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A LOW PROFILE ARCHIMEDEAN SPIRAL ANTENNA PRINTED ON A DIELECTRIC SUBSTRATE

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1. Introduction

A low profile spiral antenna backed by a conducting plane reflector in free space [1] has been numerically analyzed [2]. In the analysis, the antenna height is taken to be extremely small, i.e., one-tenth the wavelength of the test frequency. (Note that a quarter-wavelength height is conventionally used.) It has been found that the antenna can radiate a circularly polarized wave (CPW) by virtue of resistive load terminations.

This paper is a sequel to the previous paper [2], and presents further analysis of a low profile spiral antenna whose arms are printed on a dielectric substrate without resistive loads. The dielectric substrate effects on the radiation characteristics are evaluated using an integral equation characterized by the Sommerfeld-type integrals [3]. After showing the radiation characteristics, we refer to improvement in the axial ratio by making two discontinuities in the spiral arms.

2. Spiral antenna without arm break points

Fig. 1 illustrates the antenna configuration. Two spiral arms, which are defined by the Archimedean spiral function, are printed on a dielectric substrate of thickness B and relative permittivity ε_r. The substrate thickness (or the antenna height) is taken to be $B = \lambda_6/10$, where λ_6 is the free-space wavelength at a test frequency of 6 GHz. The relative permittivity is chosen to be $\varepsilon_r = 1.8$. Other configuration parameters are the same as those in Reference [2].

The current distribution along the spiral arm is determined by using an integral equation with the method of moments [3]. Note that the integral equation is formulated with the Sommerfeld-type integrals that lead to rigorous analysis including the effects of the surface waves on the radiation characteristics. The axial ratio, radiation efficiency, and radiation pattern are evaluated on the basis of the determined current distribution.

Fig. 2 shows the frequency response of the axial ratio. The axial ratio has a tendency to improve as the frequency is increased. It is found that an axial ratio of 3 dB is obtained in the vicinity of 9 GHz, where the antenna height corresponds to one-seventh the wavelength. For comparison, the axial ratio for $\varepsilon_r = 1$ is also shown by a dotted line.

The frequency response of the current distribution is shown in Fig. 3 (a). Since the current distribution is symmetrical with respect to the spiral center, only half of the current distribution is presented. It is observed that, as the frequency is increased, the standing wave decreases. The decrease in the standing wave leads to the improvement in the axial ratio shown in Fig. 2. For reference, the current distributions for $\varepsilon_r = 1$ are presented in Fig. 3(b). A comparison between the current distributions at 12 GHz reveals that the current for $\varepsilon_r = 1.8$ remains with higher amplitude over all the spiral arm due to the presence of the dielectric substrate.

Surface wave power launched in the dielectric substrate, P_{sw}, can be calculated by using the current distribution and the values obtained by residue calculations at surface-wave poles in the Sommerfeld-type integrals. (In our spiral antenna, we encounter a single pole, which corresponds to a TM_0 surface mode.) Using P_{sw}, we evaluate the radiation efficiency defined as $\eta = (P_{tot} - P_{sw}) / P_{tot} \times 100$ (%), where P_{tot} is the total input power. The radiation efficiency as a function of frequency is shown in Fig. 4. It is revealed that a radiation efficiency of more than 70% is obtained over a range of frequencies of 4 GHz to 12 GHz. The radiation efficiency at 12 GHz is calculated to be 80 %.

3. Spiral antenna with arm break points

It has been found that CPW radiation with an axial ratio of less than 3 dB is obtained at frequencies more than 9 GHz. At these frequencies, the antenna height corresponds to more than one-seventh the wavelength. To obtain the CPW radiation for a smaller antenna height than one-seventh the wavelength (at a lower frequency than 9 GHz), we analyze the case where the spiral arms have two break points [4].

Fig. 5 shows the spiral antenna with the arm break points. The arm break points are located symmetrically with respect to the spiral center. The arm length from the end point to the break point is designated as L. Other configuration parameters are the same as those in the previous section.

Fig. 6 shows the axial ratio behavior when the length L is changed. The calculations are made at 6 GHz, where the antenna height corresponds to one-tenth the wavelength. It is found that, when the locations of arm break points are appropriately chosen, the antenna can radiate a CPW with an axial ratio of less than 3 dB. An axial ratio of 9.4 dB for L = 0 (without the arm break points) can be improved to 2.6 dB for $L = 0.36\ \lambda_6$.

