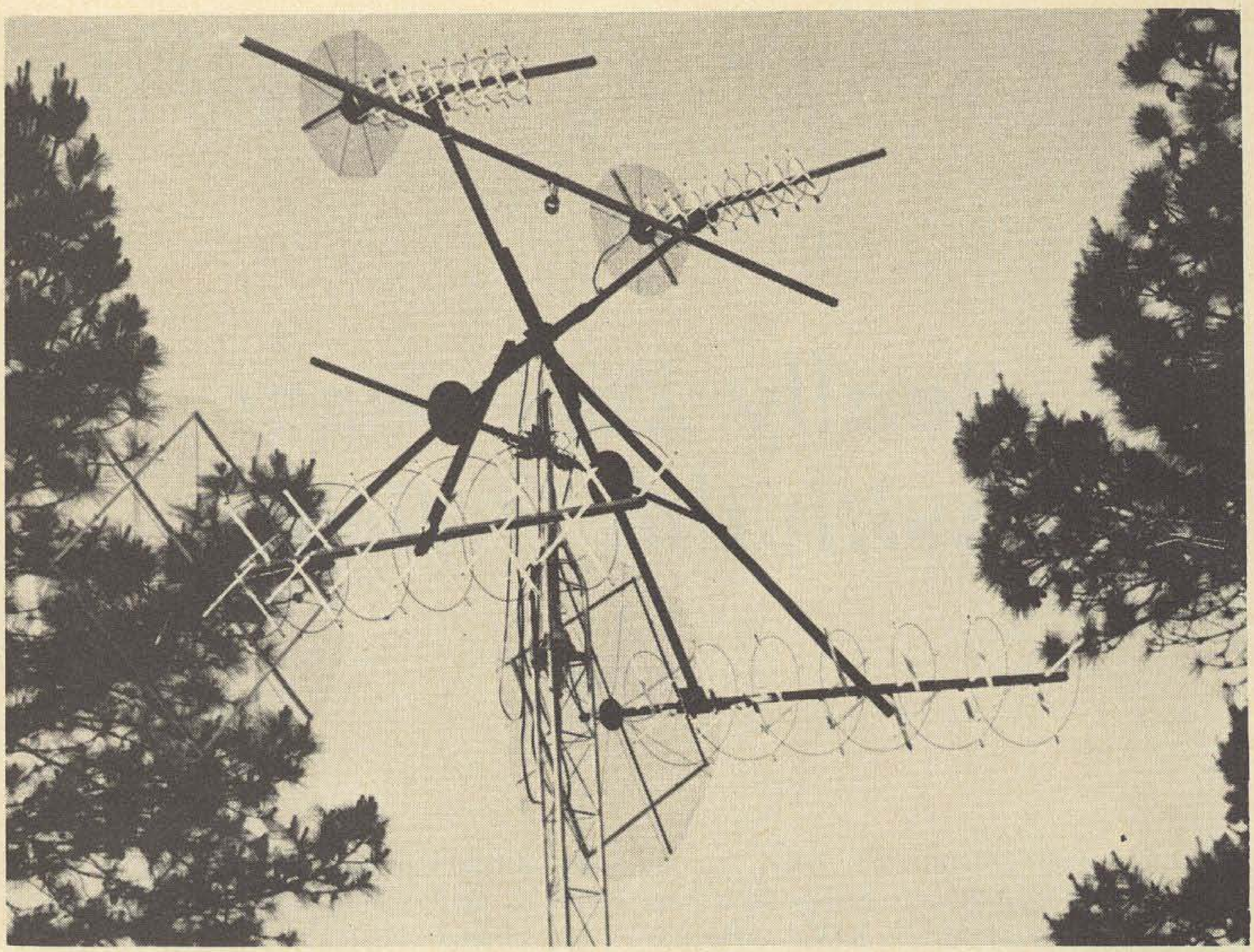
Alan L. Bridges WB4VXP
2754 Pine Hill Dr. NW
Kennesaw GA 30144

Really Zap Oscar with this Helical

Part One

The helical antenna has been around since the 1940's or earlier – it was invented by Dr. John D. Kraus, who has written many papers on helical antennas and their properties [1]. The helical beam antenna or the axial mode helix has several unusual characteristics which make it desirable for use in amateur satellite and space communications. This antenna operates as an end-fire or beam antenna and generates circularly polarized radiation. This type of radiation persists over a 2-to-1 range in frequency, while the gain is nearly maximum over this range. The gain and the beam width, as well as other characteristics of the axial mode helix, depend upon the number of turns; the more turns, the higher the gain and consequently the narrower the beam width. The axial mode helix can be used in designing a versatile, high performance antenna system since one can achieve right circular, left circular, and linear polarizations with helices. With satellite communications becoming an important facet of amateur radio (especially with OSCAR 7), an array of helices for both 2 meters and 70 centimeters with moderate gain was built during the spring and summer of 1974. The antenna array, which is shown in the photos, consists of four antennas in total, with a pair of helical beam antennas, of opposite sense, for both 2 meters and 70 centimeters, so that right circular, left circular, and linear polarizations can be selected.

If beam antennas are used with amateur radio communications satellites, such as the OSCARs, then one must be able to "track" or follow the satellite by using azimuth-elevation rotators. A narrow beamwidth or high gain antenna makes the tracking more difficult, as a narrower beamwidth requires greater pointing and tracking accuracy; when designing moderate to high gain narrow beamwidth antennas, this point must be kept in mind. It was my belief that the number of turns for a helical beam antenna for use with the OSCAR 6 & 7 satellites should be between 6 and 8 turns. Thus a desirable gain and half-power beamwidth are of the order of 10 to 15 dBi and 45 to 50 degrees, respectively. With the assistance of Cliff Burdette WA8GRE, I have made antenna pattern measurements that indicated a half-power beamwidth of 39 degrees and a gain of 16 dB over a half wave dipole for an 8 turn helix designed for 70 cm and tested at 445 MHz. A helix of more than 8 turns represents a gain too high to be used for amateur satellite communications (i.e., the beamwidth would be too narrow), unless



The antenna array completed and installed on the tower. The 70 cm helices are at the top, with the 2 m helices at the bottom. Each pair of helices are of opposite sense. The conduit or horizontal boom on which the elevation rotor is mounted is 10 feet long, making the size of the array about 11x11 feet.

very precise, automatic tracking is available.

There are, of course, certain tradeoffs that have to be made in using high gain antennas for OSCAR 6 and 7, as using an omnidirectional, low gain antenna with an effective radiated power of 80 to 100 Watts is recommended and, in fact, does not present the problems associated with successful tracking of satellite passes. But building and experimenting with helical beam antennas has been most enjoyable. This article describes the helical beam antenna, its design parameters and characteristics, the basic design, construction and installation of the helices that I have built, and antenna range measurements and results.

Circular Polarization

A brief discussion of circular polarization and the nomenclature used in describing the polarization and sense of the helices is necessary. Circular polarization is desired for space and satellite communications since periodic fading, due to the Faraday Effect as well as tumbling of the satellite, is encountered in trans-ionospheric propagation. Linear polarization is not desirable because of a periodic rotation of the polarization of the radio wave (known as Faraday rotation) as it passes through the ionosphere. For instance, a horizontally polarized antenna would receive very little energy from a wave that was initially horizontally polarized but that had become vertically polarized after traveling through the ionosphere.

With linear antennas the electric vector of the electromagnetic wave radiated from the antenna is parallel to itself, i.e. on a fixed line at all times, whereas in the case of circular polarization the electric field vector rotates continuously around an axis in the direction of propagation, that is, describes a circle. Fig. 1(a) shows how linear polarization maps out a line on a plane normal to the direction of propagation, while Fig. 1(b) shows how circular polarization maps out a circle. Detailed discussions of circular polarization can be found in References 2, 4, 5 and 6. Circular polarization can be generated by various methods, the most common being crossed linear antennas and helical antennas. The helical antenna is preferred since it has a wide bandwidth, non-critical dimensions, and high unidirectional gain, whereas crossed yagis, for instance, have narrow bandwidths, critical dimensions and impedance-matching problems. Here we are talking about either right circular polarization (r.c.p.) or left circular polarization (l.c.p.)*; alternately we speak of clockwise or anticlockwise polarization which refers to the direction of rotation of the approaching wave.

The axial mode helix can be "wound" for either r.c.p. or l.c.p., and linear polarization is obtained by feeding a left-hand and a right-hand helix in phase. Thus a versatile system can be built around the basic helical beam antenna.

Axial Mode Helix And Its Characteristics

The helix is a basic geometrical form, and can be described in terms of a conductor wound on an imaginary cylinder. The diameter of the helix and the spacing between each turn determine the performance and the radiation mode of the helix. When the circumference of the helix is of the order of 1 wavelength ($0.75\ \lambda < C\lambda < 1.33\ \lambda$, where $C\lambda$ is the circumference in wave lengths), the helix radiates in the axial or beam mode. This particular mode produces radiation that is maximum along the axis of the helix and that is circularly polarized. A broadside or omnidirectional pattern can be obtained with other dimensions, but since we are mainly interested in the beam mode we will not discuss the other modes [1,2]. The pattern shape, circular polarization, and terminal impedance are relatively stable over a wide frequency range. Basically, the axial mode is generated by using a ground plane or screen reflector mounted behind the helix conductor or driven element and fed by a coaxial line as seen in Fig. 2(a). The dimensions associated with the helix as seen in Figs. 2(a) and 2(b) are:

D = Diameter of the helix
S = Spacing between turns
α = Pitch angle = Arctan $(\frac{S}{\pi D})$
L = Length of 1 turn
n = Number of turns
A = Axial length = nS
d = Diameter of conductor
g = Distance of ground plane to first turn
G = Ground plane diameter

If one turn of the helix were unrolled on a flat plane the circumference (πD), the spacing (S), the turn length (L), and the pitch angle α are related by the triangle shown in Fig. 2(b). Since the turn length L equals:

$$\sqrt{(\pi D)^2 + S^2}$$

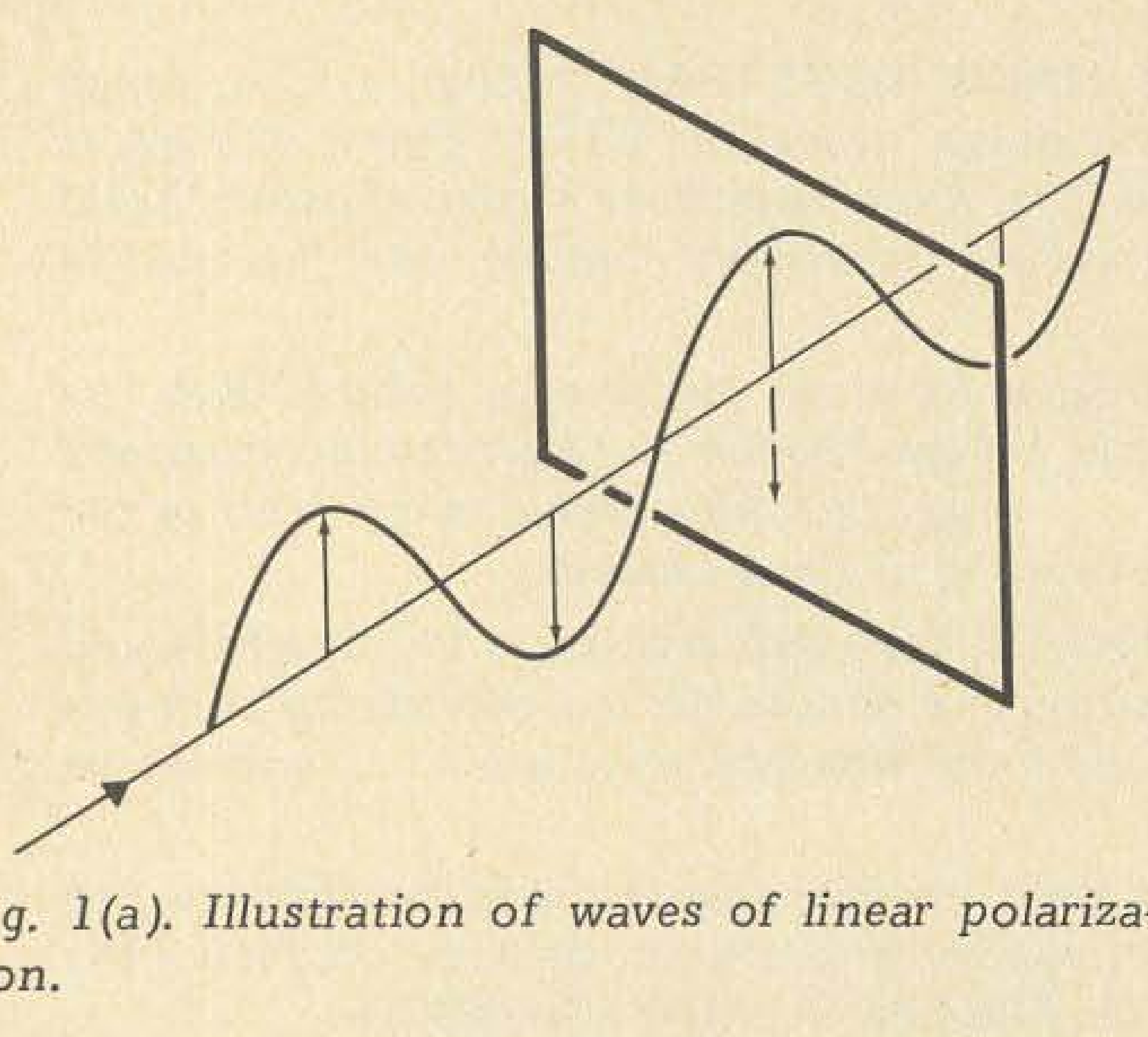


Fig. 1(a). Illustration of waves of linear polarization.

