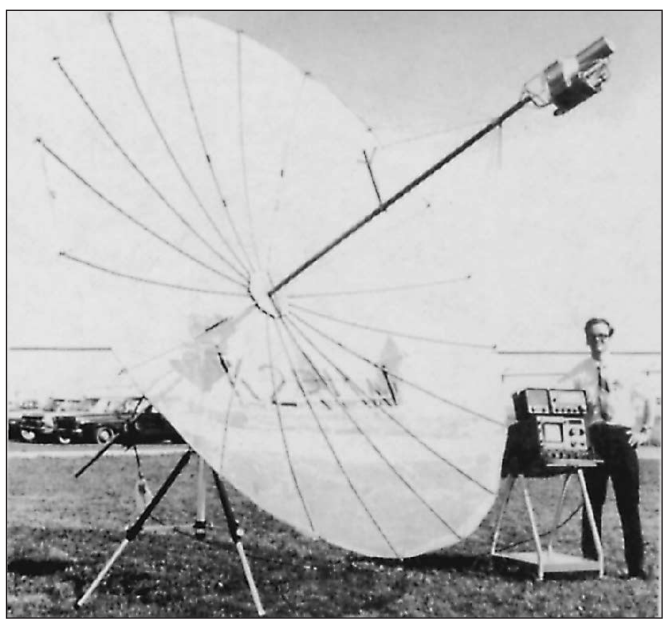


Figure 17.54 — A 12-foot stressed parabolic dish set up for satellite signal near 2280 MHz. A preamplifier is shown taped below the feed horn. The dish was designed by K2RIW, standing at the right. The complete *QST* construction article is available on this book's CD-ROM.

trunk of a car and can be assembled in 45 minutes.

The usually heavy structure that supports the surface of most parabolic dish antennas has been replaced in this design by aluminum spokes bent into a near parabolic shape by strings. These strings serve the triple function of guying the focal point, bending the spokes and reducing the error at the dish perimeter (as well as at the center) to nearly zero. By contrast, in conventional designs, the dish perimeter (which has a greater surface area than the center) is farthest from the supporting center hub. For these reasons, it often has the greatest error. This error becomes more severe when the wind blows.

Here, each of the spokes is basically a cantilevered beam with end loading. The equations of beam bending predict a near-perfect parabolic curve for extremely small deflections. Unfortunately the deflections in this dish are not that small and the loading is not perpendicular. For these reasons, mathematical prediction of the resultant curve is quite difficult. A much better solution is to measure the surface error with a template and make the necessary correction by bending each of the spokes to fit. This procedure is discussed later.

The uncorrected surface is accurate enough for 432 and 1296-MHz use. Trophies taken by this parabola in antenna-gain contests were won using a completely natural surface with no error correction. By placing the transmission line inside the central pipe that supports the feed horn, the area of the shadows or blockages on the reflector surface is much smaller than in other feeding and supporting systems, thus increasing gain. For 1296 MHz, a backfire feed horn may be constructed to take full advantage of this feature. At 432 MHz, a dipole and reflector assembly produces 1.5 dB additional gain over a corner-reflector feed system. Because the preamplifier is located right at the horn on 2300 MHz, a conventional feed horn may be used. The texts listed in the Bibliography have more information on horn antennas.

17.5 WEATHERPROOFING RELAYS AND PREAMPLIFIERS

For stations using crossed Yagi antennas for CP operation, one feature that has been quite helpful for communicating through most of the LEO satellites is the ability to switch polarization from RHCP to LHCP. In some satellite operation this switchable CP ability has been essential. For those using helical antennas or helical-fed dish antennas, we just would not have the choice to switch CP unless an entirely new antenna is added to the cluster for that purpose. Not many of us have the luxury of that kind of space available on our towers.

