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THE SMALL CIRCULAR HELICAL ANTENNA: A MORE EXACT ANALYTICAL SOLUTION.

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INTRODUCTION

The helical antenna has become the workhorse of space communications for telephone, television and data communication. It has been used both on space satellites and on the ground stations. The physical principles of helical antennas are well understood, but exact theories are scarce. Kraus [1] has derived approximate expressions for the different properties of helical antennas on the basis of a large number of experimental work. In [2] the current is assumed to be constant in magnitude and phase over the length of the small helix. Of course, this does not satisfy the boundary conditions. Also, each helix turn was approximated to a loop connected to a small dipole. In [3] a constant current in magnitude and phase (same as in [2]) is assumed and then an integration is carried out analytically.

In this paper, a triangular current distribution along the wire of the single turn helix is considered to be very close to the actual distribution. The complete analysis for the radiated field components and the radiation resistance is given and new closed form expressions are deduced. We calculated an accurate radiation pattern using the moment method and compared our result with our approximate result using the triangular current distribution as well as with the others results using uniform current distribution as in [3].

ANALYTICAL METHOD:

Consider a single turn of a small circular helical antenna of radius "a" and pitch "S" as shown in Fig.1. The triangular current distribution along the wire is given by

$$I = I_o \left(1 - \frac{|u|}{\pi}\right) \qquad -\pi < |u| < \pi \qquad (1)$$

where I_o is the peak of the current at u=0, and u is the angle coordinate of the element ds. The vector potential at an observation point $p(r,\theta,\phi)$ in free space is given by

$$\bar{A} = \frac{\mu}{4\pi} \int I \frac{e^{-jkr}}{r} \overline{ds} \qquad (2)$$

To evaluate the above integral the exponential factor is expanded in a power series and integrated term by term. After lengthy manipulations, the far-field components for a triangular current distribution along the small turn in spherical coordinates may be written as

$$E_\theta = k\omega c_1\left[\frac{4}{\pi^2} S \cos^2\theta \cos\phi + \frac{2S}{\pi^2}\sin^2\theta \cos\phi + j\left(\frac{4}{k\pi}\sin\phi \cos\theta - \frac{S}{2ka}\sin\theta\right)\right] \quad (3)$$

$$E_\phi = -k\omega c_1\left[\frac{\pi a}{2}\sin\theta + \frac{4S}{\pi^2}\cos\theta \sin\phi - j\left(\frac{4}{\pi k}\cos\phi\right)\right] \quad (4)$$

For $\theta = \pi/2$.

$$E_\theta = k\omega c_1 \left[\frac{2S}{\pi^2}\cos\phi - j\frac{S}{2ka}\right] \quad (5)$$

and

$$E_\phi = k\omega c_1 \left[\frac{-\pi a}{2} \dot{+} j\frac{4}{\pi k}\cos\phi\right] \quad (6)$$

$$\text{where} \quad c_1 = -\frac{\mu I_o a}{4\pi r_o} e^{-jkr_o} \quad (7)$$

From the last two equations (5) and (6), it can be deduced that for circular polarization ($E_\theta = \mp jE_\phi$), S must be equal to πka^2 and ϕ equal to $(2n+1)\pi/2$, n=0,1,2,.... This indicates that the circular polarization takes place only on the planes of $\phi=\pi/2$, or $3\pi/2$, with special specified length for the helix turn. These results are different from that given in [2,3].

The total power radiated by the small helix is

$$W = c_2 \left[\frac{64}{5\pi^3}S^2 + \frac{64}{3\pi k^2} + \frac{\pi S^2}{a^2 k^2} + \frac{\pi^3 a^2}{3}\right] \quad (8)$$

where

$$c_2 = \frac{k^4 \eta^2 a^2 . I_o^2}{16\pi^2} \quad (9)$$

The radiation resistance of the small turn is

$$R_r = \frac{15k^4a^2}{2\pi}\left[\left(0.82564 + \frac{2\pi}{3k^2a^2}\right)S^2 + \frac{128}{3\pi k^2} + \frac{2\pi^3 a^2}{3}\right] \quad (10)$$