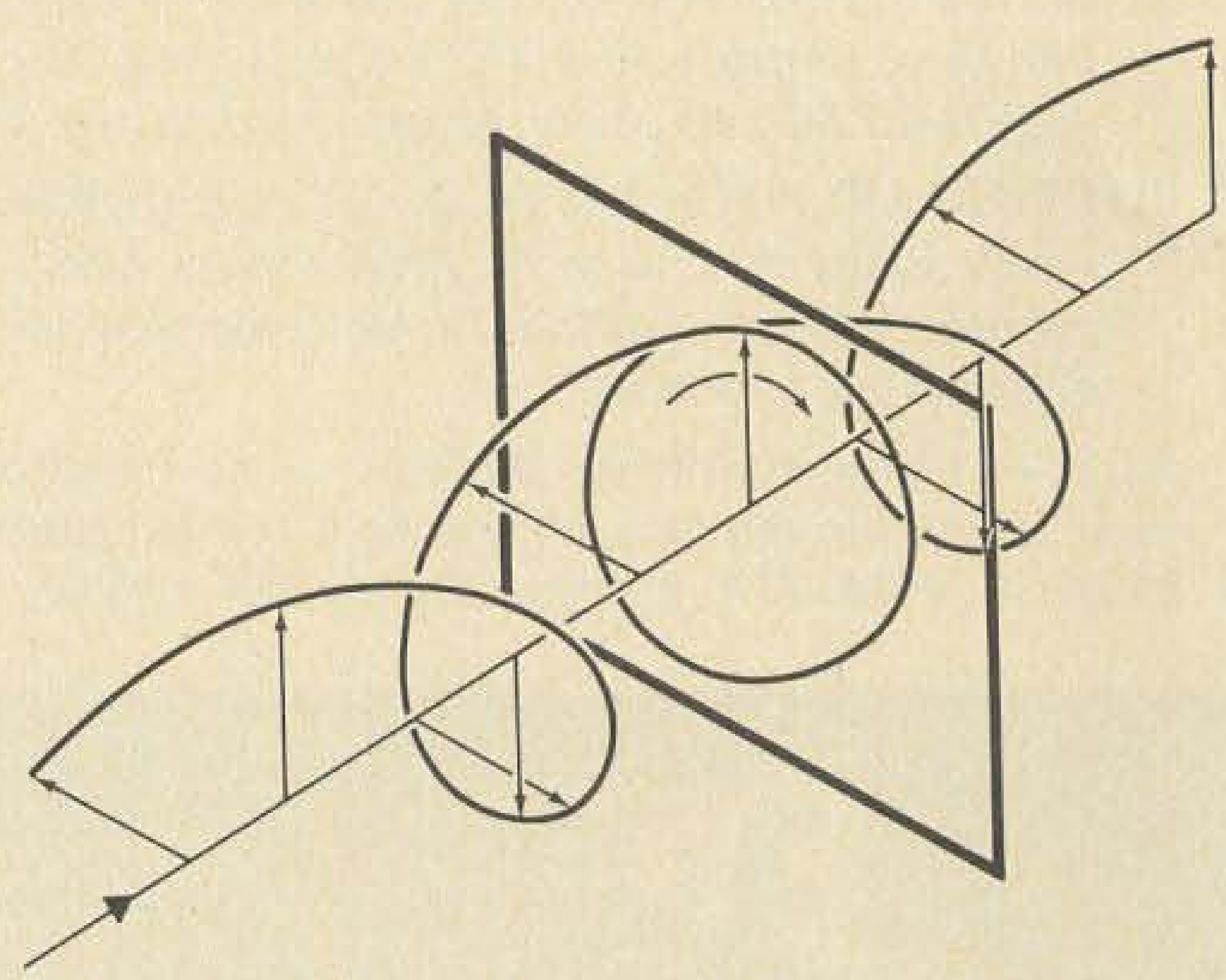


Fig. 1(b). Illustration of waves of circular polarization.

*Recommended polarizations for working OSCAR 7:

MODE	POLARIZATION SENSE Transmitting	Receiving
2m to 10m (A)	l.c.p.	- -
70cm to 2m (B)	r.c.p.	r.c.p.
435.1 MHz beacon	- -	r.c.p.

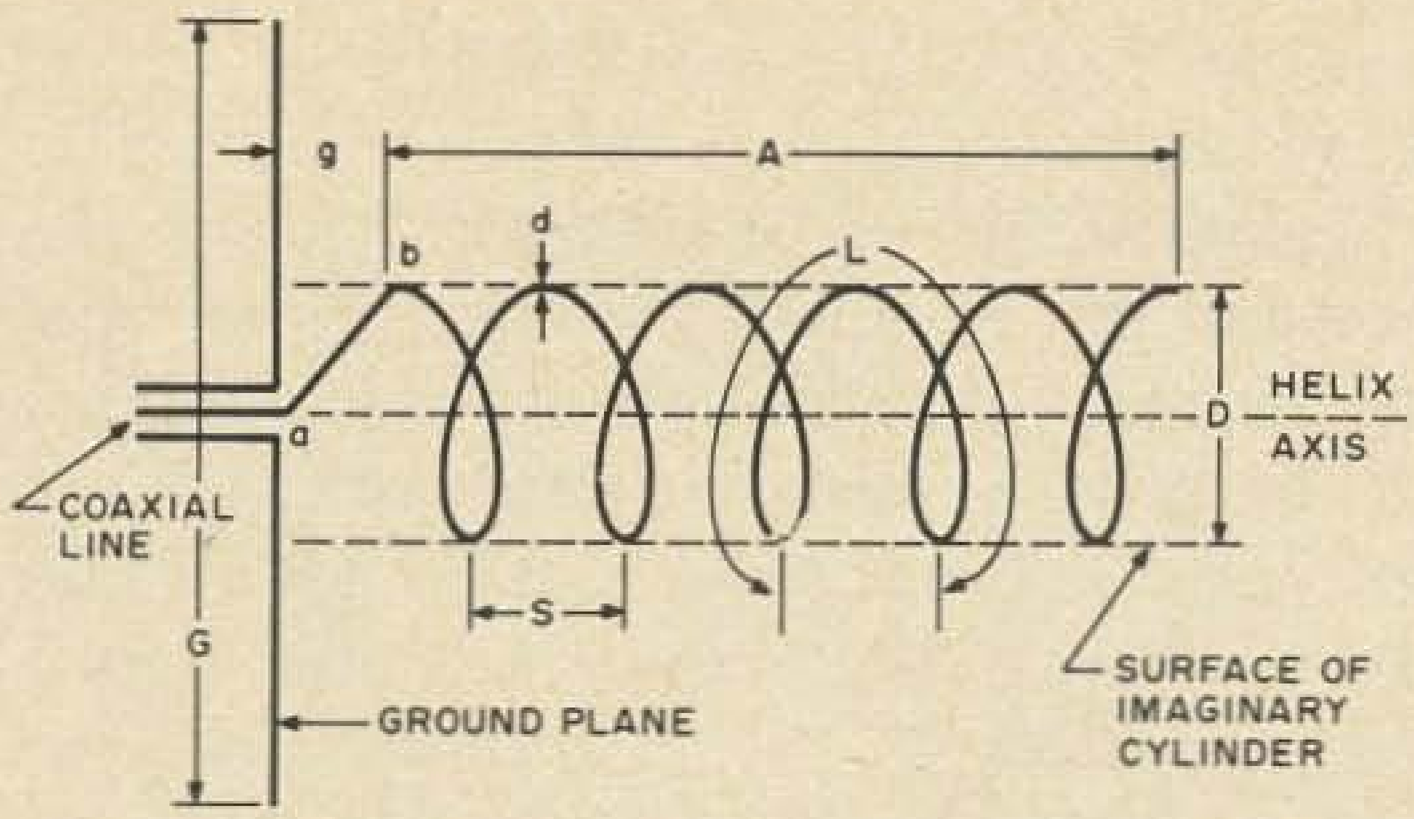


Fig. 2(a). Helix and associated dimensions.

the optimum dimensions for a helix with a turn length of the order of 1.00 λ can be found. The dimensions used in general design of a helical beam antenna, in terms of free-space wavelengths at the design frequency are as follows:

$$D = 0.32$$
$$S = 0.22$$
$$G \geqslant 0.80$$
$$g = \frac{S}{2} = 0.12\,\lambda$$

Other dimensions can be used, but in general the dimensions for the optimum helix are those listed above. These dimensions can be found from the spacing-circumference chart found in Reference 1 and also from the spacing-diameter chart found in Reference 2. The conductor diameter can be from .006 to .05 wave lengths, as the conductor diameter does not seem to critically affect the properties and performance of the axial mode helix when operating in the frequency range of this mode. Various materials can be used for the helix conductor or driven element; here I used a conductor of 3 strands of 12 gauge copperweld wire.

The characteristics of the axial mode helix, such as the gain, half-power beamwidth, axial ratio, and terminal impedance, depend upon the dimensions of the helix and also on the number of turns. In designing a helix the gain and the beamwidth are important parameters, and it is necessary to consider how long the antenna should be, i.e. the number of turns, and what the optimum dimensions should be in order to achieve the desired gain and beamwidth.

When the radiated pattern of a unidirectional antenna is concentrated into a single major lobe, the angular width of the lobe is

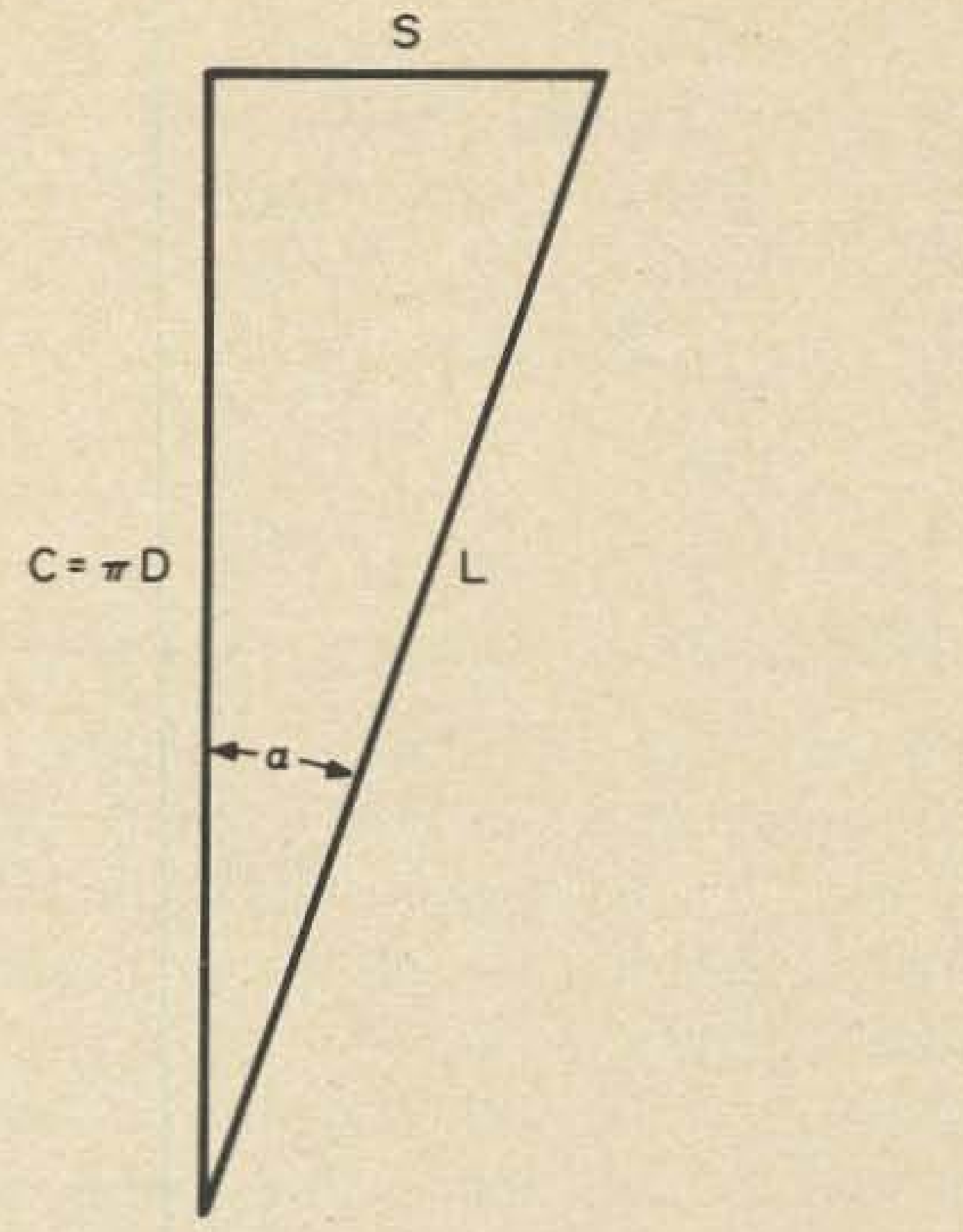


Fig. 2(b). Relation between circumference, spacing, turn length, and pitch angle of a helix.

the beamwidth. The beamwidth is adopted by measuring the beamwidth between the points on the pattern at which the power density is half its maximum value (i.e. 3 dB down). For the helix the beamwidth β between the half-power points is given by:

$$\beta = \frac{52}{C_\lambda \sqrt{nS_\lambda}} \text{ degrees,}$$

where C_λ is the circumference (expressed in terms of free-space wavelengths) and S_λ is

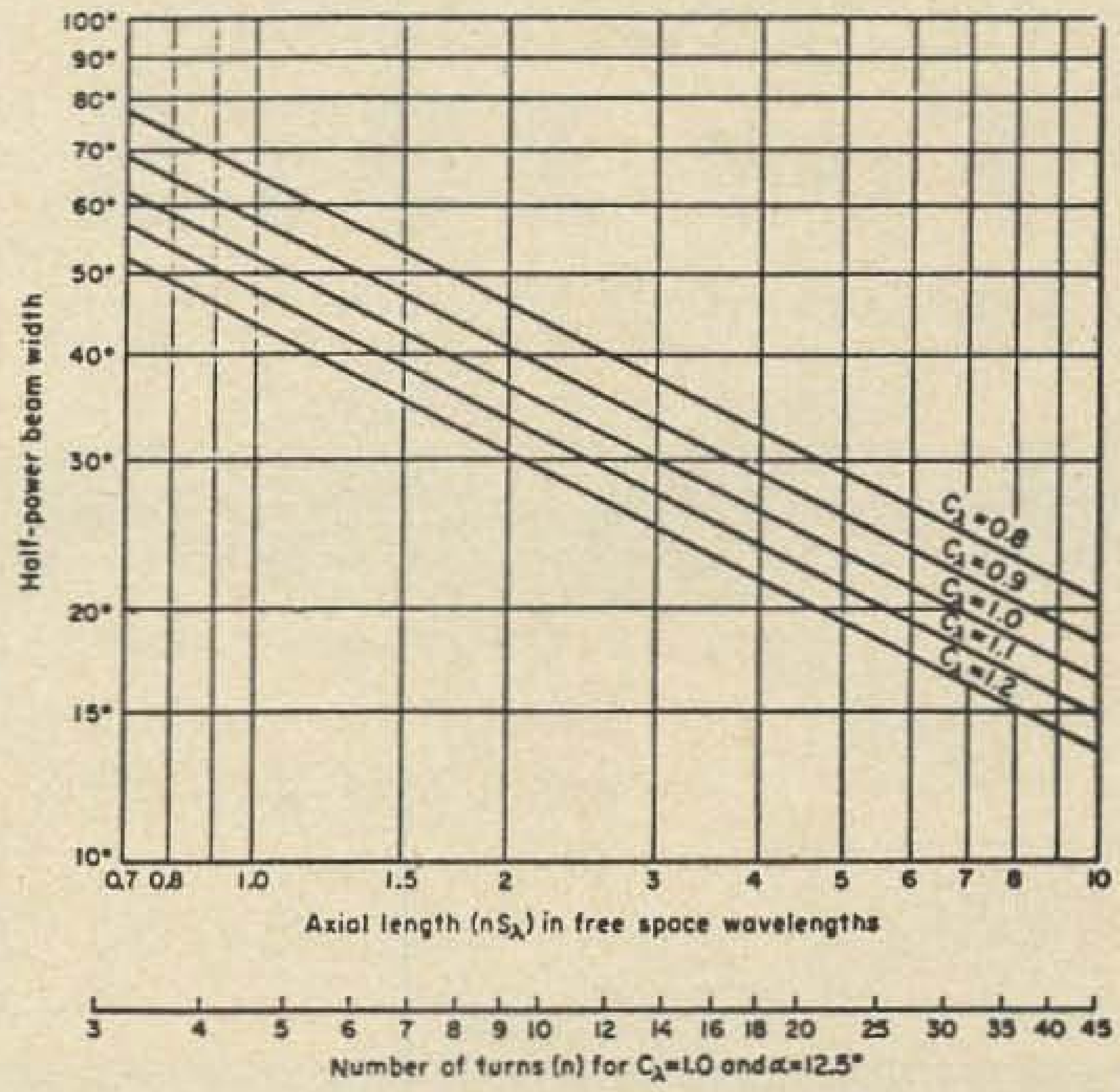


Fig. 3. Half-power beamwidth of axial mode helical antenna as a function of the axial length and circumference in free-space wavelengths and also as a function of the number of turns for C_λ= 1.0 and α = 12.5°. From Antennas, *by John D. Kraus. Copyright 1952. Used with permission of McGraw-Hill Book Company.*

