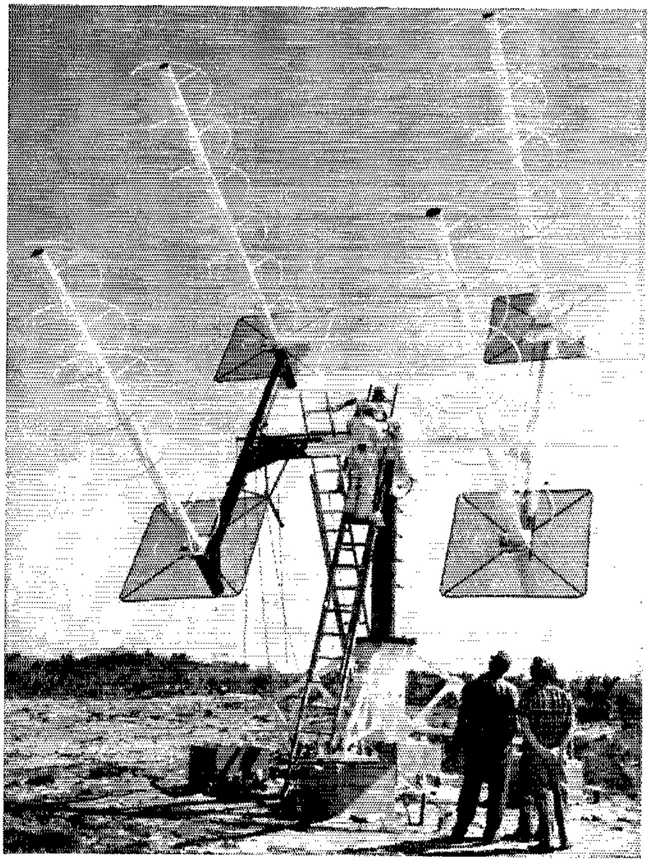
An example of a quad-helix arrangement used by the USAF (Photo courtesy of United States Air Force.)



The Basic Helical Beam

Slide Rule Absentis

BY DOUG DeMAW,* W1CER

DURING its passage through the ionosphere, a radio signal is subject to a continuous shift in polarization which, when the wave arrives at a receiving antenna of fixed linear polarization, causes periodic fading, especially apparent in v.h.f. and u.h.f. satellite work. For example, a horizontally-polarized antenna will give maximum signal output when the arriving wave happens to be passing through horizontal polarization, but will have essentially zero output at those times when the arriving wave is vertically polarized. This continuous shift in polarization, known as "Faraday rotation," is a complex phenomenon and no attempt will be made here to explain the mechanism.[1] In practice, the fading can be minimized by using antennas that transmit and receive circularly-polarized waves.

In moonbounce communication, there is another complication, in that the "sense" of the circular polarization is reversed on reflection from the lunar surface — that is, whether the polarization rotation is "right-handed" or "left-handed." Thus it becomes necessary to utilize a system that will permit the antenna's sense to be changed when switching from transmitting to receiving. A commercial version of such an antenna is being marketed and contains a set of interlaced Yagi elements, with one set vertically oriented on the boom while the other set is mounted horizontally on the same boom one-quarter wavelength away from the vertical members. A coaxial harness is used with the system to permit the sense to be switched from right- to left-hand circularity. It is believed that antennas of this type are good performers, but they are subject to matching problems and an attendant standing-wave ratio (s.w.r.) problem that is sometimes difficult to resolve.

Parabolic reflectors, used in combination with a variety of driven-element types, enjoy considerable popularity among amateurs who are active in space communications. Although antennas of this type are quite effective, they are not always easy to procure. The fabrication of home-built parabolic antennas is an exacting process and does not represent a practical starting point for the beginner. This system is also subject to the problems of proper matching. Feed-line

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* Assistant Technical Editor, *QST*.

[1] Kelso, *Radio Ray Propagation in the Ionosphere*, McGraw-Hill, p. 45, 137.

