EMPIRICAL HELIX ANTENNA DESIGN *

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ABSTRACT Empirical design relations are presented for a uniform diameter helical antenna operating in the axial mode. The antenna peak gain, HPBW, and bandwidth are expressed as a function of the helix design parameters (diameter, pitch angle, and number of turns). Computed values are compared with experimental data for various helix configurations.

INTRODUCTION The helical beam antenna is a very simple structure possessing a number of interesting properties. It is inherently broadband, provides endfire radiation with circular polarization, and requires a simple feed network. Although considerable studies have been made of the helix propagation and radiation characteristics since it was introduced by Kraus [Ref. 1] in 1947, detailed practical design information relating the antenna performance characteristics (such as gain and bandwidth) and the helix parameters are not readily available in the open literature. Helical antenna design data, based largely on Kraus' early results on helical beam antennas consisting of < 10 turns, were summarized by Harris [Ref. 2]. The purpose of this paper is to present additional design information on uniform-diameter helical antennas operating in the axial mode. Based on the results of an extensive experimental program [Ref. 3], empirical expressions are derived for the antenna peak gain, HPBW and bandwidth characteristics.

HELIX DESIGN DESCRIPTION The experimental measurements were performed in the UHF frequency range from about 650 to 1100 MHz. The helices were constructed by winding 3/16-in. diameter copper tubing (see Fig. 1) around a styrofoam cylindrical form. The helix diameter is defined as the center-to-center distance of the copper wire. A 1.125-in. diameter aluminum tubing was inserted coaxially into the foam to provide mechanical support. The helix was backed by a 10.3-in. diameter × 5-in. high circular cavity, rather than a conventional ground plane, to reduce back radiation. A 4.7-in. long linear-taper microstrip transformer constructed from teflon-fiberglas printed circuit board and placed on the bottom of the cavity (inside), was used to match the helix impedance (~ 140 ohms) to a 50-ohm coaxial input.

GAIN AND HPBW Gain and pattern measurements were made on a variety of helix configurations including fixed length helices with variable pitch angle and diameter and variable length helices with a constant diameter and constant pitch angle. Based on the measured data [Ref. 3], the antenna peak gain may be empirically expressed as

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$$G_p = 8.3 \left(\frac{\pi D}{\lambda_p}\right)^{\sqrt{N+2}-1} \left(\frac{NS}{\lambda_p}\right)^{0.8} \left[\frac{\tan 12.5^\circ}{\tan \alpha}\right]^{\sqrt{N}/2} \quad (1)$$

where D = diameter, S = πD tan α = turn spacing, N = number of turns, and λ_p is the wavelength at peak gain. The computed values for the fixed length helices (NS = constant) are compared with the measured data in Fig. 2, and those for the variable length helices (N = 5 to 35 turns) are compared in Fig. 3. The corresponding values of $\pi D/\lambda_p$ are also shown in each figure. In general, the computed values are within ±0.1 dB of the measured data.

A similar empirical expression derived for the HPBW is as follows:

$$\text{HPBW} \approx \frac{K_B \left(\frac{2N}{N+5}\right)^{0.6}}{\left(\frac{\pi D}{\lambda}\right)^{\sqrt{N}/4} \left(\frac{NS}{\lambda}\right)^{0.7}} \left(\frac{\tan \alpha}{\tan 12.5^\circ}\right)^{\sqrt{N}/4} \quad (2)$$

where K_B is a constant in degrees and λ is the free space wavelength. For the helices constructed by using the arrangement of Fig. 1, it was found that, with $K_B \approx 61.5^\circ$, Eq. (2) matches the measured data within ± few percent over the useful operating frequency range of the helix as shown in Figures 4 and 5. For helices that employ a different construction technique (e.g., tape helices that are wound on a dielectric support instead of using a metallic central support rod), Eq. (2) can still be applied but a slightly different value of K_B must be used. The measured HPBWs for the helices investigated are generally 10 to 20 percent wider than Kraus' formula [Refs. 1,2]. It should be mentioned that Eqs. (1) and (2) are not unique; however, these relations are useful as a design tool.

BANDWIDTH The helix bandwidth may be defined as the operating frequency range over which the gain drops by an allowable amount. The -3 dB and -2 dB bandwidths as a function of N may be obtained by using the curves of Fig. 6. For example, if the -3 dB or -2 dB bandwidth is desired for a given N, one determines the values of $\pi D/\lambda_h$ and $\pi D/\lambda_\ell$ from Fig. 6, where λ_h and λ_ℓ are the free space wavelengths corresponding to the upper frequency limit f_h and the lower frequency limit f_ℓ, respectively. The choice of a -3 dB or -2 dB bandwidth depends upon the antenna designer's application. The frequency limits f_h and f_ℓ may be determined by using the measured gain data [Ref. 3]. It was found that the gain varies approximately as $f^{\sqrt{N}}$ for $f < f_p/1.04$ and as $f^{-3\sqrt{N}}$ for $f > 1.03\, f_p$, where f_p is the frequency at peak gain. Thus, the bandwidth frequency ratio may be empirically expressed as

$$\frac{f_h}{f_\ell} \approx 1.07 \left(\frac{0.91}{G/G_p}\right)^{4/(3\sqrt{N})} \quad (3)$$

where G_p is the peak gain from Eq. (1). The computed bandwidth for G/G_p = -3 dB and -2 dB agrees reasonably well with the measured data (Fig. 6). The bandwidth decreases as the axial length of the helix increases. This bandwidth behavior follows the same trends described by Maclean and Kouyoumjian [Ref. 4].

