Metaspiral Antenna System

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***Abstract* – A metaspiral has a negative phase constant within a specific frequency band and a positive phase constant within a different frequency band. The circularly polarized (CP) beams radiated within these different bands have different gains. It is found that placing a dielectric plate above the metaspiral contributes to yielding a desirable situation where the gains for left-handed and right-handed CP waves are almost the same. It is also found that the input impedance is not deteriorated by the presence of the dielectric plate. The effects of removing the inner part of the dielectric plate on the antenna characteristics are also discussed.**

Keywords—Metaspiral antenna, anti-CP radiation, gains, dielectric plate.

I. Introduction

An antenna where the current flowing along the antenna arms has a positive propagation phase constant is categorized as a natural (NTR) antenna. In contrast, an antenna where the current flowing along the antenna arms has a negative propagation phase constant or a zero propagation phase constant at a specific frequency is categorized as a metamaterial-based antenna or, simply, a metamaterial (MTM) antenna. A system composed of a natural antenna with metamaterials is often called a metamaterial-inspired antenna [1].

Research on an NTR two-arm spiral antenna started in 1960 [2], where the radiation from the antenna was discussed using a transmission line model, and the existence of circularly polarized (CP) one-peak broadside radiation and conical radiation were found using electric current bands (current-band theory). However, the other antenna characteristics, including the input impedance and gain, could not be clarified due to the fact that the current-band theory was qualitative and did not express the entire current distribution along the antenna arms.

The antenna characteristics of the NTR two-arm spiral antenna were quantitatively clarified in 1976 [3], based on the current distribution obtained using an integral equation [4] with the method of moments [5]. It was found that the current along the antenna arms flows in a traveling wave fashion, decaying gradually from the antenna input terminals toward the antenna arm ends. Based on the obtained current distribution, wideband characteristics with respect to the gain and input impedance were revealed.

In 2011, an MTM two-arm spiral antenna was created [6]. It was found that the MTM two-arm spiral acted as a dual-band anti-CP antenna under a situation where the feed points were fixed at the innermost arm ends. It was also found that the gain for a left-handed (LH) CP wave, G_L, was not the same as the gain for a right-handed (RH) CP wave: G_R ($G_L \neq G_R$). Note that this kind of different anti-CP gains are also observed in an MTM single-arm spiral [7] and loop [8] antennas.

This paper investigates an antenna system composed of the MTM two-arm spiral antenna and a dielectric plate, to make the difference in the anti-CP gains as small as possible.

II. Discussion

A. Reference gain

Fig. 1 shows the configuration of an MTM two-arm spiral antenna (metaspiral). Each arm, printed on a dielectric substrate of relative permittivity ε_{r1} and thickness B_1, has M straight filaments, where the last filament length is denoted as L_M. Note that the arms are composed of numerous cells, where each cell is loaded by capacitive and inductive elements. Also note that the two arms are excited from the central terminals in balanced mode.

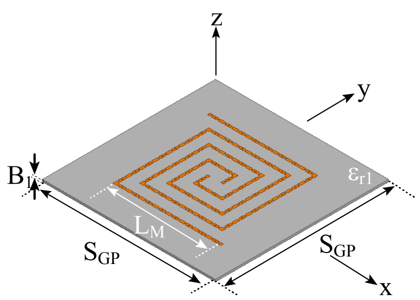

Fig. 1. Metaspiral antenna.

The antenna arm (MTM arm) is modeled using a parallel transmission line specified by the series impedance Z′ per unit length and the shunt admittance Y' per unit length. The propagation constant $\gamma = \sqrt{Z'Y'}$ for this transmission line can be adjusted to have negative and positive propagation phase constants below and above a specific frequency (transition frequency f_T), respectively. The radiation occurs within a fast wave frequency region of f_L to f_U, where the relative phase constant is −1 at f_L and +1 at f_U. For CP radiation, the antenna peripheral length (APL), which is approximately given by $4L_M$, must be larger than one guided wavelength (λ_g).