Many a would-be satellite or moonbounce enthusiast has shied away from this interesting pursuit, simply because the antenna system required for this phase of amateur-radio operation seemed to be too complex to tackle. Although a certain amount of antenna knowledge is necessary if effective results are to be had, the helical antennas discussed in this text will enable the beginner to get started in the growing field of space communication with a minimum of difficulty and expense.

radiation with this type of antenna can disturb the sense of the system, making the project additionally difficult.

Perhaps the simplest circularly-polarized antenna, and one that represents a practical starting point for the beginner in space communications, is the Kraus helical-beam antenna. The opportunity for mechanical error, causing poor performance, is minimized by the antenna's rather broad frequency response — approximately 2 to 1. Furthermore, the cost of materials used in the construction of a helical beam is modest, adding even greater appeal to the project.

This article deals with a working model of a pair of helical-beam antennas, of opposite sense, for use on 432 Mc. Other combinations of helical antennas, producing different radiation modes, are also described.

The Axial-Mode Helix

The term *helix* implies "anything having a spiral form." This is indeed an apt description of a helical beam. However, the diameter of the spirals and the spacing between them has a marked effect on the performance of the system. In this respect the circumference of the helix, in terms of wavelengths, determines whether the antennas will radiate in the "normal" or "axial" mode (Fig. 1). The axial mode of radiation produces a circularly-polarized (or nearly so) field that is maximum in the direction of the helix axis, and is the most useful mode for our purposes. (The normal mode of radiation can be compared to that of a dipole antenna where the field is maximum at right angles to the plane of the radiator.) A turn circumference of one wavelength at the operating frequency will produce the desired axial-mode pattern of radiation.

With helical beams either right- or left- hand circular polarization is possible depending on how the helix is wound. When viewing the antenna from the feed-point end, a clockwise wind will result in right-hand circular polarity while a counterclockwise wind will result in left-hand circular polarity. A screen reflector is centered behind the antenna element and the transmission line is connected between the re-reflector and the start of the helix at the point where it is adjacent to the center of the reflector.

Electrical Properties

Helical-beam antennas having as few as one or two turns will produce circularly-polarized waves, but do not deliver sufficient gain to be of interest to the average user. Generally, between 6 and 10 turns are used in the helix so that greater gain and directivity can be realized. The greater the axial length of the antenna (more turns) the more desirable the system becomes for space communications. A narrower beamwidth (Fig. 2) results as more turns are added. A 10-turn helical beam, adjusted for optimum performance, should be capable of producing between 15 and 18 decibels of forward gain when referenced against an isotropic antenna. If helical beam antennas are used for point-to-point communication in the same circuit, they must be of the same right- or left-hand thread in order to avoid the high-order signal loss resulting from cross-polarity of the two senses.

The feed-point impedance of a multiturn helical beam with a circumference on the order of 1 wavelength is normally between 100 and 200 ohms. This impedance is nearly constant with frequency and is nearly a pure resistance. The empirical relation, $R = 140\ C/\lambda$ ohms, where C represents turn circumference in wavelengths, seems to hold true on a ± 20 per cent basis for the antenna system described later. Detailed information concerning helical antennas has been presented by the antenna's designer, J. K. Kraus.[2]

The conductor material used in the helix element should be of sufficient diameter to permit reasonable surface area. Where power levels in excess of 100 watts are contemplated, the larger conductor sizes are to be preferred. A conductor diameter of 0.02 wavelength represents an ideal dimension in this application; at 432 Mc., this turns out to be 0.516 inch. However, a diameter ranging between 0.006 and 0.05 wavelength seems to suffice, making little difference in the properties of the helix in the frequency range of the beam-axial mode. The smaller dimension (0.006

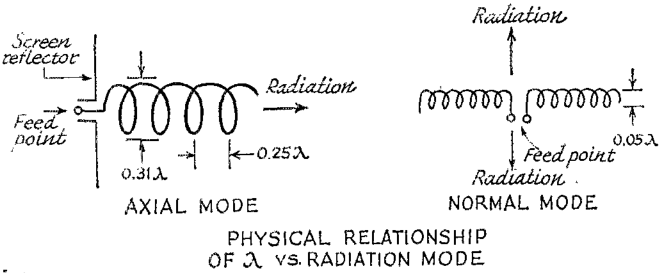

Fig. 1—A comparison of radiation modes. The helical dipole at the right has a turn spacing of approximately 0.1λ.

