Reflector spacings of helical beam antennas
by Donald O Marriage

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering
Montana State University

Abstract:
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The dimensional ,requirements for a helix to radiate in the axial or beam mode are discussed and a test helix is designed using an average of each dimension A radiation pattern is calculated for the test antenna, and radiation patterns are plotted for various reflector to first turn spacings, The reflector spacing for maximum gain is indicated# and pattern beam width is discussed.

A method of obtaining, linear polarisation with a possible gain increase is suggested.

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Approved:

E. W. Schilling

Head, Major Department

Robert L. Hunford

Chairman, Examining Committee

J. A. Nelson

Dean, Graduate Division

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ABSTRACT

Antennas possessing circular polarization characteristics have become increasingly important in recent years. Such an antenna finds an important use in aircraft to airfield and missile to control station communication, as a means of stabilizing random polarization changes of the received signal.

The dimensional requirements for a helix to radiate in the axial or beam mode are discussed and a test helix is designed using an average of each dimension.

A radiation pattern is calculated for the test antenna, and radiation patterns are plotted for various reflector to first turn spacings. The reflector spacing for maximum gain is indicated, and pattern beam width is discussed.

A method of obtaining linear polarization with a possible gain increase is suggested.

INTRODUCTION

In writing this thesis the author assumed that the reader would possess a basic knowledge of wave propagation and radiation. Accepted phrases and abbreviations commonly used in radio engineering literature are used throughout the thesis.

The object of the research leading to this thesis was to obtain a comparison of the gain of various helical beam antennas, using a tuned dipole as a reference antenna. Various reflector spacings were considered in order to obtain a maximum of antenna gain. As an added point of interest a method of obtaining linear polarization from a combination of circularly polarized helical beam antennas was considered. Some articles concerning helical antennas have appeared in engineering publications, but the author is not aware of any previous gain comparison tests. A few of the more important articles consulted appear in the "Literature Cited and Consulted" section of this thesis.

Experience in airfield to missile communications has indicated a need for more reliable communication that is free from random polarization changes caused by banking of the missile. It has been suggested that a circularly polarized antenna at the fixed-station would help to stabilize signal transmission, and permit maximum freedom of choice of location of the antenna on the aircraft. This demand for an antenna possessing circular polarization characteristics and a high-gain unidirectional pattern has made this investigation of the helical beam antenna worthwhile.

Since all dimensions were computed in terms of wavelength, the discussion is valid for any operating frequency within limitations imposed by physical construction. For the investigations a Sperry Type 710 klystron oscillator generating a frequency of 3000 MC was employed. This ultrahigh test frequency provided some definite advantages in size and spacing of antenna elements. A lower test frequency would have resulted in cumbersome antenna elements and an inconveniently large distance between transmitting and receiving antennas.

THE HELICAL ANTENNA IN GENERAL

Because the helical antenna is the general form of antenna of which the linear and loop antennas are special cases, the helical antenna may be considered as the connecting link between the two.[1] A linear antenna is merely a helix of fixed spacing between turns with the turn diameter approaching zero. Similarly, a loop antenna is formed by a helix with the spacing between turns approaching zero.

A helical antenna may radiate in any one of several modes, the two modes of interest being the normal mode and the axial or beam mode, as shown by Figure 1. Of the two, the axial mode appeared to be the most logical to investigate, since its radiation pattern is unidirectional and is circularly polarized.