The parameters are fixed to have a Bloch impedance of 80 ohms, $f_L = 2.4$ GHz and $f_U = 4.8$ GHz. Fig. 2 shows the gain as a function of frequency, designated as the reference gain G_{ref}, where the last filament length is $L_M = 8$ cm (M = 8), leading to an APL of $2.56\lambda_g$ at f_L. It is found that the gain for a left-handed (LH) circularly polarized (CP) wave, G_L, is dominant at lower frequencies below the transition frequency ($f_T = 3$ GHz) and the gain for a right-handed (RH) CP wave, G_R, is dominant at higher frequencies above f_T. It is also found that G_L is smaller than that for G_R ($G_L < G_R$).

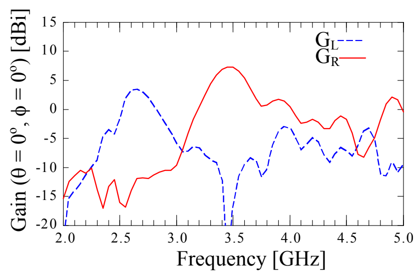

Fig. 2. Gain for the metaspiral antenna (reference gain), where S_{GP} = 130 mm, $L_M = 8$ cm (M = 8), and (ε_{r1}, B_1) = (2.6, 1.6 mm).

B. Gain adjustment

A question arises as to whether G_L can be increased and made equal to G_R. To answer this question, a dielectric plate of relative permittivity ε_{r2} and thickness B_2 is placed above the metaspiral, as shown in Fig. 3. It is inferred that the gain G_L will increase by Fabry-Perot effect when thickness B_2 is appropriately chosen.

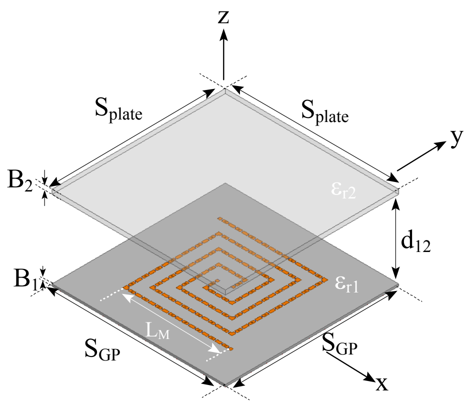

Fig. 3. Antenna system composed of a metaspiral and a dielectric plate.

Fig. 4 shows the frequency response of the gain with thickness B_2 as a parameter. It is found that there is a thickness that leads to $G_L \approx G_R$. Note that, to increase G_L, the distance d_{12} is chosen to be half the wavelength at 2.6 GHz.

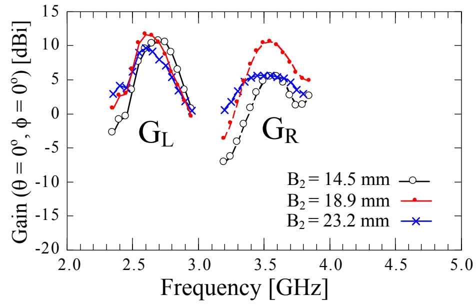

Fig. 4. Frequency response of the gain with the thickness B_2 as a parameter. The parameters are $S_{GP} = S_{plate}$ = 130 mm, d_{12} = 57.5 mm ≈ λ/2 at 2.6 GHz, and (ε_{r2}, B_2) = (6.15, varied).

The radiation patterns for $G_L \approx G_R$ (at B_2 = 18.9 mm) are shown in Fig. 5(a). For comparison, the radiation patterns in the absence of a dielectric plate are also presented. It is clear that the dielectric plate contributes to forming a narrow beam and enhancing the gain G_L.