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[2] Kraus, *Antennas*, McGraw-Hill, Chapter 7.

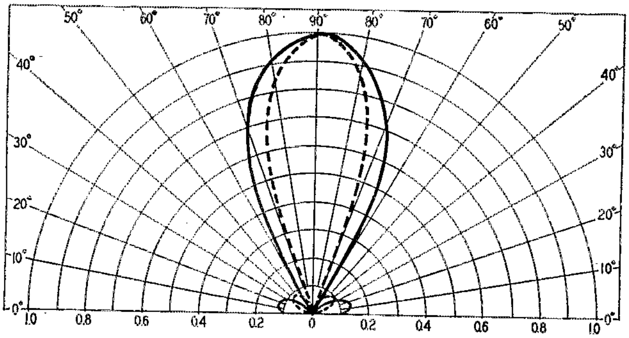

Fig. 2—A polar plot showing the relationship, in terms of beamwidth, between helical antennas with differential axial lengths and turn circumferences. The dotted line is the relative beamwidth of a 10-turn helix with a turn circumference of 1.2 wavelength. The solid line shows a relative representation of the beamwidth of an 8-turn helical antenna whose turn circumference is 1 wavelength.

wavelength) represents an element diameter of 0.154 inch, falling between Nos. 6 and 7 in wire gauge. Although No. 8 aluminum wire is slightly below the specified minimum wire size, it has been used effectively with 125 watts of 432-Mc. r.f. applied to the antenna. Since this type of wire is readily available at reasonable prices, its use can no doubt be justified. Aluminum wire was used in the models described in this article, but if a slightly heavier antenna is not objectionable, No. 6 copper wire could be substituted in its place. If cost and added weight are not important considerations to the builder, the use of ¼-inch copper tubing might be an even better choice.

The feed-point impedance of a helix having a turn circumference of 1 wavelength will be on the order of 140 ohms. The diameter of a 1-wave-length turn will be approximately 0.31 wave-length. Because of the feed-point impedance that results with this dimension a matching transformer is necessary between the antenna terminals and the transmission line. Two types of coaxial matching transformers, for converting from 140 ohms to 50-ohm transmission line, are illustrated in Fig. 6.

The reflector used in conjunction with the helical driven element should be at least 0.5 wavelength in diameter. A reflector with a diameter of 0.75 wavelength, or greater, is more commonly used and will provide a better front-to-back ratio without noticeable effect on the antenna's impedance. A 1-wavelength square reflector was used with the antennas shown in Fig. 3.

Building a Helical Beam

The completed antenna system shown in Fig. 3 contains two helical beams, each having an 8-turn driven element. Both have 25 × 25-inch reflectors that were fashioned from standard mesh-type hardware cloth. Examination of Fig. 4 will reveal the basic simplicity of the system. The reflector elements do not have sufficient rigidity to withstand long-term use and should be constructed as shown in Fig. 5 if the rigors of severe weather are not to shorten the life span of the array.

The longerons which support the helical elements are each 60 inches long and are made from 1 × 1-inch lumber. The helices are stapled