For stations with switchable-polarization Yagi antennas, experience with exposed switching relays and preamplifiers mounted on antennas have shown that they are prone to failure caused by a mechanism known as *diurnal pumping*. Often these relays are covered with a plastic case, and the seam between the case and PC board is sealed with a silicone sealant. Preamps may also have a gasket seal for the cover, while the connectors can easily leak air. None of these methods create a true hermetic seal and as a result the day/night temperature swings pump air and moisture in and out of the relay or preamp case. Under the right conditions of temperature and humidity, moisture from the air will condense inside the case when the outside air cools down. Condensed water builds up inside the case, promoting extensive corrosion and unwanted electrical conduction, seriously degrading component performance in a short time.

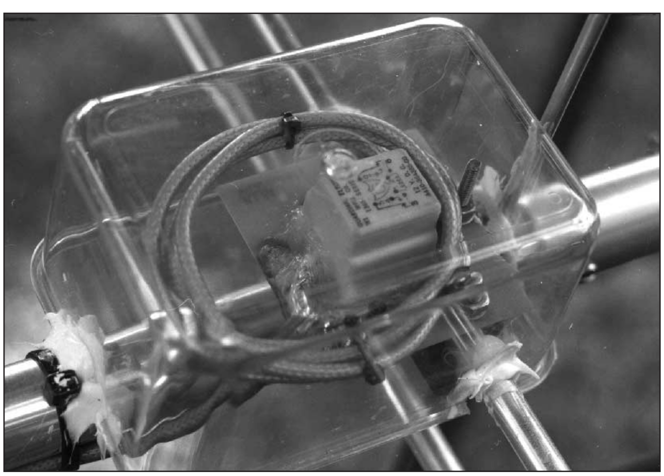


Figure 17.55 — KLM 2M-22C antenna CP switching relay with relocated balun. The protective cover is needed for rain protection, be sure to use a polystyrene kitchen box, see text. (KD1K photo)

A solution for those antennas with "sealed" plastic relays, such as the KLM CX series, is to avoid problems by making the modifications shown in **Figure 17.55**. Relocate the 4:1 balun as shown and place a clear polystyrene plastic refrigerator container over the relay. Notch the container edges for the driven element and the boom so the container will sit down over the relay, sheltering it from the elements. Bond the container in place with a few dabs of silicone adhesive sealant. (Be sure to use sealers that do not release acetic acid during curing — see the **Antenna Materials and Construction** chapter.) Position the antenna in an "X" orientation, so neither set of elements is parallel to the ground. The switcher board should now be canted at an angle, and one side of the relay case should be lower than the other. An example for the protective cover for an S-band preamp can be seen in the discussion on feeds for parabolic antennas.

For both the relay and preamp cases, carefully drill a $\frac{3}{32}$-inch hole through the low side of the case to provide the needed vent. The added cover keeps rainwater off the relay and preamp, and the holes will prevent any buildup of condensation inside the relay case. Relays and preamplifiers so treated have remained clean and operational over periods of years without problems.

Another example for the protection of remotely, tower-mounted equipment is shown in Figure 17.25, illustrating the equipment box and mast-mounted preamplifiers at the

Figure 17.56 — A NEMA 4 box is used to shelter the L-band electronics and power supply. The box flanges are convenient for mounting preamplifiers. The box is shown inverted since it is on a tilt-over tower. (KD1K photo)