N	Gain for $C_\lambda = 1.00$	Gain for $C_\lambda = 1.05$	Gain for $C_\lambda = 1.10$
3	9.99	10.42	10.82
4	11.25	11.67	12.07
5	12.214	12.64	13.04
6	13.0	13.43	13.83
7	13.675	14.10	14.5
8	14.25	14.68	15.08

Table 1. Gain of Helix as a Function of C_λ and N.

the spacing. This formula applies to helices of turns $n > 3$, $0.75\lambda < C_\lambda < 1.33\lambda$, and $12^\circ < a < 15^\circ$. The half-power beamwidth of the helical beam antenna as a function of the axial length or number of turns is shown graphically in both References 1 and 2. For 6 and 8 turn helices the half-power beamwidth calculated from this formula, with $C_\lambda = 1.00\ \lambda$, is approximately 45° and 39.8° respectively.

The power gain of the helical beam antenna, with respect to an isotropic circularly polarized source, is obtained by dividing the square of the beamwidth into the number of square degrees in a sphere, and is given by

$$\text{Gain} \approx 15\, C^2_\lambda n S_\lambda,$$ a power ratio;

or, in terms of a decibel ratio:

$$\text{Gain} \approx 11.8 + 10\ \text{Log}_{10}(C^2_\lambda n\ S_\lambda)\ \text{dBi}.$$

A graph of the power gain as a function of the number of turns and the circumference of the helix is found in Reference 2. For 6 and 8 turn helices ($C_\lambda = 1.00\lambda$) the gain for $C_\lambda = 1.00\lambda$ is 13.00 and 14.25 dBi, respectively, and for $C_\lambda = 1.05\lambda$ the gain is 13.43 and 14.68 dBi respectively. These formulas do not take into account the effect of minor lobes. Also, the gains quoted in Table 1 and above are with respect to a circularly polarized isotropic source.

The axial ratio is essentially the polarization in the direction of the helix axis and is given by:

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

When the axial ratio approaches unity the polarization is nearly circular; for $n > 3$, circular polarization should be obtained.

The terminal impedance is nearly a pure resistance for the helical beam antenna, and for a helix of 3 turns or more with $0.75\lambda < C_\lambda < 1.33\lambda$, the terminal resistance is given by (within ±20%):

$$R = 140\ C_\lambda\ \text{Ohms}$$

For a circumference of 1.00 wavelength the terminal resistance is approximately 140 Ohms. This requires impedance matching if one uses 50 Ohm coaxial cable as feedline.

References

[1] John D. Kraus, *"Antennas,"* McGraw-Hill, 1952.

[2] Edward F. Harris, "Helical Antennas," *Antenna Engineering Handbook,* editor Henry Jasik, McGraw-Hill, 1961, Chapter 7.

[3] Doug De Maw W1CER, "The Basic Helical Beam Antenna," *QST,* November, 1965, p. 20+.

[4] T. Bittan G3JVQ/DJØBQ, "Circular Polarization on 2 Meters," *VHF Communications,* Vol. 5, Edition 2, May 1973, p. 104-109.

[5] Dr. Ing. A. Hock DCØMT, "Theory, Advantages, and Types of Antennas for Circular Polarization at UHF," *VHF Communications,* Vol. 5, Edition 2, May 1973, p. 110-115.

[6] T. Bittan G3JVQ/DJØBQ, "Antenna Notebook," *VHF Communications,* Vol. 5, Edition 4, November 1973, p. 220.

Next month: Design, construction and installation.

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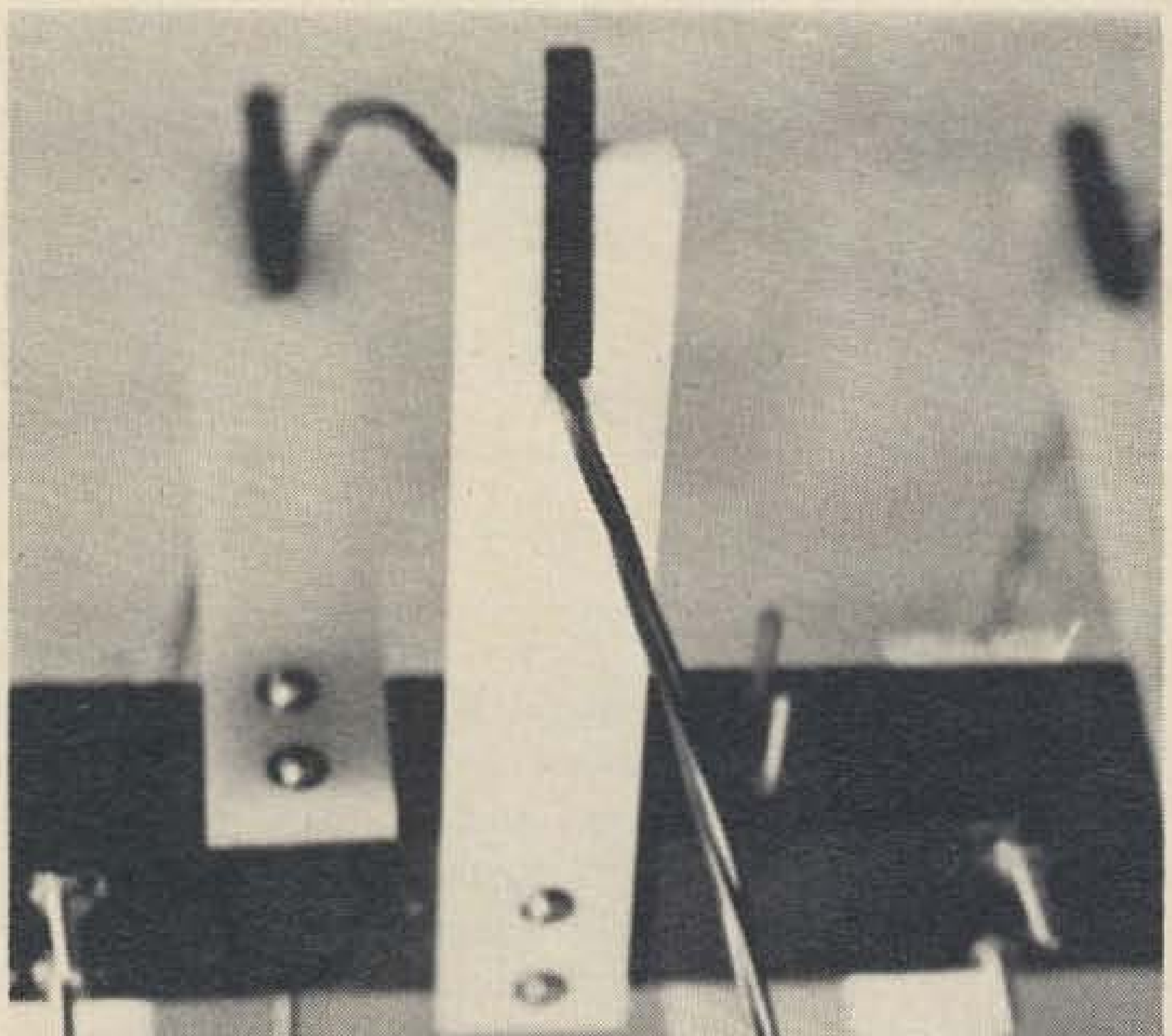
Alan L. Bridges WB4VXP
2754 Pine Hill Dr. NW
Kennesaw GA 30144

The Oscar Zapper

Part Two

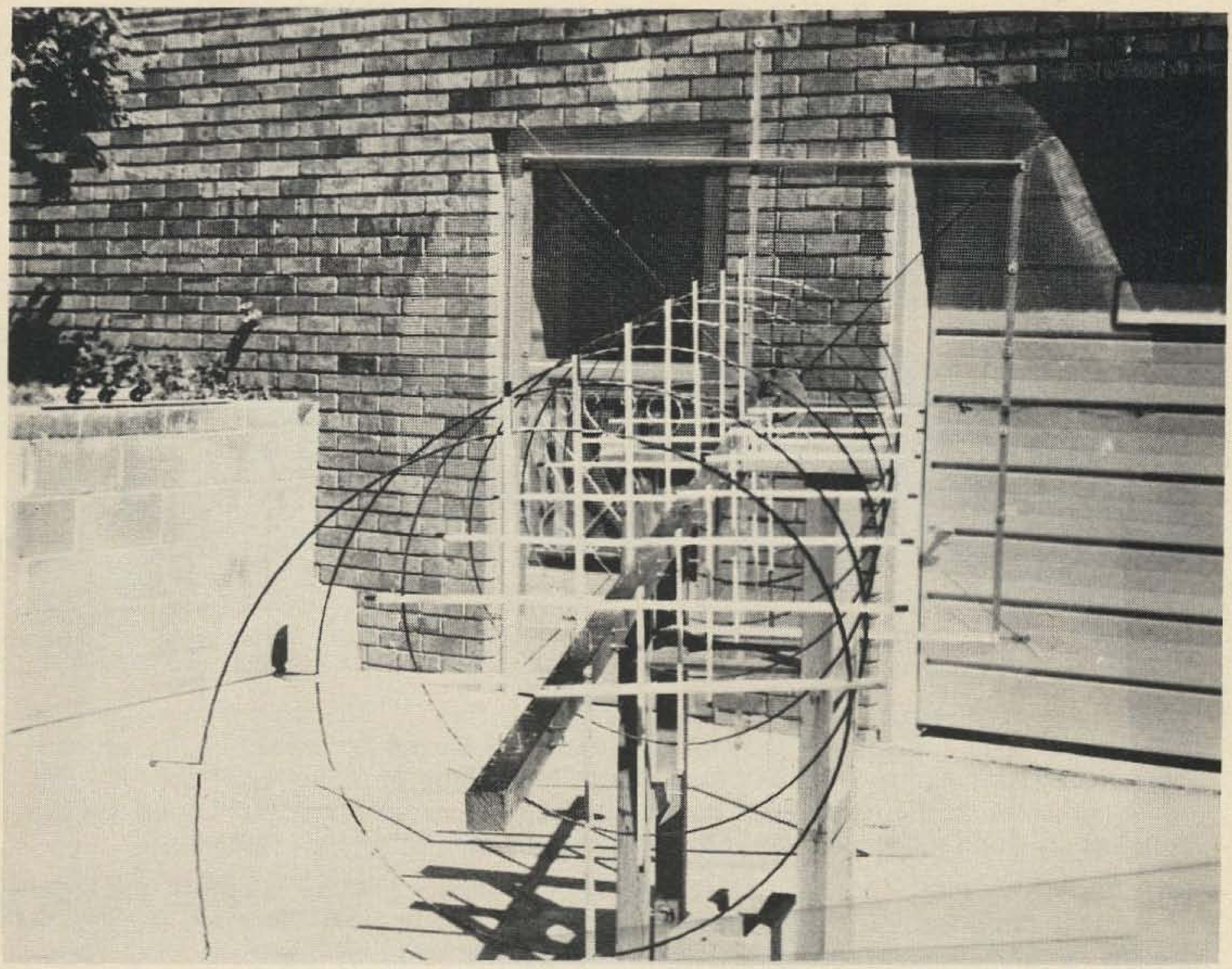


The plexiglass supports of the 70 cm helix with the helix conductor mounted on the supports and with the plexiglass rods permanently bonded to the strips. Note how close the supports are, and the spacing of the supports every 90° along the turns of the helix.

Last month, I discussed the basic characteristics and the general design parameters that one must be familiar with in talking about helices. This part of the article is devoted to the actual construction of the antennas and the installation of the array at my QTH. Basically, the antenna array is four helices mounted on a thirty foot tower with an azimuth-elevation drive. The original installation was completed last summer, but this spring I have taken the array down to modify the az-el drive; this will be discussed later on in the article.

Design, Construction And Installation

The helices that make up the array consist of a pair of antennas, of opposite sense, for both 2 meters and 70 centimeters. The basic design parameters were followed fairly closely. A circumference of 1.00λ was chosen, although after having constructed the antennas the measured or actual circumference was nearly 1.05λ, an acceptable value. The design or center frequency for the helices was 146 MHz and 432 MHz respectively for the 2 m and 70 cm bands. The dimensions corresponding to these frequencies were calculated according to the optimum design parameters, and for C_λ = 1.00λ the spacing S_λ and the diameter D_λ are summarized below.



The 2 meter helix under construction. The ground plane is 6 feet in diameter and here the helix has 8 turns instead of the 6 turns that we end up with.