The frequency response of the axial ratio for $L = 0.36\ \lambda_6$ is shown in Fig. 7. An axial ratio of less than 3 dB can also be obtained at 12 GHz. The radiation patterns at 12 GHz and 6 GHz are shown in Fig. 8, where E_R and E_L are the radiation fields of right-hand circular polarization and left-hand circular polarization, respectively. It is observed that a CPW is radiated over a wide angle coverage around the Z axis ($\theta = 0°$) at both frequencies.

4. Conclusions

The radiation characteristics of a low profile spiral antenna have been numerically analyzed in the presence of a dielectric substrate. The analysis shows that the antenna radiates a CPW with an axial ratio of less than 3 dB at 9 GHz (the antenna height corresponding to one-seventh the wavelength). As the frequency increases, the axial ratio and the radiation efficiency improve.

To obtain CPW radiation at 6 GHz, where the antenna height corresponds to one-tenth the wavelength, a technique of making two discontinuities in the spiral arms is adopted. It is found that, when the locations of the arm break points are appropriately chosen, the antenna can radiate a CPW with an axial ratio of less than 3 dB. The frequency response of the axial ratio shows that the CPW radiation is obtained at two separate frequencies of f (= 6 GHz) and 2f (= 12 GHz).

References

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[3] H. Nakano, et al., " The moment method solution for printed wire antennas of arbitrary configuration, " *IEEE Trans.*, Vol. AP-36, pp. 1667-1674, 1988.
[4] H. Nakano, et al., " Spiral antenna with arm break points, " *IEICE Japan*, Spring Meeting, B-86, 1995.

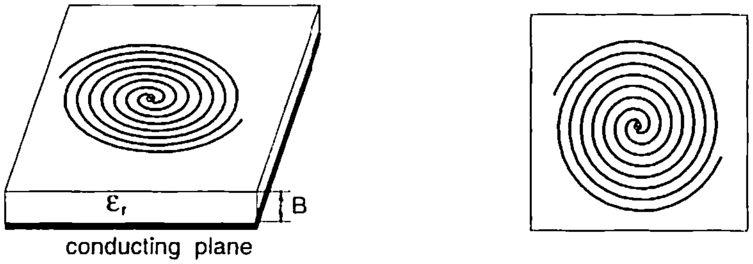


Fig. 1 · A printed spiral antenna

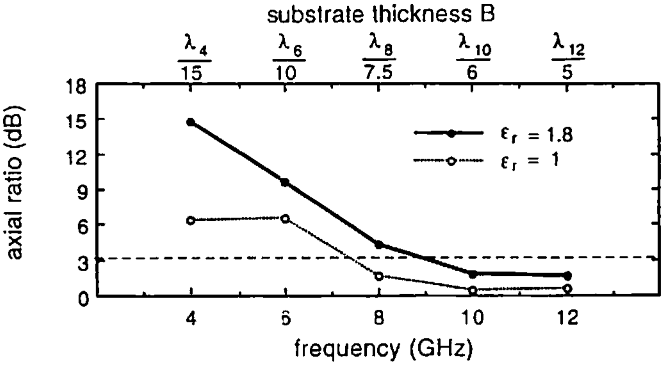
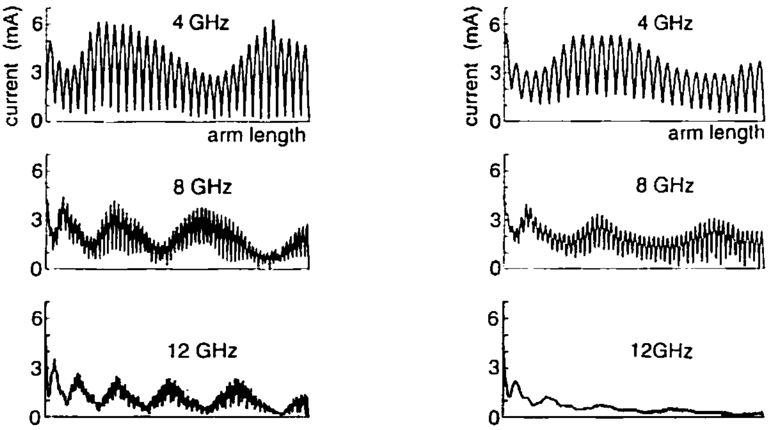