NUMERICAL RESULTS

The theory developed above is applied to a small single turn helical antenna with different lengths L and different pitch angles α. The total electric field ($\sqrt{|E_\theta|^2 + |E_\phi|^2}$) is shown in Fig.2, which indicates that the open helix tends to be a short dipole parallel to the z-axis ($\theta=0$) as α tends to 90°, and again tends to be a short dipole parallel to the y-axis as α tends to 0. The variation of the total electric field with the variation of θ in the y-z plane ($\phi=90^\circ$) is shown in Fig.3. For verification of our results for triangular current, a moment method solution for a single turn helix is obtained by a computer code prepared by the authors. Galerkin's method [4] with sinusoidal base functions was used to calculate the current distribution along the wire and hence the electric field components in free space. Figures 4,5 and 6. show the three dimensional field pattern normalized to the amplitude of the current at the feed point for $L = 0.05\lambda$ and $\alpha = 5$, by using triangular (linear) current, Moment Method and uniform current distribution . Good agreement is markedly obtained (the max. deviation is equal to 0.08 v/m) between the triangular current solution and the method of moment, this is due to a finite wire radius is included in the moment method solution. The radiation resistance of a single turn of length $L = 0.05\lambda$ with different pitch angles is shown in Fig.7. for triangular and uniform current distribution along the wire. As expected the values of the radiation resistance in case of uniform current and $\alpha = 90^{o}$ (i.e. a dipole) is four times that for triangular current distribution.

CONCLUSION

A triangular current distribution along a single turn helix is assumed. Closed form analytical expressions for the field components and the radiation resistance are obtained. The results are in excellent agreement with the moment method solution. A comparison is made between our results and that obtained by other authors, who considered a uniform current distribution along the single turn helix. The results of our analytical expressions proved to produce a very good improvement relative to that of the uniform distribution.

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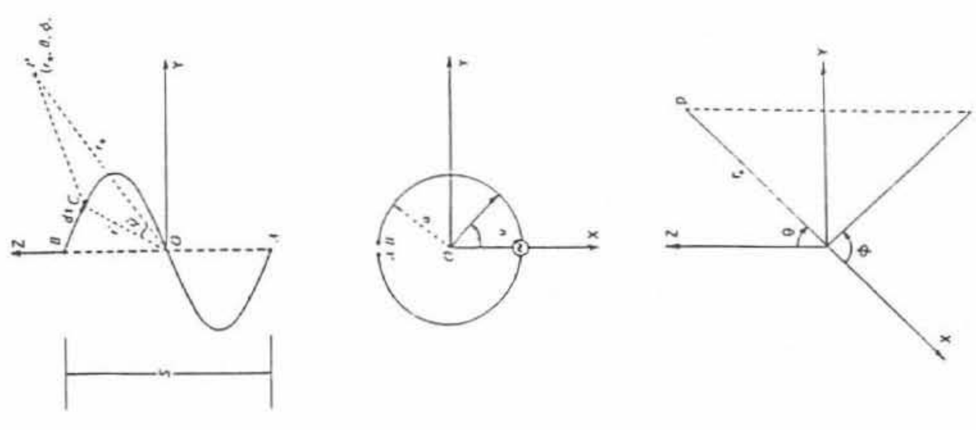

Fig.(1) Single turn helical antenna :
elevation and plan projections.

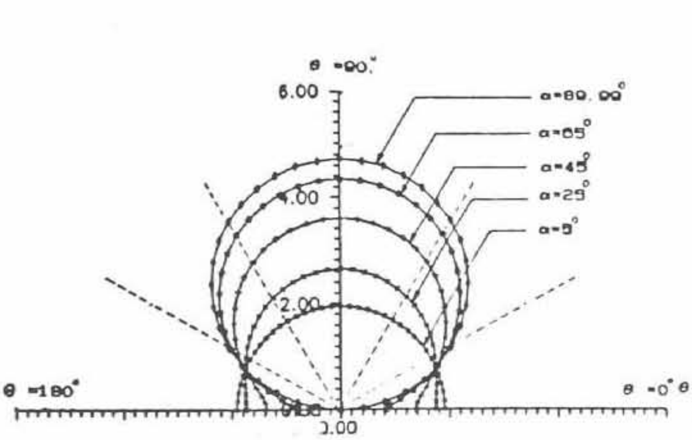

Fig.2 The total electric field for a single turn of helix for different pitch angles for L=0.05λ and ϕ=0°.

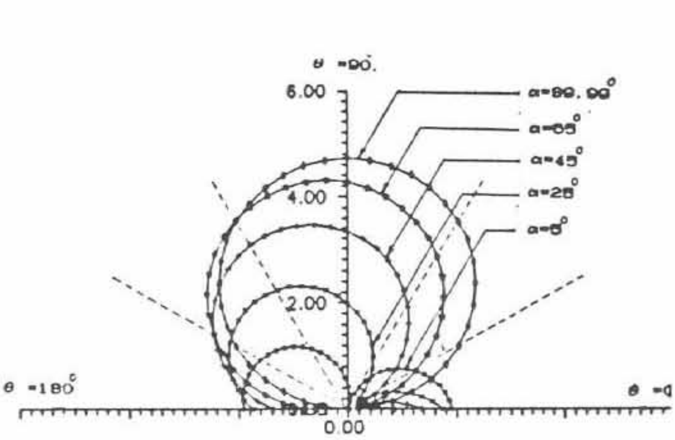

Fig.3 The total electric field for a single turn of helix for different pitch angles for L=0.05λ and ϕ=90°.