For the 2 meter helices:

$\lambda = 80.9$ in $= 2.05$ m

$C\lambda = 1.00\lambda$ (Actual value $\sim 1.05\lambda$)

$S\lambda = 0.22\lambda = 17.8$ in (Value of ~ 18 is used)

$D\lambda = 0.32\lambda = 25.9$ in

For the 70 cm helices:

$\lambda = 27.3$ in $= 69.4$ cm

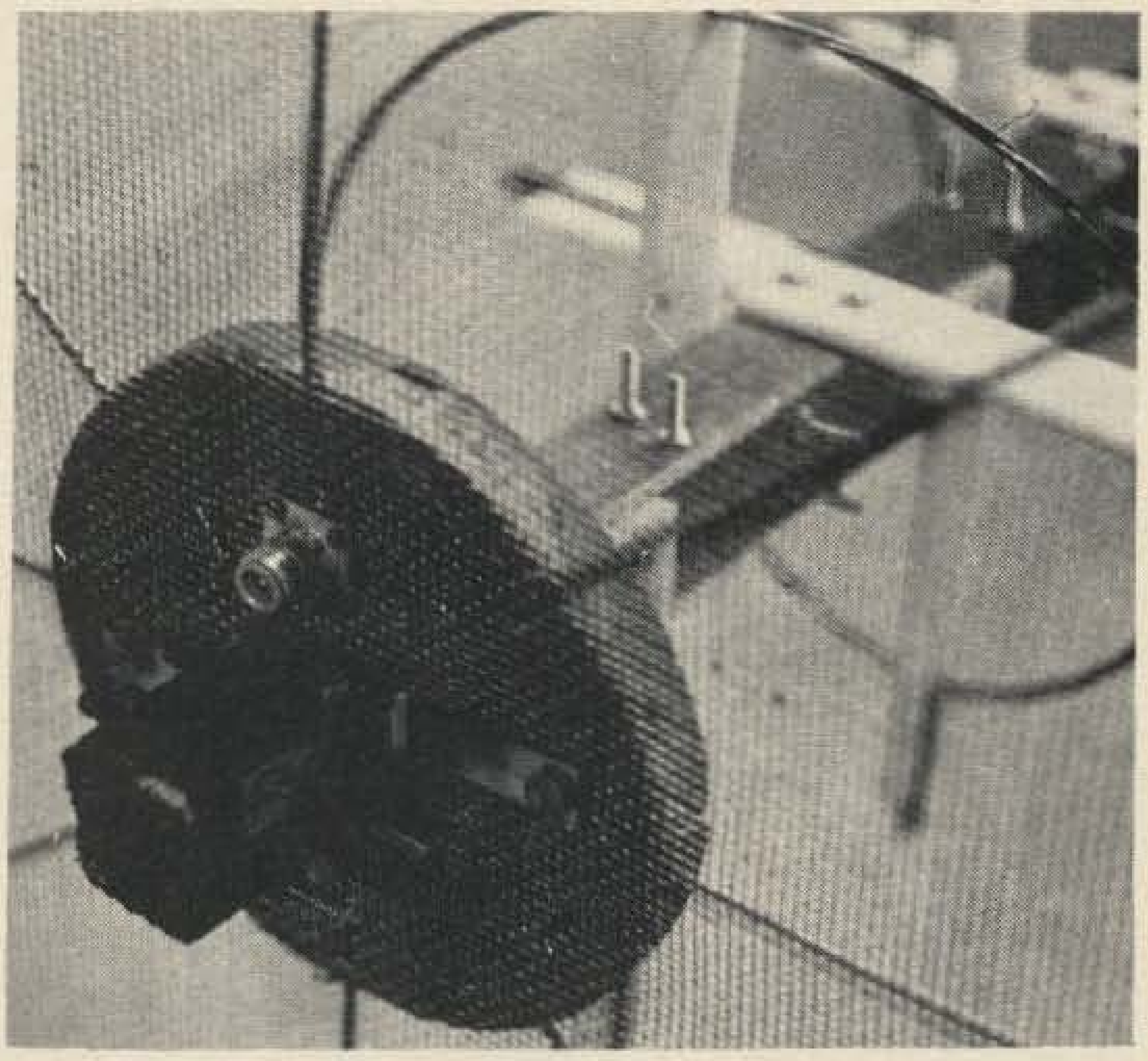
$C\lambda = 1.00\lambda$ (Actual value $\sim 1.05\lambda$)

$S\lambda = 0.22\lambda = 6.0$ in

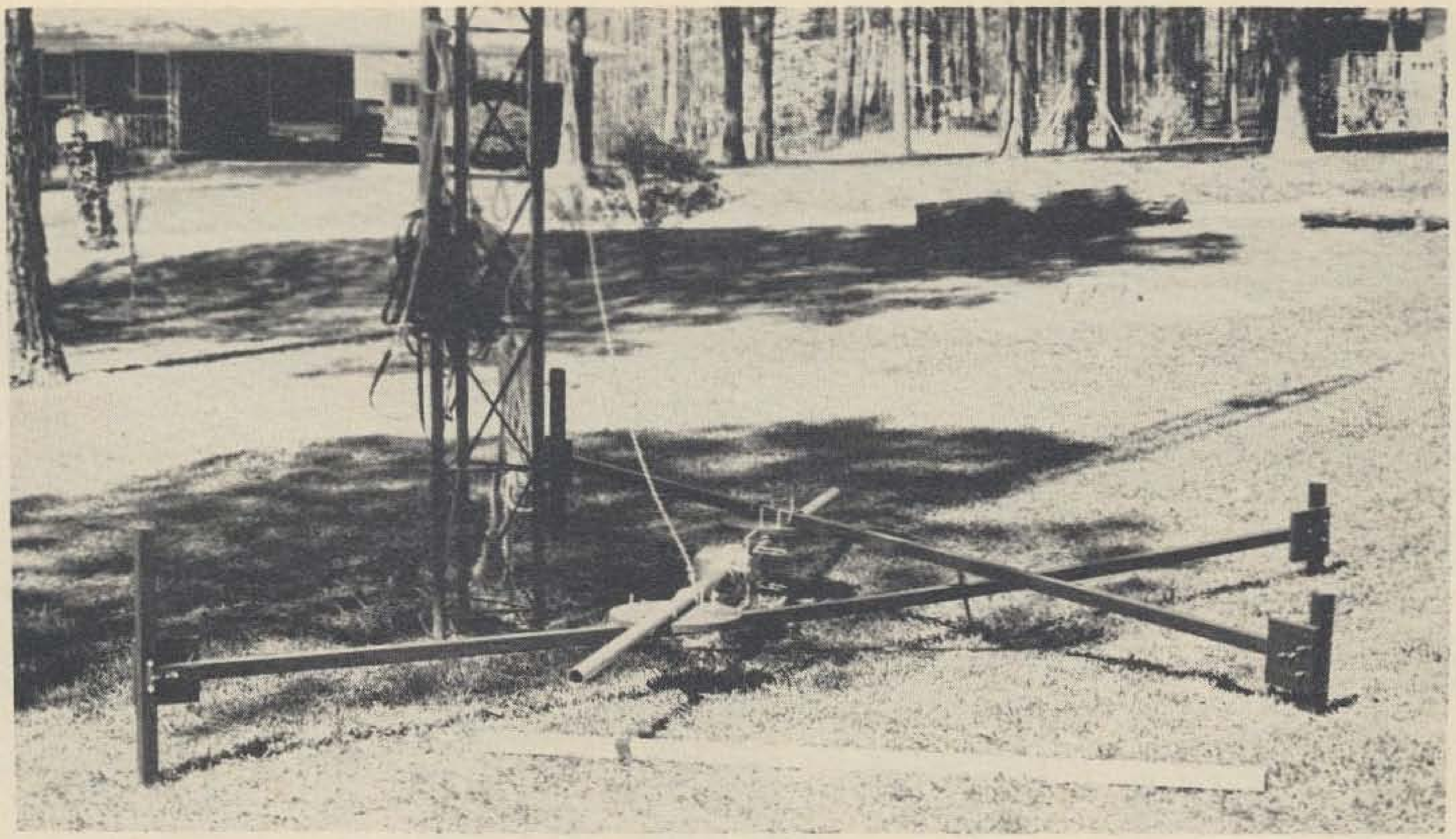
$D\lambda = 0.32\lambda = 8.8$ in

For the 2 meter helices the spacing and diameter are roughly 18 and 26 inches, whereas on the 70 cm helices the spacing and diameter are roughly 6 and 9 inches, respectively. The axial length, $nS\lambda$, plus the distance from the ground plane to the first turn of the helix, is the total length of the helix, and for the 2 m and 70 m helices this is approximately 9.75 feet and 52 inches, respectively.

After designing the antenna on paper one



The ground plane and the angle brackets used to mount it to the mast. The wooden disk fits onto the mast of the helix (70 cm helix shown here). The chassis mount type N connector is mounted about 2 inches off the axial center of the helix. Brass welding rods are used to support the hardware cloth.

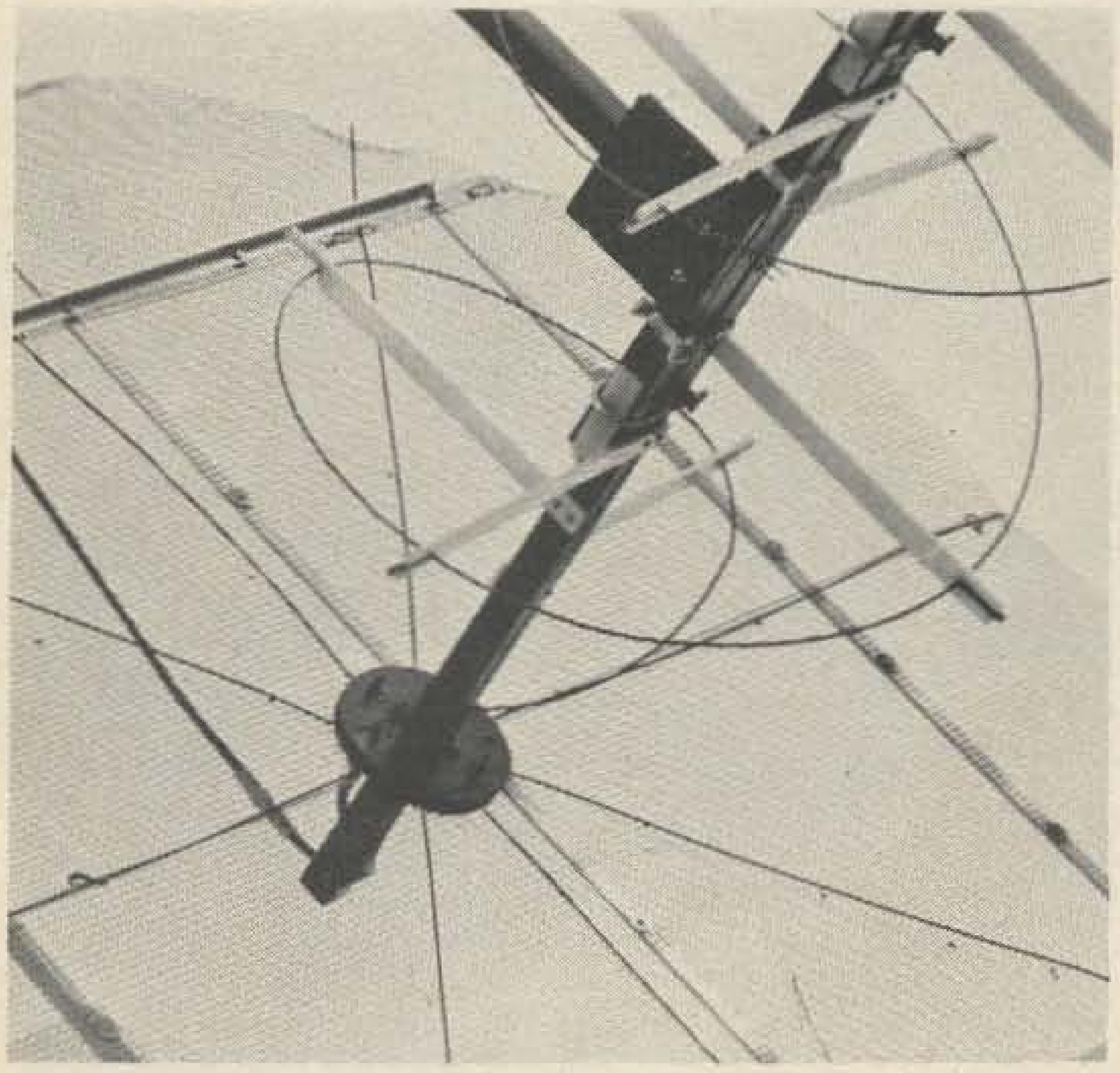


The array support structure before its completion. The "X" structure is incomplete in this picture. Here the rotator (elevation) is mounted on the horizontal boom, which is subsequently attached to the "X". Note the "T" structure on the ends of the "X". The "X" is mounted so that each leg is on the opposite side of the horizontal boom, and this requires that wood spacing be put in between the two legs at the crossover point.

must find the most practical way to assemble it and also utilize available materials. I first thought of using copper tubing for the helix conductor, but after calculating the length that was needed and figuring the cost I was easily dissuaded from this route (for 2 meters about 6.8λ of wire are used). I used three strands of 12 gauge copperweld wire. The next step in the process is to support the conductor and to engineer a support structure for the driven element that would be light, durable and structurally sound. The most important factor here is to preserve the symmetry of the helix, that is, to prevent the conductor from becoming egg-shaped. Also it is important that each turn is 1.00 wavelength long – here there is some room for error since small errors in measurements, mounting of the supports, etc., can throw off the circumference by as much as 0.10λ (an accuracy of about ±.05λ in the circumference is acceptable). Also, in designing a support structure for the driven element one must consider the ease or difficulty of winding or placing the conductor on the supports and securing the conductor firmly while adjustments are made. I decided on using a wooden antenna mast with insulating supports (plexiglass) extending out from the mast at every 90° along the turns of the helix. The pictures reveal the basic ideas and construction techniques. I used high quality 2 x 2 for the masts, treated with linseed oil and painted with outdoor enamel after measurements and drilling were completed. The insulating supports are quarter inch thick, white plexiglass; each support is about 1 inch wide and of an appropriate length for the antenna. This requires a total of (4n + 1) strips of plexiglass for n turns; I bought a large sheet of plexiglass and then cut it into small strips that were needed. Each strip was machined so that the conductor could be wound on these strips after they were mounted on the mast. Each strip has two holes drilled on the end that is to be mounted to the mast and a slot that will hold the conductor on the other end. The dimensions that yield the correct diameter and spacing after the strips are mounted and after the wire is placed on them is calculated from the geometry of this type of structure. It was necessary to make accurate measurements here as any errors would result in an egg shaped conductor, i.e. non-symmetric shape. The basic idea is to place the wire or conductor of the helix in the slot and to just wind it through so that the shape is very nearly perfect. If my measurements were accurate, then the shape of the helix would be perfect, and I think that this success can be seen in the photos.

After the wire is placed on the plexiglass supports and adjusted, a small piece of plexiglass is placed in the slot and permanently bonded to the white plexiglass support. This small piece of plexiglass is ¼ x ¼ x 2¼ inches long colored plexiglass rod. An alternate and better way to support the wire is to drill a ¼ inch diameter hole and then wind the wire through. This has been tried on prototypes (both before and after this array was completed). Once the plexiglass rods are in place and bonded, the helix conductor can still be adjusted, and is epoxied to the plexiglass supports.