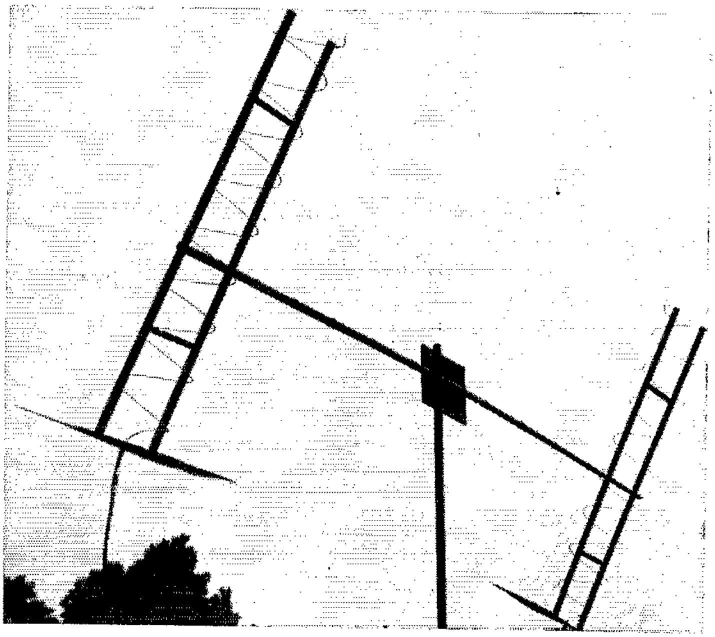

Fig. 3—The 8-turn helical beam on the right is wound for right-hand circular polarization. The antenna in the left foreground is wound for the left-hand circular mode. The quarter-wave matching section (coax and fittings) projects down from the screen reflector and is visible at the left. The individual bays are bolted to the bamboo cross member at the balance point of each bay.

to the longerons at each turn to preserve symmetry and to reinforce the driven elements. A better system would have been to use a standoff insulator at each point where the helices came in contact with the longerons, to reduce r.f. losses. An alternate method for reducing losses during damp weather would be to coat the wooden support members with exterior spar varnish or epoxy-resin paint prior to stapling the turns of the helices to them. After this is done, a few drops of epoxy glue could be placed over each stapled area to add further to the structural soundness of the system.

It is not particularly difficult to wind the helix coils but care should be taken to insure that a full wavelength-per-turn actually exists. It is easy to end up with an egg-shaped turn circumference if each spiral of the helix is not carefully placed on the longerons. The effect of such a mechanical error would be a turn circumference that was greater, or less than, the desired 1-wavelength dimension. Such an error would alter the beam width of the antenna and would result in a different feed-point impedance. The construction of the driven element can be simplified by precutting the aluminum wire to length prior to winding it on the longerons. A length of 207 inches will be correct for the 8-turn helix. To aid in the final tuneup of the antennas, an extra 6 inches of wire should be added to make a total dimension of 213 inches. This subject is discussed later.

The two antennas are identical with the exception that one of them is wound clockwise while the other is wound counterclockwise. This enables the user to select right- or left-hand polarization when engaging in moonbounce work.[3]

After the two antennas are assembled, they can be mounted on the 6-foot long horizontal boom. This cross member, visible in Fig. 3, is a 2-inch-diameter bamboo pole and is attached at its center, with two U bolts, to a 10-inch-square section of ⅜-inch plywood. A 6-foot length of 2 × 2-inch lumber would serve as a more rigid cross member and is recommended. A slight tendency toward "skewing" was experienced while using the bamboo stock, causing each bay of the antenna to have a different elevation angle during periods when a strong breeze prevailed.

A type N connector (chassis-mount variety) is installed at the center of each screen reflector. The flange of each connector is soldered to the hardware cloth to insure against poor electrical contact. The center terminal of the coax fitting is soldered to the feed-point end of the helix as shown in Fig. 4.

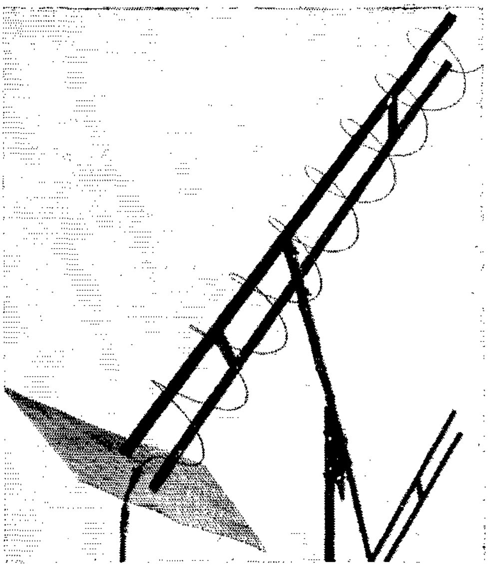

Fig. 4—A close-up view of the 8-turn helical beam. The coaxial cable and matching transformer are connected to the coax fitting at the center of the screen reflector. The helix element is attached to the wooden longerons with staples.