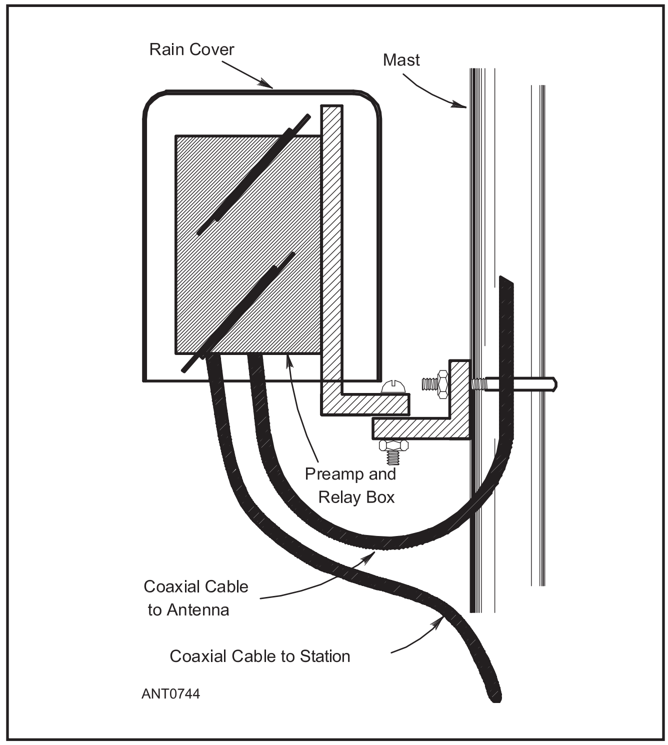


Figure 17.57 — Protection for tower-mounted equipment need not be elaborate. Be sure to dress the cables as shown so that water drips off the cable jacket before it reaches the enclosure. One hazard for such open-bottom enclosures is that of animals gnawing on the cable insulation. Flying insects also like to build their houses in these enclosures.

top of KD1K's tower. The commercial NEMA 4 equipment box, detailed in **Figure 17.56** (shown inverted), is used to protect the 23 cm power amplifier and its power supply, as well as a multitude of electrical connections. This steel box is very weather resistant, with an exceptionally good epoxy finish, but it is not sealed and so it will not trap moisture to be condensed with temperature changes. Be sure to use a box with at least a NEMA 3 rating for rainwater and dust protection. The NEMA 4 rating provides a little better protection than the NEMA 3 rating. Using a weather-rated equipment enclosure is very well worth the expense. As you can see, the box also provides some pretty good flanges to mount the mast-mounted preamplifiers for three bands. This box is an elegant solution for the simple need of rain shelter for your equipment. See **Figure 17.57**.

17.6 ANTENNA POSITION CONTROL

EME and satellite antennas have high gain and narrow main beams that must be properly aimed in two coordinates. Although polar mounts (one axis parallel to the Earth's axis) have sometimes been used, by far the most popular mounting scheme today is the elevation-over-azimuth or az/el mount. Readily available computer software can provide azimuth and elevation coordinates for the Moon, and a small computer can also control antenna positioning motors to automate the whole pointing system.

For mechanical reasons it is desirable to place the antenna's center of gravity close to the intersection of the vertical (azimuth) and horizontal (elevation) axes. On the other hand, the mounting structure must not interfere with critical active regions of the antenna. Stacked Yagis are generally mounted so that metallic supporting members are perpendicular to the radiating elements or located at midpoints where the effective apertures of separate Yagis meet. Feed lines and conducting support members must not lie in the active planes containing Yagi elements, unless they run wholly along the boom. For dual-polarization Yagis, feed lines should be routed toward the rear of each Yagi and any mid-boom support members must be nonconducting. For space communications there is nothing magical about using horizontal and vertical for the two orthogonal polarizations, and there are some advantages to mounting cross-Yagis with elements in the "X" rather than "+" orientation.

Parabolic dishes are usually mounted from behind, with counterweights extending rearward to relieve torque imbalance on the elevation axis. Jack-screw actuators designed for positioning TVRO dishes can be readily adapted for elevation control. Standard heavy-duty antenna rotators can be used for azimuth positioning of dishes up to about 3 meters in size. Larger dishes may require heavier, one-of-a-kind designs for pointing control.

17.6.1 POSITION CONTROLLERS

Operators through the years have employed many methods for the control of their antenna positions, ranging from true *arm-strong* manual positioning, to manual operation of the powered antenna azimuth and elevation rotators, to fully automated computer control of the rotators. While computer control of the rotators is not essential, operation is greatly eased with their use.