Since the helices for each band are of opposite sense, it was necessary to mount the plexiglass supports so that the sense



The 2 meter helix, showing the plexiglass supports and the rest of the mounting structure. Note the wooden disk, the hardware cloth, and the aluminum angle stock used to construct the ground plane. The angle stock is mounted on the disk, after which the hardware cloth is attached to both the disk and the supporting structure. The feedline is seen behind the ground plane. The "T" of the leg of the array support structure is attached to the mast of the 2 meter helix with 4 U-bolts.

would be correct. Also, it was noted that the wire used was wound in a right-hand sense, and when the left-hand helix was built it was necessary to uncoil it and rewind it in the opposite direction as it was placed on the structure. With the stiff wire, this turned out to be quite a difficult task.

The ground plane essentially consists of hardware cloth that is mounted on a wooden disk before installation on the mast. The larger ground plane is supported by aluminum angle stock. The ground plane diameter is 6 feet and 32 inches, respectively, for the 2 m and 70 cm helices. Two angle brackets are used to secure the ground plane to the mast.

The feedpoint is slightly off center, but this does not critically affect the performance of the antenna (although it does appear in the antenna pattern). A better ground plane would consist of a metal plate with the connector mounted on the disk; this aluminum or brass disk could be square, with radials extending out to obtain the desired dimensions of the ground plane. Before the antenna array was installed on the tower, all metal parts were coated with a rust preventive (Val Oil). The antennas were completed separately and then installed on the array support structure, but before the array was installed, Cliff Burdette WA8GRE, of the Engineering Experiment Station, Georgia Tech, and I made far-field antenna pattern measurements which will be discussed later. The array support structure is shown in the photos. In order to put up the four helices this structure must be capable of supporting them and also rotating them. Basically the azimuth rotator is a TR-44 and is mounted on a mounting plate inside the top section of the Rohn tower. The elevation rotator is an RCA 10W707 rotator. This rotator is mounted horizontally in an azimuth-elevation system similar to that used in Reference 9. A better elevation system, like the system used by K6HCP (Reference 8), is desired, even though this system seems to work well. The horizontally mounted rotator is mounted via a small steel plate to a tower mast pipe that extends up from the azimuth rotator through the top section of the tower. This pipe is quarter inch wall 2-1/8 inch diameter steel, about 4 feet long, that was found in a local junk yard. Through the elevation rotator is placed a 1-1/2 inch diameter heavy duty, 10 foot length of conduit. The basic array support structure is built about this horizontal boom. This structure is basically an "X", with a helix mounted on each leg of the "X" structure. The center or crossover point of the "X" is off center, and the horizontal boom about which the array is rotated in elevation is about 2.5 feet below this point. The points where each of the legs cross are permanently secured to each other. Each leg is about 12 feet long, and this makes the array about 11 x 11 feet. The legs are secured to the horizontal boom with a wooden disk and with U-bolts and lock-washers. The ends of the legs, where the helices are mounted, consist of a "T" made of a small piece of 2 x 2, metal mending plates, and a 6 x 6 inch piece of very hard wood. The larger helices are mounted to the "T" with four U-bolts and appropriate hardware. The smaller helices are permanently mounted to the "T"'s. A wooden brace is attached to the 2 m helices as seen in the photos. Also, a counterbalance, consisting of another 2 x 2 about 13 feet long, is attached to the upper part of the array where the smaller helices are mounted. Weights can be attached to this. The total array weighs about 80-100 pounds. Once the antennas were mounted on the structure, which itself was supported by a rope attached to a gin pole mounted at the top of the tower, it was necessary to get some help in order to haul it up. The feedline also had to be mounted and the swr checked out before the antennas were pulled all the way up and installed. The swr was checked by raising and lowering the array to a height of about 20 feet (more on this later). The tower on which the

The support structure of the helix conductor or driven element. The plexiglass strips are spaced every 90° along the turns of the helix. Also shown is the "T" used to attach the helix to the array support structure. The ground plane is to the left. Note the symmetry of the helix and also the small plexiglass rods on the ends of the plexiglass strips where the conductor is mounted and epoxied to the supports.

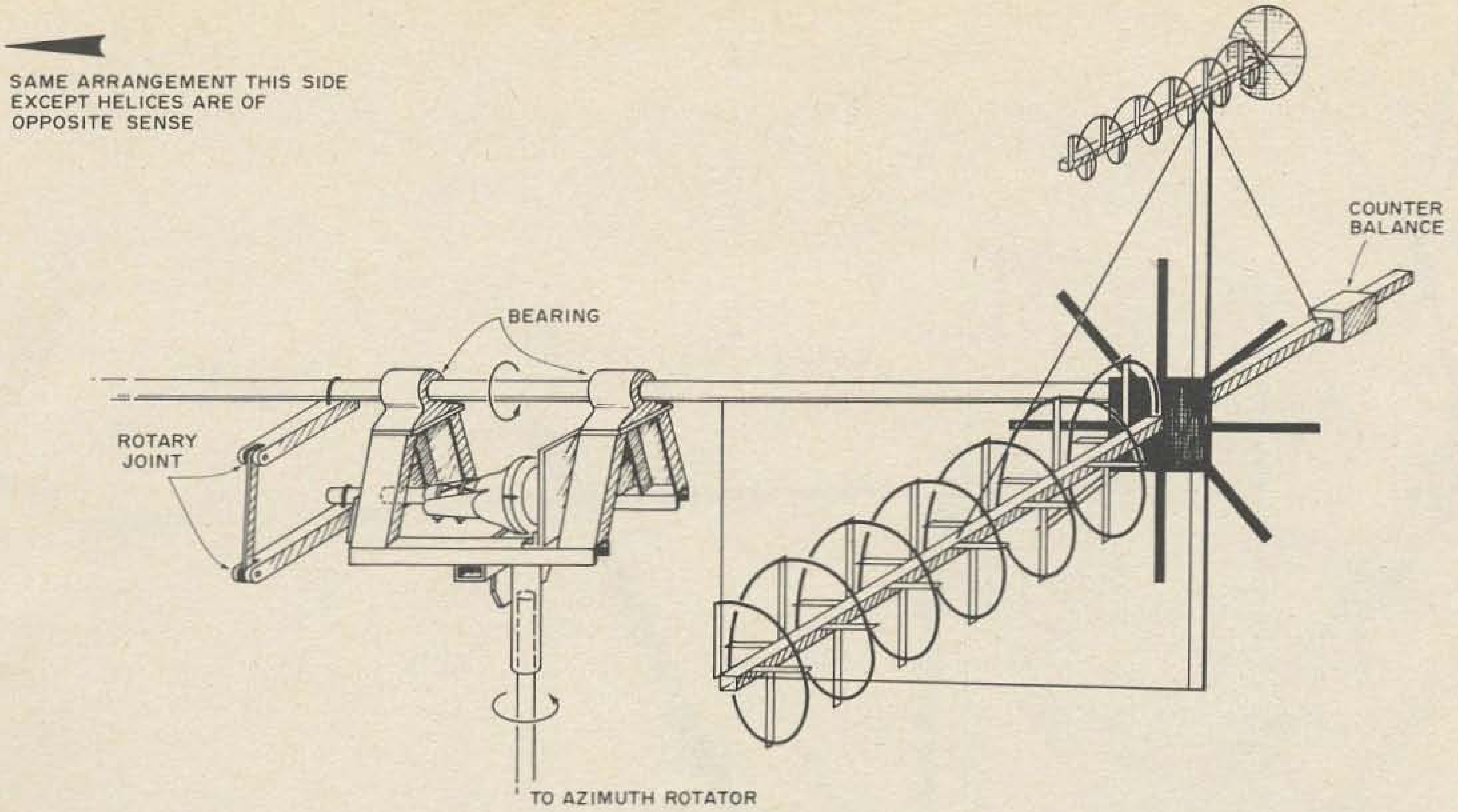
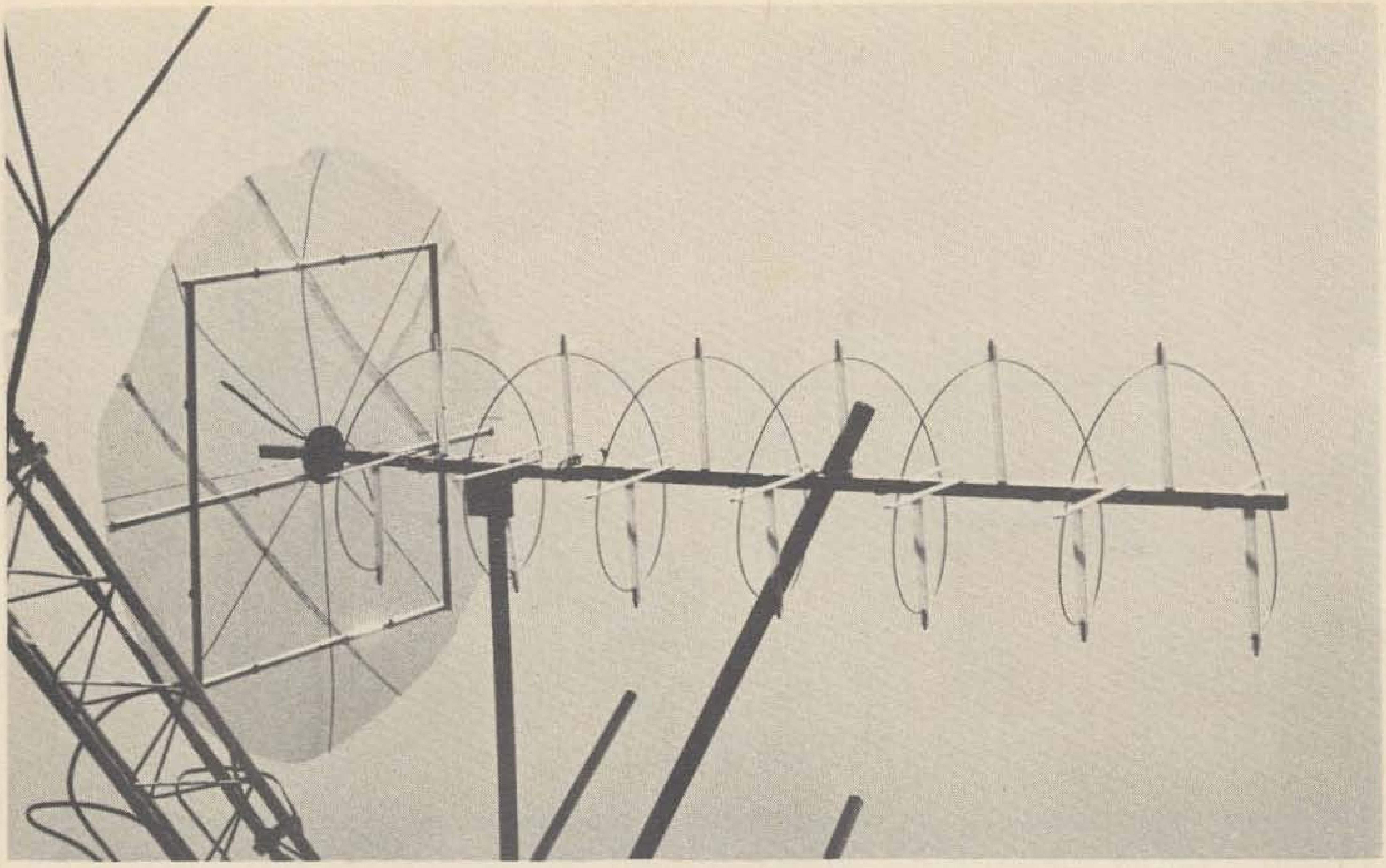


Fig. 4. Half-view of the updated version of the array, showing how the helices are mounted on the main boom and illustrating the az-el system and the antenna frame. The rotor is a Ham II mounted horizontally, covered to prevent the entrance of moisture. The main antenna boom is mounted at the top of the frame (or fork) through two bearings. This boom is rotated by the lever assembly. The rotary joints are tie rod ends (a surplus C141 assembly). At the bottom of the frame is the assembly that attaches to the azimuth rotor. Here a two inch inside diameter aluminum tube slips over a two inch outside diameter pipe, which in turn is attached to the other Ham II inside of the tower. This arrangement eliminates major stresses and windmilling of any kind.

antenna array is mounted is a Rohn 25, with a section mounted in three feet of concrete. It is about 27 feet high and is non-guyed. To install the array I used a regular gin pole plus a commercial gin pole designed specifically to be used with Rohn towers. The antenna array was hauled up by using a block and tackle hoist as well as the two gin poles. The last two feet were the most difficult, and eventually after much sweat and some very exasperating work hurrying to get the bolts secured, while the people on the ground held the array suspended in the air, the array was installed. Both the antennas and the array have been successfully subjected to hail storms and high winds – and even two tornadoes which passed through the area.

Since the original construction and installation were completed last summer, there have been some additions and changes in the array. First of all, during February 1975 there were two severely damaging tornadoes in the Atlanta area. One struck the McCollum Airport, which is less than ½ mile from my QTH, and the other one destroyed a great part of northwest Atlanta. With the one that struck here in Kennesaw, my antenna array felt the high winds and hence suffered some damage. As I now travel most of the time as a sales representative, I came home to find that the tornado and the high winds left the array windmilling, i.e. rotating freely in the wind and just barely attached by a safety (aircraft) cable that I had installed just in case this might happen. I immediately lowered the array as I did not want it to fall if another tornado came through. I had been planning to lower it anyway to revise the az-el system and redo the basic mounting of the antennas.

During May and June I redid the array. In my original installation the problems were mainly mechanical, i.e. mounting of the antennas and rotating them in elevation was not as strong as I had hoped. Basically the new az-el drive and antenna frame, which can be seen in Fig. 4, was designed so that a large moonbounce antenna array could be rotated easily. A drive system like this has been used by DJ9JT (see Ref. 16). The basic arrangement consists of a frame, very similar



The 2 meter helix as viewed from ground level with a telephoto lens.

to a telescope fork, through which the main antenna boom is mounted. This boom is supported by bearings. The elevation drive is mounted in the lower part of the fork assembly. Here a Ham II mounted horizontally is to be used. A short section of tubing connects the drive motor to the mechanical arrangement used to drive the main mast. This is a basic lever, with the rotary joints being surplus tie rod ends. When the drive motor is engaged, the upper boom will rotate as does the lower boom, due to the lever-action. A chain drive could have been used instead of this particular arrangement. The main boom is 6061-T6 aluminum tubing, with an o.d. of 2.5 inches. This boom is 21 feet long and all of the antennas are mounted about this boom. The fork was made up of surplus materials, mostly aluminum, and was HeliArc welded. At the center of the fork on the bottom side, a piece of 2 inch i.d. 6061-T6 aluminum tubing is HeliArc welded. A 2 inch o.d. pipe can be inserted and then secured; the other end is then attached to the azimuth rotor (Ham II). This fork assembly has eliminated major stresses that caused most of the problems in my original mount. Also, I have replaced the TR-44 with a new Ham II. The major problem is wind resistance, and since the Ham II has a 7.5 square foot rating as compared to the 2.5 square foot rating of the TR-44, this replacement has eliminated tendencies of the array to whip around in the wind (mainly the clamps slipped). I am also using the Ham II in elevation. This has also been successfully done at Philco in Vandenburg, California, as well as by Jacques Cousteau on his research ship. The major cost factor here was the rotors, as everything else used surplus or otherwise cheaply available materials.