Although some controversy seems to exist with regard to the correct spacing between the first turn of the helix and the reflector, it was learned during experimentation with the antenna models described here that no significant change in feed-point impedance occurred when this dimension was varied. The first turn was started ⅛ wavelength away from the screen reflector, as some textbooks recommend, and impedance measurements were made. Then the first turn was made to start directly at the coaxial terminal on the reflector (Fig. 4) and the feed-point impedance remained the same. Intermediate spacings, between these two extremes, resulted in but minor changes in the feed-point resistance, so the first turn of the helix was started at the coax fitting in the manner illustrated in the photographs of Figs. 3 and 4.

If aluminum wire is used for the helices, a special soldering flux will be necessary.[4] If copper wire is used for the driven elements, no special flux will be required because copper will accept solder without difficulty.

Impedance Matching

A low standing-wave ratio is of paramount importance at 432 Mc. To make the system as efficient as possible in this regard, a matching transformer, Fig. 6, is installed between the antenna feed point and the 50-ohm transmission line to the equipment. In this instance, a match must be effected between the "ball park" figure of 140 ohms at the antenna terminals, and the 50-ohm transmission line impedance.

The formula for determining the correct impedance value for a coaxial quarter-wave matching transformer is

$$Z_o = \sqrt{Z_s Z_r}\ \text{ohms} \qquad (1)$$

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[3] Because the antenna system at KP4BPZ is designed to transmit in a right-hand circular sense, and receive in a left-hand circular sense, it is important that stations at the opposite end of the circuit be equipped with antennas capable of matching both the left- and right-hand senses when communicating with KP4BPZ. (Stations at this end of the circuit should transmit in the right-hand circular sense and receive in the left-hand circular mode.)

[4] Sal-Met Soldering Flux (available from Burstein-Applebee Co., 1012 McGee St., Kansas City 6, Missouri).

where Z_o = Desired transformer impedance
Z_s = Transmission-line impedance
Z_r = Antenna impedance

The required impedance for matching the 140-ohm terminal resistance of the helix antennas to 50-ohm transmission line is 83.7 ohms. Unfortunately, this is not a standard ohmic value for manufactured cables, so a compromise must be accepted if one does not wish to build a matching section of the ideal value. A ¼-wavelength section of RG-11/U cable (75 ohms) was used with the antennas shown in Fig. 3 and the resultant s.w.r. was 1.8:1. A closer match can be obtained by using the 81-ohm transformer described in Fig. 6. By substituting a length of 5/32-inch diameter brass or copper stock for the No. 6 copper wire shown, the impedance will increase to 83 ohms—a value that closely matches the desired 84-ohm figure. No. 6 wire is shown because it is more readily available than the 5/32-inch diameter stock. Other combinations of inner- and outer-diameter conductor dimensions can be used to secure the same impedance.

It is a simple matter to calculate the sizes of the inner and outer conductors that are required for various impedances in matching sections of this type. The dimensions can be found from

$$Z_o = 138 \log \frac{b}{a} \qquad (2)$$

where Z_o = Desired transformer impedance
a = Outside diameter of the inner conductor (inches)
b = Inside diameter of outer conductor (inches)

