Extremely low-profile helix radiating a circularly polarized wave

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Abstract—It is revealed that the combination of low pitch and a small number of turns realizes a low-profile helix as a radiating element of circular polarization. A two-turn helix of 4° pitch angle shows a bandwidth of 12% for a 3 dB axial-ratio criterion.

I. INTRODUCTION

THE radiation behavior of a helical antenna with a finite ground plane has been analyzed using numerical techniques [1]. The numerical results show that the helix whose circumference is on the order of one wavelength inherently radiates in the back-fire mode, and that the back-fire mode is changed into the forward-fire mode by a large ground plane. It should be noted that the forward-fire mode helixes analyzed so far have pitch angles of more than 10°.

This paper refers to forward-fire mode helixes with low pitch angles of less than 7°. A low-pitch helix has been recognized as an ineffective radiating element for a circularly polarized wave (CPW) [2] and has never been used in practice. The numerical results presented in this paper, however, lead to new aspects of a low-pitch helix as an effective radiating element.

II. DESIGN OF EXTREMELY LOW-PROFILE HELIX

A. Helix Configuration and Numerical Method

Fig. 1 shows a helix mounted on a ground plane of infinite extent. The inner conductor of a coaxial line used for the feed is bent at height h above the ground plane and extended to the starting point of the helix proper. The bending angle is 90°. The configuration parameters are designated as follows: pitch angle α, helical circumference c, wire radius ρ, and number of helical turns n. To reduce the helix height sufficiently, we consider helixes with low pitch angles, which have never been used in practical applications. The pitch angle in this paper is taken to be in a range of 4°–7°, while the helical circumference c, the wire radius ρ, and the bending height h are fixed to be conventional values, i.e., $c = 25$ mm $= 1 \lambda_{12}$, $\rho = 0.5$ mm $= 0.02\lambda_{12}$, and $h = 1.25$
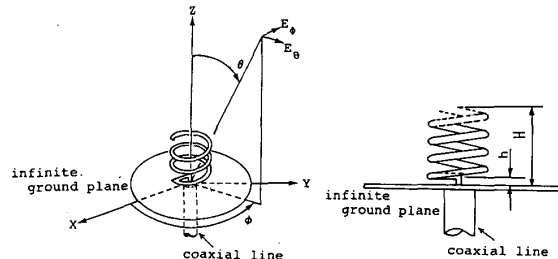
Fig. 1. Configuration.

mm $= 0.05 \lambda_{12}$, where $\lambda_{12}(= 25$ mm$)$ is the free-space wavelength at 12 GHz.

The condition that a perfectly conducting ground plane under the helix is of infinite extent can lead to a numerical model of a bidirectional helix, due to the image effect of the real helical arm. To obtain the current distribution on the helical arm, the moment method is applied to a Pocklington-type integral equation for an arbitrary wire configuration [3]. The application of the moment method requires subdivisions of more than 16 segments per helical turn, taking account of the convergence of the numerical results. The current distribution obtained is used to calculate the radiation characteristics.

B. Numerical Results

Fig. 2 shows the calculated current distribution and radiation patterns of a 10-turn long helix with a low pitch angle of 4°, at a test frequency of 12 GHz. The axial ratio on the Z-axis is poor, a value of 4.5 dB, confirming the criticism that a low-pitch helix is not an effective antenna for radiating a CPW. The deterioration in the axial ratio is also found for other low pitch angles, as shown in Fig. 3.

Recent theoretical investigations [4], [5] have shown, however, that there are two ways to overcome the axial ratio deterioration: 1) tapering the helical turns near the open end, to reduce the reflected current from the arm end, and 2) using only the first few helical turns where the decaying current travels from the feed point to the first minimum point. This paper adopts the latter technique, which allows the realization of a low-profile helix.