I have also modified the mounting of the helices. This time I did not use this "X" mounting as before, but used more of an "H" type mounting as seen in Fig. 4. I have also tried to make the array as lightweight as possible by redoing the mounting, adding counterbalancing, and by reducing the weight of the groundplane on the 2 meter helices. On the 2 meter groundplane: Here I have replaced the whole groundplane with a 3/16 inch thick aluminum plate, about 15 in. by 15 in., that has 8 radials of aluminum mounted on it. I also have a lighter mesh that is 4 feet by 4 feet, and this is attached to the radials which extend out as in the drawing. This reduced the weight considerably, as I used really heavy hardware cloth on the original version. Also, I have remounted the helix so that the 2 meter helix can be mounted on the main boom. By having a 6 to 8 foot extension of 2 x 2 beyond the balance point, I can counterbalance the antenna by adjusting a weight along this mast. I have tried to mechically beef up the array in this process, and have also added a gin pole with a winch to lower and raise it.

Impedance Matching

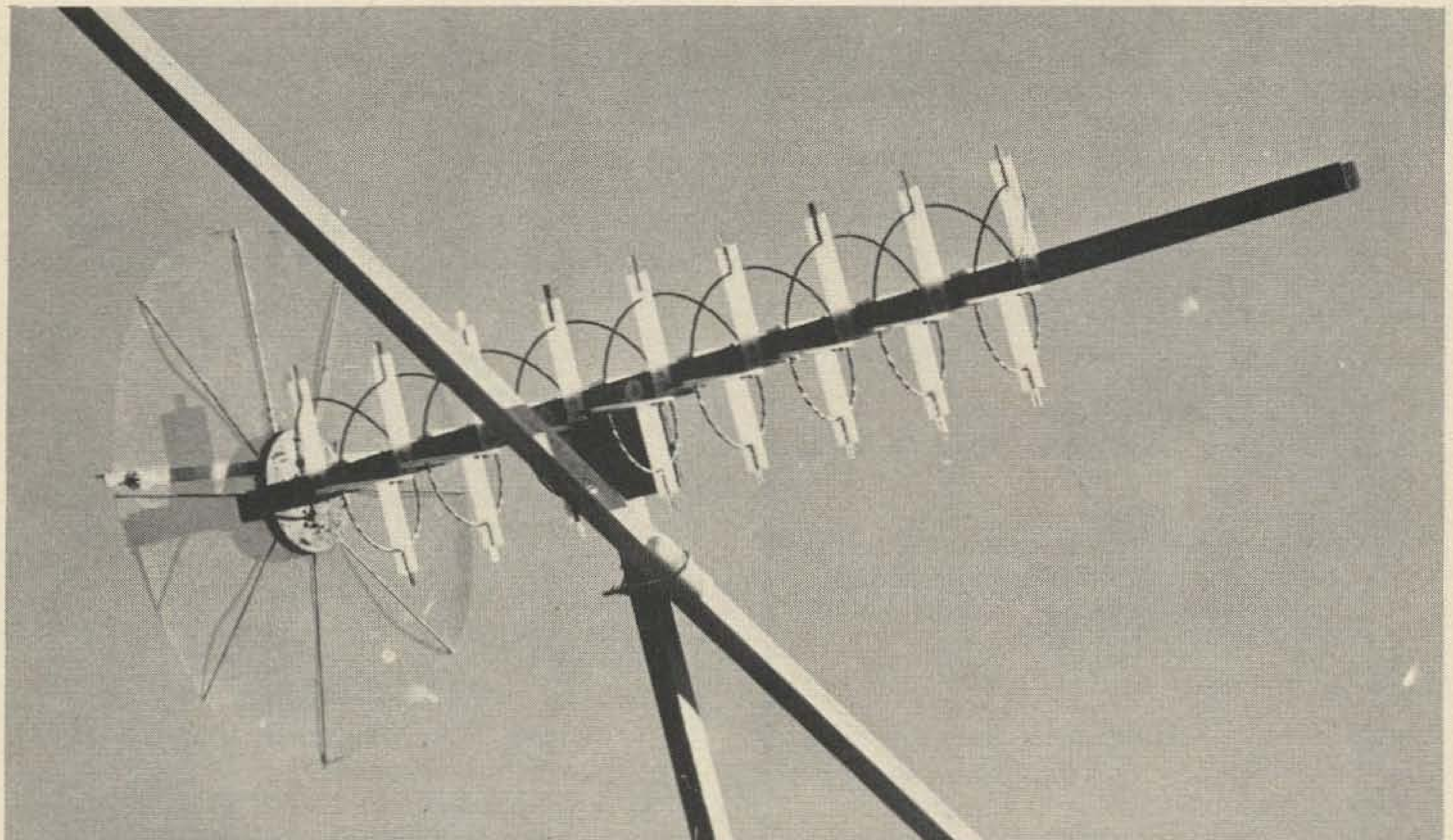
The helix has a terminal impedance of 140 Ohms and is pure resistance. Since 50 Ohm cable was used to feed the antennas, it was necessary to match the 50 Ohm impedance of the RG-8 polyfoam coax to the 140 Ohm terminal resistance of the helix. A quarter-wave coaxial matching transformer is used as in Reference 4. The formula used to determine the correct impedance value is:

$$Z_o = \sqrt{Z_s \quad Z_a} \text{ Ohms},$$

where Z_o is the desired impedance, Z_s is the transmission line impedance, and Z_a is the antenna impedance. This is 83.7 Ohms in this case, and a value of 75 Ohms is very close. Here RG-11/U was used for the matching section and RG-8/U polyfoam coax was used for the feedline. The matching section was made according to the formula:

$$\text{Length (feet)} = \frac{246\ V}{f}$$

where V is the velocity factor for the RG-11/U (approximately .66) and f is the frequency in MHz. Two alternate and even better matching systems are described by Doug De Maw W1CER, in Reference 4. Swr measurements were made with the antenna about 20 feet off the ground, and trimming the driven element was done by lowering the antennas within the reach of a step ladder. An initial swr of 1.7 to 1.8 was obtained on the 2 meter helices, while a similar one was obtained on the 70 cm helices. By trimming



The 70 cm helix mounted on one of the legs of the antenna array support structure. The ground plane is 32 inches in diameter, and has brass welding rods as well as one piece of angle bracket for support. The "T" structure is permanently attached to the mast. The 13 foot long counterbalance is attached with a U-bolt to the leg of the "X". Besides acting as a counterbalance, the 2x2 keeps the two 70 cm helices from whipping around during wind or rotation.

the driven elements, an swr of about 1.5 to 1 was obtained. A better swr could be obtained if a matching section with an impedance of about 83 to 84 Ohms were used.

To obtain a better match and hence a lower swr, I have talked with Mike Staal K6MYC, at KLM Electronics, about building a sleeve balun to match the 140 Ohm terminal impedance of the helix to 50 Ohm coax. By this time I will have either built one myself or else have had them made by Mike. The big problem in popularity of the helix has probably been the impedance matching, and since it is very easy to build the helices and get them working, it would be worth the cost of getting a sleeve balun made by someone who makes them professionally.

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Next month: Measurements and conclusions.

. . . WB4VXP

Alan L. Bridges WB4VXP
2754 Pine Hill Dr. NW
Kennesaw GA 30144

The Oscar Zapper

Conclusion

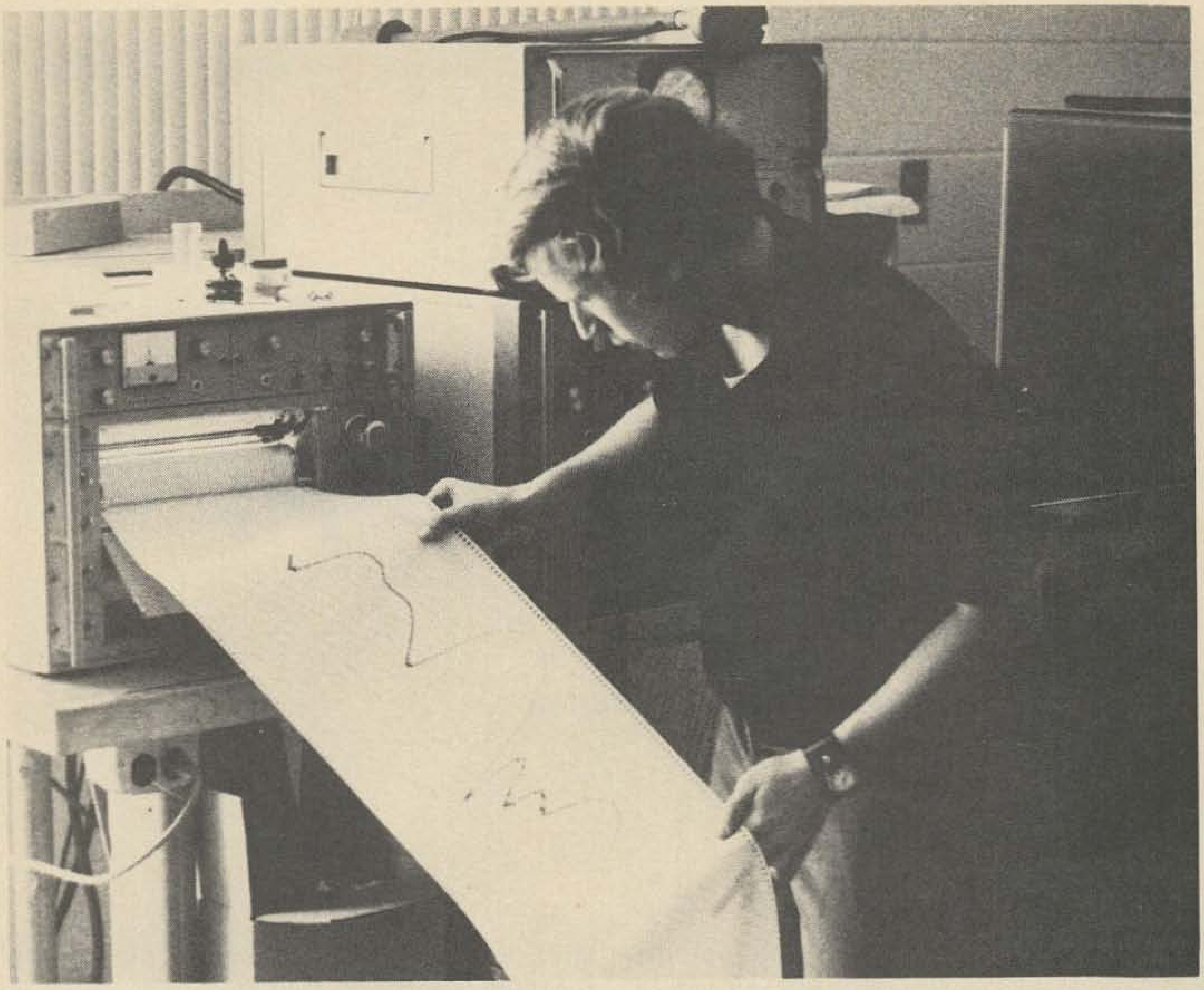
In beginning this project I felt that the helices would work very well and would yield a 12 to 15 dBi circular gain. I also thought that it was necessary to measure the gain as well as the antenna radiation pattern, so that the performance of the helices could be verified. Since I was a graduate student in physics at Georgia Tech, the antenna pattern was measured using the facilities that are available at the Georgia Tech Engineering Experiment Station and the Antenna Lab of the School of Electrical Engineering. I hoped to be able to perform the antenna measurements and actually see if the pattern (i.e. the beamwidth) and the gain of the antenna were comparable to the theoretical pattern and gain. Cliff Burdette WA8GRE, Research Scientist at the Georgia Tech Engineering Experiment Station, and I made the pattern measurements in April and May of 1974 (before the array was completed).

The 70 centimeter helix was measured on the outdoor antenna range located on the roof of the Electrical Engineering Building at Georgia Tech. Instrumentation consisted of a Scientific-Atlanta amplitude receiver, a series 1520 pattern recorder, a UHF oscillator, and an antenna positioner control and turntable. A block diagram of the measurements setup is shown in Fig. 5. Using this configuration, patterns of the principal planes of the antenna were measured for both linearly and circularly polarized transmitting antennas. The antenna range is, however, not free from reflections. Nearby objects such as building corners and a crane prevented us from obtaining "free space" conditions. However, the far-field pattern can be measured since the far-field distance for the two antennas was only ten feet, as given by:

$$\text{Far-field Distance} = \frac{2(D_1 + D_2)^2}{\lambda}$$

where D_1 and D_2 are the largest aperture dimensions of the transmitting and test antennas, respectively. At this distance, the reflections should be approximately 40 dB below the maximum signal of the test antenna.

The measurement of an antenna pattern (i.e. the far-field pattern) involves the test antenna, whose pattern is being measured, and another antenna located at a certain



Cliff Burdette WA8GRE observes one of the antenna patterns as it is generated by the recorder. Equipment used in the pattern measurements is located in the background.

distance away, that is, in the far-field region. The test helix is used as a receiving antenna and at the same time rotated about a vertical axis through the desired angles in measuring the pattern. The test antenna was operated in the axial mode with right circular polarization. Two different transmitting antennas were employed – a half-wave dipole and a 3 turn helix of the same polarization of the test antenna. Pattern cuts were taken using both transmitting antennas. The measured beamwidth of the test helix is approximately 39 degrees (and corresponds to the theoretical value). This represents an adequately directive antenna for amateur satellite communications. The pattern nulls are quite good and nearly symmetric. The patterns, shown in Figs. 7 and 8, do show a slight asymmetry or distortion. This might be due to the location of the feedpoint of the test antenna. The helix was fed approximately 2 inches to the left of the axial center. This effectively produces a "tilt" in the pattern of the antenna. The level of the first lobe is approximately 16 dB below the level of the main beam of the antenna. However, this tilt is more likely to be a result of the antenna range itself as the reflections from the building and the crane and other factors can very easily cause such a tilt. The level of the first lobe cannot be pinned down because the pattern is slightly nonsymmetric. One lobe is 9 dB down, while the other is 16 dB down, as shown on the 40 dB plot of the pattern (Fig. 7). A minimum level of about 10 dB below the level of the main beam is desirable.

