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Design Analysis of X-Band Helical Antennas

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The dependence of the gain-radiation characteristics of helical antenna on the design parameters, viz. antenna length, diameter, turn spacing and number of turns is discussed. This analysis can be utilized in the design of gain optimized helix antenna for the microwave X-band frequencies 8.5-11.0 GHz. Theoretical radiation and impedance characteristics are compared with the experimental results.

The helix or helical antenna is of a simple structure and achieves circularly polarized radiation characteristics and wide-band applications especially in the UHF-5 GHz frequencies[1-8]. Axial mode helix antennas have found extensive applications in radio astronomy, satellite communication and ground-end of the space telemetry and missile system[3-8]. The gain-radiation characteristics of helix antenna is dependent upon the design parameters like length L_λ, diameter D_λ or the circumference $C_\lambda = \pi D_\lambda$ turn spacing S_λ, conductor diameter d_λ, number of turns N and pitch angle α as shown in Fig. 1 (inset). The optimum values of the design parameters are generally determined experimentally. Besides, sufficient design data for the X-band applications are not available in literature. The purpose of this communication, therefore, is to investigate the dependence of gain radiation characteristics of the helix parameters, and to develop an analysis for the gain optimized helices in the 8.5-11.0 GHz range of frequency.

The measurement of antenna power gain P_G, half-power beam width θ_E and input impedance Z_A are carried out for the axial-mode helix antennas in the 8.5-11.5 GHz frequencies. Each of the helix parameters L_λ, D_λ, S_λ and d_λ is optimized individually keeping the other three parameters the same to facilitate comparison and achieve meaningful results. Fig. 1 shows the relative power gain P_G against L_λ, D_λ, S_λ and d_λ, respectively, at 11.0 GHz corresponding to the curves 1, 2, 3, 4.

The experimental results discussed earlier can be utilized in the analysis and design of an increased directivity high gain axial-mode helical antenna. The array factor, expressed by the relation

$$E = \sin(\pi/2N)\frac{\sin N\pi(S_\lambda - L_T/\beta)}{\sin \pi(S_\lambda - L_T/\beta)} \qquad \ldots(1)$$

where length per turn $L_T = (C_\lambda^2 + S_\lambda^2)^{1/2}$ and β represents the relative phase velocity of the wave travelling along the helix conductor, can be optimized by minimizing the second differential of Eq. (1) with respect to L_T for constant values of S_λ and N.

Letting $(S_\lambda - L_T/\beta) = U$ $\qquad \ldots(2)$

the function

$$F(U) = 1/\sin^3 U[\sin NU(2\cos^2 U + (1 - N^2)\sin^2 U) - \cos NU(2N\cos U\sin U)] \qquad \ldots(3)$$

should be minimized to achieve optimized high directivity condition. Fig. 2 shows the function $F(U)$ plotted against U for parameter realizing high gain, viz. $S_\lambda = 0.32$ and $N = 11$, respectively. The magnitude of relative phase velocity $\beta = 0.76$ has been utilized since this value is considered to realize high directivity condition[3]. The minimum values of M_1, M_2 and M_3 are located at $U = -2.1$, -2.5 and -2.9, respectively. These values of U and Eq. (2) may now be utilized in

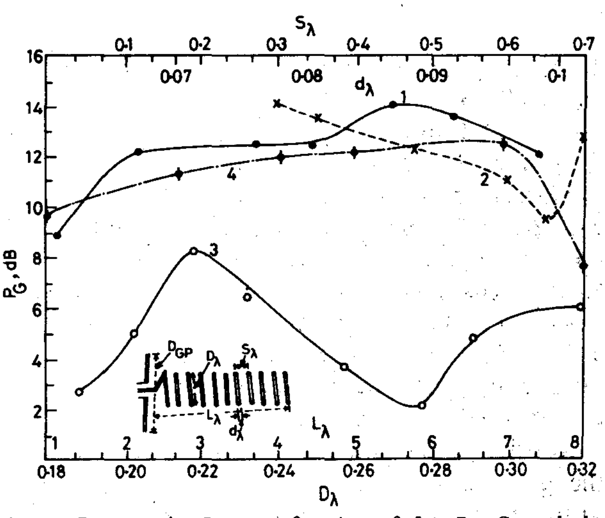

Fig. 1—Power gain P_G as a function of L_λ, D_λ, S_λ and d_λ, respectively at 11.0 GHz (Inset shows the helix antenna parameters.)