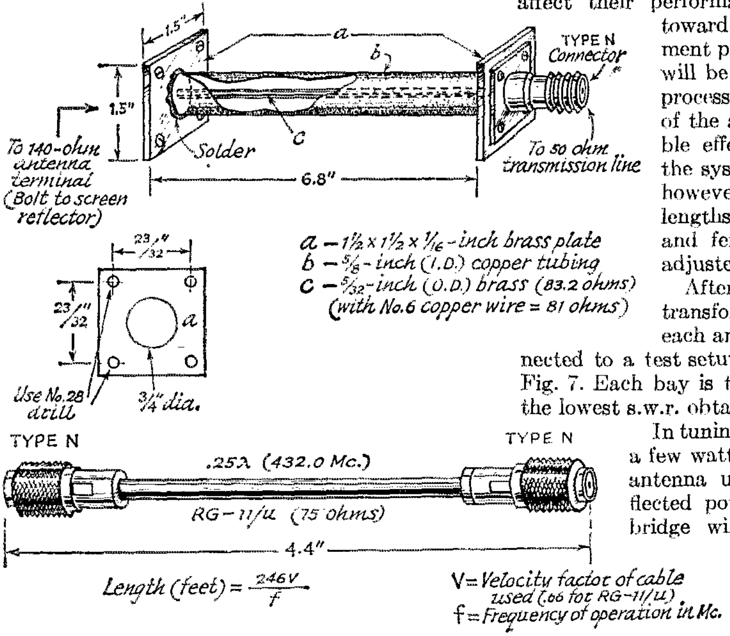

Fig. 6—Details of a matching transformer (top) which can be made from copper tubing. A compromise matching section made from RG-11/U cable (bottom).

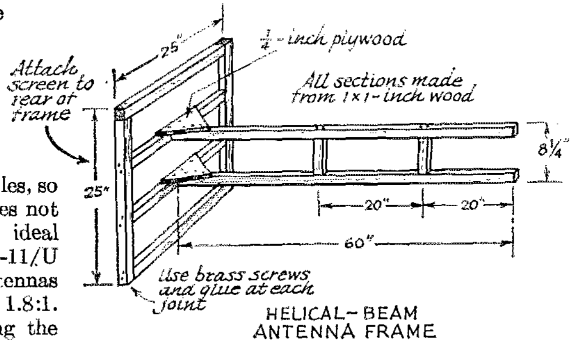

Fig. 5—A wooden framework of this type, treated with spar varnish or epoxy-resin paint, will be sufficiently strong to withstand severe weather.

By employing a double-stub tuner near the feed point of the antenna, a precise match between the transmission line and the helix can be obtained. Since a device of this type must contain two tunable quarter-wave coaxial sections, the mechanical requirements may be somewhat beyond the capabilities of the average ham-radio workshop. Detailed information connected with the design and fabrication of such an assembly has been published.[5]

Antenna Adjustment

After the antennas have been attached to their supporting framework, they can be mounted to the mast and set in place on the tower. (A 5-foot triangular TV tower was used with the models in Fig. 3.) Although the antennas are but a few feet above ground, proximity effect will not affect their performance if they are pointed toward the sky during the adjustment period. A wooden stepladder will be helpful during the tuneup process and may be left in the field of the antennas without undesirable effects being introduced into the system. The antennas should, however, be kept several wavelengths away from trees, buildings and fences while they are being adjusted.

After installing the matching transformers at the feed point of each antenna, they should be connected to a test setup of the kind illustrated in Fig. 7. Each bay is tuned individually, and for the lowest s.w.r. obtainable.

In tuning for minimum s.w.r., apply a few watts of 432-Mc. energy to the antenna under test. The initial reflected power readings on the s.w.r. bridge will be quite high because of the added length of the driven element, mentioned earlier in the text. Place the transmitter in standby

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[5] Johnson, *Transmission Lines and Networks*, McGraw-Hill, Chapter 7.
RSGB, *The Amateur Radio Handbook*, Chapter 14.