The gain measurements were made by direct comparison with a dipole, and the resulting gain was approximately 16 dB over a half-wave dipole. Since the gain measurements were made at 445 MHz, the gain at 432 MHz (the design frequency) would be less; nevertheless, the pattern results that

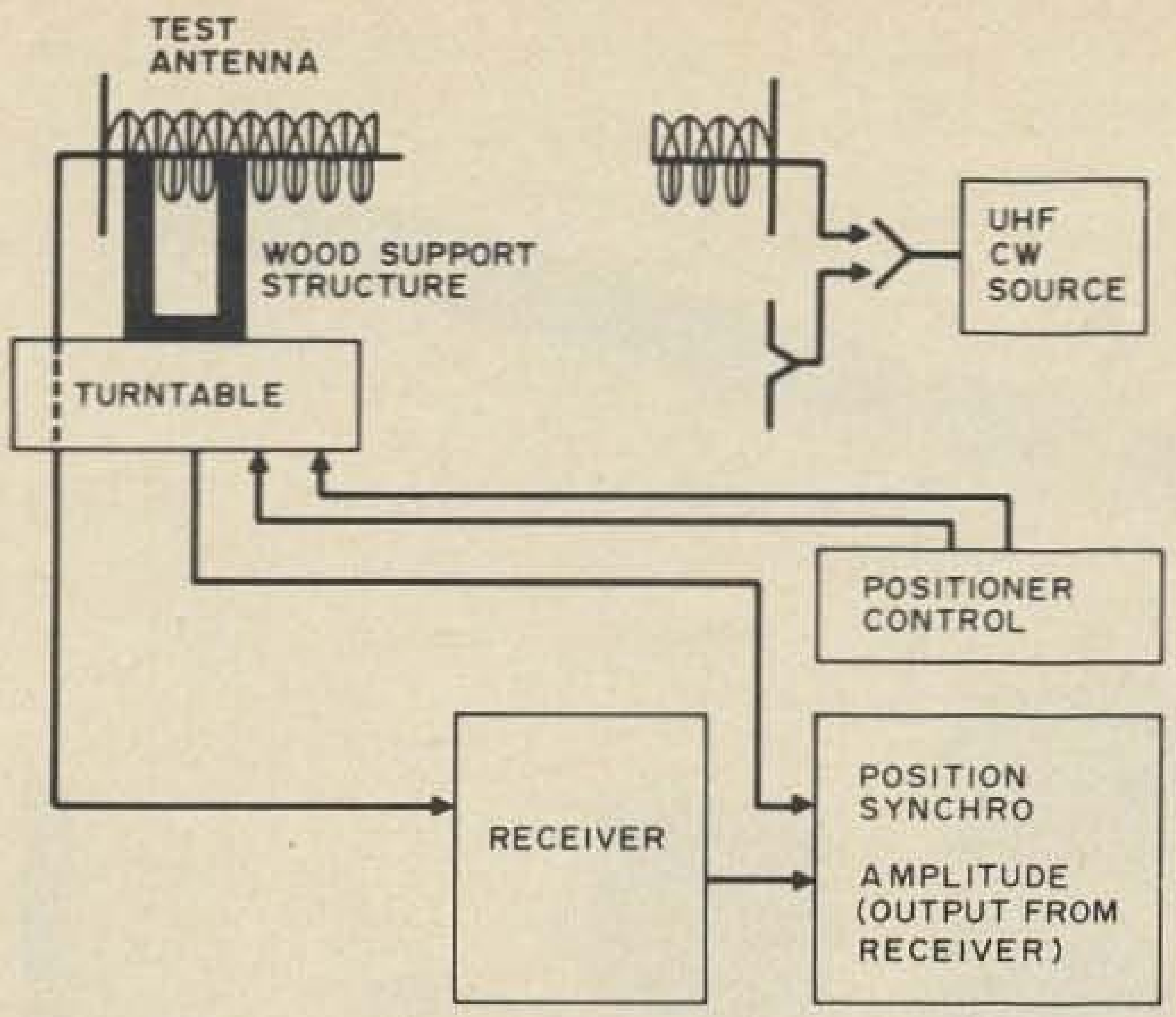


Fig. 5. Block diagram of antenna pattern measurements setup.

were obtained indicate that these antennas should be performing very well.

My results almost exactly correlate with Dr. Kraus's original graphs, i.e., the measured beamwidth and the theoretical beamwidth are practically the same. Since the center or design frequency is 432 MHz and since the gain depends on the circumference C, the number of turns n, and the spacing S, it can be easily seen that, as one goes to a higher frequency or frequencies above the design frequency, the gain will correspondingly increase [from Gain = $11.8 + 10 \text{ Log}_{10}(C^2 nS)$]. Likewise, at frequencies below the center frequency the gain will decrease. Here the measured gain at 445 MHz corresponds to the correct increase, so at 432 MHz the gain should be about 14.7 dBi circular.

Another very important measurement is the axial ratio or ellipticity, especially where circularly polarized antennas such as helices are concerned. Here the axial ratio is the ratio of the major axis to the minor axis of the polarization ellipse. For the axial mode helix the axial ratio is described approximately by AR = 2n + 1/2n, where n is the number of turns. For n greater than 3, the axial ratio will be nearly unity.

I tried two different ways of determining the polarization. The pattern method utilizes a linearly polarized directional antenna and also a circularly or elliptically polarized test antenna. A polarization pattern is traced out in this method. Basically, a circle is generated for circular polarization.

The other method is the circular component method. In this case, it is necessary to use two circularly polarized antennas of opposite sense. One must compare the relative signals of the two helices, E_{lcp} and E_{rcp}, to find the axial ratio:

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

If the axial ratio is positive, then the wave is right circularly polarized. For these helices, AR will be very nearly unity. In my radiation pattern measurements I used two three turn helices of opposite sense plus the eight turn test helix for 432 MHz. Suffice it to say that the 8 turn helix was right circularly polarized (AR approximately 1.07, as compared to 1.0555 theoretical).

Conclusion

A lot can be said about helices and their good characteristics, and how they can be successfully used on the amateur bands. I

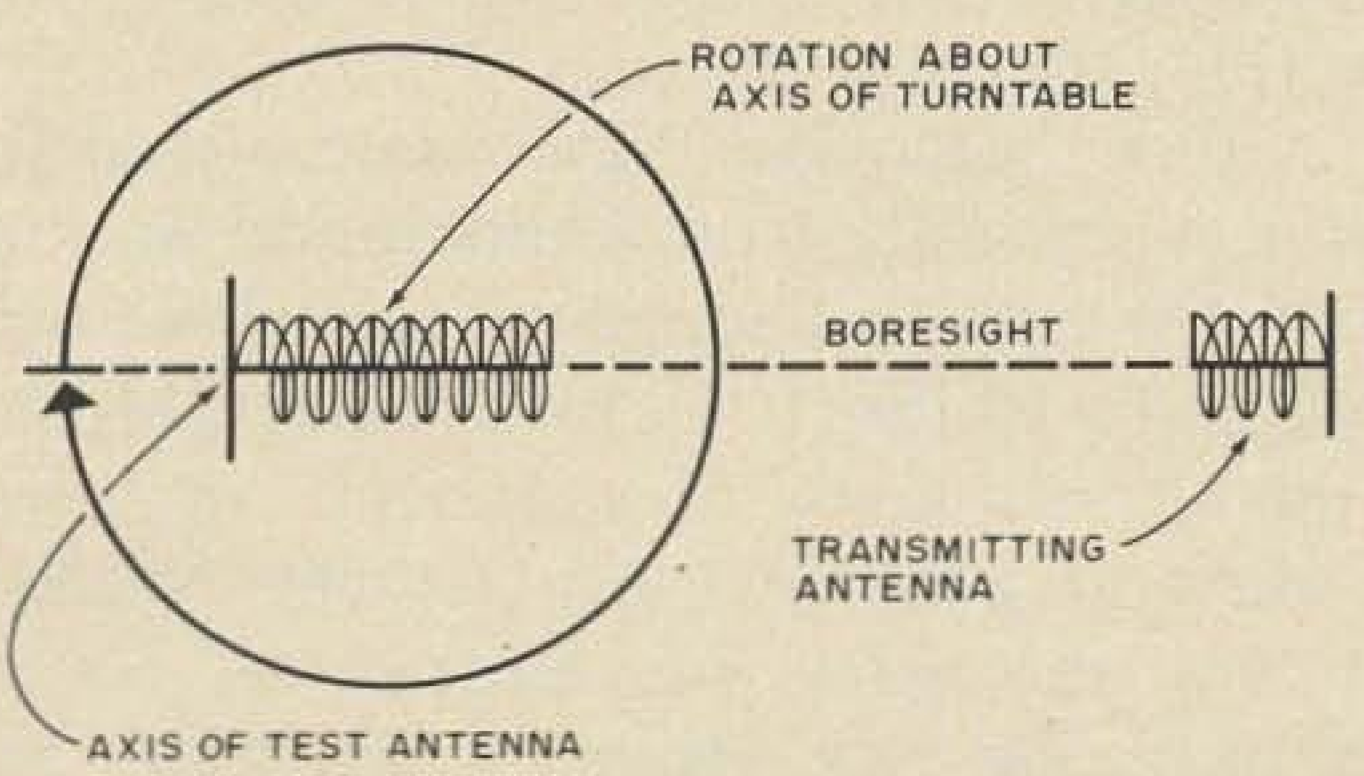


Fig. 6(a). Pattern measurement using test antenna for reception.

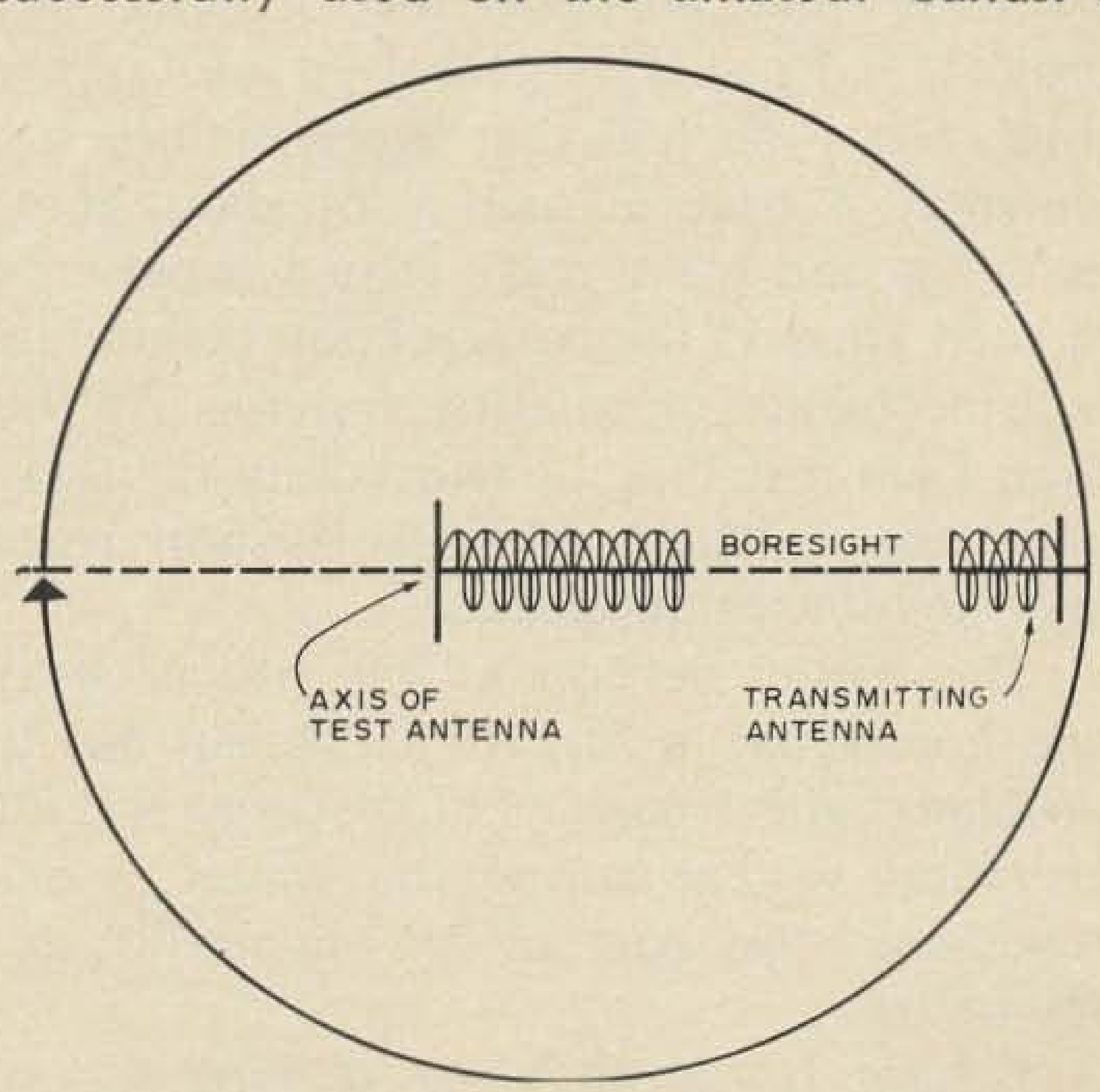
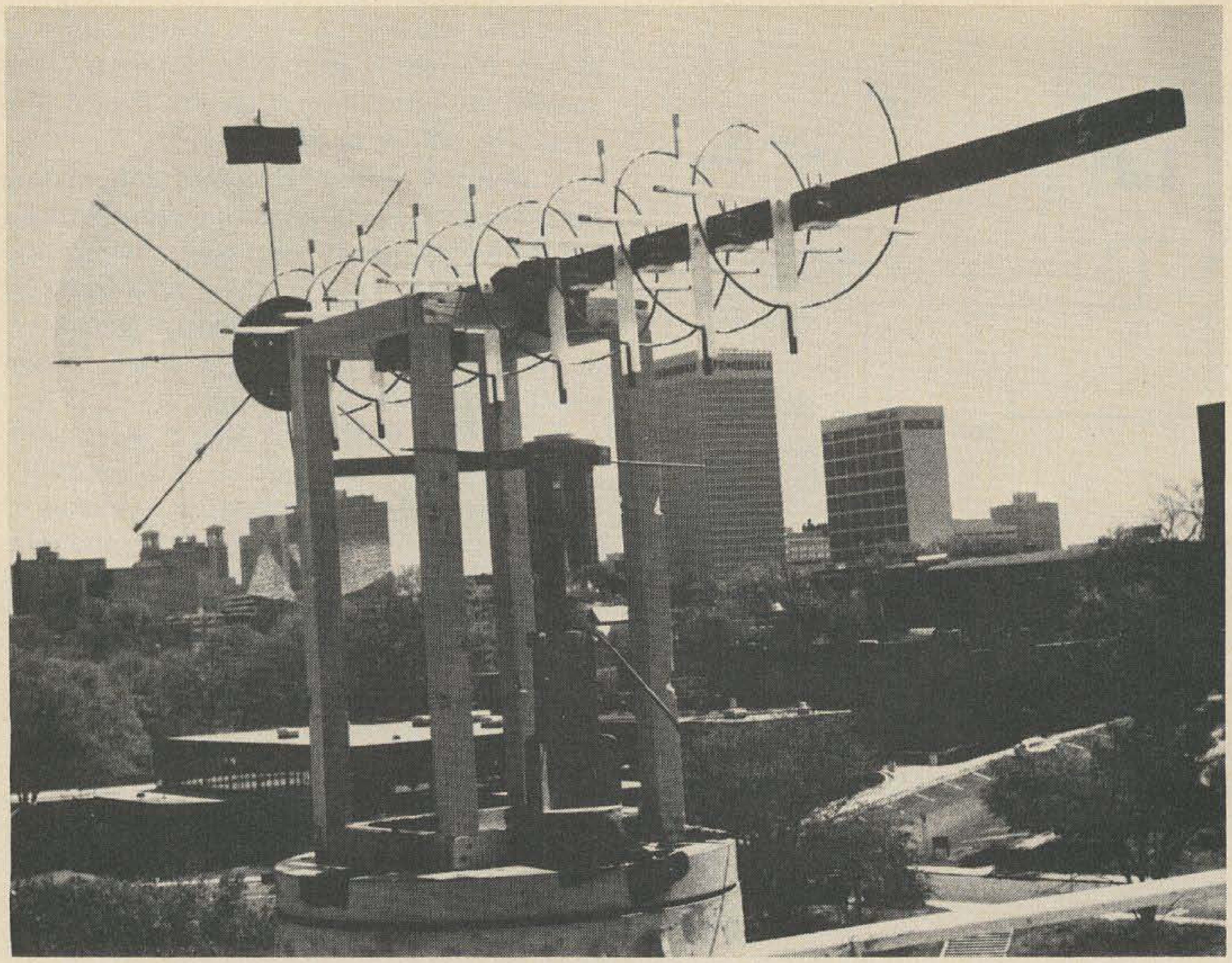


