Chapter 19

Antenna Systems for Space Communications

There are two basic modes of space communications: satellite and earth-moon-earth (EME—also referred to as moonbounce). Both require consideration of the effects of polarization and elevation angle, along with the azimuth directions of transmitted and received signals.

Signal polarization is generally of little concern on the HF bands, as the original polarization direction is lost after the signal passes through the ionosphere. Vertical antennas receive sky-wave signals emanating from horizontal antennas, and vice versa. It is not beneficial to provide a means of varying the elevation angle in this case, because at HF the takeoff angle is not significantly affected. With satellite communications, however, because of polarization changes, a signal that would disappear into the noise on one antenna may be S9 on one that is not sensitive to polarization direction. Elevation angle is also important from the standpoint of tracking and avoiding indiscriminate ground reflections that may cause nulls in signal strength.

These are the characteristics common to both satellite and EME communications. There are also characteristics unique to each mode, and these cause the antenna requirements to differ in several ways—some subtle, others profound. Each mode is dealt with separately in this chapter after some basic information pertaining to all space communications is presented.

Fig 1—An aggressive approach to steering a giant EME antenna—a 5-inch gun turret from a destroyer.

Antenna Positioning

Where high-gain antennas are required in space communications, precise and accurate azimuth and elevation control and indication are necessary. High gain implies narrow beamwidth in at least one plane. Low orbit satellites such as FO-12 move through the window very quickly, so azimuth and elevation tracking are essential if high gain antennas are used.

These satellites are fairly easy to access with moderate power and broad coverage antennas. The low power, high-gain approach is more sophisticated, but the high power, low-gain solution may be more practical and economical.

Some EME arrays are fixed, but these are limited to narrow time windows for communication. The az-el positioning systems described in the following sections are adaptable to either satellite or modest EME arrays. **Figs 1** and **2** illustrate one of the more ambitious ventures in positioning a large EME array.

Fig 2—The gun mount of Fig 1 with its "warhead" attached—a home-made 42-foot parabolic dish. This is part of the arsenal of Ken Kucera, KAØY.

AN AZ-EL MOUNT FOR CROSSED YAGIS

The mounting system of **Figs 3**, **4** and **5** was originally described by Katashi Nose, KH6IJ, in June 1973 *QST*. (See the Bibliography at the end of this chapter.) The basic criteria in the design of this system were low cost and ease of assembly. The choice of a crossed Yagi system was influenced by the ready availability of Yagi antennas from dealers. Methods of feeding such arrays are discussed later in this chapter.

Fig 3 shows the assembled array. The antennas are eight-element Yagis. Fig 4 is a head-on view of the array, showing the antennas mounted at 90° with respect to each other and 45° with respect to the cross arm. Coupling between the two Yagis is minimal at 90°. By setting the angle at 45° with respect to the cross arm, coupling is reduced (but not eliminated).

Determine length d in Fig 4 by pointing the array straight up and rotating it. Length d should be the minimum distance necessary for the elements to clear the tripod base when this is done. In the array shown in Fig 3, a 5-foot section of TV mast serves the purpose.

The Mounting Tripod

A mounting tripod can be made of aluminum railing, called "NuRail," of which all manner of swivels, crosses and T fittings are available. The least expensive method, however, is to purchase a TV-antenna tripod. These tripods sell for such low prices

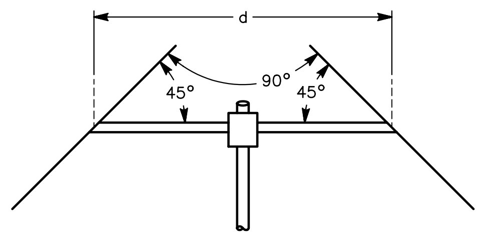


Fig 4—An end-on view of the crossed Yagi antennas shows that they are mounted at 90° to each other, and at 45° to the cross boom.

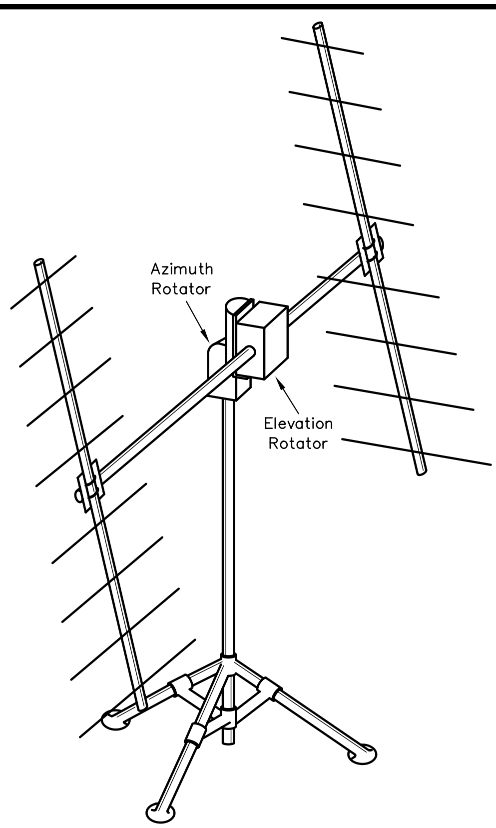


Fig 3—A crossed Yagi antenna system can be assembled using off-the-shelf components such as Hy-Gain Yagis, Cornell-Dubilier or Blonder-Tongue rotators and a commercially made tripod.

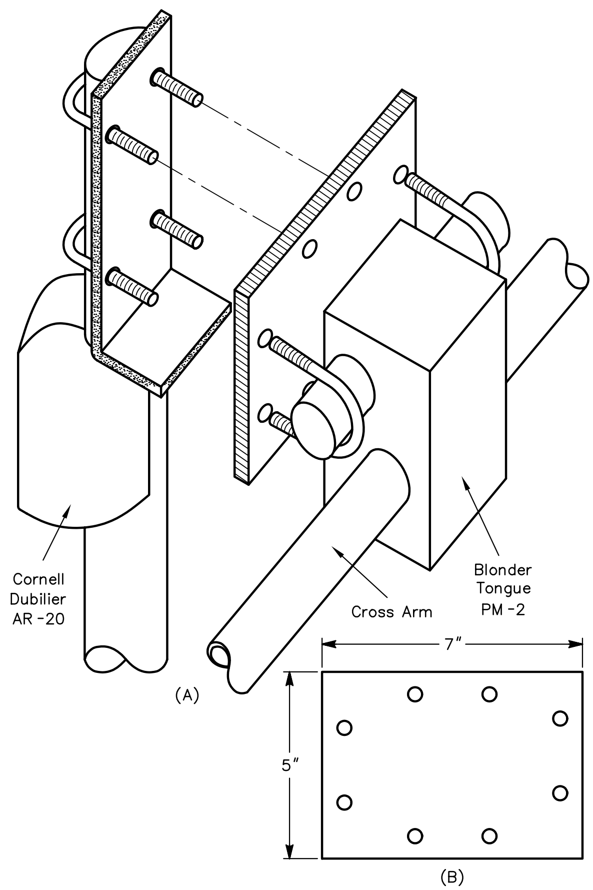


Fig 5—The method of mounting two rotators together. A pair of PM-2 rotators may also be used. The adapter plate (B) may be fabricated from 1/4-inch thick aluminum stock, or a ready made plate is available from Blonder-Tongue.

that there is little point in constructing your own. Spread the legs of the tripod more than usual to assure greater support, and be sure that the elements of the antenna clear the base in the straight-up position.

Elevation and Azimuth Rotators

Any medium-duty rotator can be used for azimuth rotation in this system. The elevation rotator should be one that allows the cross arm of the array to be rotated on its axis when supported at the center.

Fig 5 shows the mounting of the two rotators. The flat portion of the Cornell-Dubilier AR-20 rotator makes an ideal mounting surface for the elevation rotator. If commercially fabricated components are to be used throughout, a mounting plate similar to that shown in Fig 5B can be purchased. The adapter plate may be used to fasten two rotators together.

ELEVATION CONTROL USING SYNCHROS

Many amateurs have adapted TV rotators such as the Alliance U-100 and U-110 for use as elevation rotators. For small OSCAR antennas with wide beamwidths, these rotators perform satisfactorily. Unfortunately, however, the elevation of antennas with the stock U-100 and U-110 rotators is limited to increments of 10°. This limitation, combined with the possibility of the control box losing synchronization with the motor, can cause the actual antenna elevation to differ from that desired by as much as 30° or 40° at times. With high gain, narrow beamwidth arrays, such as those needed for EME work and for high altitude satellites (Phase III), this large a discrepancy is unsuitable. (Rotators designed specifically for use in the horizontal position should be used for EME antennas. The elevation readout system described here will provide superior accuracy when used with most rotators.)

This indication system uses a pair of *synchro transformers* to provide an accurate, continuous readout of the elevation angle of the antenna array. The Alliance rotator control unit is modified so that the motor can be operated to provide a continuously variable angle of antenna elevation. Jim Bartlett, K1TX, described this system in June 1979 *QST*.

The synchro or Selsyn is a specialized transformer. See **Fig 6A**. It can be best described as a transformer having three secondary windings and a single *rotating* primary winding. Synchros are sometimes called "one-by-threes" for this reason.

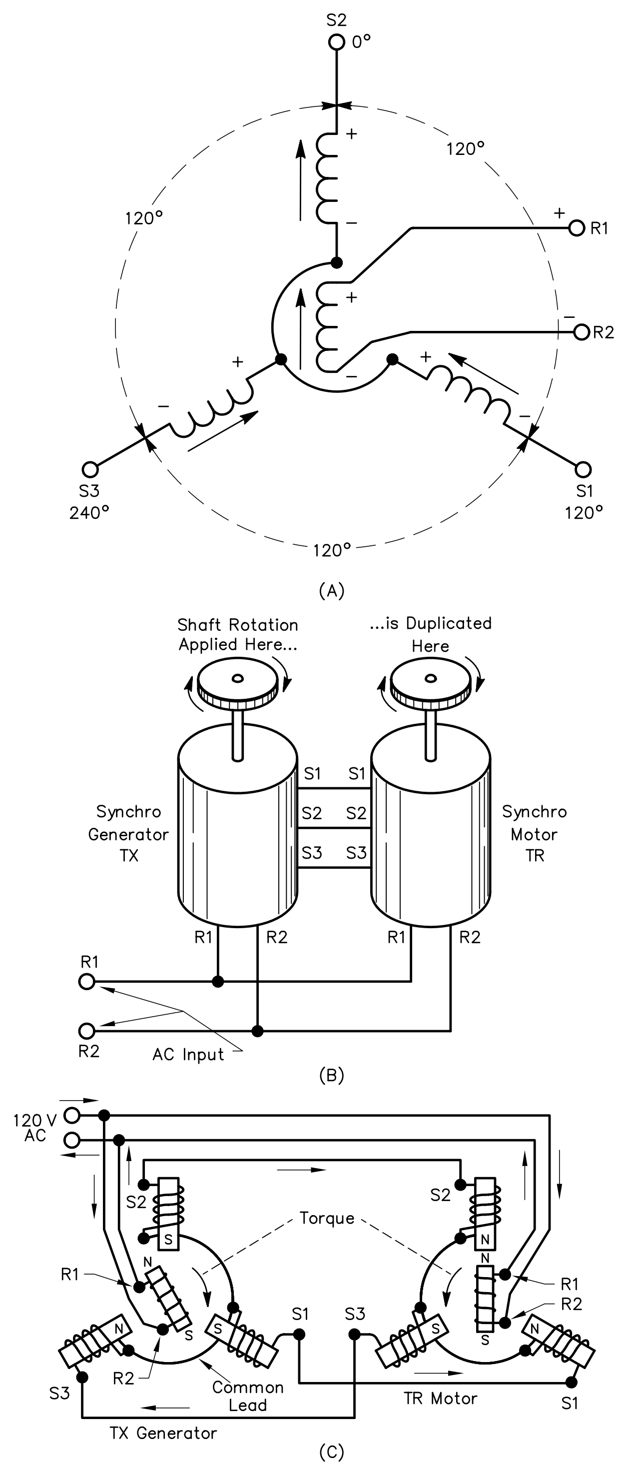


Fig 6—At A, a schematic diagram of the synchro or Selsyn transformer. Connection of two synchros in a repeater loop is shown at B. The drawing at C shows the instantaneous forces in the repeater loop with the rotor shafts at different positions. The "TX" and "TR" notations stand for torque transmitter and torque receiver, respectively. Synchros are sometimes listed in catalogs by these "type" symbols.

When two synchros are connected together as in Fig 6B and power is applied to their primary windings, the shaft attached to the rotating primary in one synchro will track the position of the shaft and winding in the other. When two synchros are used together in such an arrangement, the system is called a *synchro repeater loop*.

In repeater loops, one synchro transformer is usually designated as the one where motion is initiated, and the other repeats this motion. When two synchro transformers are used in such a repeater loop, the individual units can be thought of as "transmitter" and "receiver," or *synchro generator* and *synchro motor*, respectively. In this application (where one unit is located at the antenna array and another is used as an indicator), the antenna unit is referred to as the generator and the indicator unit the motor.

The synchro generator is so named because it electrically transmits a rotational force to the synchro motor. The motor, also sometimes called the *receiver*, *follower* or *repeater*, receives this energy from the generator, and its shaft turns accordingly.

Physical Characteristics

Synchro transformers, both generator and motor types, resemble small electric motors, with only minor differences. Generator and motor synchros are identical in design for all practical purposes. The only difference between them is the presence of an inertia damper—a special flywheel—on units specifically designated as synchro motors. For antenna use, the inertia damper is not a necessity.

Fig 6A shows the synchro transformer schematically. In each synchro, there are two elements: the fixed secondary windings, called the *stator*, and the rotatable primary, called the *rotor*. The rotor winding is connected to a source of alternating current, and the shaft is coupled to a controlling shaft or load—in this case, the antenna array or elevation readout pointer. An alternating field is set up by the rotor winding as a result of the ac voltage applied to it. This causes voltages to be induced in the stator windings. These voltages are representative of the angular position of the rotor.

The stator consists of many coils of wire placed in slots around the inside of a laminated field structure, much like that in an electric motor. The stator coils are divided into three groups spaced 120° around the inside of the field with some overlap to provide a uniform magnitude of attractive force on the rotor. The leads from the rotor and stator windings are attached to insulated terminal strips, usually located at the rear of the motor or generator housing. The rotor connections are labeled R1 and R2, and the stator connections S1, S2 and S3. These are shown in Fig 6A. These rotor and stator designations are standard identifications.

Synchro Transformer Action

Synchros operate much like transformers. The main difference between them is that in a synchro, the primary winding (rotor) can be rotated through 360°.

The ac applied to the synchro rotor coil varies, but the most common ratings are 115 V/60 Hz, 115 V/400 Hz, and 26 V/400 Hz. The 400-Hz varieties are easier to find on the surplus market, but are more difficult to use, as a 400-Hz supply must be built. Bartlett, K1TX, used 90-V/60-Hz synchros for this project, and the 90 V required was obtained by using two surplus transformers back to back (one 6.3 V and one 5 V). Regardless of the voltage or line frequency used, synchros should be fused, and *isolated from the ac mains by a transformer*. This is important to ensure a safe installation.

The voltages induced in the stator windings are determined by the position of the rotor. As the rotor changes position and different values are induced, the direction of the resultant fields changes.

When a second synchro transformer is connected to the first, forming a generator/motor pair or repeater loop, the voltages induced in the three generator stator coils are also induced into the respective motor stator coils. As long as the two rotor shafts are in the same position, the voltages induced in the stator windings of the generator and motor units are equal. These voltages are of opposite polarity, however, because of the way the two units are connected together. This results in a zero potential difference between the stators in the two synchro units, and no current flows in either set of stator coils.

With the absence of current flow, no magnetic field is set up by the stator windings, and the system is in mechanical equilibrium. (There are no unbalanced forces acting on either rotor.) This situation exists whenever the two rotors are aligned in identical angular positions, regardless of the specific angle of displacement from the zero point (S2).

The repeater action of the two-synchro system occurs when one rotor is moved, causing the voltages in the system to become unbalanced. When this happens, current flows through the stator coils, setting up magnetic fields that tend to pull the rotors together so that the static (equilibrium) condition again exists. A torque results from the magnetic fields set up in both units, causing the two rotors to turn in opposite directions until they align themselves.

The generator shaft, however, is usually attached to a control shaft or large load (relative to that attached to the motor shaft) so that it cannot freely rotate. Thus, as long as the motor rotor is free to move, it will remain in alignment with the generator rotor. Fig 6C shows the instantaneous forces present in a repeater loop when one rotor is turned.

Selecting the Synchros

Synchro operating voltages are not critical. Most units will function with voltages as much as 20% above or 30% below their nominal ratings. Make sure the transformer(s) you use will handle the necessary current. **Fig 7A** shows how to connect two transformers to obtain 90 V for the units used in this project.

Synchro transformers normally found in surplus catalogs and at flea markets may not be suitable for this application. Some of the types you should not buy are ones marked *differential generator, differential synchro* or *resolver synchro.* These synchros are designed for different uses.

Most catalogs list synchro transformers with their ratings and prices. Look for the least expensive set of synchros that will operate at the required voltage and line frequency. When comparing specifications, look for synchros that have a high torque gradient (accuracy). It is possible to obtain accuracy as good as ±1° with a properly installed synchro readout system.

When the synchros have been obtained and a power supply designed, begin construction of the elevation system. Check the synchros by connecting the two units as shown in Fig 6B. Verify proper operation. Set the synchros aside and begin modification of the Alliance rotator-control unit (if you have decided to use an Alliance rotator).