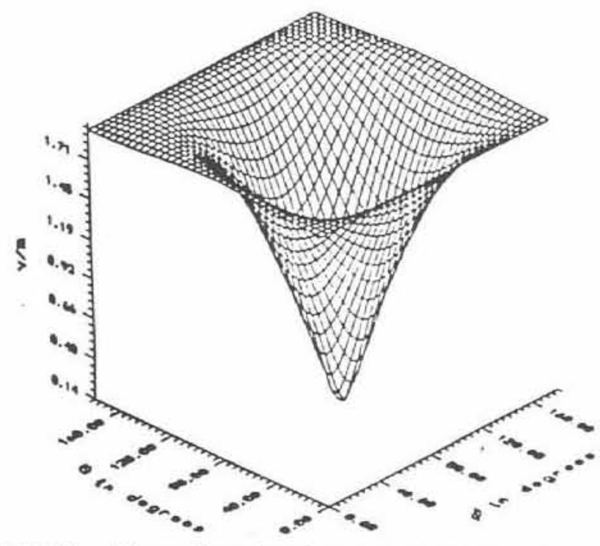

Fig.(4) Three dimensional amplitude field pattern L=0.05λ and α=5° (Linear Current)

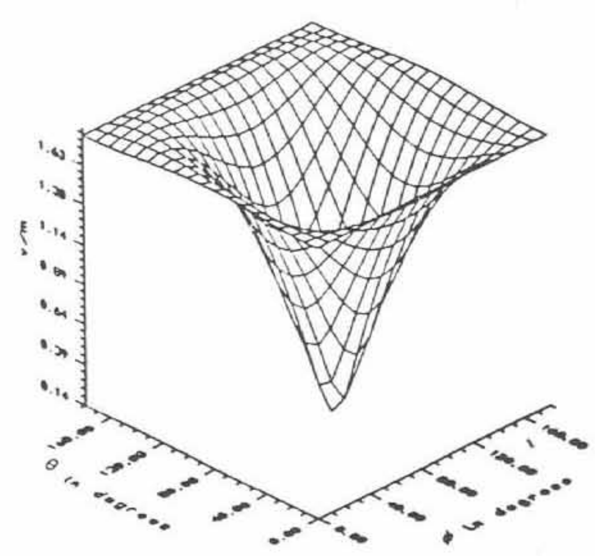

Fig.(5) Three dimensional amplitude field pattern L=0.05λ and α=5° (Moment Method)

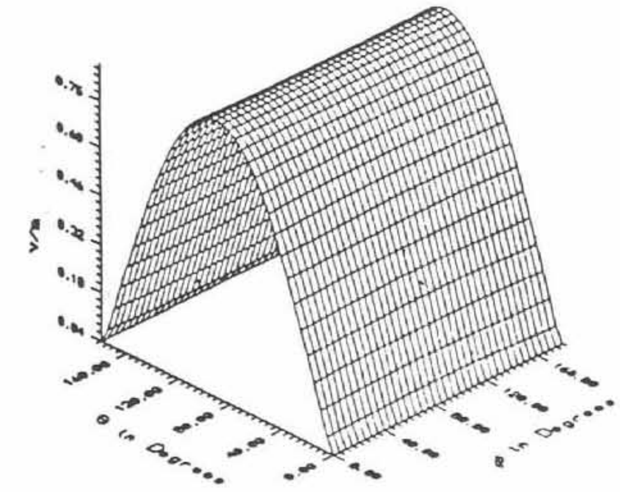

Fig.(6) Three dimensional amplitude field pattern L=0.05λ and α=5° (Uniform Current)

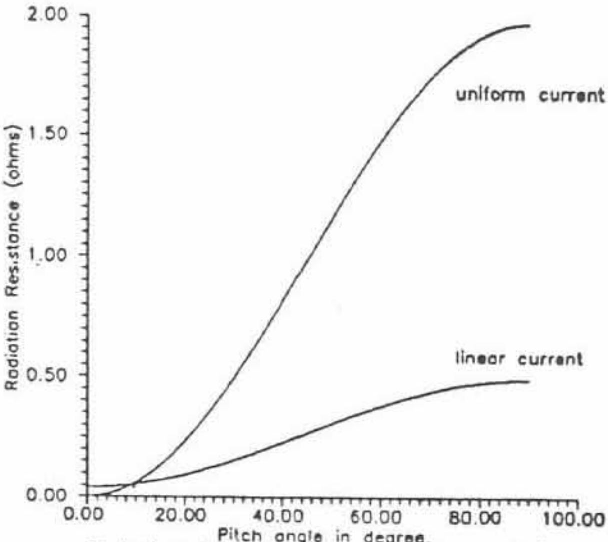

Fig.(7) Variation of Radiation Resistance with Pitch angle for L/λ=0.05.