A circularly polarized wave may quite properly be considered to consist of a vertically polarized wave imposed on a horizontally polarized wave, with both waves traveling in the same direction. Then, at any point which the waves pass, the two electric fields are in time quadrature with one another. The electric field intensity of the vertically polarized wave is represented by

$$e_v = A \operatorname{Sin} wt$$

and the electric field intensity of the horizontally polarized wave is represented by

$$e_h = A \operatorname{Cos} wt$$

1. Kraus, J.D., 1950, ANTENNAS, p 173, McGraw-Hill Book Company, Inc., New York and London

since it differs in phase by 90°. Then the resultant field intensity vector at any instant of time has a magnitude equal to $\sqrt{e_v^2 + e_h^2}$ and this vector makes an angle ϕ with the horizontal, where $\tan \phi = \frac{e_v}{e_h} = \tan wt$. It is apparent, then that the resultant field intensity vector is constant in magnitude and appears to rotate in the plane of the wave at a speed of w radians per second.[2]

For purposes of simplicity in discussion it will be advantageous to assign a set of symbols to the various helix dimensions. Therefore, let

D = diameter of the helix (center to center)

C = circumference of helix = πD

S = spacing between turns (center to center)

θ = pitch angle = $\arctan S/\pi D$

L = length of one turn

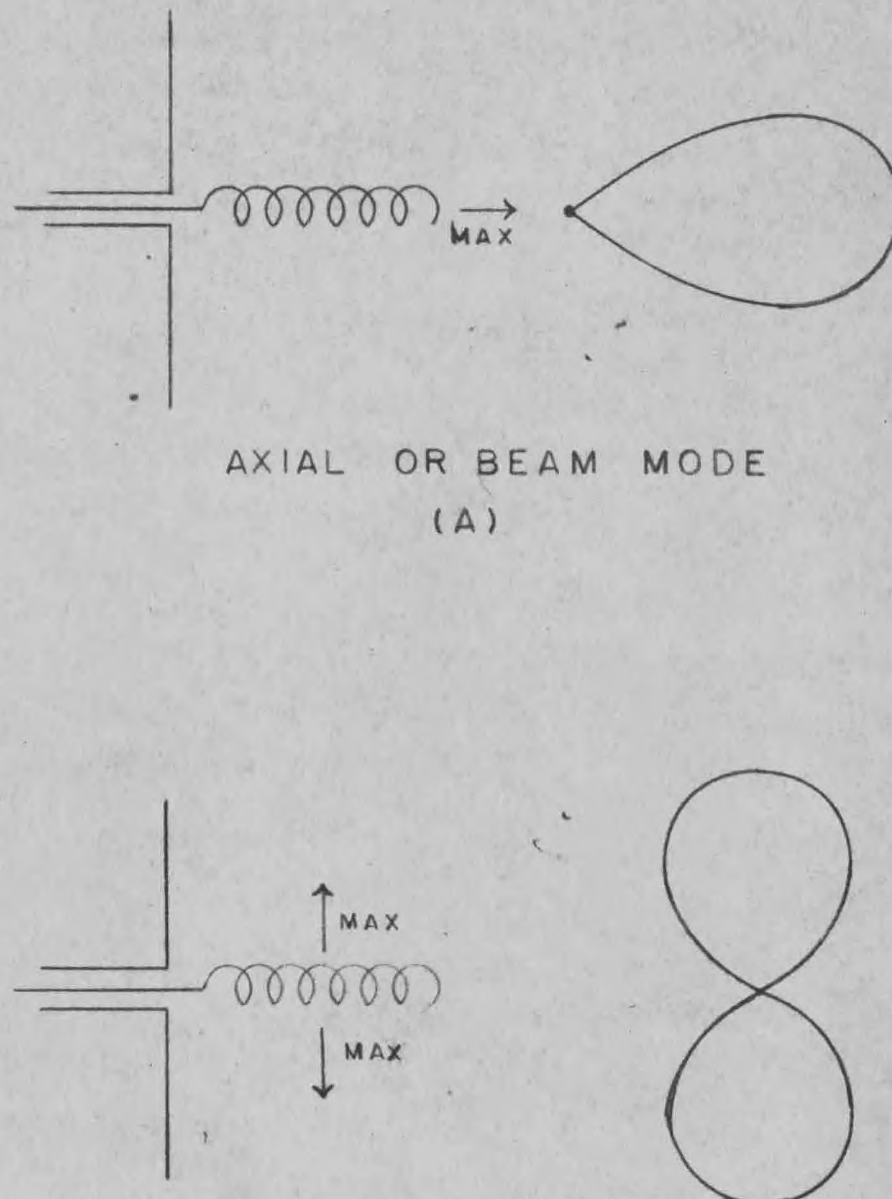
n = number of turns

A = axial length of helix = nS

d = diameter of the helix conductor

These dimensions are indicated in Figure 2, and the relations between circumference, spacing, turn length, and pitch angle are demonstrated. The subscript λ denotes the dimension is measured in free-space wave lengths.

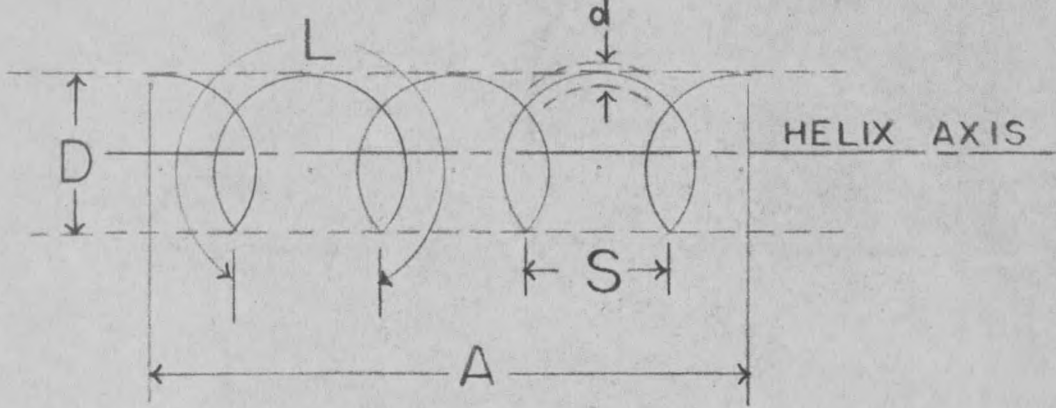
2. Geo. H. Brown and O.M. Woodward, Jr., 1947, "A Circularly Polarized Omnidirectional Antenna", RCA Review, Vol. 8, p 259.



AXIAL OR BEAM MODE
(A)

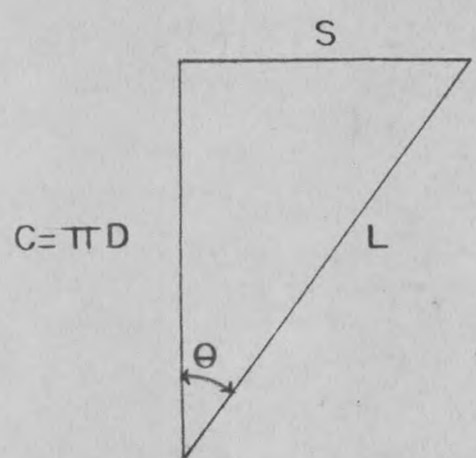
NORMAL MODE
(B)

FIG. I



HELIX DIMENSIONS

FIG. 2



HELIX DIMENSION RELATIONS

FIG. 3

THE AXIAL MODE OF RADIATION

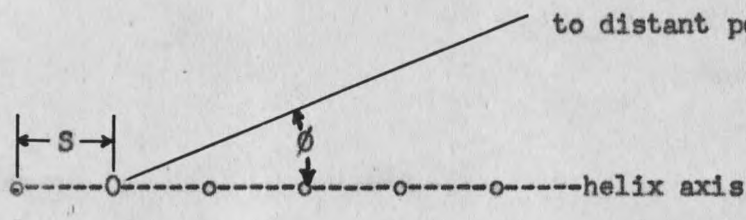
To understand the nature of the axial or beam mode of radiation, the antenna may be assumed to have a single uniform traveling wave along its conductor. Then, by the principle of pattern multiplication, the far field pattern of the helix is the product of the pattern of one turn and the pattern of an array of n isotropic point sources, where the spacing, S, between sources is equal to the turn spacing.