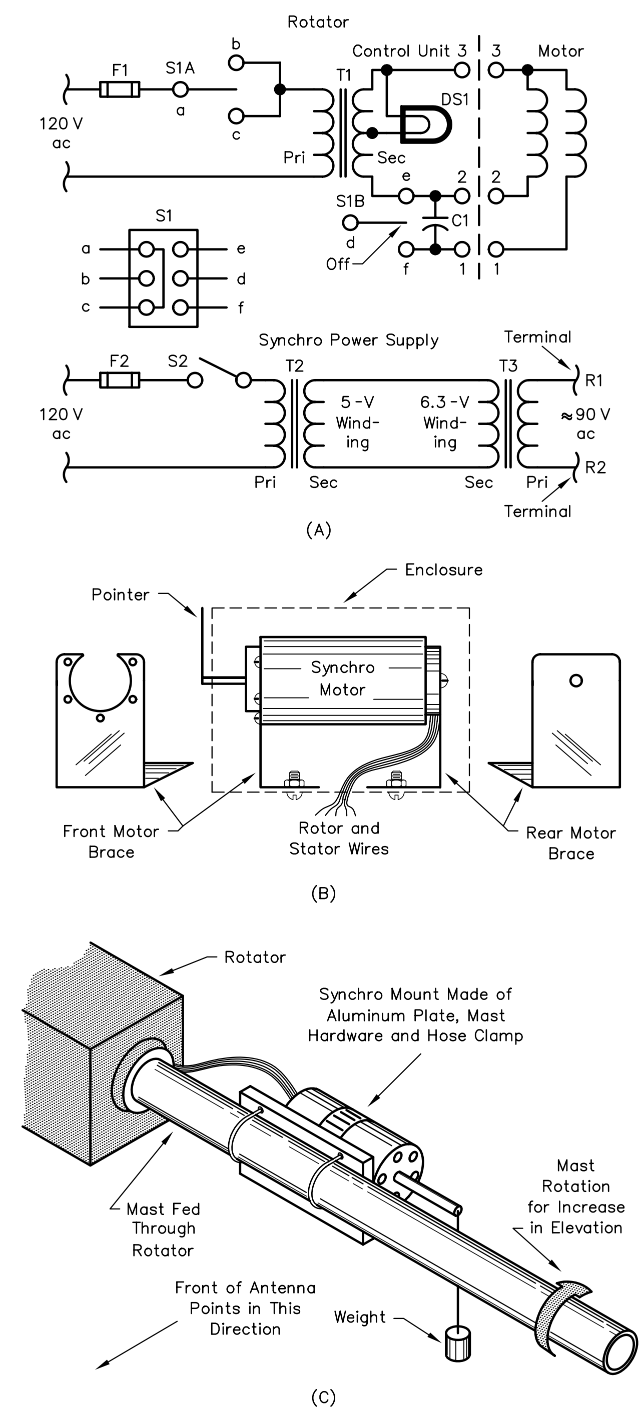


Fig 7—Shown at A are the circuits for the modi-=fied control unit and the synchro power supply. T1, DS1 and C1 are from the stock U-100 or U-110 control box. See text. At B, the mounting method used to secure the synchro motor is shown. Details of the synchro generator mounting are shown at C. See text for description of materials.

F1, F2—1 A, 250 V fuse.

S1—DPDT momentary contact, center off toggle switch.

S2—SPST toggle switch.

T2, T3—Transformers selected for proper voltage to synchro rotor.

The Alliance Rotator-Control Unit

Remove the transformer, capacitor and pilot light from the control unit and discard the rest. Mount the transformer and capacitor in a small, shallow enclosure, like the one shown in **Fig 8**. The synchro power supply will also be mounted in this box.

Wire the rotator control circuit as shown in Fig 7A. The transformer, pilot light and capacitor shown are the ones removed from the Alliance control unit. Add a fuse at the point shown. The 120-V input to this circuit can be tied to that of the power supply circuit if desired. This allows for a common fuse and power switch. The rating of the fuse depends on the current drain of the synchros used, but a 1-A fuse should be ample to handle the control and power supply circuits. Note that there are four wires in the Alliance control system. Only three are needed here; the fourth wire is not used.

Test the control unit before mounting the rotator on the mast. Connect the motor to the modified control unit and check to see that it rotates properly in both directions when S1 is activated. This switch should be a DPDT, momentary on, center off toggle switch. Next install the synchro power supply inside the rotator-control enclosure. Some type of multiconnector plug and jack combination should be used at the rear of the cabinet so the rotator and synchro control wires can be easily disconnected from the control box. Eight wires are used between the control unit and the synchro and rotator mounted at the antenna array. An 8-pin, octal connector set and standard 8-wire rotator cable were used in this project. A suitable alternative connector set is Calectro F3-248 (male cord) and F3-268 (female chassis).

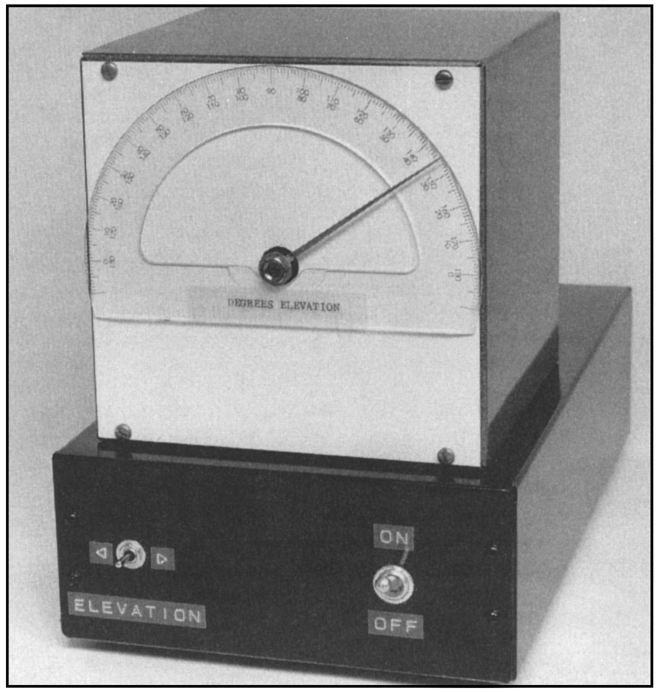


Fig 8—The completed control/readout unit for antenna elevation. The dial face was made from a plastic protractor.

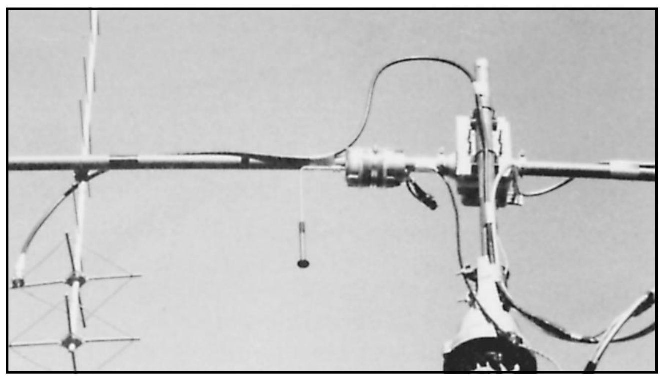


Fig 9—Close-up photo of the synchro transformer mounting method. The weighted arm is kept short to minimize wind effects on elevation readout.

Mechanical Details

The synchro motor providing the elevation readout is mounted inside a cube-shaped chassis. (Any suitable chassis will do.) Two aluminum brackets support the motor inside the box, as shown in Fig 7B. The motor is positioned to allow the shaft to protrude through the front panel of the enclosure. The pointer is fashioned from a scrap of copper sheet, and soldered to the edge of a washer. This is secured to the shaft between two nuts. A large protractor that fits the front of the enclosure serves as the dial face.

Mounting and Calibration

The synchro generator mounting is shown in Fig 7C. An aluminum plate is drilled and fitted with standard hardware. Cut two slots between the clamps, and insert a large stainless steel hose clamp through the slots and around the generator casing. After positioning the synchro, tighten the clamp. The generator is mounted close to the rotator and directly behind the elevation mast when the antennas are pointed at the horizon.

The elevation and azimuth rotators are mounted in the normal fashion, as shown in **Fig 9**. Elevation of the antennas causes generator shaft rotation through a weighted rod fastened to the synchro shaft, as shown in Fig 7C.

As the antenna array is elevated, the synchro generator moves through an arc starting behind the elevation mast, through a position directly below the mast, to one in front of it. During the swing through this arc, gravity keeps the weighted rod perpendicular to the ground, and the synchro shaft turns in proportion to the elevation angle. (If high winds are common in your area, keep the “plumb-line” swing arm short so gusts of wind won’t cause fluctuations in the elevation readout.)

The easiest way to calibrate the system is to attach the antennas and synchro to the mast when the elevation rotator is at the end of rotation (at a stop). Do this so any movement must be in the direction that will elevate the array with respect to the horizon. With the antennas pointing at the horizon, set the synchro motor pointer to 0° at one end of the protractor scale. The proper “zero” end depends on the specific mounting scheme used at the antenna.

If the generator is mounted as shown in Fig 7C and all connections are properly made, the elevation needle should swing from right to left as the antennas move from zero through 90 to 180°. If not, remove power from the system and interchange the S1 and S3 wires at the indicator motor.

A RADIO-COMPASS ELEVATION READOUT SYSTEM

As described by Jim Bartlett, K1TX, in September 1979 *QST*, an MN-98 Canadian radio compass and a Sperry R5663642 synchro transmitter combine to make a highly precise elevation indicator. These components, displayed in **Fig 10**, may be available from Fair Radio Sales Co., PO Box 1105, Lima, OH 45802. The AY-201 transmitter is *not* suitable for this project.

Place the MN-98 indicator face down on a soft cloth on a flat surface and remove the rear cover of the indicator unit. Disconnect the four wires that go to the glass-metal feedthrough located on the back panel. This frees the rear cover. Remove the rear cover and put it aside. Drill a small hole in the rear of the case, next to the edge of the feedthrough. (See **Fig 11A**.) Do this *carefully*, making sure that the drill

Fig 10—The MN-98 Canadian radio compass and Sperry R5663642 synchro transmitter. Note the small knob at the upper right-hand corner of the indicator face. This can be used to calibrate the system without making any changes at the antenna end. By turning this knob, you can rotate the degree markings around the outside of the dial face so that any desired heading can be placed in line with the pointer.

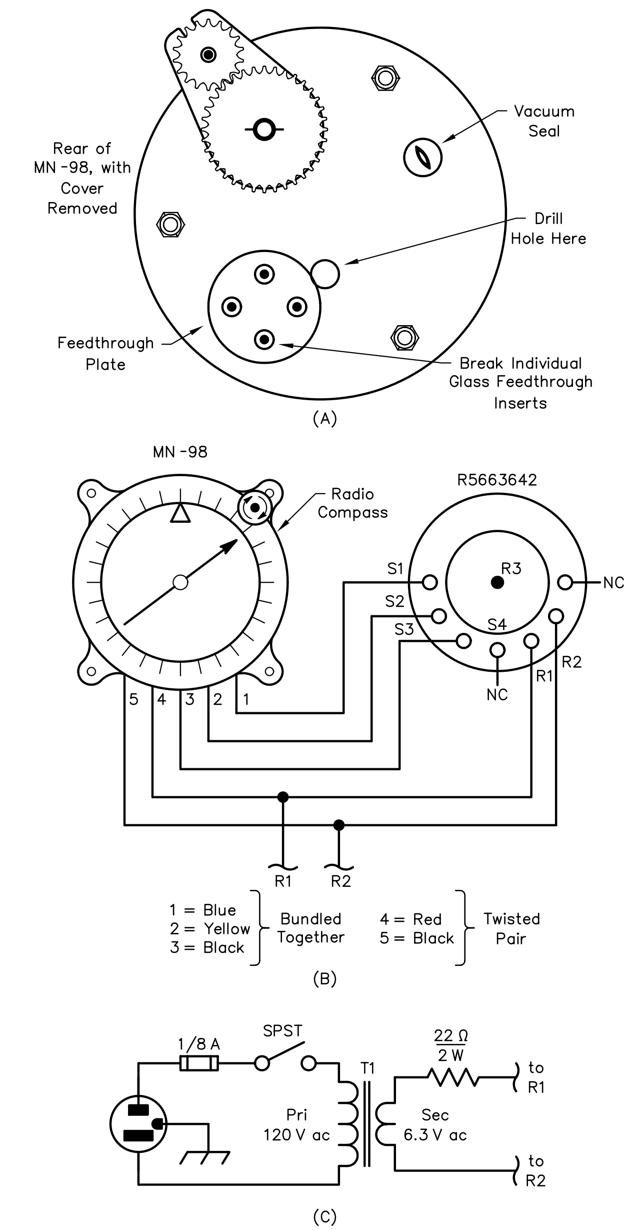


Fig 11—The rear of the MN-98 Canadian radio compass is shown at A. The drawing at B shows the interconnecting method used between the MN-98 and the Sperry synchro transmitter. The schematic diagram at C shows the power supply used with this indicator system. T1 can be Radio Shack 273-1384 or any junk-box 6.3-V transformer.

bit doesn't push through into the inside of the indicator shell and get tangled in the wiring. When the bit breaks through the metal casing, the pressurized seal will be broken.

Using a small screwdriver and a hammer, tap each of the individual glass feedthrough inserts, cracking them. Try to keep the screwdriver from pushing the broken pieces of glass down into the enclosure where they could get lodged in the dial mechanism. Attempt to shake all the pieces of glass out of the case. The remaining part of the feedthrough can be removed by heating with a soldering iron and prying with a screwdriver or needle-nosed pliers.

After the feedthrough has been removed, gently pull the ends of the wires out through the hole left by the feedthrough. Clip off the feedthrough terminal pins. There are five wires—a group of three and two others. The group of three will probably be blue, yellow and black. The other two wires twisted together should be red and black. Fig 11B shows how these are connected to the terminals on the synchro transmitter in a five-wire system.

Construction of the System

Fig 11C shows the schematic diagram of a simple 6.3-V ac power supply for the indicator system. Because the synchro and indicator were originally designed to operate from 26 V at 400 Hz, a 6.3-V transformer is acceptable for use at 60 Hz. A 22-Ω resistor is wired in series with the synchros to limit current and thus eliminate an annoying buzzing sound in the indicator unit at certain pointer positions.

The indicator, along with the power supply, can be mounted in a small metal enclosure. Include a fuse, ON-OFF switch, and three-wire line cord. At the synchro transmitter end (at the antenna), provide some kind of shield to keep weather from affecting the system.

A small weight, cut in the shape of a large pie section and drilled to fit the synchro transmitter shaft, can be mounted on the shaft and shielded with a small margarine tub which is taped or glued to the outside of the synchro casing. This arrangement should allow free movement of the weight, yet keep high winds or heavy icing from affecting the indicator. The synchro transmitter should be mounted to the mast in such a way that it will rotate with the antennas, causing the weight to turn the shaft.

Antennas for Satellite Work

This section contains a number of antenna systems that are practical for satellite communications. Some of the simpler ones bring space communications into the range of any amateur's budget.

RECEIVING ANTENNAS FOR 29.4 MHz

Fig 12 shows three antennas suitable for satellite downlink recep-

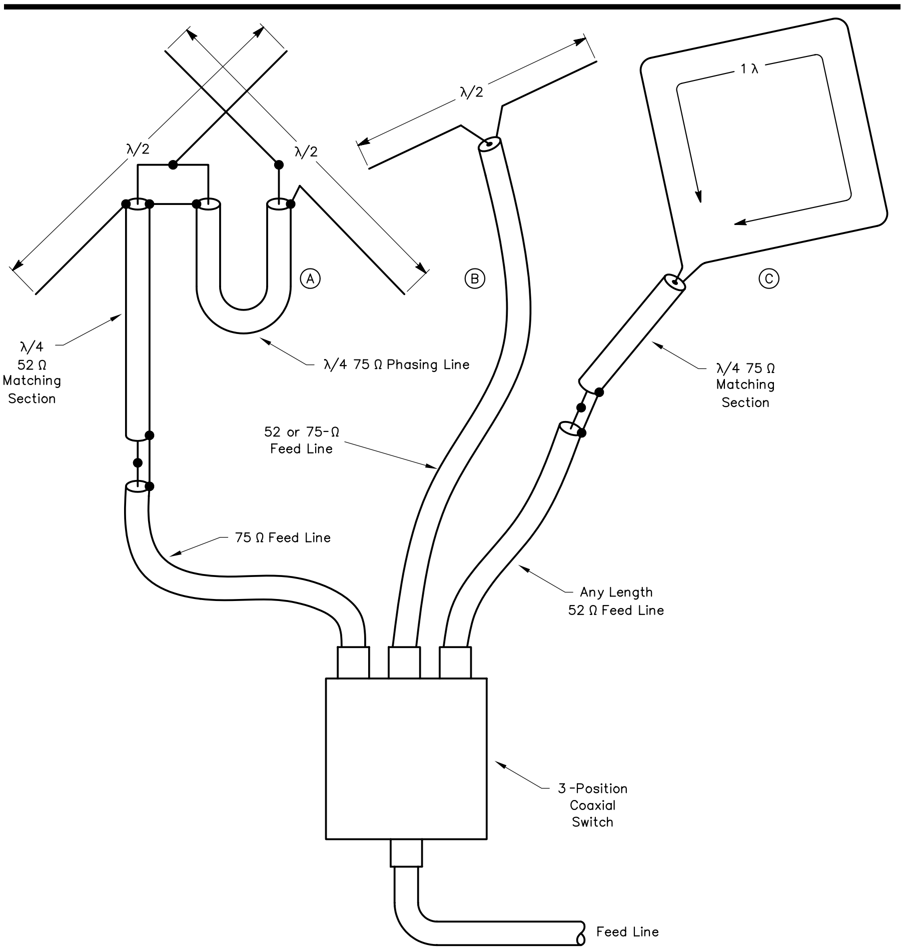


Fig 12—Any one of three 29-MHz antennas—a turnstile (A), rotary dipole (B), or horizontal loop (C)—may be selected for OSCAR downlink reception.

tion at 29 MHz. At A is a turnstile, an antenna that is omnidirectional in the azimuth plane. The vertical pattern depends on the height above ground. (This subject is treated in detail in Chapter 3.) The circular polarization of the turnstile at high elevation angles reduces signal fading from satellite rotation and ionospheric effects.

The antenna at B is a simple rotatable dipole for use when a satellite is near the horizon and some directivity is helpful.When horizontally mounted, the full-wave loop at C gives good omnidirectional reception for elevation angles above 30°. It should be mounted at least $^1/_8$ λ above ground. It is difficult to predict which antenna will deliver the best signal under any circumstances. All are inexpensive, and the most effective amateur satellite stations have all three, with a means of selecting the best one for the existing conditions. For low-altitude satellites, conditions should be expected to change in the matter of a few minutes.

A 146-MHz TURNSTILE ANTENNA

The 146-MHz antenna of **Fig 13** is simple and effective for use with OSCAR Modes A, B and J. The antenna, called a turnstile-reflector array, can be built very inexpensively and put into operation without the need for test equipment. The information contained here is based on a September 1974 *QST* article by Martin Davidoff, K2UBC.

Experience with several amateur satellites has shown that rapid fading is a severe problem in satellite work. Fortunately, the ground station has control over two important parameters affecting fading: cross polarization between the ground-station antenna and OSCAR antenna, and nulls in the ground-station antenna pattern. Fading that results from cross polarization can be reduced by using a circularly polarized ground-station antenna. Fading caused by radiation pattern nulls can be overcome by (1) using a rotatable, tiltable array and continuously tracking the satellite or (2) using an antenna with a broad, null-free pattern. The turnstile-reflector array solves these problems, as it is circularly polarized at high elevation angles and has a balloon-like high-angle directivity pattern. At lower elevation angles the polarization is elliptical. (Circular and elliptical polarizations are discussed later in this chapter.)