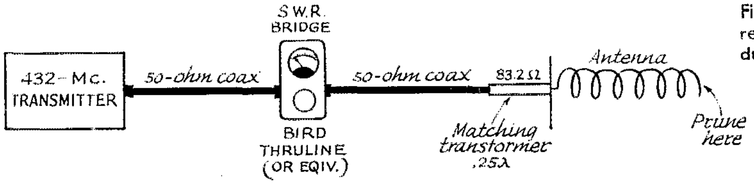

Fig. 7—A block diagram of the recommended test setup for use during antenna adjustments. A u.h.f.-type s.w.r. bridge is needed to assure reasonable accuracy during the tests.

and snip off about ⅛ inch of stock from the far end of the helix. Turn the transmitter on and once again observe the s.w.r. reading. Repeat this procedure until a drop in reflected power is noted. When this stage is reached, limit the amount of each snip to approximately 1/16 inch to prevent passing beyond the dimension that provides the lowest s.w.r. reading. When no further reduction in reflected power is possible, cease pruning. The s.w.r. will be on the order of 1.5:1, or slightly higher, once the best null is reached. Repeat the process just described, while tuning the remaining helical-antenna bay.

Using the Antennas

A number of possibilities exist for the gainful application of circularly-polarized antennas. The Oscar work, previously carried out on 2 meters, is expected to continue. A helical beam antenna built to 144-Mc. dimensions would respond better than other types to the ever-changing signal polarity from Oscar. Since satellites are continuously tumbling as they orbit, their transmitted signals tend to arrive on earth in kaleidoscope fashion. A circularly-polarized antenna is capable of responding to whatever signal polarity may arrive at a given instant. A marked reduction in signal fading will result from the use of a circularly-polarized antenna, making the helical array quite desirable for satellite work. Similarly, the fading that is experienced over rough terrain when operating on 432 Mc. should be lessened because of the antenna's ability to respond to signals affected by polarity shift.

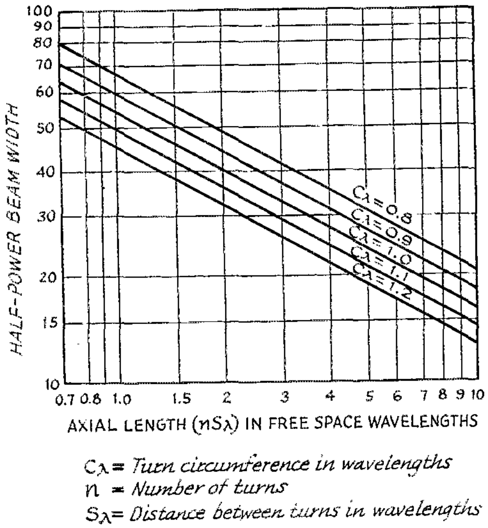

Fig. 9—A chart for determining the half-power beamwidth of helical antennas using different turn circumferences (in wavelengths) and different axial lengths.

In moonbounce communications, a left-hand circular-sense antenna and a right-hand circular-sense antenna can be used without the need for antenna switching because you will normally be transmitting in the right-hand circular mode and receiving in the left-hand mode. In addition, approximately 30 decibels of circuit isolation results from the two antennas being of opposite sense, reducing the complexity of receiver front-end isolation.

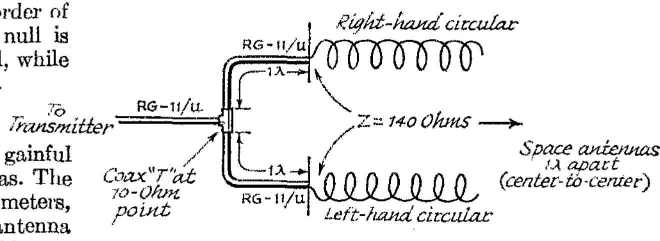

Fig. 8—A right- and a left-hand circularly-polarized helical antenna can be combined to produce a linear radiation pattern. This result is possible by feeding the two bays in phase, as shown.

