Extremely low-profile helix radiating a circularly polarized wave

MIMAKI, Hiroaki / YAMAUCHI, Junji / NAKANO, Hisamatsu / HONMA, Teruaki / TAKEDA, Haruo

(出版者 / Publisher)
IEEE
(雑誌名 / Journal or Publication Title)
IEEE Transactions on Antennas and Propagation / IEEE Transactions on Antennas and Propagation
(号 / Number)
6
(開始ページ / Start Page)
754
(終了ページ / End Page)
757
(発行年 / Year)
1991-06

Extremely Low-Profile Helix Radiating a Circularly Polarized Wave

Hisamatsu Nakano, *Senior Member, IEEE,* Haruo Takeda, Teruaki Honma, Hiroaki Mimaki, and Junji Yamauchi, *Member, IEEE*

***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 $h = 1.25$ mm $= 0.05\ \lambda_{12}$, where $\lambda_{12}(= 25$ mm) is the free-space wavelength at 12 GHz.

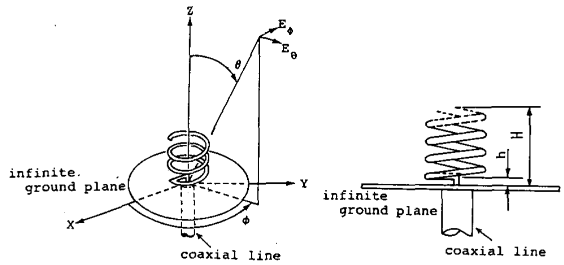


Fig. 1. Configuration.

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

Manuscript received April 9, 1990; revised December 6, 1990.
H. Nakano, H. Mimaki, and J. Yamauchi are with the College of Engineering, Hosei University, Koganei, Tokyo 184, Japan.
H. Takeda was with the College of Engineering, Hosei University, Tokyo, Japan. He is now with NEC Co. Ltd., Tokyo, Japan.
T. Honma was with the College of Engineering, Hosei University, Tokyo, Japan. He is now with Dainidenden Co. Ltd., Tokyo, Japan.
IEEE Log Number 9143717.

0018-926X/91/0600-0754$01.00

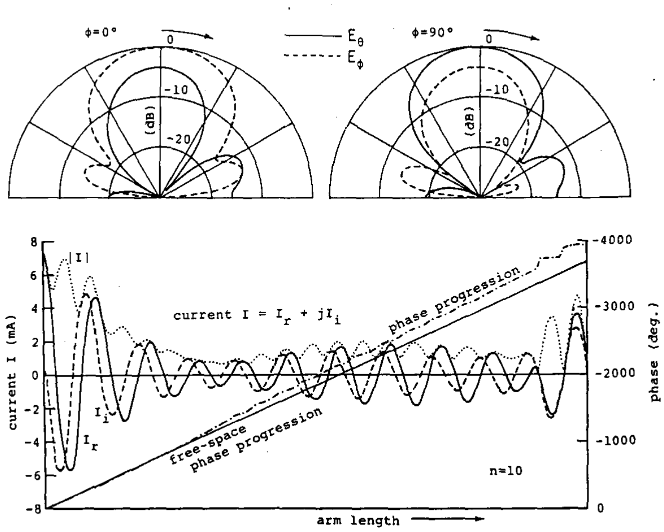


Fig. 2. Current distribution and radiation pattern (n = 10).

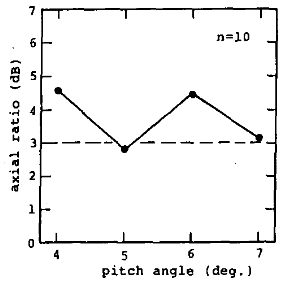


Fig. 3. Axial ratio (n = 10).

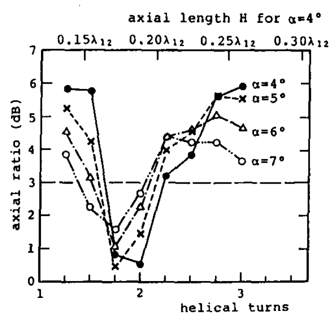


Fig. 4. Axial ratio versus helical turns.

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-

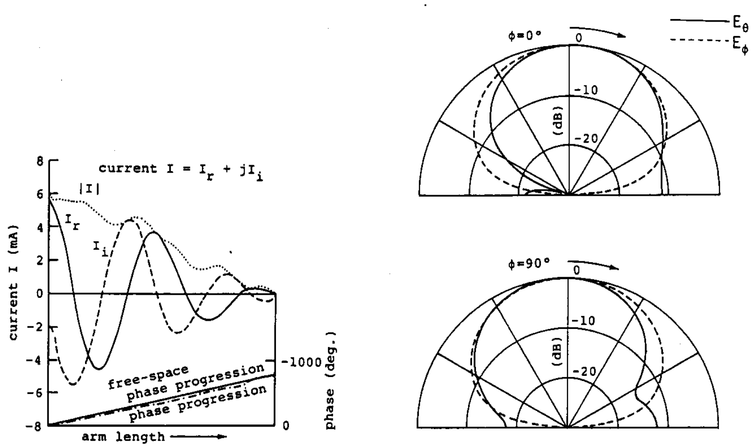


Fig. 5. Current distribution and radiation pattern ($n = 2$, $\alpha = 4°$).