Construction

The mast used to support the two dipoles is made of wood, being 2 inches square and 8 feet long. The dipoles may be made of #12 copper wire, aluminum rod, or tubing. The reflecting screen is 20 gauge hexagonal poultry netting, 1-inch mesh, stapled to a 4-foot square frame made of furring strips. Hardware cloth can be used in place of the poultry netting. Corner bracing of the reflector screen provides increased mechanical stability. Spar varnish applied to the wooden members will extend the service life of the assembly.

Dimensions for the two dipole antennas and the phasing network are shown in **Fig 14**. Spacing between the dipole antennas and the reflecting

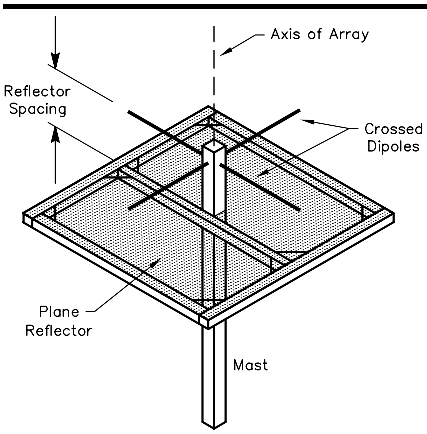


Fig 13—The turnstile-reflector (TR) array consists of crossed dipoles above a 4-foot square screen reflector.

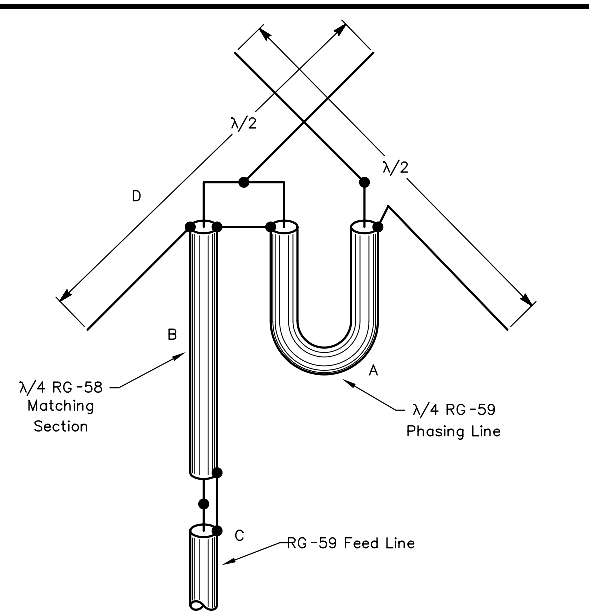


Fig 14—Dimensions and connections for the turnstile antenna. The phasing line is 13.3 inches of RG-59 coax (velocity factor = 0.66). A similar length of RG-58 cable is used as a matching section between the turnstile and the feed line. The phasing line length should be corrected for lines with other velocity factors.

screen affects the antenna radiation pattern. Choose the spacing for the pattern that best suits your needs from data in Chapter 3, and construct the antenna accordingly. A spacing of 3/8 λ (30 inches) is suggested. This distance provides a theoretical pattern response of ±1.5 dB at all angles above 15°. Spacings greater than 30 inches will increase the response at elevation angles lower than 15°, but at the expense of nulls in the pattern at higher angles. The feed-point impedance of the array will vary somewhat, depending on the spacing between the dipole elements and the reflecting screen.

Circular Polarization

The ideal antenna for random polarization is one with a circularly polarized radiation pattern. There are two commonly used methods for obtaining circular polarization. One is with crossed linear elements such as dipoles or Yagis. An array of crossed Yagis is shown in **Fig 15**. The second common method is with the helical antenna, described later in this chapter. Other methods also exist, such as with the quadrifilar helix (see Maxwell Bibliography listing at the end of this chapter).

Polarization *sense* is a critical factor, especially in EME work or if the satellite uses a circularly polarized antenna. In physics, clockwise rotation of an *approaching* wave is called "right circular polarization," but the IEEE standard uses the term "clockwise circular polarization," for a *receding* wave. Amateur technology follows the IEEE standard, calling clockwise polarization for a receding wave as right-hand. Either clockwise or a counter-clockwise sense can be selected by reversing the phasing harness of a crossed Yagi antenna. The sense of a helical antenna is fixed, determined by its physical construction

In working through a satellite with a circularly polarized antenna, it is necessary to have the capability of switching the polarization sense. This is because the sense of the received signal reverses when the satellite passes its nearest point to you. If the received signal has right hand circular polarization as the satellite approaches, it will have left hand circularity as the satellite recedes. There is a sense reversal in EME work, as well, because of a phase reversal of the signal as it is reflected from the surface of the moon. A signal transmitted with right-hand circularity will be returned to the Earth with left-hand circularity.

Mathematically, linear and circular polarization are special cases of elliptical polarization. Consider two electric-field vectors at right angles to each other. The frequencies are the same, but the magnitudes and phase angles vary. If either one or the other of the magnitudes is zero, linear polarization results. If the magnitudes are the same and the phase angle between the two vectors (in time) is 90°, circular polarization results. Any combination between these two limits gives elliptical polarization.

Crossed Linear Antennas

Dipoles radiate linearly polarized signals, and the polarization direction depends on the orientation of the antenna. **Fig 16** shows the electric-field or E-plane patterns of horizontal and vertical dipoles at A and B. If the two outputs are combined with the correct phase difference (90°), a circularly polarized wave results,

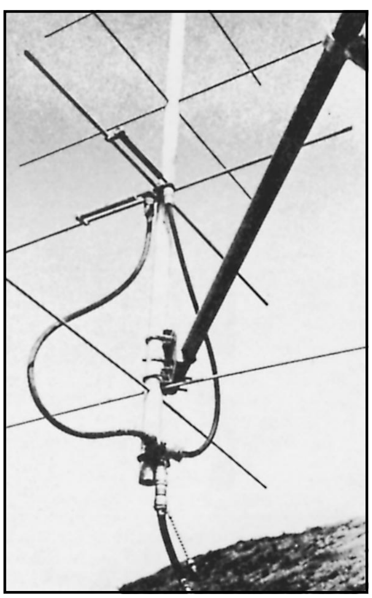


Fig 15—This VHF crossed Yagi antenna design by KH6IJ was presented in January 1973 QST. Placement of the phasing harness and T connector is shown in the lower half of the photograph. Note that the gamma match is mounted somewhat off element center for better balance of RF voltages on elements.

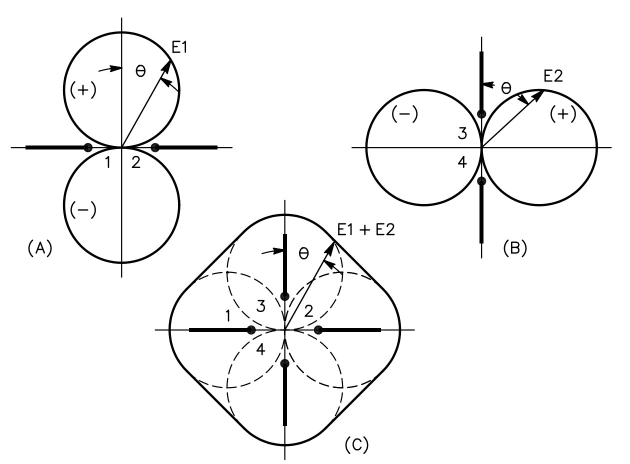


Fig 16—Radiation patterns looking head-on at dipoles.

and the resulting electric-field pattern is shown in Fig 16C. Note that because the electric fields are identical in magnitude, the power from the transmitter must be equally divided 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.

As previously mentioned, a 90° phase shift must exist between the two antennas. The simplest way to obtain the shift is to use two feed lines with one section that is $^1/_4\ \lambda$ longer than the other, as shown in **Fig 17A**. These separate feed lines are then paralleled to a common transmission line to the transmitter or receiver. Therein lies one of the headaches of this system—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.) A practical construction method for implementing the system of Fig 17A is given in **Fig 18**.

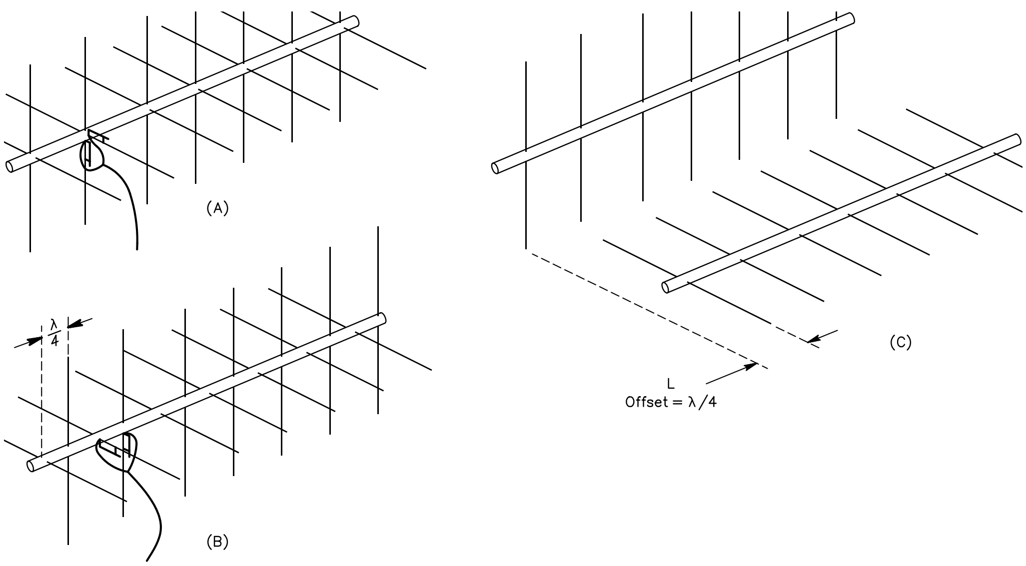


Fig 17—Evolution of the circularly polarized Yagi. The simplest form of crossed Yagi, A, is made to radiate circularly by feeding the two driven elements 90° out of phase. Antenna B uses the same line length for both feeds, but has the elements of one bay $^1/_4\ \lambda$ forward from those in the other. Antenna C offers polarization diversity with elliptical polarization. With separate booms, the elements in one set are perpendicular to those in the other. The set on the right has its elements $^1/_4\ \lambda$ forward of those on the left.

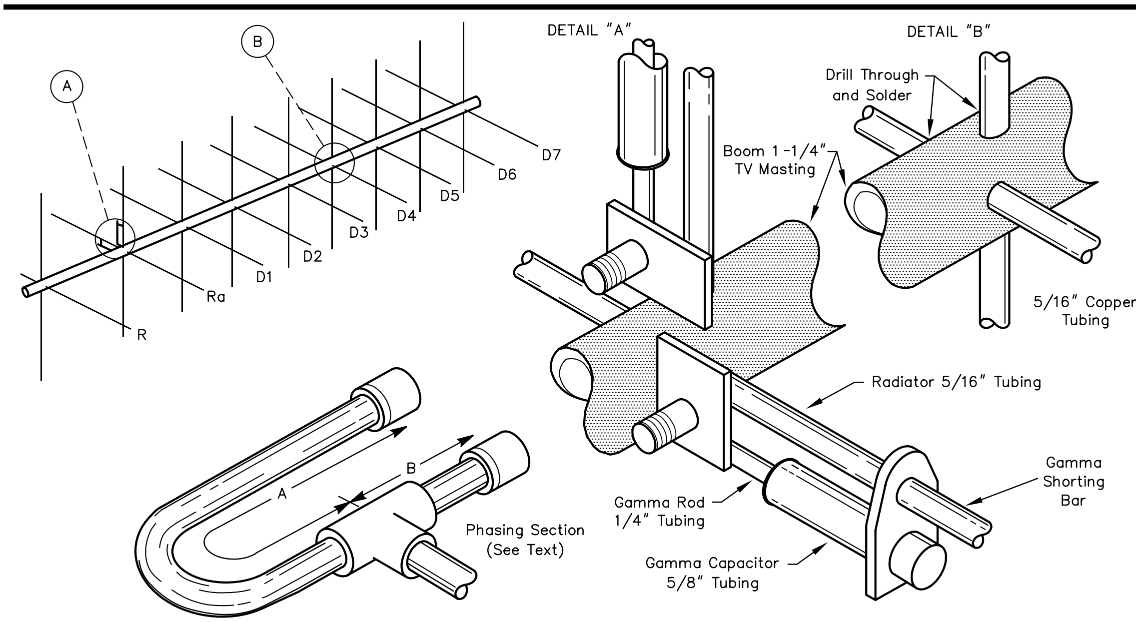


Fig 18—Construction details of a crossed Yagi antenna.

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. Type N or BNC connectors are preferable to the UHF variety.

Another method of obtaining circular polarization is to use equal length feed lines and place one antenna $^1/_4$ λ ahead of the other. This method is shown at B of Fig 17. The advantage of equal-length feed lines is that identical load impedances will be presented to the common feeder. With the phasing-line method, any mismatch at one antenna will be magnified by the extra $^1/_4$ λ of transmission line. This upsets the current balance between the two antennas, resulting in a loss of polarization circularity.

Fig 17C shows a popular method of mounting off-the-shelf Yagi arrays—at right angles to each other. The two arrays may be physically offset by $^1/_4$ λ and fed in parallel, as shown, or they may be mounted with no offset and fed 90° out of phase. Neither of these arrangements produces true circular polarization. Instead, polarization diversity is obtained with elliptical polarization from such a system.

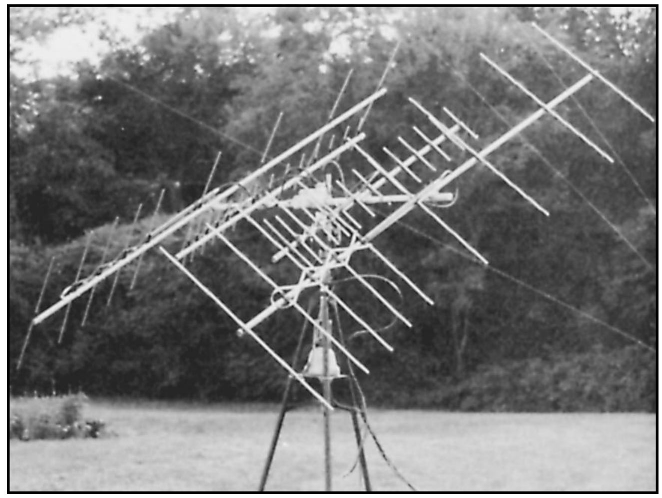


Fig 19—An elliptically polarized antenna system for satellite communications on 146 and 435 MHz. The array is assembled from KLM log periodic Yagis.

ELLIPTICALLY POLARIZED ANTENNAS FOR 144 AND 432-MHz SATELLITE WORK

The antenna system described here offers polarization diversity, with switchable right-hand or left- hand elliptical polarization. The array can be positioned in both azimuth and elevation. This system makes use of commercially available antennas (KLM 9-element 145-MHz and KLM 14-element 435-MHz antennas), rotators (Alliance U-110 and Telex/Hy-Gain Ham series or Tailtwister) and coaxial relays which are combined in a way that offers total flexibility.

This setup is suited for Mode B or Mode J satellite operation. As shown in **Figs 19** and **20**, the whole assembly is built on a heavy-duty TV tripod so that it can be roof-mounted. The idea for this system came from Clarke Greene, K1JX.

System Outline

The antennas shown in the photographs are actually two totally separate systems sharing the same azimuth and elevation positioning systems. Each system is identical in the way it performs—one system for 145 MHz and one for 435 MHz. Individual control lines allow independent control of the polarization sense for each system. This is mandatory, as often a different polarization sense is required for the uplink and downlink. Also, throughout any given pass of a satellite, the required sense may change.

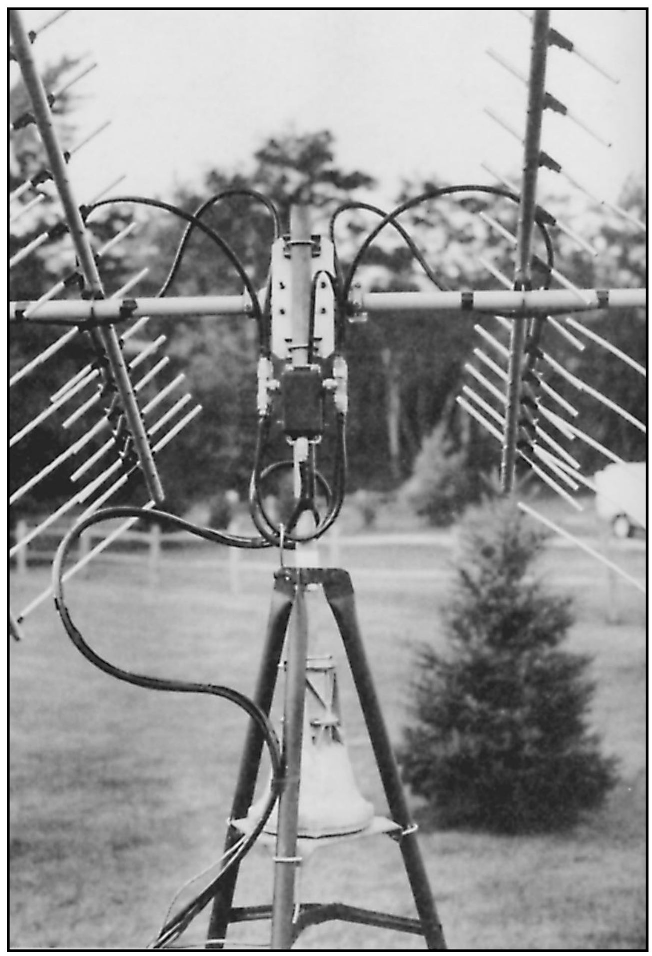


Fig 20—The polarization sense of the antenna is controlled by coaxial relays and phasing lines. The 146 and 435-MHz systems are controlled independently.

Mechanical Details

The azimuth rotator is mounted inside the tripod by means of a Rohn 25 type of rotator plate. See Fig 20. U bolts around the tripod legs secure the plate to the tripod. A length of 1-inch galvanized water pipe (the mast) extends from the top of the rotator through a homemade aluminum bearing at the top of the tripod. Because a relatively small diameter mast is used, several pieces of shim material are required between it and the body of the rotator to assure that the mast will be aligned in the bearing through 360° of rotation. This is covered in detail in the Telex/Hy-Gain rotator instruction sheets.

The Alliance U-110 elevation rotator is mounted to the 1-inch water pipe mast by means of a $^1/_8$-inch aluminum plate. TV U-bolt hardware provides a good fit for this mast material. The cross arm that supports the antennas is a piece of $1^1/_4$-inch-thick fiberglass rod, 6 feet in length. Other materials can be used, but the strength of fiberglass makes it desirable as a cross arm. This should be a consideration if you live in an area that is frequented by ice storms. Although it is relatively expensive (about $3 to $4 per foot), one piece should last a lifetime.