A more effective moonbounce antenna would result from arranging each bay so that it contained four helical beams. The added gain, increase capture area (aperture) and improved directivity would be well worth the added effort. An example of such an array is shown in the photograph on page 20. Four helices per bay should be capable of yielding as much as 20 decibels of gain, or more, if carefully constructed and matched. A unique matching system for use with quad-helical beams is described in *The Radio Amateur's Handbook*, and should be adaptable to 432-Mc. use.[6]

$$\text{BEAM WIDTH DEGREES} = \frac{115}{C_\lambda \sqrt{n S_\lambda}}$$

When using the helical-beam array (Fig. 3) for moonbounce work, the elevation will have to be changed by loosening the U-bolts on the horizontal cross member, changing the elevation angle of the antennas, then tightening the U-bolts again. A similar procedure is required when changing the azimuth angle of the system. Since this represents a very crude form of Az-El control, the user of such an antenna system may prefer to mount antenna rotators at the appropriate points in the structure for more rapid positioning

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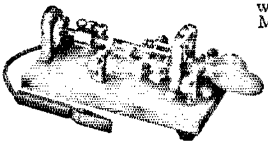
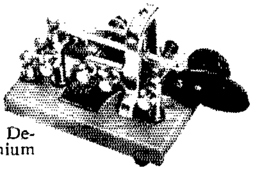
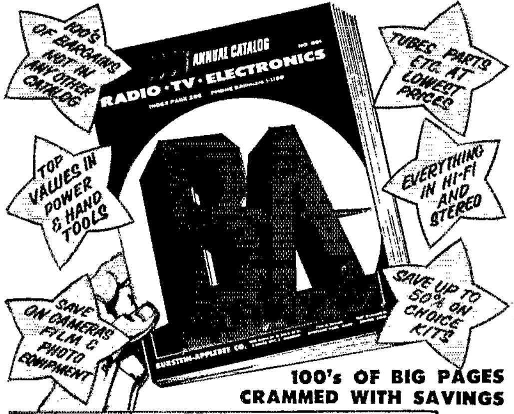
[6] ARRL, *The Radio Amateur's Handbook*, 42nd ed., p. 463.







The Basic Helical Beam

(*Continued from page 26*)

of the antennas. The latter is recommended.

For point-to-point communications, the more common linear polarization may be desired. By feeding a left- and a right-hand helix in phase, as illustrated in Fig. 8, linear polarization will result. By rotating *one* of the antennas on its axis 180 degrees, vertical or horizontal polarization may be secured. A feed-line switching system could no doubt be conceived to enable the user to select either bay of the antenna for right- or left-hand circular polarization. The versatility of such an antenna system would certainly qualify it as an all-purpose array.

In Conclusion

The antenna system outlined in this text should not be construed to represent the ideal array, as such. Although the signals from KP4BPZ, via the earth-moon-earth (e.m.e.) path on 432 Mc., were copied Q5 during most of the July 24, 1965 tests, while using the antennas in Fig. 3, better results would have been possible if four helices per bay had been used. A single 8-turn helical antenna is a practical starting point for the beginner and represents the minimum starting point for space communications. The enterprising v.h.f./u.h.f. enthusiast can exploit the helical-beam antenna far beyond the possibilities listed in this article. In this regard, multibay arrays of helical antennas have been used successfully for radioastronomy work during the past decade — offering undisputed evidence of their value in space communications.

Although the dimensions of a helix are somewhat larger when applied to 2-meter use, a 4- or 5-turn driven element (either right- or left-hand polarity) would be useful for satellite monitoring because of the circular polarization mode. With increased array dimensions, the helical antenna should serve quite well for both transmitting and receiving in connection with 144-Mc. satellite work. So if you're a space-communications buff, and are interested in "rolling your own" at a minum of expense, the helical beam may be your answer. And even nicer still; the hardware store just around the corner from you has the material you will need to build your helix!

I wish to express my gratitude to W1QMR and K1TKZ for their efforts in building the antennas shown in Fig. 3. QST

Boston or Bust

(*Continued from page 86*)

Hotel Reservations should be made directly with the Sheraton-Boston Hotel, Boston, Mass. Special ARRL Convention rates are:

Good	$12 single	$18 twin
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