For many years, one of the key control units for rotators has been the *Kansas City Tracker* (KCT) board installed in your computer. This device is no longer available new but many are in use or available used. Information on the KCT is available from AMSAT (**www.amsat.org**).

A recent trend for amateur antenna control has been evolving in the form of a standalone controller that translates computer antenna-position information into controller commands with an understanding of antenna-position limits. AMSAT-NA has developed the LVB Tracker by G6LVB (**www.g6lvb.com**) shown in **Figure 17.58** that can be obtained in several different forms of kits or completely assembled from AMSAT. This tracker uses an internal PIC microcontroller that uses a 10-bit ADC encoder for rotator position feedback, resulting in sub-degree precision for both elevation and azimuth. Yaesu (**www.yaesu.com**) also sells the GS-232 computer control interface that can be used for tracking with their G-5500 az/el rotator system. AlfaSpid (**www.alfaradio.ca**) also manufactures an az/el rotator.

Other position readout and control options are available. For many years ham operators have employed synchros, or *selsyns*, for their position readouts. These are specialized transformers, using principles developed over sixty years ago and employed in such devices as surplus "radio compass" steering systems for aircraft. While the position readout of these devices can be quite precise, in general they only provide a visual position indication, one that is not easily adapted to computer control. I8CVS employs such a system at his station and he uses a weighted arm on the elevation synchro to provide a constant reference to the Earth's gravity vector.

The more up-to-date, computer-friendly position readout methods used these days are usually based on precision potentiometers or digital position encoders. **Figure 17.59** shows a variety of digital encoders employed by WØLMD. He notes that such systems, while providing a very high precision of angular position, they are not absolute systems and that once calibrated, they must be continually powered so they do not lose their calibration. Precision potentiometers, on the other hand, provide an absolute position reference, but with a precision that is limited to the quality of the potentiometer, typically 0.5% (0.45° in elevation and 1.80° in azimuth) to 1.0%. So the choices have their individual limits, unless a lot of money is spent for very precise commercial systems.

Figure 17.58 — AMSAT-NA LVB Tracker Box assembly.

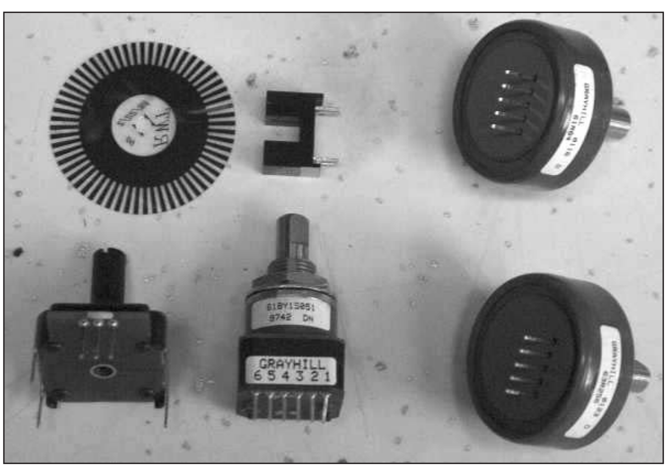


Figure 17.59 — WØLMD has experimented with highly precise optical encoders for his antenna position systems. See text. (WØLMD photo)

17.6.2 ELEVATION CONTROL

Satellite antennas need to have elevation control to point up to the sky. This is the "el" part of az/el control of satellite