Electrical Details

As the antenna systems are identical, this description applies to both. As mentioned earlier, it is possible to obtain polarization diversity with two separate antennas mounted apart from each other as shown in the photographs. One advantage of this system is that the weight distribution on each side of the elevation rotator is equal. As long as the separation between antennas is small, performance should be nearly as good as when both sets of elements are on a single boom. There is no operational difference between true circular polarization and the polarization diversity provided by this antenna system.

Because of mutual coupling between the arrays, the two feed-point impedances will not be identical, but from a practical standpoint the differences are almost insignificant. One antenna must be fed 90° out of phase with respect to the other. For switchable right-hand and left-hand polarization, some means must be included to shift a 90° phasing line in series with either antenna. Such a scheme is shown in **Fig 21**. Since two antennas are essentially connected in parallel, the feed impedance will be half that of either antenna alone. The antennas used in this system have a 52-Ω feed-point impedance. RG-133 (95-Ω coax) proves difficult to locate. RG-63 (125-Ω impedance) may be used with a slightly higher mismatch. As can be seen in the drawing, the phasing line is always in series with the system feed point and one of the antennas. As shown, the antenna on the left receives energy 90° ahead of the one on the right. When the relay is switched, the opposite is true.

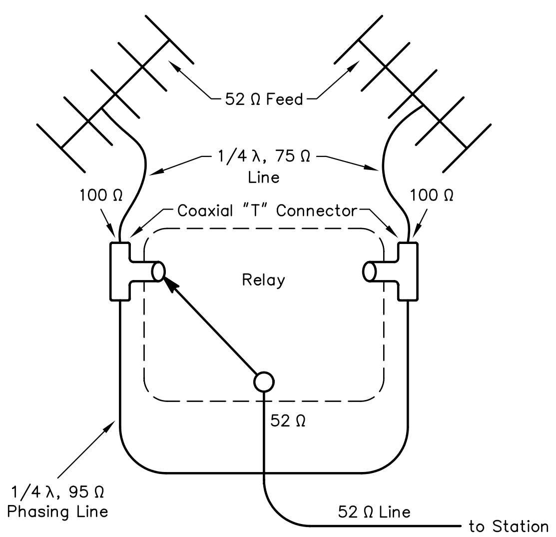


Fig 21—Electrical diagram of the switchable polarization antenna system, complete with cable specifications. When calculating the lengths of individual cables, be sure to include the proper velocity factor of the cable used.

It is not necessary to use single quarter wavelengths of line. For example, the 75-Ω impedance-transforming lines between each antenna and the relay can be any odd multiple of $^1/_4$ λ, such as $^3/_4$, $^5/_4$, $^7/_4$ λ, etc. The same is true for the 95 or 125-Ω phasing line.

Keep track of phasing-line lengths. This is especially important when determining which position of the relay will yield right or left-hand polarization. You will probably find it necessary to use a number of quarter wavelengths, because a single quarter wavelength of line is extremely short (when the velocity factor is taken into consideration). The lengths used in this system are shown in **Fig 22**. Try to use the shortest practical lengths, because the SWR bandwidth of the array decreases as the number of quarter wavelengths of line is increased.

Antenna Systems for EME Communications

The tremendous path loss incurred over an EME circuit places stringent requirements on Earth station performance. Low-noise receiving equipment, maximum legal power and large antenna arrays are required for successful EME operation. Although it is possible to copy some of the better-equipped stations with a single Yagi antenna, it is unlikely that such an antenna can provide reliable two-way communication. Antenna gain of at least 20 dB is required for reasonable success. Generally speaking, more antenna gain yields the most noticeable improvement in station performance, as the increased gain improves both the received and transmitted signals.

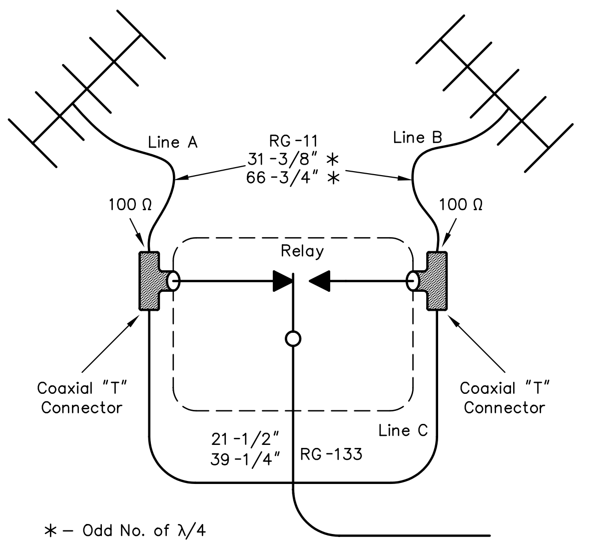


Fig 22—The basic antenna system for switchable right or left-hand elliptical polarization. Lines A and B step the 52-Ω antenna impedance up to 100 Ω. The phasing line is made from 95-Ω coaxial cable to provide a good match to the 100-Ω system. See text for a detailed description of the system. The shorter lengths are for 435.15 MHz and the longer lengths are for 145.925 MHz. The line lengths shown are for a 66% velocity factor.

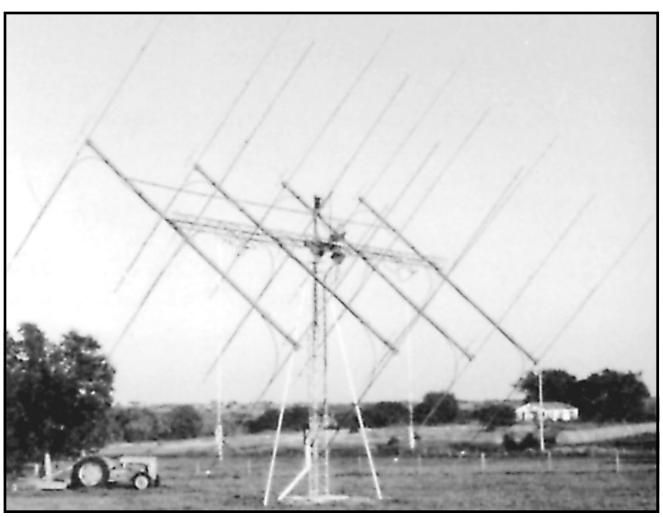


Fig 23—The EME antenna system used at N5BLZ consists of twelve 17-element, long boom 144-MHz Yagis. The tractor, lower left, really puts this array into perspective!

Several types of antennas have become popular among EME enthusiasts. Perhaps the most popular antenna for 144-MHz work is an array of either 4 or 8 long boom (14 to 15 dB gain) Yagis. The 4-Yagi array provides approximately 20 dB gain, and the 8-antenna system gives an approximate 3 dB increase over the 4-antenna array. At 432 MHz, 8 or 16 long boom Yagis are often used. Yagi antennas are commercially available, and can be constructed from readily available materials. Information on maximum gain Yagi antennas is presented in Chapter 18.

A moderately sized Yagi array has the advantage that it is relatively easy to construct, and can be positioned in azimuth and elevation with commercially available equipment. Matching and phasing lines present few problems. 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 as far as building complicated chain driven systems to allow constant polarization adjustment of all the Yagis in a large array. Polarization shift of EME signals at 144 MHz is fairly slow, and the added complexity of the cross-polarized antenna system or a sophisticated chain-driven polarity adjustment scheme may not be worth the effort. At 432 MHz, where the polarization shifts at a somewhat faster rate, an adjustable polarization system offers a definite advantage over a fixed one.

The Yagi antenna system used by Ed Stallman, N5BLZ, is shown in **Fig 23**. The system is comprised of 12 144-MHz long boom 17-element Yagi antennas. The Yagi arrays of Timo Korhonen, OH6NU, and Steve Powlishen, K1FO, are shown in **Figs 24** and **25**, respectively.

Quagi antennas (made from both quad and Yagi elements) are also popular for EME work. Slightly more gain per unit boom length is possible as compared to the conventional Yagi. Additional information on the Quagi is presented in Chapter 18.

The collinear array is another popular 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. Many operators using collinear arrays use 160-element or larger systems.

As with Yagi and Quagi antennas, the collinear cannot be adjusted easily for polarity changes. From a constructional standpoint, there is little difference in complexity and material costs between the collinear and Yagi arrays.

The parabolic dish is another antenna that is used extensively for EME work. Unlike the other antennas described, the major problems associated with dish antennas are mechanical ones. Dishes approaching 20 feet in diameter are required for successful EME operation on 432 MHz. Structures of this size with wind and ice loading place a severe strain on the mounting and positioning system. Extremely rugged mounts are required for large dish antennas, especially when used in windy locations.

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

Another advantage of this antenna is in the feed system. Th polarization of the feed, and therefore the polarization of the antenna, can be adjusted with little difficulty. It is a relatively easy matter to devise a system whereby the feed can be rotated remotely from the shack. Changes in polarization of the signal can thereby be compensated for at the operating position.

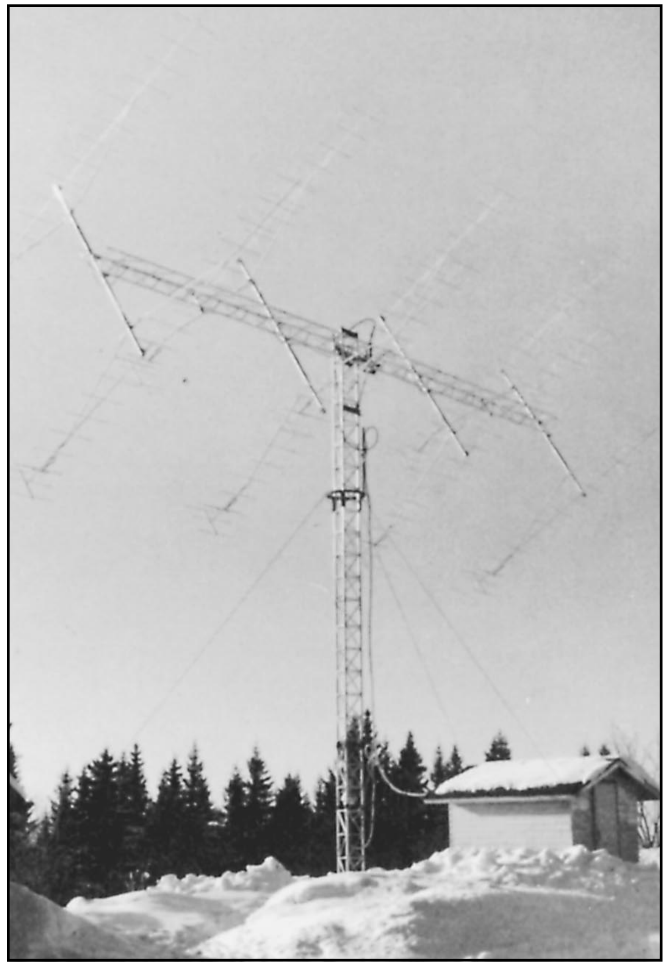


Fig 24—The Yagi array used for EME at OH6NU/OH6NM.

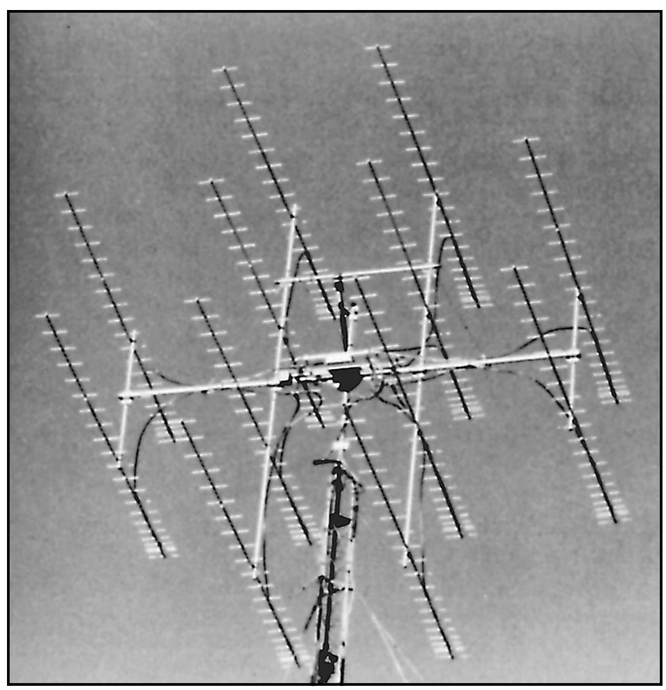


Fig 25—K1FO uses this system for serious moonbounce work.

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 parabolic dish under construction by Dave Wardley, ZL1BJQ, is shown in **Fig 26**. The 20-foot stressed parabolic dish used at F2TU is shown in **Fig 27**. More information on parabolic dish antennas is given later in this chapter and in Chapter 18.

Antennas suitable for EME work are by no means limited to the types described thus far. Rhombics, quad arrays, helicals and others can also be used. These antennas have not gained the popularity of the Yagi, Quagi, collinear and parabolic dish, however.

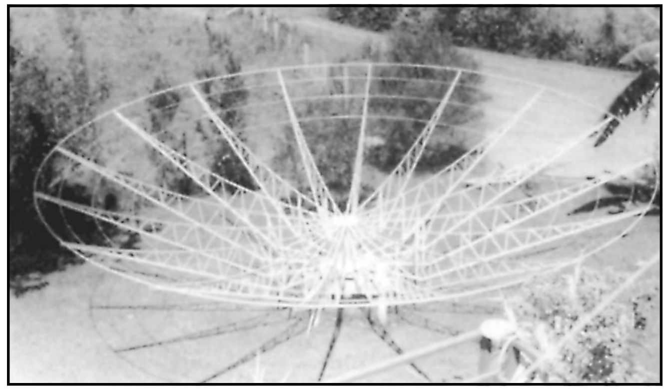


Fig 26—The 1/2-inch wire mesh is about all that is needed to complete this 7-meter diameter dish at ZL1BJQ.

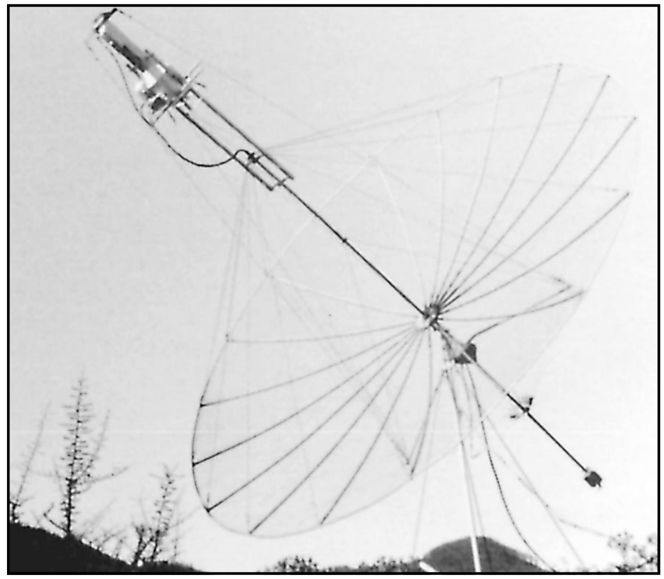


Fig 27—This 20-foot stressed parabolic dish is used for EME work at F2TU on 432 and 1296 MHz.

A 12-Foot Stressed Parabolic Dish

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 antenna 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 collinear arrays, the loss of the phasing harness increases as the size increases. The corresponding component of the parabola is lossless air between the feed horn and the reflecting surface. If there are few surface errors, the efficiency of the system stays constant regardless of antenna size. This project was presented by Richard Knadle, K2RIW, in August 1972 *QST*.

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.

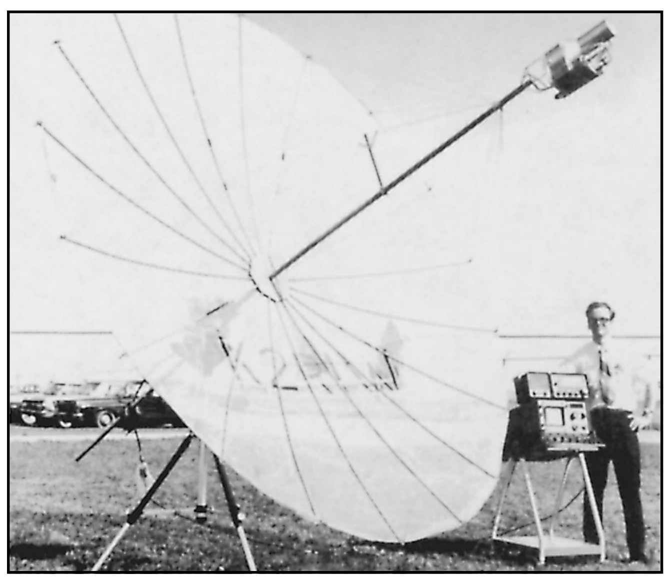


Fig 28—A 12-foot stressed parabolic dish set up for reception of Apollo or Skylab signals near 2280 MHz. A preamplifier is shown taped below the feed horn. The dish was designed by K2RIW, standing at the right. From QST, August 1972.

Such an antenna is shown in **Fig 28**. This parabolic dish is lightweight, portable, easy to build, and can be used for 432 and 1296-MHz mountaintopping, as well as on 2300, 3450 and 5760 MHz. Disassembled, it fits into the 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 string. 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 in a later section.

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.

Construction

Table 1 is a list of materials required for construction. Care must be exercised when drilling holes in the connecting center plates so assembly problems will not be experienced later. See **Fig 29**. A notch in each plate allows them to be assembled in the same relative positions. The two plates should be clamped together and drilled at the same time. Each of the 18 $^{1}/_{2}$-inch diameter aluminum spokes has two no. 28 holes drilled at the base to accept no. 6-32 machine screws

Table 1
Materials List for the 12-Foot Stressed Parabolic Dish

1) Aluminum tubing, 12 ft × $^{1}/_{2}$ in. OD × 0.049-in. wall, 6061-T6 alloy, 9 required to make 18 spokes.
2) Octagonal mounting plates 12 × 12 × $^{1}/_{8}$ in., 2024-T3 alloy, 2 required.
3) 1$^{1}/_{4}$ in. ID pipe flange with setscrews.
4) 1$^{1}/_{4}$ in. × 8 ft TV mast tubing, 2 required.
5) Aluminum window screening, 4 × 50 ft.
6) 130-pound test Dacron trolling line (available from Finney Sports, 2910 Glansman Rd, Toledo, OH 43614.)
7) 38 ft #9 galvanized fence wire (perimeter).
8) Two hose clamps, 1$^{1}/_{2}$ in.; two U bolts; $^{1}/_{2}$ × 14 in. Bakelite rod or dowel; water-pipe grounding clamp; 18 eye bolts; 18 S hooks.