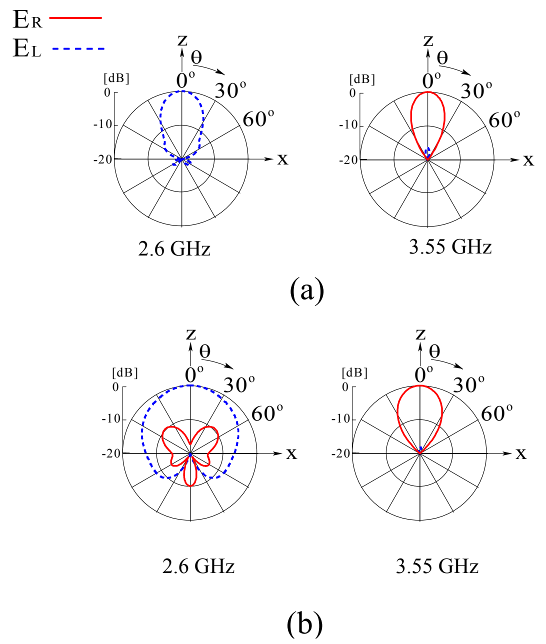

Fig. 5. Radiation patterns. (a) In the presence of a dielectric plate, where $S_{GP} = S_{plate}$ = 130 mm, d_{12} = 57.5 mm ≈ λ/2 at 2.6 GHz, and (ε_{r2}, B_2) = (6.15, 18.9 mm). (b) In the absence of a dielectric plate.

C. Dielectric plate with a hole

The active region for the LH CP radiation is outside that for the RH CP radiation. Based on this fact, a situation is investigated where the central region of the dielectric plate is partially removed, as shown in Fig. 6. The removal section is denoted as $S \times S \times B_2$.

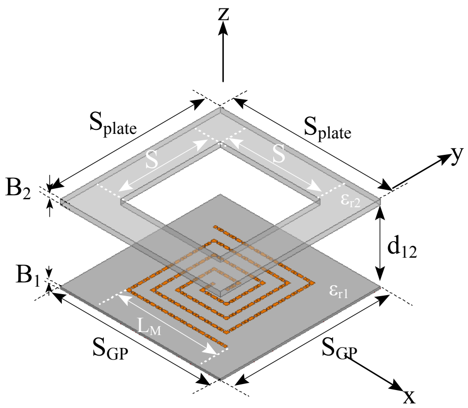

Fig. 6. Removal of central section of the dielectric plate, where S_{GP} = S_{plate} = 130 mm, d_{12} = 57.5 mm ≈ λ/2 at 2.6 GHz, (ε_{r2}, B_2) = (6.15, 18.9 mm) and S is varied.

Fig. 7 shows the frequency response of the gain with the side length S as a parameter, where B_2 is fixed (B_2 = 18.9 mm). As S is increased, G_L decreases due to the reduction of Faby-Perot effect. However, a relationship of $G_L \approx G_R$ is obtained as long as S is not large. Note that the input impedance is not affected if the removal section from the dielectric plate is small.

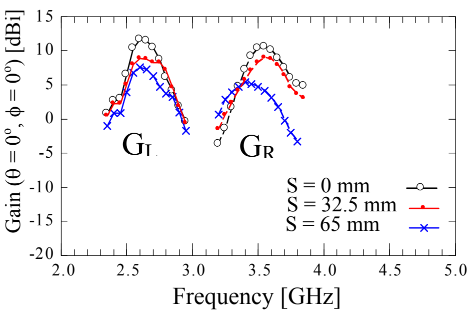

Fig. 7. Frequency response of the gain with the side length S as a parameter. S_{GP} = S_{plate} = 130 mm, d_{12} = 57.5 mm ≈ λ/2 at 2.6 GHz, (ε_{r2}, B_2) = (6.15, 18.9 mm) and S is varied.

III. Conclusions

The metaspiral antenna acts as a dual-band anti-CP wave radiation element. The gain G_L (at the lower frequencies below the transition frequency f_T) is smaller than the gain G_R (at the higher frequencies above f_T). It is found that an antenna system composed of the metaspiral and a dielectric plate increases G_L and creates a relationship of $G_L \approx G_R$. The radiation patterns at $G_L \approx G_R$ are similar to each other. It is also found that the relationship $G_L \approx G_R$ is maintained as long as the removal section from the dielectric plate ($S \times S \times B_2$) is not large.

References

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