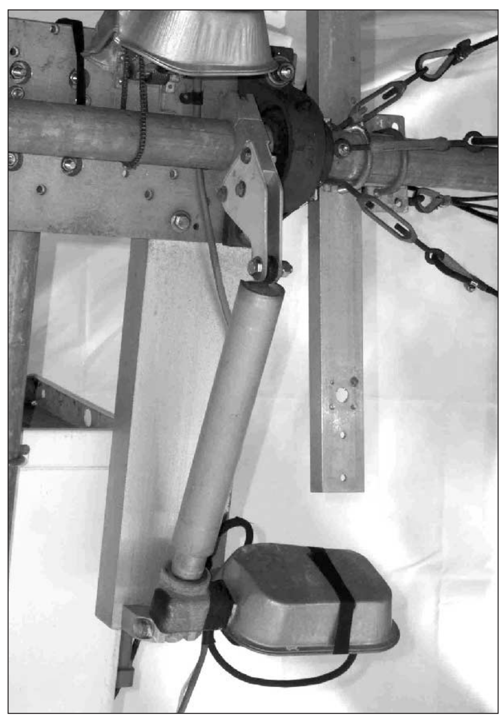


Figure 17.60 — KD1K's homebrew elevation rotator drive using a surplus-store drive screw mechanism. Note also the large journal bearing supporting the elevation axis pipe shaft. (KD1K photo)

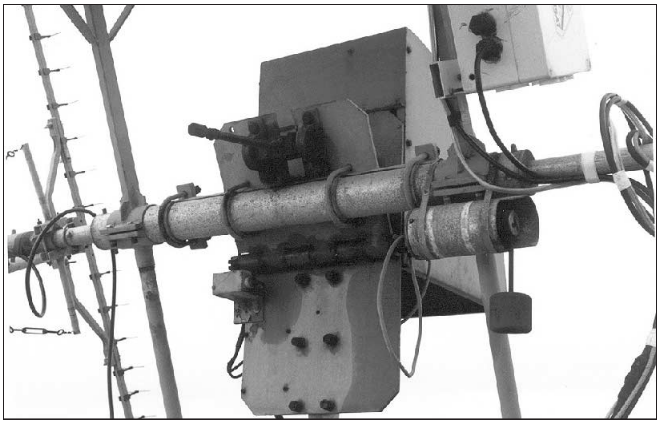


Figure 17.61 — I8CVS's homebrew elevation mechanism using a very large, industrial hinge as the pivot and a jackscrew drive. (I8CVS photo)

antennas. Generally, elevation booms for CP satellite antennas need to be nonconducting so that the boom does not affect the radiation pattern of the antenna. In the example shown next, the elevation boom center section is a piece of extra-heavy-wall 1½-inch pipe (for greater strength) with a tubular fiberglass-epoxy boom extension for the 70 cm antenna and a long home-brew extension for the 2 meter antenna. The boom uses large PVC pipe reinforced with four braces of Phillystran nonmetallic guy cable. (PVC pipe is notoriously flexible, but the Phillystran cables make a quite stiff and strong boom of the PVC pipe.) For smaller installations, a continuous piece of fiberglass-epoxy boom can be placed directly through the elevation rotator.

Elevation boom motion needs to be powered and one solution by KD1K, shown in **Figure 17.60**, uses a surplus jackscrew drive mechanism. I8CVS has also built his own robust elevation mechanism. (See **Figure 17.61.**) Note in each of these applications the methods used to provide bearings for the elevation mechanism. In KD1K's case, the elevation axis is a piece of heavy-duty 1½-inch pipe, ($1\frac{15}{16}$-inch OD) and large 2 inch journal bearings are used for the motion. I8CVS uses a very large hinge to allow his motion.

Robust commercial solutions for az/el rotators have given operators good service over the years. See **Figure 17.62**. Manufacturers such as Yaesu and M^2 are among these suppliers. One operator, VE5FP, found a solution for his az/el rotator needs by using two low-cost, lightweight TV rotators as shown in Figure 17.62.