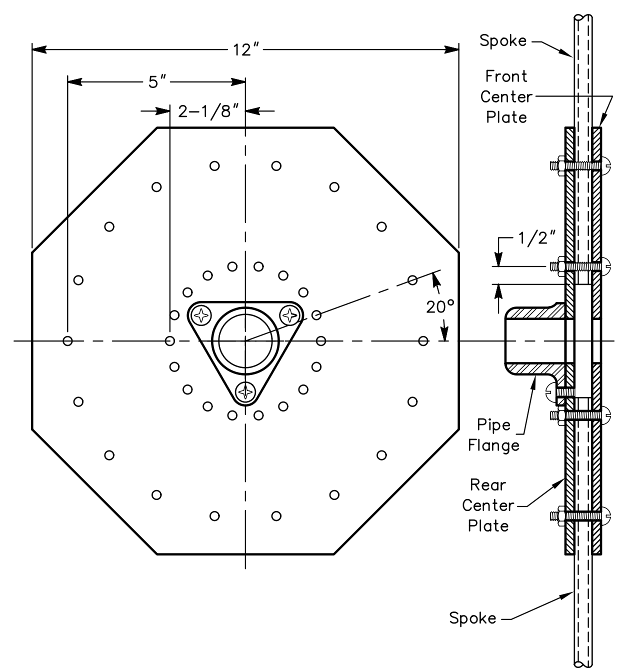


Fig 29—Center plate details. Two center plates are bolted together to hold the spokes in place.

that go through the center plates. The 6-foot long spokes are cut from standard 12-feet lengths of tubing. A fixture built from a block of aluminum assures that the holes are drilled in exactly the same position in each spoke. The front and back center plates constitute an I-beam type of structure that gives the dish center considerable rigidity.

A side view of the complete antenna is shown in **Fig 30**. Aluminum alloy (6061-T6) is used for the spokes, while 2024-T3 aluminum alloy sheet, 1/8 inch thick, is used for the center plates. (Aluminum has approximately three times the strength-to-weight ratio of wood, and aluminum cannot warp or become water logged.) The end of each of the 18 spokes has an eyebolt facing the dish focal point, which serves a dual purpose:

1) To accept the #9 galvanized fence wire that is routed through the screw eyes to define the dish perimeter, and

2) To facilitate rapid assembly by accepting the S hooks which are tied to the end of each of the lengths of 130-pound test Dacron fishing string.

The string bends the spokes into a parabolic curve; the dish may be adapted for many focal lengths by tightening or slackening the strings. Dacron was chosen because it has the same chemical formula as Mylar. This is a low-stretch material that keeps the dish from changing shape. The galvanized perimeter wire has a 5-inch overlap area that is bound together with baling wire after the spokes have been hooked to the strings.

The aluminum window screening is bent over the perimeter wire to hold it in place on the back of the spokes. Originally, there was concern that the surface perturbations (the spokes) in front of the screening might decrease the gain. The total spoke area is so small, however, that this fear proved unfounded.

Placing the aluminum screening in front of the spokes requires the use of 200 pieces of baling wire to hold the screening in place. This procedure increases the assembly time by at least an hour. For contest and mountaintop operation (when the screening is on the back of the spokes) no fastening technique is required other than bending the screen to overlap the wire perimeter.

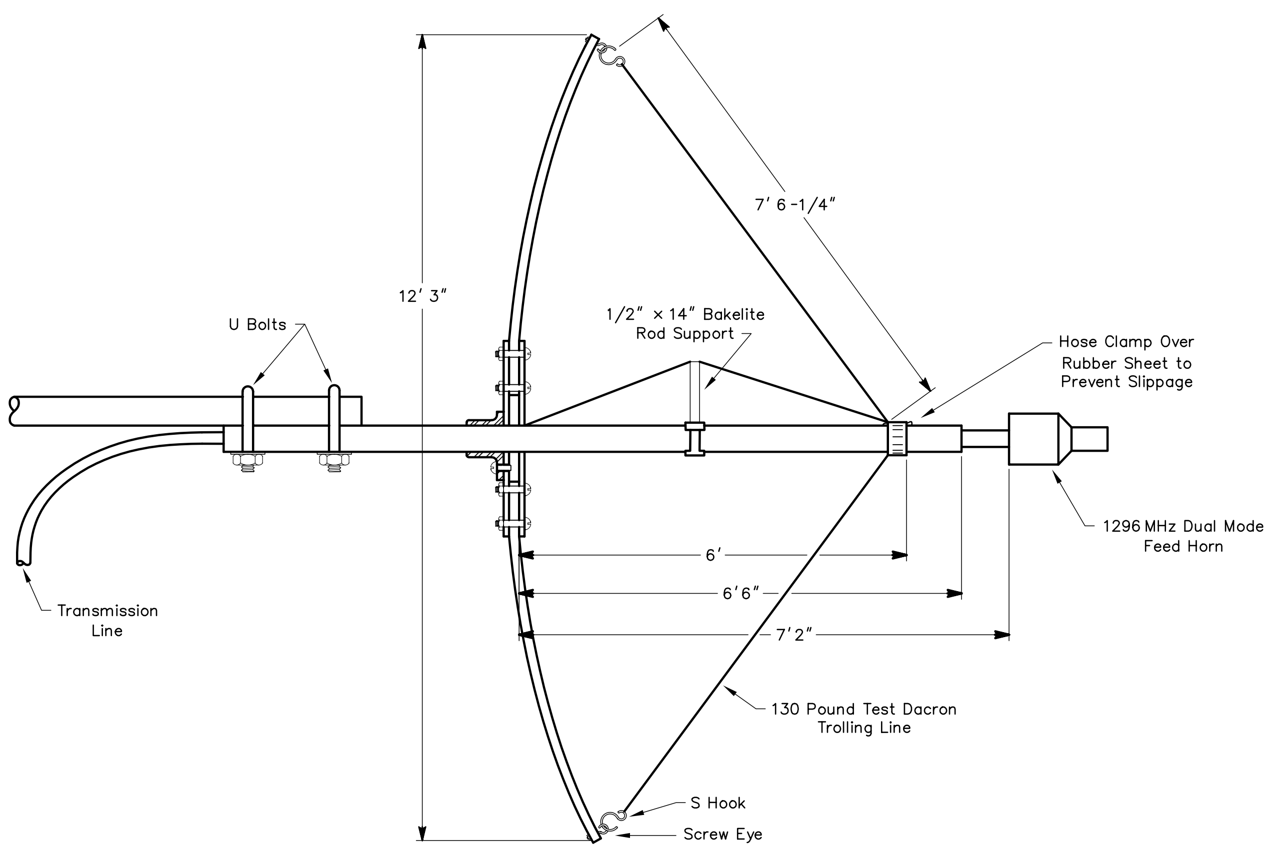


Fig 30—Side view of the stressed parabolic dish.

The Parabolic Surface

A 4-foot wide roll of aluminum screening 50 feet long is cut into appropriate lengths and laid parallel with a 3-inch overlap between the top of the unbent spokes and hub assembly. The overlap seams are sewn together on one half of the dish using heavy Dacron thread and a sailmaker's curved needle. Every seam is sewn twice; once on each edge of the overlapped area. The seams on the other half are left open to accommodate the increased overlap that occurs when the spokes are bent into a parabola. The perimeter of the screening is then trimmed. Notches are cut in the 3-inch overlap to accept the screw eyes and S hooks.

The first time the dish is assembled, the screening strips are anchored to the inside surface of the dish and the seams sewn in this position. It is easier to fabricate the surface by placing the screen on the back of the dish frame with the structure inverted. The spokes are sufficiently strong to support the complete weight of the dish when the perimeter is resting on the ground.

The 4-foot wide strips of aluminum screening conform to the compound bend of the parabolic shape very easily. If the seams are placed parallel to the E-field polarization of the feed horn, minimum feedthrough will occur. This feedthrough, even if the seams are placed perpendicular to the E field, is so small that it is negligible. Some constructors may be tempted to cut the screening into pie shaped sections. This procedure will increase the seam area and construction time considerably. The dish surface appears most pleasing from the front when the screening perimeter is slipped between the spokes and the perimeter wire, and is then folded back over the perimeter wire. In disassembly, the screening is removed in one piece, folded in half, and rolled.

The Horn and Support Structure

The feed horn is supported by 1$^1/_4$-inch aluminum television mast. The Hardline that is inserted into this tubing is connected first to the front of the feed horn, which then slides back into the tubing for support. A setscrew assures that no further movement of the feed horn occurs. During antenna gain competition the setscrew is omitted, allowing the $^1/_2$-inch semirigid CATV transmission line to move in or out while adjusting the focal length for maximum gain. The TV mast is held firmly at the center plates by two setscrews in the pipe flange that is mounted on the rear plate. At 2300 MHz, the dish is focused for best gain by loosening these setscrews on the pipe flange and sliding the dish along the TV mast tubing. (The dish is moved instead of the feed horn.)

The fishing strings are held in place by attaching them to a hose clamp that is permanently connected to the TV tubing. A piece of rubber sheet under the hose clamp prevents slippage and keeps the hose clamp from cutting the fishing string. A second hose clamp is mounted below the first as extra protection against slippage.

The high efficiency 1296-MHz dual mode feed horn, detailed in **Fig 31**, weighs 5$^3/_4$ pounds. This

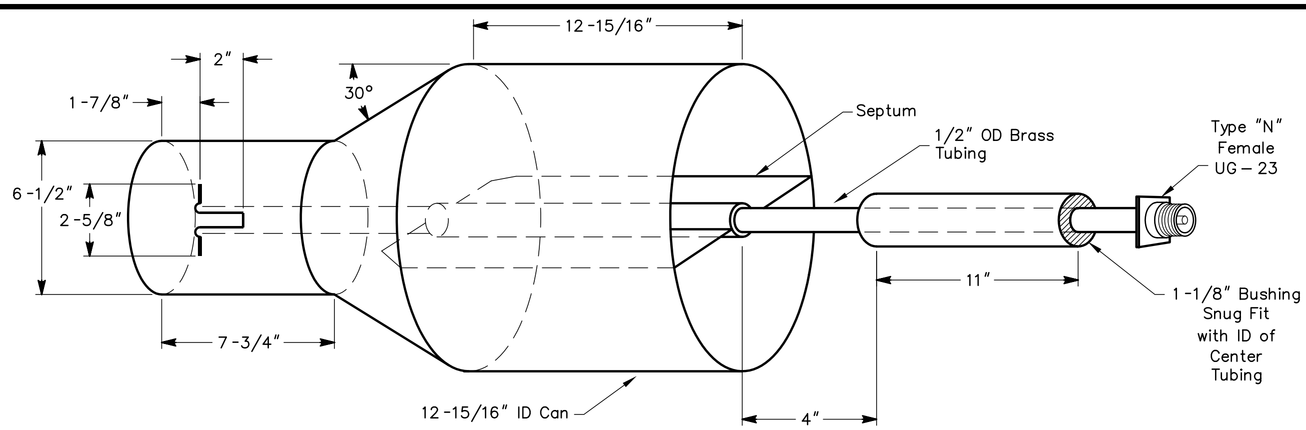


Fig 31—Backfire type 1296-MHz feed horn, linear polarization only. The small can is a Quaker State oil container; the large can is a 50-pound shortening container (obtained from a restaurant, Gold Crisp brand). Brass tubing, $^1/_2$-inch OD, extends from UG-23 connector to dipole. Center conductor and dielectric are obtained from $^3/_8$-inch Alumafoam coaxial cable. The dipole is made from $^3/_{32}$-inch copper rod. The septum and 30° section are made from galvanized sheet metal. Styrofoam is used to hold the septum in position. The primary gain is 12.2 dBi.

weight causes some bending of the mast tubing, but this is corrected by a 1/2-inch diameter bakelite support, as shown in Fig 30. This support is mounted to a pipe grounding clamp with a no. 8-32 screw inserted in the end of the rod. The bakelite rod and grounding clamp are mounted midway between the hose clamp and the center plates on the mast. A double run of fishing string slipped over the notched upper end of the bakelite rod counteracts bending.

The success of high efficiency parabolic antennas is primarily determined by feed horn effectiveness. The multiple diameter of this feedhorn may seem unusual. This patented dual mode feed, designed by Dick Turrin, W2IMU, achieves efficiency by launching two different kinds of waveguide modes simultaneously. This causes the dish illumination to be more constant than conventional designs.

Illumination drops off rapidly at the perimeter, reducing spillover. The feed backlobes are reduced by at least 35 dB because the current at the feed perimeter is almost zero; the phase center of the feed system stays constant across the angles of the dish reflector. The larger diameter section is a phase corrector and should not be changed in length. In theory, almost no increase in dish efficiency can be achieved without increasing the feed size in a way that would increase complexity, as well as blockage.

The feed is optimized for a 0.6 f/d dish. The dimensions of the feeds are slightly modified from the original design in order to accommodate the cans. Either feed type can be constructed for other frequencies by changing the scale of all dimensions.

Multiband Use

Many amateurs construct multiband antenna arrays by putting two dishes back to back on the same tower. This is cost inefficient. The parabolic reflector is a completely frequency independent surface, and studies have shown that a 0.6 f/d surface can be steered seven beamwidths by moving the feed horn from side to side before the gain diminishes by 1 dB. Therefore, the best dual band antenna can be built by mounting separate horns side by side. At worst, the antenna may have to be moved a few degrees (usually less than a beamwidth) when switching between horns, and the unused horn increases the shadow area slightly. In fact, the same surface can function simultaneously on multiple frequencies, making crossband duplex operation possible with the same dish.

Order of Assembly

1) A single spoke is held upright behind the rear center plate with the screw eye facing forward. Two 6-32 machine screws are pushed through the holes in the rear center plate, through the two holes of the spoke, and into the corresponding holes of the front center plate. Lock washers and nuts are placed on the machine screws and hand tightened.

2) The remaining spokes are placed between the machine screw holes. Make sure that each screw eye faces forward. Machine screws, lock washers, and nuts are used to mount all 18 spokes.

3) The no. 6-32 nuts are tightened using a nut driver.

4) The mast tubing is attached to the spoke assembly, positioned properly, and locked down with the setscrews on the pipe flange at the rear center plate. The S hooks of the 18 Dacron strings are attached to the screw eyes of the spokes.

5) The ends of two pieces of fishing string (which go over the bakelite rod support) are tied to a screw eye at the forward center plate.

6) The dish is laid on the ground in an upright position and #9 galvanized wire is threaded through the eyebolts. The overlapping ends are lashed together with baling wire.

7) The dish is placed on the ground in an inverted position with the focus downward. The screening is placed on the back of the dish and the screening perimeter is fastened as previously described.

8) The extension mast tubing (with counterweight) is connected to the center plate with U bolts.

9) The dish is mounted on a support and the transmission line is routed through the tubing and attached to the horn.

Parabola Gain Versus 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

±λ/8 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 ±λ/8. (A λ/8 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 1/8-λ 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 1/3). These small RMS accuracy requirements have discouraged many constructors who confuse them with ± peak errors.

Fig 32 may be used to predict the resultant gain of various dish sizes with typical errors. There are a couple of surprises, as shown in **Fig 33**. 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. 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.

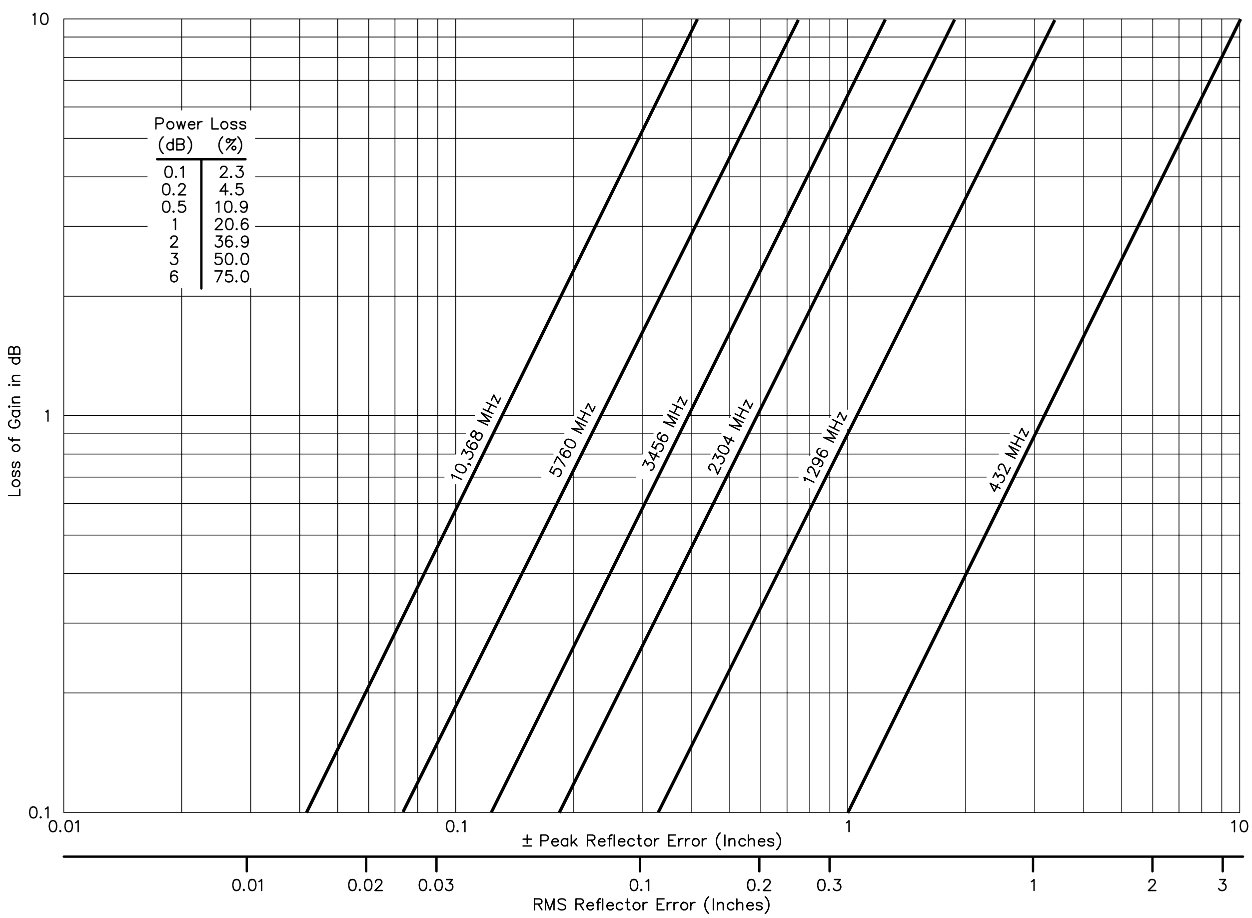


Fig 32—Gain deterioration versus reflector error. Basic information obtained from J. Ruze, British IEE.