The array pattern or array factor for a linear array of n isotropic point sources of equal amplitude and spacing is given by[3]

$$E = \frac{\sin n\frac{\psi}{2}}{\sin \frac{\psi}{2}} \qquad (1)$$

where is the total phase difference of the fields from adjacent sources, referring to Figure 4, and is given by

$$\psi = S_r \cos \phi + g \qquad (2)$$



AN ARRAY OF ISOTROPIC POINT SOURCES

Figure 4

If g is the phase difference between adjacent sources, and

$$S_r = \frac{2\pi S}{\lambda}$$

3. Kraus, J.D., 1950, ANTENNAS, pp. 76-79, McGraw-Hill Book Company, Inc., New York and London.

equation (2) becomes, for the helix antenna,

$$\psi = 2\pi \left(S_\lambda \cos \phi - \frac{L_\lambda}{p} \right) \tag{4}$$

where p is the relative phase velocity along the helical conductor. The axial mode of radiation, by definition, requires that the fields from all sources be in phase at a distant point on the helix axis. This condition is simply the ordinary end-fire condition for a linear array, and requires that

$$\psi = -2\pi m \tag{5}$$

The negative sign indicates the fact that the phase of source (2) is retarded by $2\pi\frac{L_\lambda}{p}$ with respect to source (1), and each succeeding source is similarly retarded with respect to the preceding source.

Considering a distant point on the helix axis, $\phi = 0$, and

$$\frac{L_\lambda}{p} = S_\lambda + m \tag{6}$$

Using the approximate value of $p = 1$ and $m = 1$ (axial mode),

$$L_\lambda - S_\lambda = 1 \qquad \text{or} \qquad L - S = \lambda \tag{7}$$

which is an approximate expression between spacing and turn length for a helix antenna radiating in the axial mode. Referring again to Figure 3, it is seen that

$$L^2 = \pi^2 D^2 + S^2 \tag{8}$$

and equation (7) may be rewritten as

$$D_\lambda = \sqrt{\frac{2S_\lambda + 1}{\pi}} \qquad \text{or} \qquad C_\lambda = \sqrt{2S_\lambda + 1} \qquad (9)\ (10)$$

Solving equation (6) for p, again considering the case where $m = 1$, we have

$$p = \frac{L_\lambda}{S_\lambda + 1} \tag{11}$$

From Figure 3, p can also be expressed

$$p = \frac{1}{\sin \theta + \frac{\cos \theta}{C_\lambda}} \tag{12}$$

which demonstrates the required variation of phase velocity as a function of circumference for the axial radiation mode. Direct measurements performed by Kraus agree with equation (12), that the value of p may be considerably less than unity. The effect of a value of relative phase velocity less than unity is to broaden the calculated radiation pattern, as can be seen by a considerations of the equations involved.

Investigating this problem, Hansen and Woodyard derived an "increased directivity condition" given by

$$\psi = -(2\pi m + \frac{\pi}{n}) \tag{13}$$

which, when $\phi = 0$ results in

$$p = \frac{L_\lambda}{S_\lambda + m + \frac{n}{2}} \tag{14}$$

For the case where m = 1,

$$p = \frac{L_\lambda}{S_\lambda + \frac{2n + 1}{2n}} \tag{15}$$

or

$$p = \frac{1}{\sin \theta + \frac{(2n+1)}{2n} \frac{\cos \theta}{C_\lambda}} \tag{16}$$

which for large values of n reduces to equation (12). The values of p calculated from the "increased directivity condition" of Hansen and Woodyard are in close agreement with measured values of the relative phase velocity on helices radiating in the axial mode. It appears then, that the increased directivity condition occurs as a natural condition with such helices.[4]