Fig. 6(b). Pattern measurement using test antenna for transmission.



The test antenna used during antenna pattern and gain measurements was the 8 turn 70 cm helix shown here. The helix was mounted on a wooden structure and placed on top of the turntable. The half-wave dipole used during gain measurements is located toward the front of the helix in the center of the picture.

feel that these antennas deserve more attention than they have gotten, even though I do not expect everyone to rush out and build an array like the one that I have. The project, as I call it, has involved a lot of my time, but I do feel that every minute was worth it. I have learned a lot about these antennas and have really gained experience in such areas as the construction techniques and mechanics of rotating systems. At this time I am installing or reinstalling the array with the updated azimuth-elevation rotor and the remounted helices.

The earlier version of the helical array was completed in August, 1974, but due to problems with balancing of the array and the elevation system during the winter, I had redesigned this part of it – hopefully, for the better.

I have found that, by making use of surplus materials in putting the array back together, I could come up with both a small investment and a mechanically sound antenna array. Also, in remounting the helices I decided that a counterbalance system should be installed, since I had found it very hard to balance the first array. Improper balance alone would cause rotor problems. By eliminating, in this updated version, the major stresses encountered with the elevation drive, the mechanical problems are solved, which means I can use the antennas more without having to keep working on the array.

Other "gleanings" have come out of the project, basically from building and working with the helices. I somehow found the time to build a 10 turn helix for 2 meters, which I entered in a home brew antenna measuring contest at a hamfest last October. Needless to say, this array was quite large, but its performance was what I expected and brought a first place in the "most gain" category of the contest. From this helix,

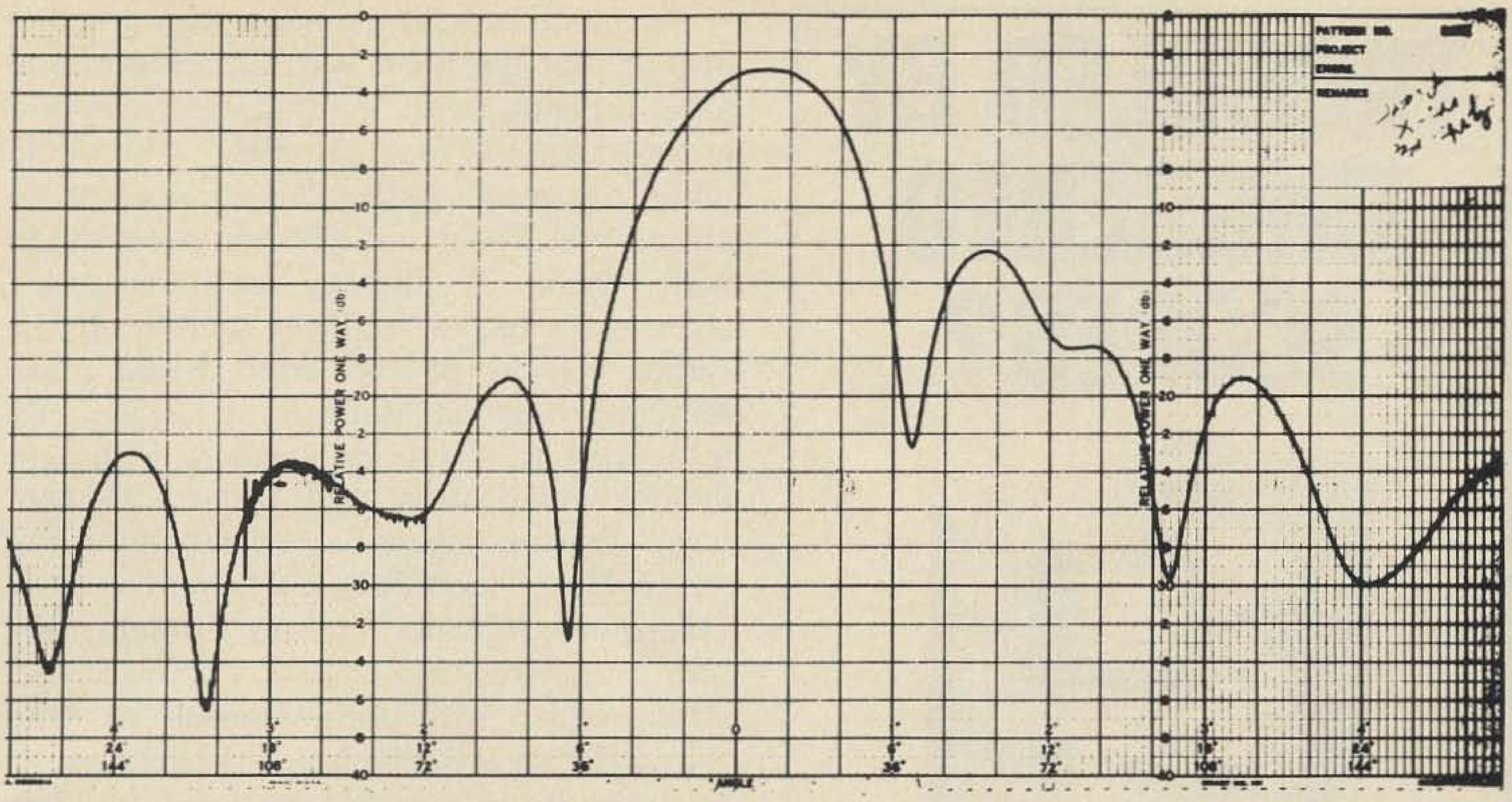


Fig. 7. Radiation pattern for 8 turn helix taken on a 40 dB rectangular recorder.

which was basically designed to be built and taken apart in less than an hour, I have found that a ground plane made of an aluminum plate with 8 radials will suffice. Here my original installation was too heavy and the ground plane for the 2 meter helix

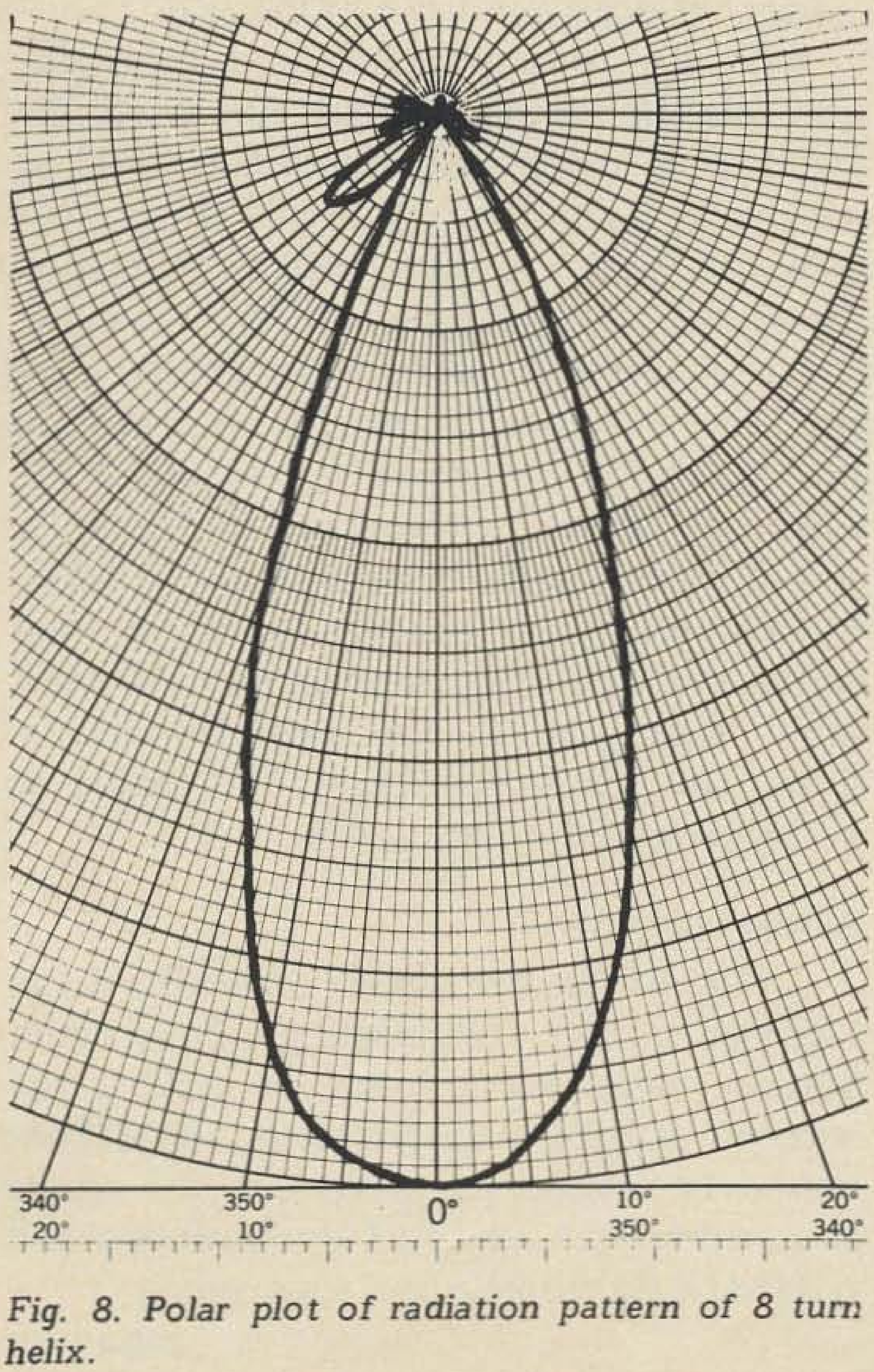


Fig. 8. Polar plot of radiation pattern of 8 turn helix.

was the major factor. So in redoing the array I have tried to reduce the weight where possible without sacrificing any of the performance of the antenna.

Another factor in putting together these antennas was utilizing materials available at the lowest possible cost. The plexiglass supports, which can be used up to 1000 MHz, were spaced at 90 degree intervals along the turns of the helix, even though other spacing could have been used. Also, 120 degree spacing on a triangular crossed sectioned boom could be used, depending upon the band of operation and the type of wire used for the conductor of the helix.

Fiberglass or aluminum can be used for the boom. Aluminum does not degrade the wide band characteristics of the helix when it is used primarily as a narrow band antenna, although the helix conductor must be insulated from the aluminum boom.

Since the helix is pretty broadbanded, i.e., a design at 160 MHz will operate well at 137 MHz and 220 MHz, so construction techniques depend on its basic use or application (Ref. 1, 2 – see *73* #178, page 64). For instance, a high performance array of helices could be built for working moonbounce, possibly using 4 helices of about 20 turns to obtain about 24 dBi circular gain. (Or possibly more than four antennas could be stacked to get more gain, such as is done by W8JK's 96 helix array at Ohio State.)

As far as satellite work is concerned, I believe that the helix will out-perform any other antenna (with the possible exception of a parabolic dish at 432 MHz). The whole point in putting together this array was to be able to use antennas of different polarization with Oscar 7, thereby optimizing the chances for success with the satellite. In the earlier version of the array I did make receiving tests on Mode B of Oscar 7. By using the 6 turn helix on 2 meters, with right circular polarization, and also a 4 element yagi, I have compared signal fading on this mode. Here I used both a 2 meter converter (Microwave Modules) and my Gonset GSB-2 SSB transceiver on 2 meters. I received very strong signals with both antennas, but with the yagi I do get fading every 5 to 7 minutes or so. With the helix and the yagi both tilted at 30 degrees and only rotated in azimuth, I have found that the fading problem inherent in the yagi is not found with the helix. I did not really take any qualitative measurements or data on this, but when I do get this updated version I do plan to make some serious polarization measurements of both modes of Oscar 7 and also of Oscar 6.

With the rotor problems and re-installation of the array, I have not used the antennas as much as I should have. Making use of the tracking capability of the array, I plan to make some more polarization measurements, switching from right circular, left circular, and linear polarizations. Here also, the array will be diverse, as I can use the rcp helix for Mode B, the lcp helix for Mode A on 2 meters, and the lcp helix at 432 MHz for the beacon at 435, 1 MHz. By choosing the number of turns that correspond with just enough gain to work Oscar, and with the appropriate polarizations, this array will truly be capable of performing well in all respects.

Acknowledgments

I wish to thank WA8GRE, Cliff Burdette, Georgia Tech Engineering Experiment Station, who assisted me in making the antenna pattern measurements and collaborated in writing the section of the article concerning that subject. I also wish to thank WB4KUX for his help and suggestions.

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