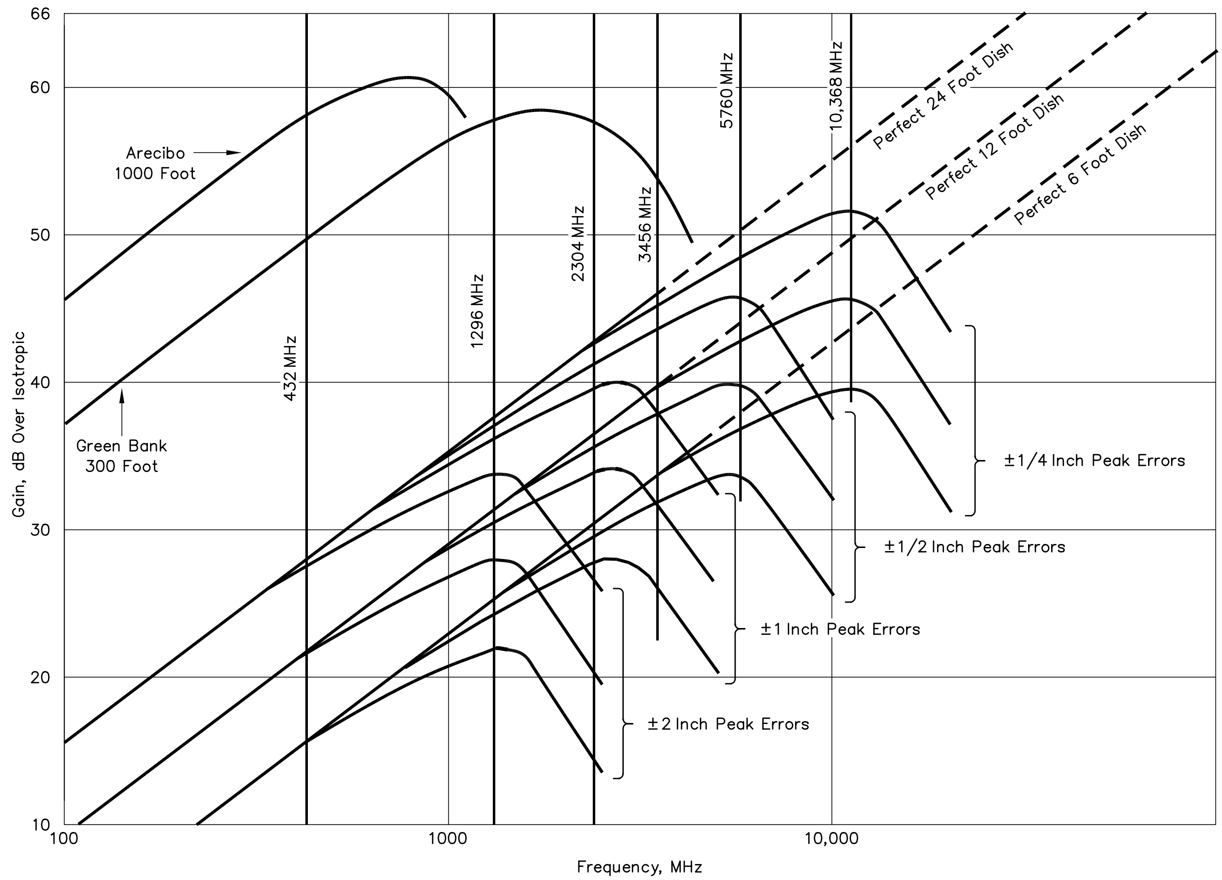


Fig 33—Parabolic-antenna gain versus size, frequency, and surface errors. All curves assume 60% aperture efficiency and 10-dB power taper. Reference: J. Ruze, British IEE.

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 built dipole and splasher feed 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 dB of gain on 2300 MHz, however, making it worthy of consideration.

The near-field range of this 12-foot stressed dish (actually 12 feet 3inches) 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 3/4 radius), and a correction was made. A recheck showed one main lobe, and the solar noise was almost 3 dB stronger.

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

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 mi/h 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-dB gain potential, it is a very good trade-off.

Poultry netting is very poor material for 2300 MHz and above, because the hole dimensions approach $^1/_2\ \lambda$. 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 $^1/_2$-inch mesh weighs 20 pounds per 100 square feet and has a wind loading characteristic of 162 pounds with 60 mi/h winds. The filled aperture is 16%, and this material is useful to 2300 MHz.

A rather interesting material worthy of investigation is $^1/_4$-inch reinforced plastic. It weighs only 4 pounds per 100 square feet. The plastic melts with many universal solvents such as lacquer thinner. If a careful plastic-melting job is done, what remains is the $^1/_4$-inch spaced aluminum wires with a small blob of plastic at each junction to hold the matrix together.

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 **Fig 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. Under ice and snow conditions, smaller aperture materials may become clogged, causing the surfacing material to act as a solid "sail." Ice and snow have a rather minor effect on the reflecting properties of the surface, however.

3) Amateurs who live in areas where ice and snow are prevalent should consider a de-icing scheme such as weaving enameled wire through the screening and passing a current through it, fastening water-pipe heating tape behind the screening, or soldering heavy leads to the screening perimeter and passing current through the screening itself.

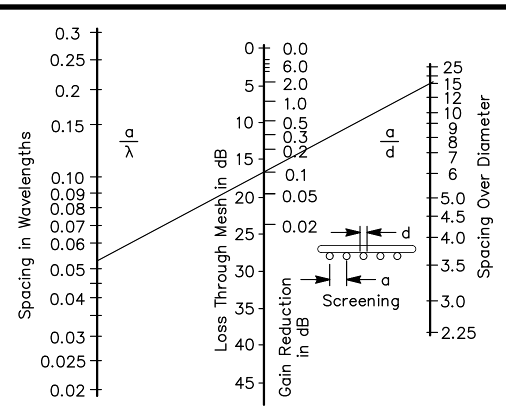
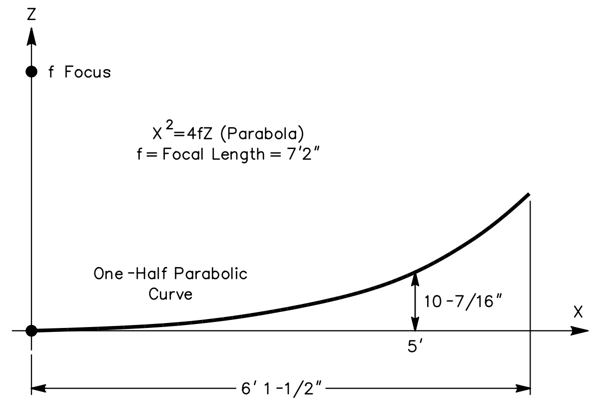


Fig 34—Surfacing material quality.

A Parabolic Template

At and above 2300 MHz (where high surface accuracy is required), a parabolic template should be constructed to measure surface errors. A simple template may be constructed (see **Fig 35**) by taking a 12-foot 3-inch length of 4-foot wide tar paper and drawing a parabolic shape on it with chalk. The points for the parabolic shape are calculated at 6-inch intervals and these points are connected with a smooth curve.

For those who wish to use the template with the surface material installed, the template should be cut along the chalk line and stiffened by cardboard or a wood lattice frame. Surface error measurements should take place with all spokes installed and deflected by the fishing lines, as some bending of the center plates does take place.



X	Z (to Nearest 1/16″)	X	Z
0.5′	1/8″	3.5′	5 -1/8″
1.0′	7/16″	4.0′	6 -11/16″
1.5′	15/16″	4.5′	8 -1/2″
2.0′	1 -11/16″	5.0′	10 -7/16″
2.5′	2 -5/8″	5.5′	12 -11/16″
3.0′	3 -3/4″	6.0′	15 -1/16″

Fig 35—Parabolic template for 12-foot, 3-inch dish.

Variations

All the possibilities of the stressed parabolic antenna have not been explored. For instance, a set of fishing lines or guy wires can be set up behind the dish for error correction, as long as this does not cause permanent bending of the aluminum spokes. This technique also protects the dish against wind loading from the rear. An extended piece of TV mast is an ideal place to hang a counterweight and attach the rear guys. This strengthens the structure considerably.

The Helical Antenna

The axial-mode helical antenna was introduced by Dr John Kraus, W8JK, in the 1940s. The material in this section was prepared by Domenic Mallozzi, N1DM.

This antenna has two characteristics that make it especially interesting and useful in many applications. First, the helix is circularly polarized. As discussed earlier, circular polarization is simply linear polarization that continually rotates as it travels through space. In the case of a helical array, the rotation is about the axis of the antenna. This can be pictured as the second hand of a watch moving at the same rate as the applied frequency, where the position of the second hand can be thought of as the instantaneous polarization of the signal.

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 that has both broad bandwidth and high gain. The benefit of this property is that, when used for narrow-band 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 results 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 by Bill Sykes, G2HCG, on VHF voice schedules over nonoptical paths, in cases where linearly polarized beams did not perform satisfactorily. (See Bibliography.) An array of linear antennas was used to develop a circularly polarized radiation pattern in this case. The helix is also a good antenna for long-haul commercial TV reception.

Another use for the helical antenna is the transmission of color ATV signals. Many beam antennas (when adjusted for maximum gain) have far less bandwidth than the required 6 MHz, or have nonuniform 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 nonoptical paths. The helix exhibits maximum gain (within 1 dB) over at least 6 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

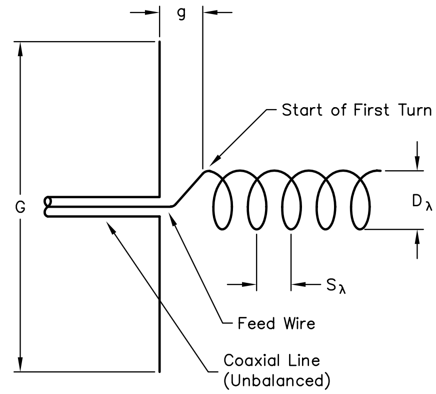
The helical antenna is an unusual specimen in the antenna world, in that its physical configuration gives a hint to its electrical performance. A helix looks like a large air-wound coil with one of its ends fed against a ground plane, as shown in **Fig 36**. The ground plane is a screen of 0.8 λ to 1.1 λ diameter (or on a side for a square ground plane). The circumference (C_λ) of the coil form must be between 0.75 λ 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. (It is possible, through special techniques, to make axial-mode helicals with as little as one turn.) 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

$$\alpha = \arctan \frac{S_\lambda}{C_\lambda}$$

These constraints result in a single main lobe along the axis of the coil. This is easily visualized from **Fig 37**. Assume the winding of the helix comes out of the page with a clockwise winding direction. (The winding can also be a counterclockwise—this results in the opposite polarization sense.)

A helix with a C_λ of 1 λ has a wave propagating from one end of the coil (at the ground plane). The "peak" (+) of the wave appears opposite the "valley" (–) of the wave. This corresponds to a dipole "across" the helix—with the same polarization as the instantaneous polarization of the helix at time T.

At a later time (T′), the "peak" and "valley" of the wave are at a slightly different angle rela-



C_λ = 0.75 to 1.33 λ
S_λ = 0.2126 C_λ to 0.2867 C_λ
G = 0.8 to 1.1 λ
g = 0.12 to 0.13 λ

$$\text{AR (axial ratio)} = \frac{2n+1}{2n}$$

S_λ = axial length of one turn
D_λ = diameter of winding
G = ground plane diameter (or side length)
g = ground plane to first turn distance
$C_\lambda = \pi D_\lambda$ = circumference of winding
n = number of turns
Gain (dBi) = 11.8 + 10 log ($C_\lambda^2 n S_\lambda$)

$$\text{Half power beamwidth (HPBW)} = \frac{52}{C_\lambda \sqrt{nS_\lambda}} \text{ degrees}$$

$$\text{Beamwidth to first nulls} = \frac{115}{C_\lambda \sqrt{nS_\lambda}} \text{ degrees}$$

Input impedance = 140 C_λ ohms
L_λ = length of conductor in one turn

$$= \sqrt{(\pi D_\lambda)^2 + S_\lambda^2}$$

Fig 36—The basic helical antenna and design equations.

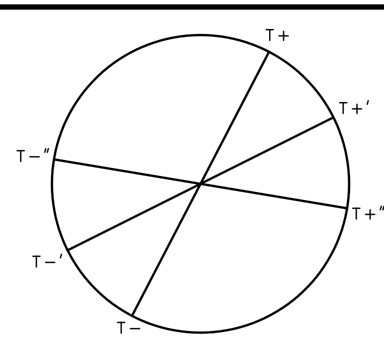


Fig 37—A helical antenna with an axial ratio of 1.0 produces pure circular polar-ization. See text.

tive to the original dipole. The polarization of the dipole antenna at this instant is slightly different. At an instant of time later yet (T″), the dipole has again "moved," changing the polarization slightly again.

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. True circular polarization results.

Physicists and engineers formerly had opposite terms for the same sense of polarization. Recently, the definition of polarization sense used by the Institute of Electrical and Electronic Engineers (IEEE) has become the standard. 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, and a counterclockwise wind results in left-hand circular polarization. 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 30 dB results from the cross polarization alone.

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

$$AR = \frac{2n + 1}{2n}$$

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.

Another method of measuring axial ratio was presented in *73* by A. Bridges, WB4VXP. (See the Bibliography at the end of this chapter.) The linear antenna is replaced by two circularly polarized antennas of equal gain but opposite polarization sense. Taking the amplitude measurement with first one and then the other, the following equation is used to calculate axial ratio:

$$AR = \frac{E_{rcp} + E_{lcp}}{E_{rcp} - E_{lcp}}$$

where

E_{rcp} is the voltage measured with the right-hand circularly polarized test antenna

E_{lcp} is the voltage measured with the left-hand circularly polarized test antenna

This equation gives not only the axial ratio, but also indicates the polarization sense. If the result is greater than zero, the antenna being excited is right-hand circularly polarized, and left-hand if negative. This method is useful to those measuring other types of elliptically polarized antennas with polarization senses that are not easily determined.

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

$$Z = 140 \times C_\lambda$$

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

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

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

$$BW = \frac{52}{C_\lambda \sqrt{n S_\lambda}}$$

The diameter of the helical antenna conductor should be between 0.006 λ 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 a clean radiation pattern is desired. 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 poultry netting.)

MATCHING SYSTEMS

Because helical antennas present impedances on the order of 110 to 180 Ω, the antenna must be matched for use with a 52-Ω transmission line. Matching systems for helical antennas are classified two ways: narrow band and wide band. Narrow band is generally recognized to represent bandwidths less than 25%. Narrow-band matching techniques are relatively straightforward; matching systems useful over the full frequency range of a helix are a bit more involved.

Many matching techniques are available. Some of the proven methods are discussed here. For narrow-band use, the simplest impedance-matching technique is the use of a $^1/_4$-λ series transformer. A 1-λ circumference helix has a feed-point impedance of approximately 140 Ω, so the transformer must be $^1/_4$ λ of 84-Ω transmission line. This line can be fabricated in microstrip form, or a piece of air-dielectric coax can be built, as shown by Doug DeMaw in November 1965 *QST*. (See Bibliography.)

Another solution is to design the helix so that its feed-point impedance allows the use of a standard impedance line for the matching transformer. This method was shown by D. Mallozzi in the March 1978 *AMSAT Newsletter*. This helix was designed with a circumference of 0.8 λ, resulting in an input impedance of 112 Ω. Standard 75-Ω coaxial cable can be used for the $^1/_4$-λ matching transformer in this case, as shown in **Fig 38**. Yet another matching method is to use a series section. For example, a 125-Ω helix may be matched to 52-Ω line by inserting 0.125 λ of RG-133 (95-Ω impedance) in the 52-Ω line at a distance of 0.0556 λ from the antenna feed point. Series section matching is discussed in Chapter 26.

The physical construction of a $^1/_4$-λ transformer or a series section at UHF is a project requiring careful measurement and assembly. For narrow bandwidths at relatively low frequencies (below 148 MHz), the familiar pi network can be used for impedance matching to helical antennas. Other matching methods are discussed in the references listed in the Bibliography at the end of this chapter.

Two series transformers can be used to allow operation of a helical antenna over its entire bandwidth (see **Fig 39**). This method is in use in a number of helical antenna installations and provides good performance.

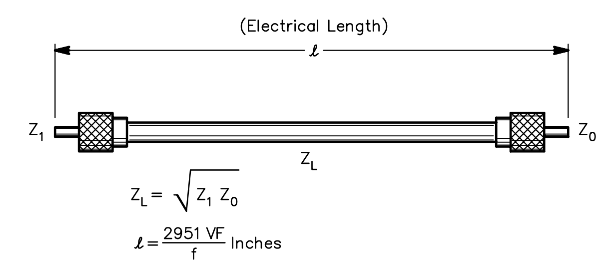


Fig 38—Narrow-band matching technique using a $^1/_4$-λ series transformer. In the length equation, VF = velocity factor of the cable; f = frequency, MHz.

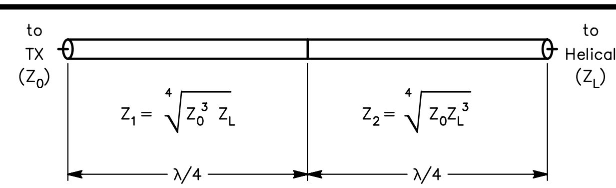


Fig 39—The dual series quarter-wave transformer is another means of matching 52-Ω coaxial cable to a helical antenna.

SPECIAL CONFIGURATIONS

Many special helical antenna configurations have been developed. These special configurations usually address improvements in one or more of four areas:

1) Easing mechanical construction.
2) "Cleaning up" the radiation pattern (reducing sidelobes and backlobes), and increasing gain.
3) Maximizing bandwidth.
4) Improving terminal characteristics.

Increasing the bandwidth of a helical antenna is not usually required in amateur applications. Many of the professional journals listed in the Bibliography have published articles discussing this subject, however. The other improvements listed all have applications in amateur work.

For example, the mechanical difficulty of making a helical antenna of the required diameter with the required conductor diameter is formidable at and below 148 MHz. Square or triangular winding forms are simpler than round forms at these frequencies. These configurations offer more mechanical stability under icing and wind conditions. Measurements indicate that if the perimeter of the form remains constant, it makes little difference in helical antenna characteristics if the cross-sectional shape is circular, square or triangular.