Measurements of single-turn helix radiation patterns have indicated that the single-turn pattern may be closely approximated as

$$E_t = \text{Cos}\,\phi \tag{17}$$

Since this pattern is very broad in comparison to the array factor, particularly if n is large, the array factor will predominate in the pattern multiplication, and an approximation in the single-turn pattern is justified. By substituting equation (15) in equation (4) and simplifying, the expression for ψ becomes

$$\psi = 360° \left[S_\lambda (1 - \text{Cos}\,\phi) + \frac{n}{2} \right] \tag{18}$$

The normalized radiation pattern, considering equations (1) and (17) becomes

$$E = \left(\text{Sin}\,\frac{90°}{n}\right) \frac{\text{Sin}\,\frac{n\psi}{2}}{\text{Sin}\,\frac{\psi}{2}} \tag{19}$$

where n is the number of turns. The term $(\text{Sin}\,\frac{90°}{n})$ is a normalizing factor to make the maximum value of E unity.

4. Bagby, C.K., 1948, "A Theoretical Investigation of Electromagnetic Wave Propagation of the Helical Beam Antenna", master's thesis, Department of Electrical Engineering, The Ohio State University.

CONSTRUCTION OF THE TEST ANTENNA

Because it was not practical in the time available to construct a large number of helices to produce axial mode radiation, it was decided to construct one which would be a typical helical beam antenna. That is, one which had dimensions lying midway between the upper and lower limits of the dimensions required for axial mode radiation. Referring to the preceding equations and to the spacing-circumference chart of Kraus,[5] it is seen that the required conditions for the beam mode of radiation are

$$0.7 < C < 1.4$$

$$0.1 < S < 0.5$$

$$7° < \theta < 21°$$

Selecting an average value of C as 1.0 wave lengths, and θ as 13°, S is 0.23 wave lengths. To eliminate any effects of small ground planes, a circular reflector 2.0 wave lengths in diameter was employed. For the helix conductor, AWG No. 12 copper wire was used, with the fed end tapered to the size of the coaxial line center conductor. Various spacings of the reflector from the first turn were obtained by a combination of sliding the reflector along the conductor, and bending the first turn. Since the total number of turns was 7, and bending the first turn had an effect of increasing or decreasing the total turns by only 0.1 turn, it was assumed the total number of turns remained constant.

Because coaxial transmission line was employed, there was very little

5. Kraus, J.D., 1950, ANTENNAS, p 176, McGraw-Hill Book Company, Inc., New York and London.

choice of stub location for impedance matching of the helix antenna to the transmission line. To achieve maximum flexibility in matching, a double stub was employed, with a spacing of 5/8 wave lengths between stubs.[6] The matching unit was placed as near as possible to the helix in order to minimize losses in the length of line between helix and stubs. The received signal was rectified by a crystal inserted in the coaxial line, the rectified current actuating a micro-ammeter.

The Sperry Type 710 klystron oscillator was operated at approximately 1100 volts d-c. This produced sufficient radiated power to cause full scale deflection of the receiving antenna meter when the helix was employed, with the transmitting and receiving antennas separated by approximately 35 feet. A dipole with a corner reflector was employed as a transmitting antenna to produce a nearly plane wave free from unwanted reflections from objects behind and near the transmitting site. The complete test apparatus is shown in Figure 5 and a close-up of the antennas is shown in Figure 6. The helix support shown in both photographs is polystyrene to eliminate dielectric support losses. To show transmitting and receiving antennas in one photograph, it was necessary to move them considerably closer together than the test distance of 35 feet.

A calibration curve for the meter and crystal rectifier employed is shown in Figure 7. For a horizontally polarized system, the voltage at the receiving dipole terminals varies as the cosine of the angle which the dipole makes with the horizontal. Using a crystal rectifier in the

6. Martin, Thomas L. Jr., 1950, ULTRAHIGH FREQUENCY ENGINEERING, pp 237-241, Prentice-Hall, Inc., New York.