over the range of frequencies 1.8 to 1, which means that the opposite sense of circular polarization is suppressed by more than 30 dB.

The radiation patterns show no essential difference between the models of Fig. 1(a) and (b). Both have the form which is typical for helical antennas (compare, e.g.,  $Kraus^4$ ). However, the model of Fig. 1(c) showed lower sidelobe level, as can be seen in Fig. 3.

The input impedance of the antenna of Fig. 1(c) was measured over the frequency range from 2.2 GHz ( $kR = 2\pi R/2$ , R = 0.74) to 4.2 GHz (kR = 1.41). A plot of the impedance variation on the Smith Impedance Chart was located within a circle of VSWR = 1.27 around the value of 102 ohms. Another model of the same form as in Fig. 1(c) but with a different reflector angle ( $\phi_4 = 25^\circ$ ), over the same frequency range, yielded an impedance plot located within a circle of VSWR = 1.34 around the value 69 ohms. It appears that by varying the reflector angle  $\phi_4$  the input impedance can be adjusted to the desired design value.

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## The Helicone—A Circularly Polarized Antenna with Low Sidelobe Level

Abstract—An axial mode helix in a conical horn produces a circularly polarized pencil beam of low sidelobe level over a 2-to-1 bandwidth. The gain of the combination or "helicone" is four times that of a simple helix of the same length and the sidelobes are 15 to 20 dB lower.

A helix-conical horn combination, or "helicone," has been found to yield much improved performance over a simple helix. It consists of a helix excited in the axial mode<sup>1</sup> inside a conical horn, with the axial length of the helix approximately equal to the altitude of the truncated cone, indicated in Fig. 1. A simple helix is also shown for comparison. Typically, the cone mouth diameter is about  $3\lambda$ , the base plate (ground plane) diameter is  $0.75\lambda$  with a 10-turn 14° helix, and the cone angle is about  $45^\circ$ .

The far field of the antenna is characterized by extremely low sidelobe levels and by an almost axially symmetric pencil beam. The measured farzone patterns of a simple 10-turn helix are compared in Fig. 2 with a helicone having the dimensions described previously. The patterns were measured with a linearly polarized test antenna in a plane normal to the aperture and are typical of patterns measured in any plane normal to the aperture and in any axial rotation of the test antenna. The half-power beamwidth (HPBW) of this helicone is about  $17^{\circ}$  as compared to  $33^{\circ}$  for the simple 10-turn helical antenna; the first sidelobe level is down almost 20 dB from -14 dB for the helix to -33 dB for the helicone. This low sidelobe and backlobe level is valuable for radio astronomy and other applications.

The helicone has a pattern bandwidth of 2-to-1, where patterns of the type shown in Fig. 2 (solid line) are obtained over the entire frequency range. The aperture distribution is highly tapered and is of the form  $1 - r^2$ , where r = 0 at the center of the mouth and unity at the edge. The impedance bandwidth is also 2-to-1, with a resistance of about 100 ohms and a reactance varying from -20 to -55 ohms, depending on the exact input configuration and frequency.

The axial ratio of the helicone on axis is substantially the same as that on the axis of the helix alone, i.e.,  $(2N+1)/2N^1$ . The low axial ratio on axis is maintained over the 2-to-1 bandwidth. However, the axial ratio increases for angles off axis, so that the axis of the helicone is not an aspect of polarization stationarity. The axial ratio may reach 2-to-1 at 20° off axis.

The helicone has superior bandwidth properties as compared to a conical horn excited from a circularly polarized waveguide with the  $TE_{11}$ 

Manuscript received February 15, 1967. <sup>1</sup> J. D. Kraus, Antennas. New York: McGraw-Hill, 1950, pp. 173-216.



Fig. 1. (a) An axial mode helical beam antenna. (b) A typical helicone.



Fig. 2. A comparison of measured far-zone power patterns for the helix and the helicone on a polar decibel scale; patterns were measured with a linearly polarized test antenna.

mode. It also has lower on-axis axial ratio and lower sidelobe level than a conical horn excited by a short helix of 2 to 4 turns.

An approximate expression for the directivity D of the helicone has been found empirically, for mouth diameters between  $2\lambda$  and  $4\lambda$ , to be

$$D = 7.8 d_{4}^{2}$$

where  $d_{\lambda}$  is the mouth diameter in wavelengths. For example, a helicone of mouth diameter 3.2 $\lambda$  has  $D \simeq 80$  or about 19 dB. Since the HPBW of the helicone is about half that of a helix of the same axial length, it has the same HPBW as a simple helix four times as long. The mutual coupling between helicones used in an array is very small, due to the extremely low side radiation.

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