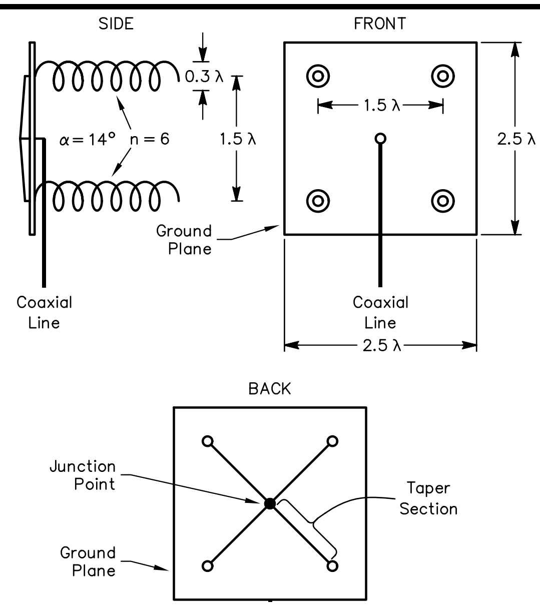


Fig 40—An array of four helicals on a common ground screen can provide as much gain as a single helix with four times as many turns as the individual helicals in the array. The benefits of this design include a cleaner radiation pattern and much smaller turning radius than a single long helix. See Fig 41 for detail of taper section.

Helical Antenna Variations

"Cleaning up" the radiation pattern (minimizing extraneous minor lobes) and increasing the gain of the helix can be done in a number of ways. The most common method of doing this is to mount three or four helical radiators on a single reflector and feed them in phase. This results in high gain with a cleaner radiation pattern than can be obtained with a single helical radiator having enough turns to obtain the same gain. Four 6-turn helicals mounted as shown in **Fig 40** exhibit essentially the same gain as a single 24-turn helix. The turning radius of the quad array of helicals is smaller than the turning radius of a single helix of equal gain. The four elements are fed in parallel, using the feed method shown in **Fig 41**.

Another method of reducing extraneous lobes is to use the helix to excite a conical horn. This method is somewhat cumbersome mechanically, but is useful in situations where very clean radiation patterns are required.

Combining two "good" antennas can sometimes result in a single "better" antenna. This is the case when a helix is used to feed a parabolic dish. The high gain inherent in the dish and the circular polarization afforded by the helix combine to make an excellent antenna for satellite and EME communications.

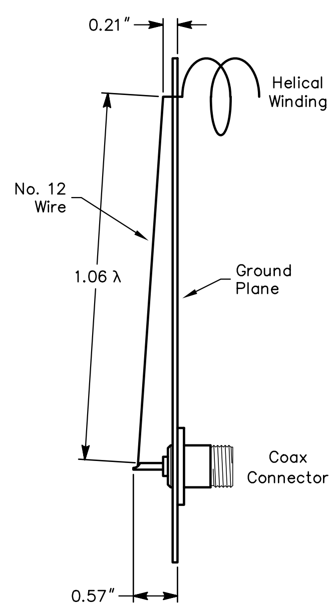


Fig 41—A diagram of one of the four tapered lines shown in Fig 40. This feed arrangement allows an array of four helicals to be fed directly with a 52-Ω line.

Such an antenna was built and tested at 465 MHz. The bandwidth was measured at more than 60 MHz. The antenna produces circular polarization with a sense opposite that of the feed helix. (The sense is reversed in reflection of the wave front from the parabolic surface.) This antenna is much easier to build than other types of circularly polarized dishes, because the mechanical construction of the feed is simpler.

This feed system is attractive to those who wish to use any of the common TVRO dishes that are available at reasonable cost. The gain of this combination at a given frequency is based on the illumination efficiency and size of the dish used.

When using short helical antennas in a quad array for reception, wiring a series resistor of 155 Ω $^1/_4$ λ from the open end of each helix improves the array performance. The sidelobe levels decrease, and matching and circularity (axial ratio) increase as a result of this modification. This performance improvement has been attributed to resistor dissipation of the unradiated energy reflected back toward the feed from the open end of the windings.

Publications such as *IEEE Transactions on Propagation and Antennas* and similar professional journals are a good source of information on the uses of helical antennas. University libraries often have these publications available for reference.

A Switchable Sense Helical Antenna

Constructing a pair of helix antennas for the 435-MHz band is quite simple. One antenna is wound for RHCP, and the other for LHCP, as shown in **Fig 42**. A good UHF relay and some Hardline are all that is needed to complete the system. Inexpensive, readily available materials are used for construction, and the dimensions of the helicals are not critical. Fig 36 shows the helix formulas and dimensions.

This antenna has a 70% bandwidth, and is ideal for a high gain, broad beamwidth satellite tracking antenna. This switchable antenna system and 50 to 100 W of RF output yield respectable signals on the Phase III satellites.

A detail of the complicated portion of the helix is shown in **Fig 43**. **Table 2** contains a keyed list of parts for the array. A good starting point for con-

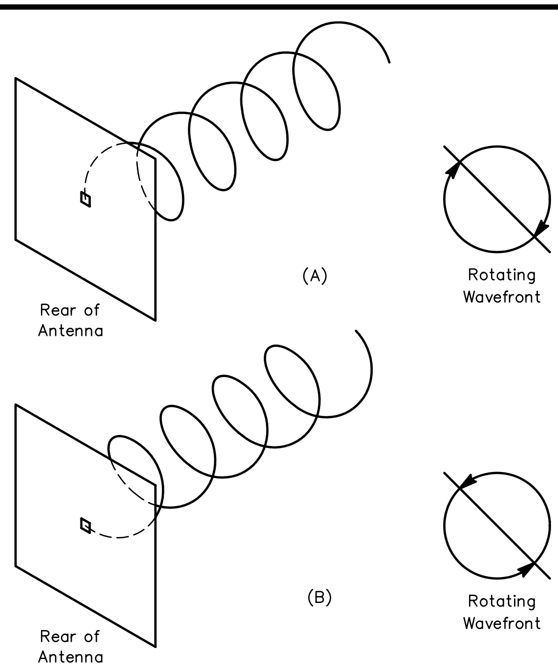


Fig 42—Right-hand circular polarization, A. Left-hand circular polarization, B.

Table 2
Parts List for the Helix Mounting Detail Shown in Fig 43

Piece No.	*Description*	*Comments*
1	U bolt, TV type	Use to bolt antenna to elevation boom
2	U bolt spacer	As above
3	U bolt nut with with lock washer	As above
4	Reflector mounting plate (see Fig 44)	Rivet through reflector to boom brackets
5	Type N coaxial receptacle	Rivet to mounting plate
6	1 × 2-inch heavy gauge wire mesh	Reflector, cut approx. 22 inches square
7	Helix boom-to-reflector brackets	Rivet through reflector to mounting plate
8	No. 8-32 bolts with nuts and washers	Bolt boom brackets to boom
9	Boom, approx. 1×1-inch tomato stake	2 pieces, 6 ft long.
10	Boom spacer, 1×1-inch	Boom to bolt; cut to give 9-inch spacing
11	No. 8 wood screws with washers	Attach spacers to boom (three places)

Notes:
1) Mount reflector mounting plate to boom brackets, leaving 9-in. clearance for boom.
2) Wire mesh may be bent to provide clearance for U bolts.
3) When positioning the reflector mounting plate, try to center the coaxial receptacle in the wire mesh screen.

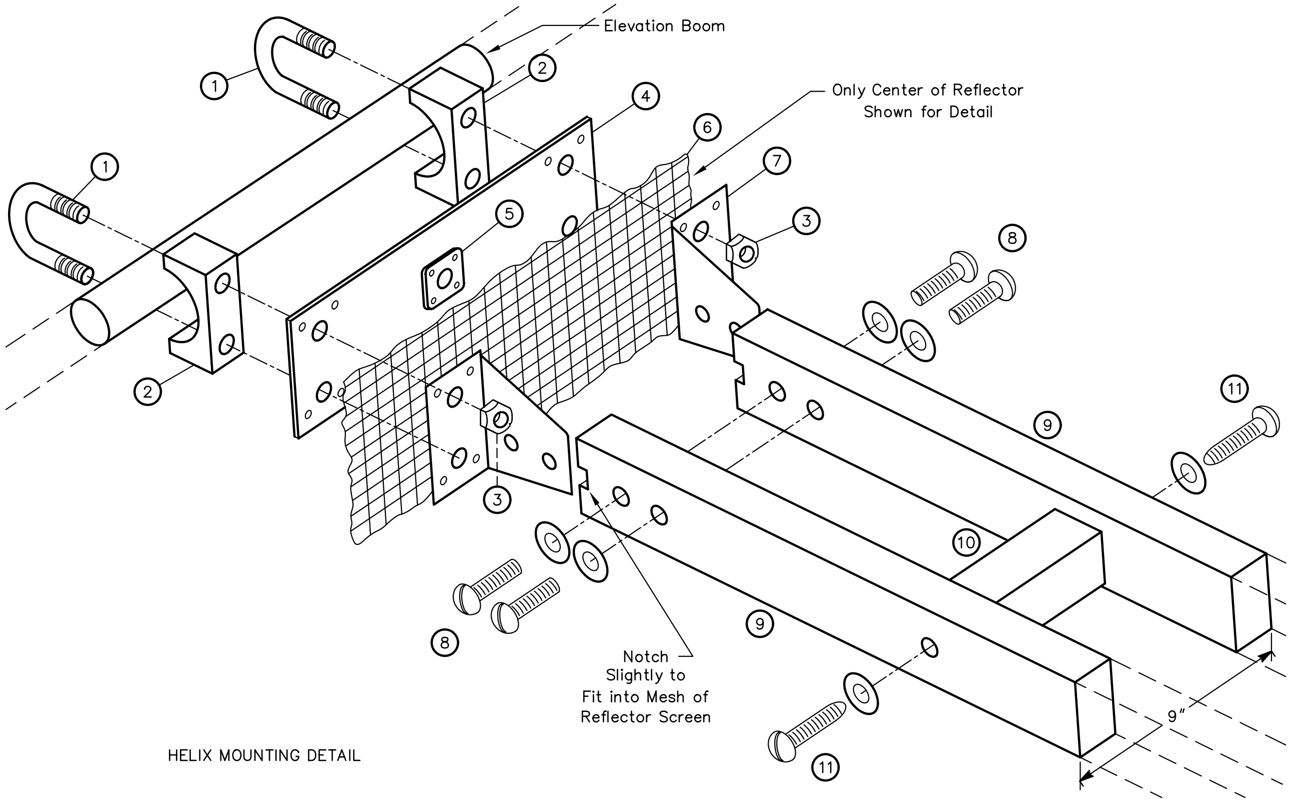


Fig 43—The details of the helix mounting arrangement. See Table 2 for a number-keyed parts list.

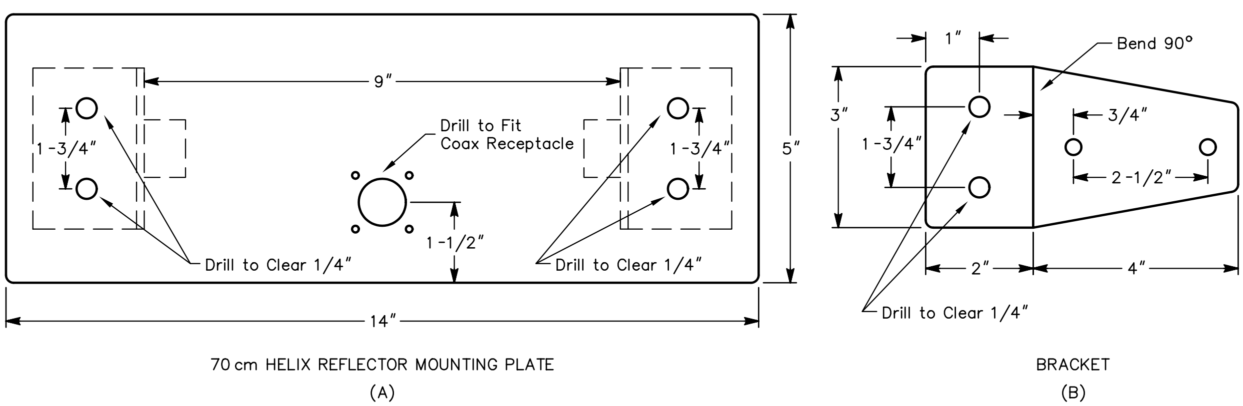


Fig 44—At A, the helix reflector mounting plate (part no. 4 in Table 2). At B, the boom brackets (part no. 7 in Table 2).

struction is the reflector, which is made of heavy wire mesh. This wire mesh is used in most UHF TV "bow tie" antennas. Wire companies and many hardware stores supply this material in 4-foot widths. It is 14-gauge galvanized steel, and sells for approximately $1.60 to $2 per lineal foot. A piece of mesh 2 × 4 feet is required to build two antennas. Trim the mesh so that no sharp ends stick out.

The next step is to make the reflector mounting plates and boom brackets. Follow the dimensions shown in **Fig 44**. Heavy aluminum material is recommended; 0.060 inch is the minimum recommended thickness. Thicker material is more difficult to bend, but two bends of 45° spaced about 1/4 inch apart will work fine for the brackets in this case. The measurements shown are for TV type 1 3/4 inch U bolts. If you use another size, change the dimensions appropriately. Drill the four holes in the reflector mounting plate and mount the coax receptacle, using pop rivets or stainless steel hardware.

Check the clearance between the coax receptacle and the elevation boom before final assembly. The thickness of the U-bolt spacers will affect this clearance. Mount a short piece of pipe (the same size as the elevation boom you will be using) to the U bolts, wire mesh reflector, reflector mounting plate and boom brackets. The elevation boom is shown in Fig 43. Position the plate in the center of the wire mesh reflector. (It may be necessary to bend some of the mesh to clear the U bolts.) Finger tighten the U bolts so the plate can be adjusted to fit the mesh.

The wood boom assembly shown in Fig 43 consists of two 6-foot wooden tomato stakes joined by spacers in three places. Mount one spacer in the center and the other spacers 1 foot from each end. Notch the ends of the boom to fit into the mesh. When the correct alignment is obtained, clamp the assembly together and drill holes for rivets or bolts through the reflector mounting plate, brackets and wood boom assembly. When drilling the boom holes, place the reflector flat on the floor and use a square so the boom is perpendicular to the reflector. Mark the boom through the holes in the boom bracket. When the assembly is complete, coat the wood boom with marine varnish.

The most unusual aspect of this antenna is its use of coaxial cable for the helix conductor. Coax is readily available, inexpensive, lightweight, and easy to shape into the coil required for the helix. Nine turns requires about 22 feet of cable, but start with 25 feet and trim off any excess. The antenna of **Fig 45** uses FM-8 coaxial cable, but any coax that is near the $^{1}/_{2}$-inch diameter required can be used. (The cable used must have a center conductor and shield that can be soldered together.)

Strip about 4 inches off one end of the cable down to the center conductor, but leave enough braid to solder to the center conductor. Solder the braid to the center conductor at this point. Measure the exposed center conductor 3.3 inches from the short and cut off the excess. (This is dimension g in Fig 36.)

Wind the 25-foot length of coax in a coil about 10 inches in diameter. Fig 42 shows which way to wind the coil for RHCP or LHCP. Slip the coil over the boom and move the stripped end of the cable toward the coax receptacle, which is the starting point of the nine turns. Solder the center conductor to the coax receptacle, and start the first turn 3.3 inches from the point of connection at the coax receptacle.

Use tie wraps to fasten the coax to the wood boom. Mark the boom using dimension S_λ in Fig 36. The first tie wrap is only half this distance when it first comes in contact with the boom; each successive turn on that side of the boom will be spaced by dimension S_λ. Use two tie wraps so they form an X around the boom and coax. Once the first wrap is secure, wind each turn and fasten the cable one point at a time. Before each turn is tightened, make sure the dimensions are correct.

When all nine turns are wound, check all dimensions again. Cut the coax at the ninth turn, strip the end, and solder the braid to the center conductor. The exposed solder connections at each end of the coax conductor should be sealed to weatherproof them.

A coaxial 75-Ω $^{1}/_{4}$-λ matching section as shown in Fig 38 is connected in series with the feed line at the antenna feed point. The length of this cable (including connectors) is 4.5 inches if the cable used has a velocity factor of 0.66. Lengths for other types of cable can be calculated from the equation in the drawing.

The impedance of the helix is approximately 140 Ω. To match the 52-Ω transmission line, a transformer of 85.3 Ω is required. The 75-Ω cable

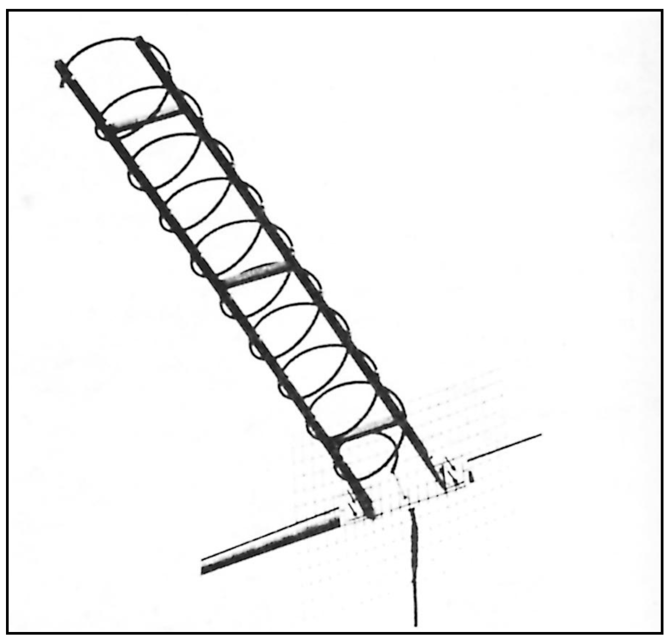


Fig 45—A close-up view of the 435-MHz helical antenna, designed and built by Bernie Glassmeyer, W9KDR.

used here is close enough to this value for a good match.The transformer should be connected directly to the female connector mounted on the reflector mounting plate. Use a double female adapter to connect the feed line to the matching transformer. Weatherproof the connectors appropriately.

To mount these antennas on an elevation boom, a counterbalance is required. The best way to do this is to mount an arm about 2 feet long to the elevation boom, at some point that is clear of the rotator, mast and other antennas. Point the arm away from the direction the helicals are pointing, and add weight to the end of the arm until balance is obtained. The completed antenna is shown in Fig 45.

Do not run long lengths of coax to this antenna, unless you use Hardline. Even short runs of good RG-8 coax are quite lossy; 50 feet of foam dielectric RG-8 has a loss of 2 dB at 430 MHz. There are other options if you must make long runs and can't use Hardline. Some amateurs mount the converters, transverters, amplifiers and filters at the antenna. This can be easily done with the helix antenna; the units can be mounted behind the reflector. (This also adds counterweight.) If this approach is used, check local electrical codes before running any power lines to the antenna.