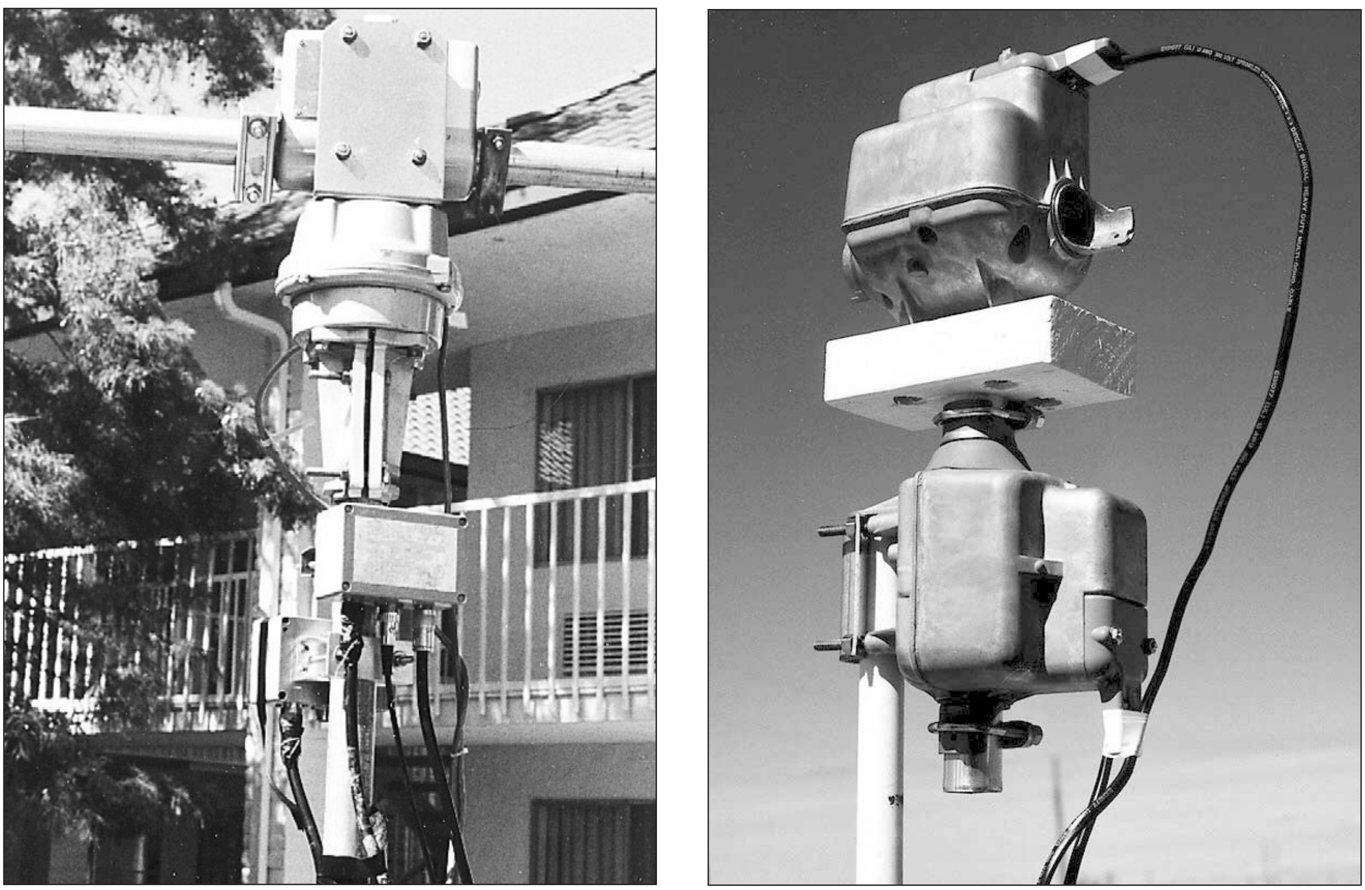


Figure 17.62 — At left, Yaesu az/el antenna-rotator mounting system is shown. Note that antenna loads must be more carefully balanced on this rotator than in the previously shown systems. At right, VE5FP has a solution for his az/el rotators by bolting two of them together as described in "An Inexpensive Az-El Rotator System" published in December 1998 *QST*.