Fig. 2 Axial ratio vs. frequency



(a) $\varepsilon_r = 1.8$ (b) $\varepsilon_r = 1$

Fig. 3 Current distributions

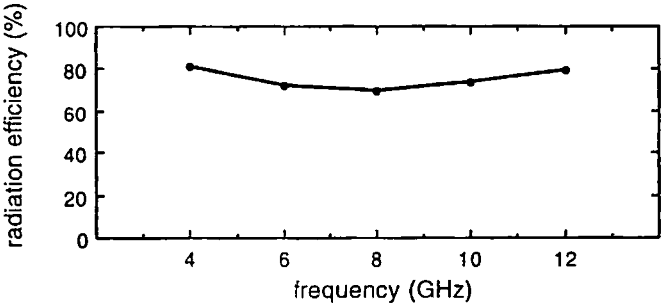


Fig. 4 Radiation efficiency vs. frequency

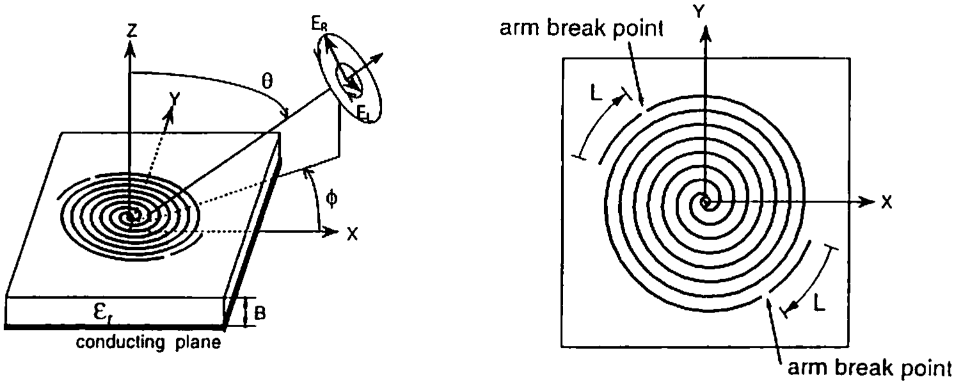


Fig. 5 A printed spiral antenna with arm break points

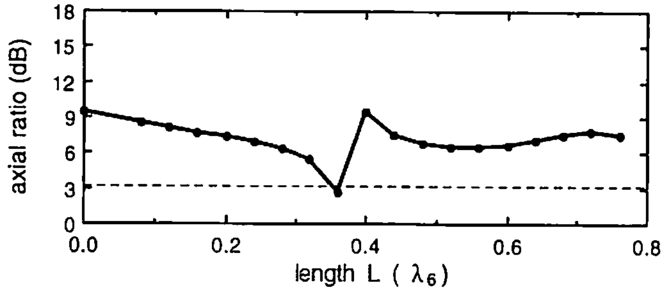


Fig. 6 Axial ratio vs. length L at 6 GHz

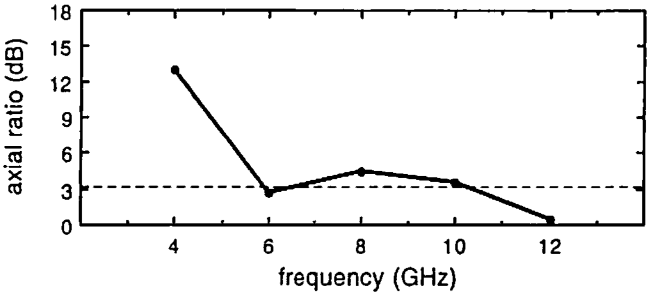
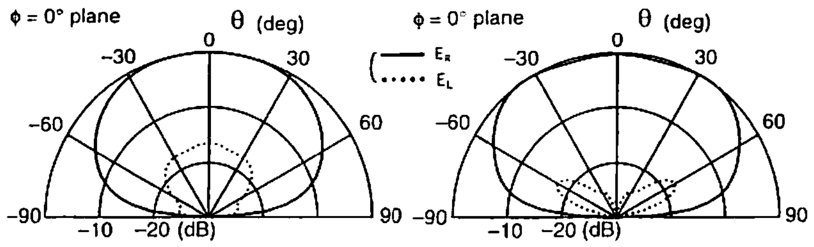


Fig. 7 Axial ratio vs. frequency for printed spiral antenna with arm break points



(a) 6 GHz (b) 12 GHz

Fig. 8 Radiation patterns of printed spiral antenna with arm break points