52-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* (**Fig 46**). Connect the helix conductor to the N connector as close to the ground screen as possible (**Fig 47**). Then adjust the first turn of the helix to maintain uniform spacing of the turns.

This modification goes a long way toward curing a deficiency of the helix—the 140-Ω nominal feed-point impedance. The traditional $^1/_4$-λ matching section has proved difficult to fabricate and maintain. But if the helix is fed at the periphery, the first half 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

$$Z_0 = 138 \log \frac{4h}{d}$$

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 swoops 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 52 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 52-Ω match at practical (small) values of h. In this case, a strip of thin brass shim stock or flashing copper can be

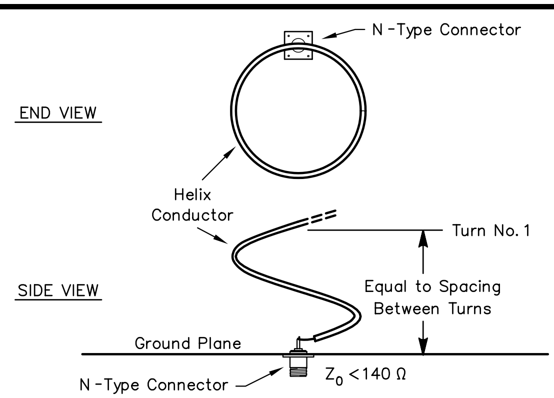


Fig 46—End view and side view of peripherally fed helix.

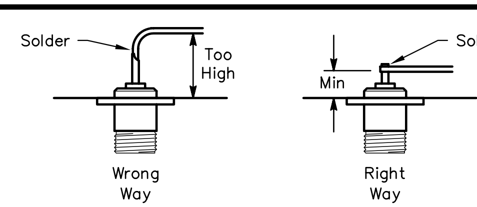


Fig 47—Wrong and right ways to attach helix to a type N connector for 52-Ω feed.

soldered to the first quarter turn of the helix conductor (**Fig 48**). This effectively increases the conductor diameter, which causes the impedance to decrease further yet. The edges of this strip can be slit every $^1/_2$ 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.

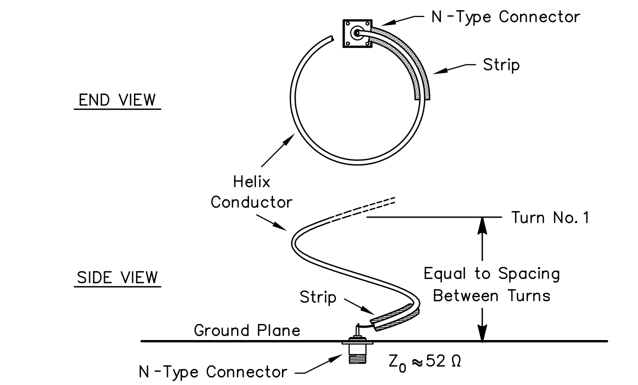


Fig 48—End view and side view of peripherally fed helix with metal strip added to improve transformer action.

Portable Helix for 435 MHz

Helicals for 435 MHz are excellent uplink antennas for Mode B satellite communications. The true circular polarization afforded by the helix minimizes signal "spin fading" that is so predominant in these operations. The antenna shown in **Fig 49** 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.

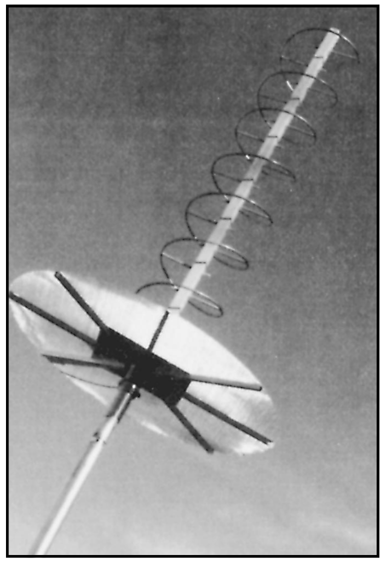


Fig 49—The portable 435-MHz helix, assembled and ready for operation. (WØCY photo)

As mentioned previously, 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, however. Most of the materials specified are available in any well supplied "do it yourself" hardware or building supply store. The materials required to construct the portable helix are listed in **Table 3**.

The portable helix consists of eight turns of $^1/_4$-inch soft copper tubing spaced around a 1-inch fiberglass tube or maple dowel rod 4 feet 7 inches long. Surplus aluminum jacket Hardline can be used in lieu of the copper tubing if necessary. The turns of the helix are supported by 5-inch lengths of $^1/_4$-inch maple dowel that are mounted through the 1-inch rod in the center of the antenna.

Table 3
Parts List for the Portable 435-MHz Helix

Qty	*Item*
1	Type N female chassis mount connector
18 ft	$^1/_4$-in. soft copper tubing
4 ft	1-in. ID galvanized steel pipe
1	5 ft × 1-in. fiberglass tube or maple dowel
14	5-in. pieces of $^1/_4$-in. maple dowel (6 ft total)
1	$^1/_8$-in. aluminum plate, 10 in. diameter
3	2 × $^3/_4$-in. steel angle brackets
1	30 × 30-in. (round or square) aluminum screen or hardware cloth
8 ft	$^1/_2$ × $^1/_2$ × $^1/_2$-in. aluminum channel stock or old TV antenna element stock
3	Small scraps of Teflon or polystyrene rod (spacers for first half turn of helix)
1	$^1/_8$ × 5 × 5-in. aluminum plate (boom to mast plate)
4	1$^1/_2$-in. U bolts (boom to mast mounting)
3 ft	#22 bare copper wire (helix turns to maple spacers)

Assorted hardware for mounting connector, aluminum plate and screen, etc.

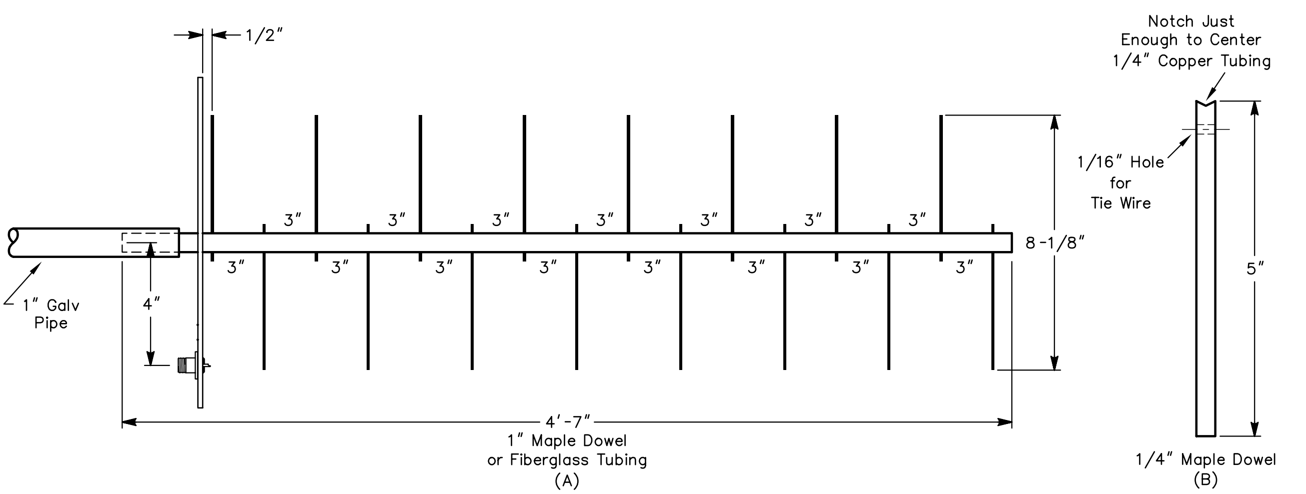


Fig 50—At A, the layout of the portable 435-MHz helix is shown. Spacing between the first 5-inch winding-support dowel and the ground plane is $^1/_2$ inch; all other dowels are spaced 3 inches apart. At B, the detail of notching the winding-support dowels to accept the tubing. As indicated, drill a $^1/_{16}$-inch hole below the notch for a piece of small wire to hold the tubing in place.

Fig 50A shows the overall dimensions of the antenna. Each of these support dowels has a V shaped notch in the end to locate the tubing (see Fig 50B).

The rod in the center of the antenna terminates at the feed-point end in a 4-foot piece of 1-inch ID galvanized steel pipe. The pipe serves as a counterweight for the heavier end of the antenna (that with the helical winding). The 1-inch rod material that is inside the helix must be nonconductive. Near the point where the nonconductive rod and the steel pipe are joined, a piece of aluminum screen or hardware cloth is used as a reflector screen.

If you have trouble locating the $^1/_4$-inch soft copper tubing, try a refrigeration supply house. The perforated aluminum screening can be cut easily with tin snips. This material is usually supplied in 30 × 30-inch sheets, making this size convenient for a reflector screen. Galvanized $^1/_4$-inch hardware cloth or copper screen could also be used for the screen, but aluminum is lighter and easier to work with.

A $^1/_8$-inch thick aluminum sheet is used as the support plate for the helix and the reflector screen. Surplus rack panels provide a good source of this material. **Fig 51** shows the layout of this plate.

Fig 52 shows how aluminum channel stock is used to support the reflector screen. (Aluminum tubing also works well for this. Discarded TV antennas provide plenty of this material if the

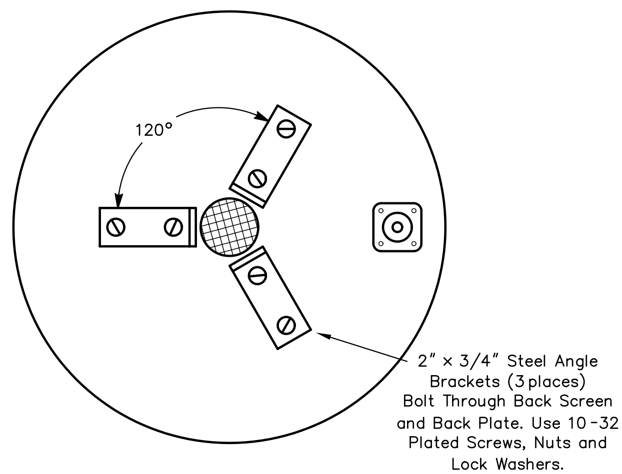


Fig 51—The ground plane and feed-point support assembly. The circular piece is a 10-inch diameter, $^1/_8$-inch thick piece of aluminum sheet. (A square plate may be used instead.) Three 2 × $^3/_4$-inch angle brackets are bolted through this plate to the back side of the reflector screen to support the screen on the pipe. The type N female chassis connector is mounted in the plate four inches from the 1-inch diameter center hole.

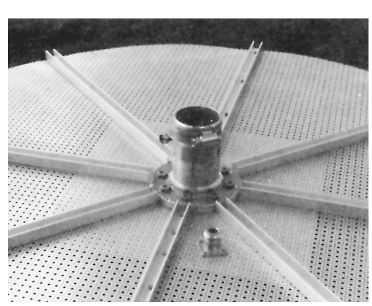


Fig 52—The method of reinforcing the reflector screen with aluminum channel stock. In this version of the antenna, the three angle brackets of Fig 51 have been replaced with a surplus aluminum flange assembly. (WØCY photo)

channel stock is not available.) The screen is mounted on the bottom of the 10-inch aluminum center plate. The center plate, reflector screen and channel stock are connected together with plated hardware or pop rivets. This support structure is very sturdy.

Fiberglass tubing is the best choice for the center rod material. Maple dowel can be used, but is generally not available in lengths over 3 feet. If maple must be used, the dowels can be spliced together by drilling holes in the center of each end and inserting a short length of smaller dowel into one of them. One of the large dowel ends should be notched, and the end of the other cut in a chisel shape so that they fit together. The small dowel can then be epoxied into both ends when they are fitted together. **Fig 53** illustrates this method of splicing dowels. The splice in the dowels should be placed as far from the center plate as possible to minimize stress on the connection.

Mount the type N connector on the bottom of the center plate with the appropriate hardware. The center pin should be exposed enough to allow a flattened end of the copper tubing to be soldered to it. Tin the end of the tubing after it is flattened so that no moisture can enter it. If the helix is to be removable from the ground-plane screen, do not solder the copper tubing to the connector. Instead, prepare a small block of brass, drilled and tapped at one side for a no. 6-32 screw. Drill another hole in the brass block to accept the center pin of the type N connector, and solder this connection. Now the connection to the copper tubing helix can be made in the field with a no. 6-32 screw instead of with a soldering iron.

Refer to Fig 50A. Drill the fiberglass or maple rod at the positions indicated to accept the 5-inch lengths of $^1/_2$-inch dowel. (If maple doweling is used, the wood must be weatherproofed as described below before drilling.) Drill a $^1/_{16}$-inch hole near the notch of each 5-inch dowel to accept a piece of #22 bare copper wire. (The wire is used to keep the copper tubing in place in the notch.) Sand the ends of the 5-inch dowels so the glue will adhere properly, and epoxy them into the main support rod.

Begin winding the tubing in a clockwise direction from the reflector screen end. First drill a hole in the flattened end of the tubing to fit over the center pin of the type N connector. Solder it to the connector, or put the screw into the brass block described earlier. Carefully proceed to bend the tubing in a circular winding from one support to the next.

Fig 54 shows how the first half turn of the helix tubing must be positioned about $^1/_4$ inch above the reflector assembly. It is important to maintain this spacing, as extra capacitance between the tubing and ground is required for impedance-matching purposes.

Insert a piece of #22 copper wire in the hole in each support as you go. Twist the wire around the tubing and the support dowel. Solder the wire to the tubing and to itself to keep the tubing in the notches. Continue in this way until all eight turns have been wound. After winding the helix, pinch the far end of the tubing together and solder it closed.

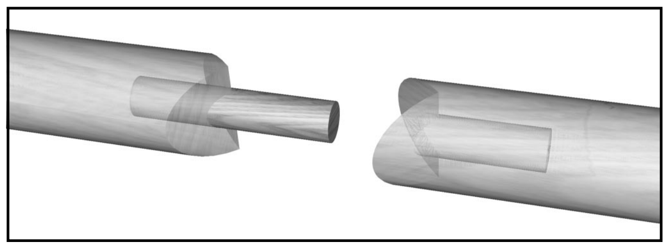


Fig 53—Close-up view of the dowel-splicing method. One dowel is notched, and the other is cut in a wedge shape to fit into the notch. Before this is done, both ends are drilled to accept a small piece of dowel ($^1/_4$ inch), which is glued into one of the ends. The large dowels should both be weatherproofed before splicing.

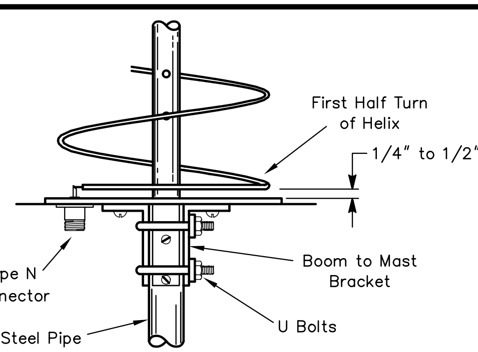


Fig 54—Side view of the helix feed-point assembly. The first half turn of the helix should be kept between $^1/_4$ and $^1/_2$ inch above the ground screen during winding. The height above the screen is adjusted for optimum match to a 52-Ω transmission line after the antenna is completed.

Weatherproofing the Wood

A word about preparing the maple doweling is in order. Wood parts must be protected against the weather to ensure long service life. A good way to protect wood is to boil it in paraffin for about half an hour. Any holes to be drilled in the wooden parts should be drilled *after* the paraffin is applied, as epoxy does not adhere well to wood after it has been coated with paraffin. The small dowels can be boiled in a saucepan. Caution must be exercised here—the wood can be scorched if the paraffin is too hot. Paraffin is sold for canning purposes at most grocery stores.

The center maple dowel is too long to put in a pan for boiling. A hair drier can be used to heat the long dowel, and paraffin can then be rubbed onto it. Heat the wood again to impregnate the surface with paraffin. This process should be repeated several times to ensure proper weatherproofing. Wood parts can also be protected with three or four coats of spar varnish. Each coat must be allowed to dry fully before another coat is applied.

The fiberglass tube or wood dowel must fit snugly with the steel pipe. The dowel can be sanded or turned down to the appropriate diameter on a lathe. If fiberglass is used, it can be coupled to the pipe with a piece of wood dowel that fits snugly inside the pipe and the tubing. Epoxy the dowel splice into the pipe for a permanent connection.

Drill two holes through the pipe and dowel and bolt them together. The pipe provides a solid mount to the boom of the rotator, as well as most of the weight needed to counter-balance the antenna. More weight can be added to the pipe if the assembly is "front-heavy." (Cut off some of the pipe if the balance is off in the other direction.)

The helix has a nominal impedance of about 105 Ω in this configuration. By varying the spacing of the first half turn of tubing, a good match to 52-Ω coax should be obtainable. If the SWR cannot be brought below about 1.5:1, a 6-inch length of copper flashing material can be added to the first half turn of the helix, as shown in **Fig 55**. The flashing material should be added as close to the coaxial cable connector as possible.

When the spacing has been established for the first half turn to provide a good match, add pieces of polystyrene or Teflon rod stock between the tubing and the reflector assembly to maintain the spacing. These can be held in place on the reflector assembly with silicone sealant. Be sure to seal the type N connector with the same material.

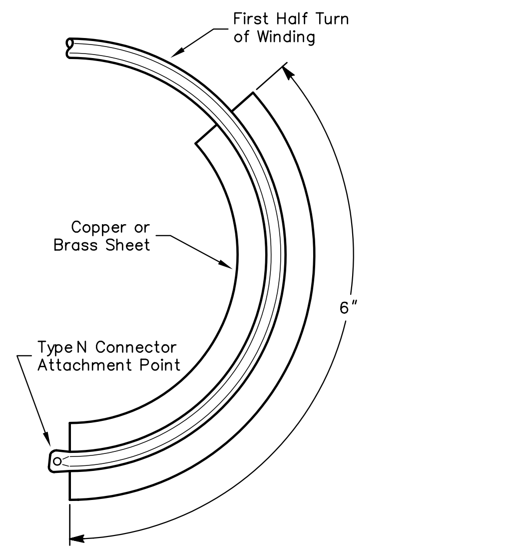


Fig 55—If the match to the antenna cannot be obtained with the tubing alone, a 6-inch piece of copper flashing material can be soldered to the bottom of the first turn of the helix, starting very close to the feed point. The spacing can then be adjusted for best match as described in the text. When the appropriate spacing has been found, affix Teflon or polystyrene blocks between the screen and the winding with silicone sealant to maintain the spacing.

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