17.6.3 WRAPS: A PORTABLE SATELLITE ANTENNA POSITIONING SYSTEM

This design was originally published as an article of the same name by Mark Spencer, WA8SME, in the January 2014 issue of *QST*. The full article is included on the CD-ROM accompanying this book, including all construction details and references.

Design

WRAPS is a portable, battery operated satellite antenna rotator system using commercial, off-the-shelf (COTS) parts. It can be built using simple hand tools with a minimum of machine work. This rotator system should be an affordable alternative to the industry standard — the Yaesu G-5500 system — which is an excellent and proven rotator for base station operations. It is a limited-duty rotator intended for small handheld Arrow and Elk class satellite antennas, and can be used to receive Fox satellite signals.

The positioning system is powered by a 12 V battery such as a small sealed UPS battery. The cost of parts, including all the associated cabling and computer interfaces, is approximately $275, compared with about $1300 for the G-5500 system. This design includes a USB interface that works with *SatPC32* and other satellite tracking software packages running the EASYCOM protocol. WRAPS is designed for lightweight antennas only, and is not intended to handle large antenna arrays. It is not weatherproof, nor designed for continuous unattended operation.

Figure 17.63 shows a block diagram of the WRAPS circuitry. The heart of the WRAPS circuit is a PIC microcontroller that:

- Receives positioning commands from the satellite tracking program which runs on the personal computer (PC)
- Translates those commands into rotator positions (analog to digital converter values).

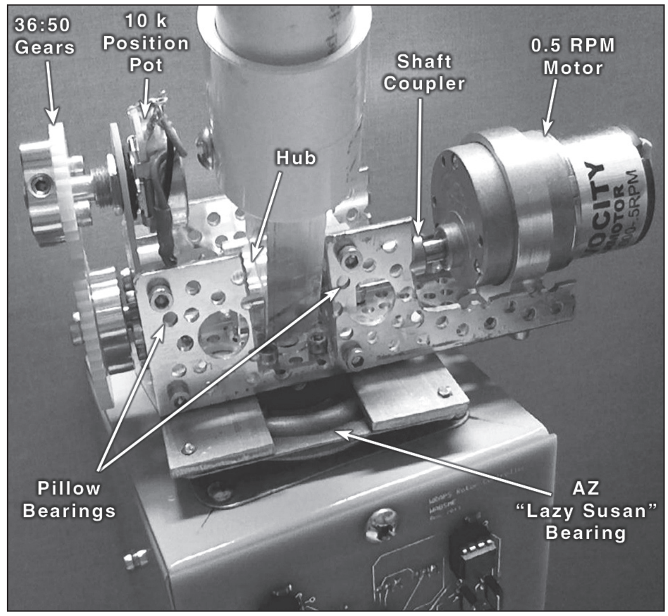


Figure 17.64 — The elevation (el) positioning assembly. (Mark Spencer, WA8SME)

- Reads the current rotator positions and determines if a position change is required, and if so, in which direction.
- Commands the motors ("MOT" in the figure) to turn in the proper direction.
- Monitors the motors as they move.
- Stops the motors when they reach the commanded position.
- Waits for the next position update.

The motors are controlled through the individual H-bridge circuits using a pulse width modulation (PWM) produced by the PIC microcontroller to set the motor speed.