REFERENCES

1. J. D. Kraus, "Helical beam antenna," Electronics, pp. 109-111, Apr. 1947; also, Antennas, McGraw-Hill 1950, Ch. 7.
2. E. F. Harris, "Helical antennas," in Antenna Engineering Handbook, H. Jasik, Ed., McGraw-Hill, 1961, Ch. 7.
3. H. E. King, J. L. Wong, "Characteristics of 5 to 35 turn uniform helical antennas," IEEE Trans v. AP-28, 291-296, 1980.
4. T. S. M. Maclean and R. G. Kouyoumjian, "The bandwidth of helical antennas," IRE Trans. v. AP-7, Special Supplement pp. S379-S386, Dec. 1959.

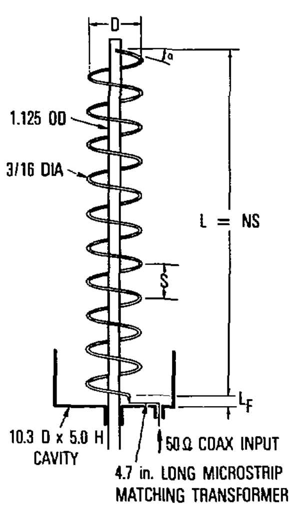


Fig. 1 Helix Configuration

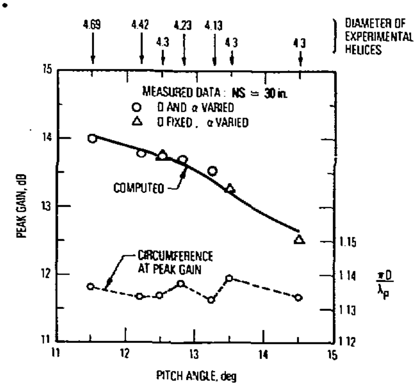


Fig. 2 Gain vs Pitch Angle; NS = 30"

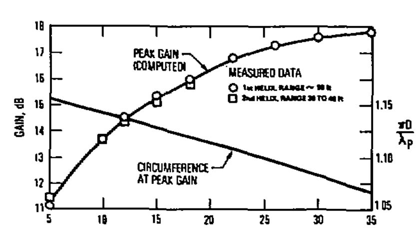
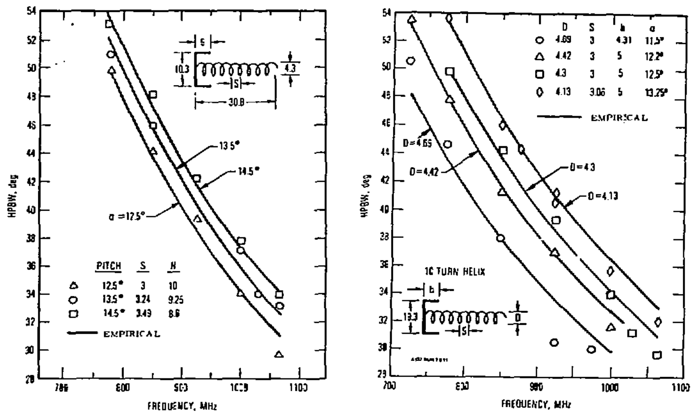


Fig. 3 Peak Gain vs N; α = 12.8°



a. α = 12. 5^{o}, 13. 5^{o} and 14. 5^{o}; D = 4. 3 in.

b. D = 4. 13 in. to 4. 69 in.; N = 10 turns

Figure 4 HPBW for Fixed Length Helices vs Frequency

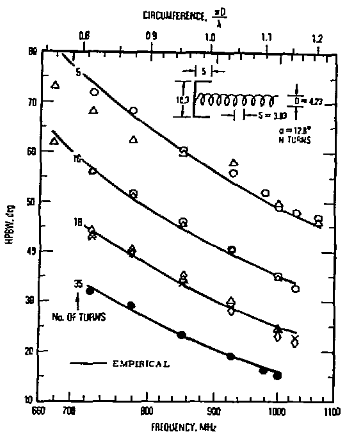


Fig. 5 HPBW vs Frequency
N = 5, 10, 18, 35;
α = 12. 8^{o}, D = 4. 23 in.

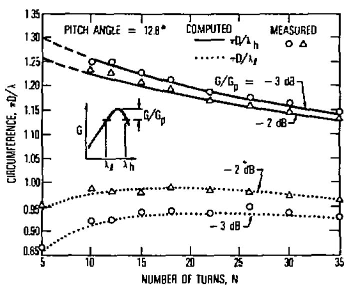


Fig. 6 Bandwidth vs N;
α = 12. 8^{o}, D = 4. 23 in.