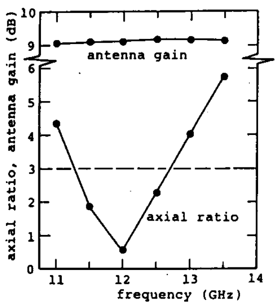


Fig. 6. Frequency responses of axial ratio and antenna gain ($n = 2$, $\alpha = 4°$).

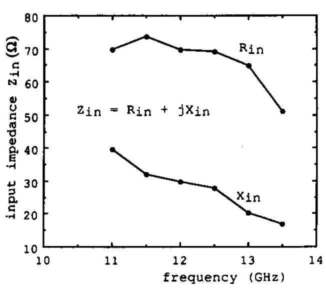


Fig. 7. Frequency response of input impedance ($n = 2$, $\alpha = 4°$).

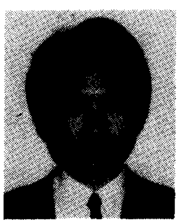
vided the helix radiates a CPW. Input impedance values are about 70 Ω resistive and about 30 Ω reactive at frequencies from 11.5 to 12.5 GHz.

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].

References

[1] H. Nakano, J. Yamauchi, and H. Miamki, "Backfire radiation from a monofilar helix with a small ground plane," *IEEE Trans. Antennas Propagat.*, vol. 36, pp. 1359–1364, 1988.
[2] J. D. Kraus, *Antennas*. New York: McGraw-Hill, 1947.
[3] H. Nakano, *Helical and Spiral Antennas*. New York: *Res. Studies Press*, Wiley, 1987.
[4] H. Nakano, Y. Samada, and J. Yamauchi, "Axial mode helical antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-34, pp. 1143–1148, 1986.
[5] H. Nakano, N. Asaka, and J. Yamauchi, "Radiation characteristics of short helical antenna and its mutual coupling," *Electron. Lett.*, vol. 20, pp. 202–204, 1984.
[6] H. Nakano, H. Mimaki, H. Takeda, and J. Yamauchi, "A low-profile helix radiating a circularly polarized wave," in *ISAP89* Tokyo, Japan, 1989, pp. 501–504.



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.

Since 1973, he has been a member of the faculty of Hosei University, where he is now a Professor of Electrical Engineering. His research topics are numerical methods for microwave antennas and scattering problems. He was a Visiting Associate Professor at Syracuse University (May to September 1981), where he worked on numerical analysis of electromagnetic coupling between wires and slots; a Visiting Professor at University of Manitoba (March to September 1986) working on analysis of microstrip antennas; and a Visiting Professor at University of California, Los Angeles (September 1986 to March 1987) working on microstrip line antenna analysis.

Dr. Nakano is a member of the Institute of Electronics, Information and Communication Engineers of Japan. While in Canada he was a recipient of an international scientific exchange award from the Natural Sciences and Engineering Research Council of Canada. In 1987 he received the Best Paper Award of the Institute of Electronic Engineers Fifth International Conference on Antennas and Propagation.

He is the author of more than 100 refereed papers on antenna problems, and is the author of a book, *Helical and Spiral Antennas* (Research Studies Press, Wiley).

Haruo Takeda was born in Tokyo, Japan, on February 15, 1966. He received the B.E. and M.E. degrees from Hosei University, Tokyo, Japan, in 1988 and 1990, respectively.

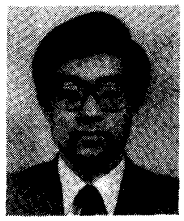
He joined the NEC Co. Ltd., Tokyo, in 1990.

Mr. Takeda is a member of the Institute of Electronics, Information and Communication Engineers of Japan.

Teruaki Honma was born in Tokyo, Japan, on April 13, 1966. He received the B.E. and M.E. degrees in electrical engineering from Hosei University, in Tokyo, Japan, in 1989 and 1991, respectively.

He joined the Dainidenden Co. Ltd., Tokyo, in 1991.

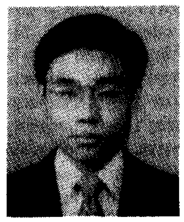
Mr. Honma is a member of the Institute of Electronics, Information and Communication Engineers of Japan.



Hiroaki Mimaki was born in Yamaguchi, Japan, on December 7, 1952. He received the B.E. degree in electronic engineering from Tokyo Denki University, Tokyo, Japan, in 1976 and the M.E. degree in electrical engineering from Hosei University, Tokyo, in 1981.

He is currently an assistant at Hosei University. His research interests are in thin wire antennas.

Mr. Mimaki is a member of the Institute of Electronics, Information and Communication Engineers of Japan.



Junji Yamauchi (M'85) was born in Nagoya, Japan, on August 23, 1953. He received the B.E., M.E., and Dr.E. degrees from Hosei University, Tokyo, Japan, in 1976, 1978 and 1982, respectively.

From 1984 to 1988, he served as a Lecturer at the Electrical Engineering Department of Tokyo Metropolitan Technical College. Since 1988, he has been a member of the Faculty of Hosei University, where he is an Associate Professor of Electrical Engineering. His research interests include circularly polarized antennas and waveguides.

Dr. Yamauchi is a member of the Institute of Electronics, Information and Communication Engineers of Japan.