WRAPS makes use of precision parts manufactured for

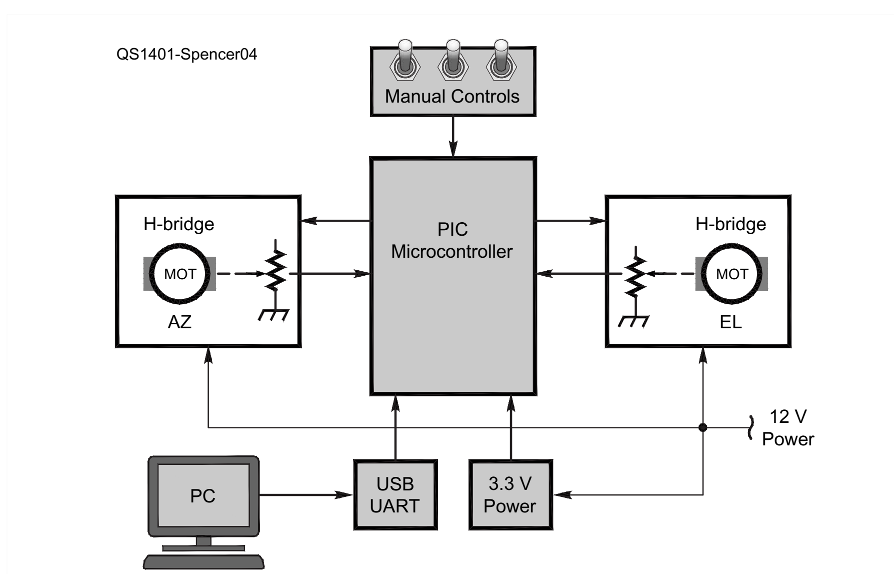


Figure 17.63 — The WRAPS antenna positioning system block diagram.

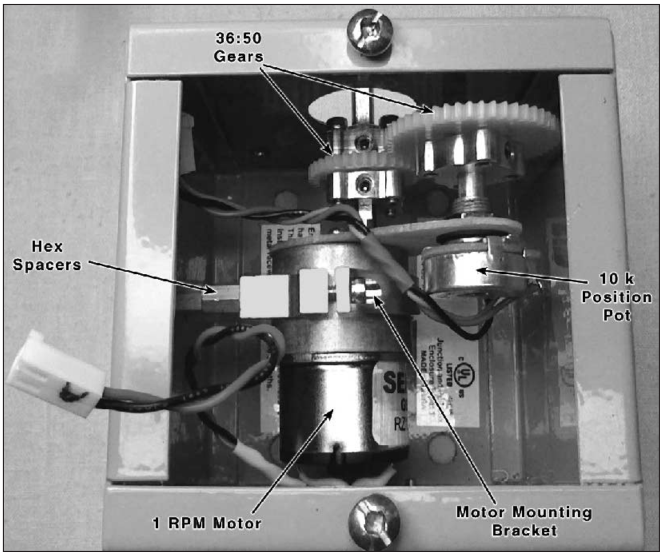


Figure 17.65 — The azimuth (az) positioning assembly. (Mark Spencer, WA8SME)

the robotics community. **Figure 17.64** illustrates the elevation (el) part of the rotator. The el rotator uses a geared 0.5 rpm dc motor that provides excellent torque at an affordable price. Construction is similar to an "erector set" project. There are a couple of cutouts required in the aluminum channel chassis of the el rotator. These cuts are easy to make with a hand hacksaw, and the rough edges can be cleaned up with a metal file. Eleven holes must be drilled in the rotator chassis box along with some hacksaw, drill, and tap work on two metal brackets made from home improvement store aluminum stock supplies. Finally, a few PVC pipe fitting parts require some drilling. The az rotator is a 1 rpm motor mounted inside the rotator body enclosure along with the associated position potentiometer as seen in **Figure 17.65**.

The azimuth (az) and elevation (el) rotator positions are determined by the wiper positions of wire-wound potentiometers that are connected to the motors by a pair of 36:50 ratio gears. Make the brackets for accurately mounting the potentiometers from circuit board material.

The microcontroller program is written in the C programming language. Position switches allow you to manually position the rotator motors. A calibration (CAL) button switch allows adjustments in the firmware if the system gets out of calibration. The rotator is set to 0 degrees az and 0 degrees el, press the CAL button, and that location is stored in the PIC microcontroller program. Then, set the rotator to 359 degrees az and 90 degrees el, press the CAL button to store the other stop position in the PIC program.

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