Unfortunately, the minimum point in the current distribution is not clearly defined for low-pitch helices. Therefore, calculations are made for helixes of up to three turns. Fig. 4 shows calculated results of axial ratio on the Z-axis as a function of the helical turns. The upper horizontal axis is the
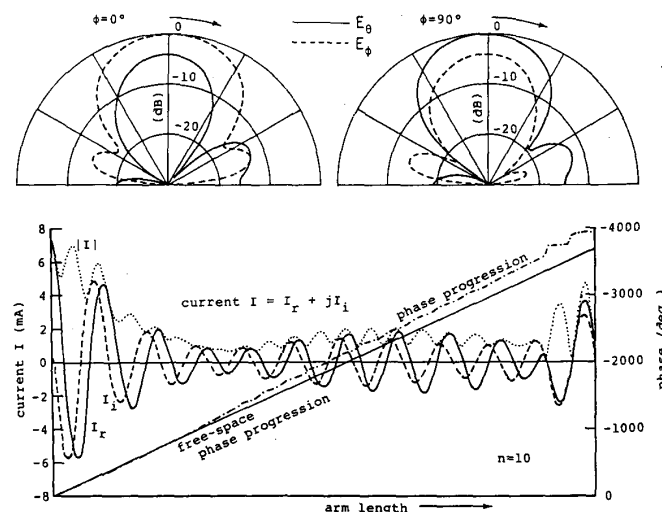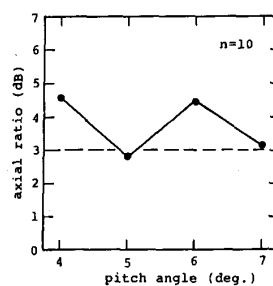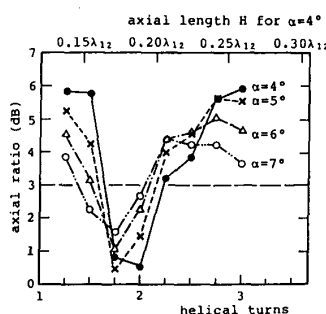
Fig. 2. Current distribution and radiation pattern ($n = 10$).
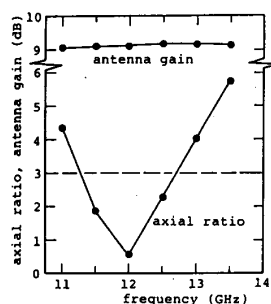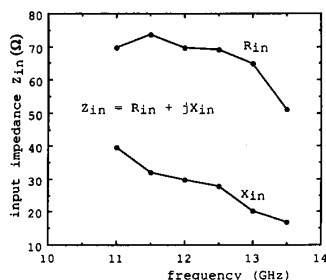

Fig. 3. Axial ratio ($n = 10$).

Fig. 4. Axial ratio versus helical turns.

axial length H for a $4°$ pitch angle helix, expressed in terms of the free-space wavelength. It is found that excellent axial ratios are obtained, even though the axial lengths are extremely short, i.e., the helix has a low profile.

A $4°$ pitch, two-turn helix has an axial ratio of 0.5 dB with an axial length of 0.19 wavelengths. Fig. 5 shows the current distribution and radiation patterns for this case. The phase progression of the current distribution changes linearly with a phase velocity being approximately equal to that in free space. The half-power beamwidth of the radiation pattern is about $70°$ in both principal planes.

Fig. 6 shows the frequency responses of the axial ratio and antenna gain for the above-mentioned two-turn helix of $4°$ pitch angle. The antenna gain is calculated to be approximately 9 dB, which is comparable to a gain realized by a conventional long helix for an axial length of 0.9 wavelengths, a circumference of one wavelength, and a pitch angle of $12.5°$. The bandwidth for an axial ratio of less than 3 dB is calculated to be 12% for this two-turn helix.

Frequency response of the input impedance is another interesting topic. Fig. 7 shows that the input impedance $Z_{in} = R_{in} + jX_{in}$ can be regarded as being constant, pro-
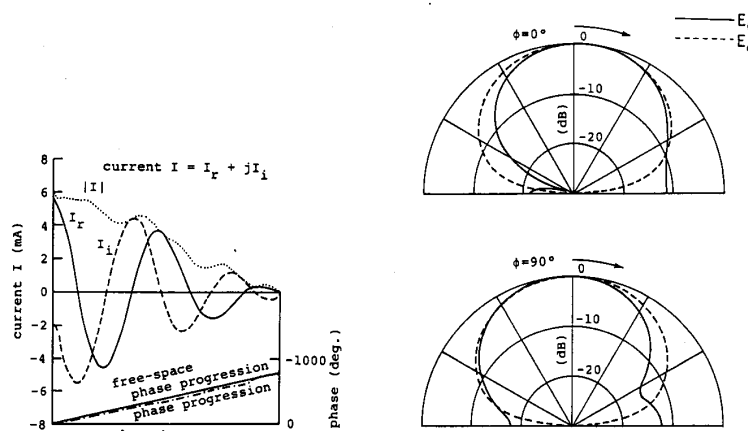
Fig. 5. Current distribution and radiation pattern ($n = 2$, $\alpha = 4°$).

Fig. 6. Frequency responses of axial ratio and antenna gain ($n = 2$, $\alpha = 4°$).

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Fig. 7. Frequency response of input impedance ($n = 2$, $\alpha = 4°$).

vided the helix radiates a CPW. Input impedance values are about 70 Ω resistive and about 30 Ω reactive at frequencies from 11.5 to 12.5 GHz.

III. CONCLUSION

The combination of low pitch and a small number of turns allows us to realize a low-profile helix as a radiating element of circular polarization. It is revealed that a two-turn helix of 4° pitch angle shows a bandwidth of 12% for a 3 dB axial-ratio criterion. The proposed helix can be applied to an element of array antennas [6].

Hisamatsu Nakano (M'75–SM'87) was born in Ibaraki, Japan, on April 13, 1945. He received the B.E., M.E., and Dr.E. degrees in electrical engineering from Hosei University, Tokyo, Japan, in 1968, 1970, and 1974, respectively.

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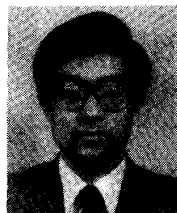
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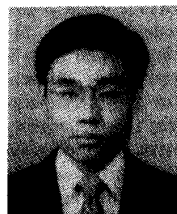
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