Table 1—Design Parameters and Characteristics of High Directivity Antennas
($S_\lambda = 0.32$; $N = 11$; $\beta = 0.76$; $f = 11.0$ GHz, $\lambda = 2.7$mm; $d_\lambda = 0.07$ and $DGP = 10\lambda$)

Antenna	U	C_λ	D_λ	L_T	P_G dB	θ_E deg	VSWR	AR
1	−2.1	0.68	0.22	0.76	—	See text	—	—
2	−2.5	0.79	0.25	0.86	14.0	16.0	1:5	1.4
3	−2.9	0.89	0.28	0.89	12.1	13.5	1.5	1.5

Note:

S_λ	Spacing between two consecutive turns expressed in wavelengths
N	Number of turns
P	Operating frequency
λ	Operating wavelength
β	Phase change coefficient $= 2\pi/\lambda$
d_λ	Conductor diameter expressed in wavelengths
D_λ	Helix diameter expressed in wavelengths
$DGP(\lambda)$	Ground plate diameter expressed in wavelengths
L_T	Turn length $= \sqrt{C_\lambda^2 + S_\lambda^2}$
P_G(dB)	Power gain of the antenna
θ_E	Beam width in degrees
VSWR	Voltage standing wave ratio
AR	Axial ratio

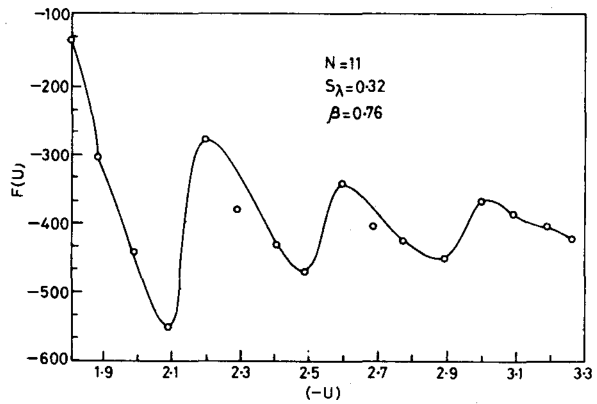

Fig. 2—Plot of function $F(U)$ against U for $N = 11$ and $S_\lambda = 0.32$ wavelengths helix antenna

determining the optimum values of helix diameter D_λ and length per turn L_T.

Axial mode directivity helix antenna designed for $U = -2.1$ could not be operated successfully due to technical fabrication details as it represents an antenna with $D_\lambda = 0.22$ and helix values of 5.9 mm (for 11.0 GHz frequency) and conductor diameter $d_\lambda = 0.07$ (i.e. 2.6 mm). However, the two other values $U = -2.5$ and -2.9 did realize satisfactory operation as shown in Table 1. Our studies show that the antenna 2 achieves satisfactory gain radiation characteristics at 11.0 GHz as compared to antenna 3.

Relative power gain $P_G = 14$ dB was obtained with the gain variation of ± 1.2 dB in the entire 8.5-11.0 GHz X-band frequencies. The measured input impedance Z_A is approximately 72 ohm with VSWR less than 1.5 : 1 in the entire band. Beam widths of value -3 dB between 16° and 22° were also observed. However, the gain radiation characteristics of a cylindrical helix antenna can be improved by approximately 2 dB by suitably tapering from half the helix antenna length L_λ to the radiating end diameter $D_T = 0.19\lambda$.

Microwave helix antennas can thus be operated in the axial mode only and to achieve optimized gain radiation characteristics such that $L_\lambda = 4.5$; $D_\lambda = 0.24$; $S_\lambda = 0.32$; $d_\lambda = 0.08$; $N = 11$ for the cylindrical antenna. For the conical antennas, the antenna should be tapered gradually from half its length to the radiating end diameter $D_T = 0.19\lambda$ which realizes better gain radiation characteristics. Relative power gains between 14 and 16 dB (± 1.2 dB) are attainable in 8.5-11.0 GHz X-band frequencies. Values of C_λ, S_λ for a given N can be determined from the design expression given by Eq. (2). Typical values of impedance $|Z_A|$, half power beam width θ_E and pitch angle α for microwave helical antenna are 66 ohms, 22-28° and 22°, respectively. The ground plate increases the overall power gain by 1.5 dB but does not affect θ_E and $|Z_A|$ appreciably. However, the ground plate ranging in diameter from 4-6 wavelengths is useful in reducing the minor side-lobes.

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