An Electromagnetic Metamaterial Spiral Antenna

#H. Nakano, J. Miyake, Y. Oishi, H. Oyanagi, and J. Yamauchi
Department of Science and Engineering, Hosei University
Koganei, Tokyo, Japan 184-8584
nakano@hosei.ac.jp

Abstract

A novel spiral antenna, designated as the "electromagnetic metamaterial spiral", is proposed. The antenna arm is composed of numerous cells, each having a series capacitance and a shunt inductance. This antenna radiates right-handed and left-handed circularly polarized waves. The radiation characteristics are calculated and discussed.

Keywords : Spiral, Left-handed operation, Circularly Polarized Wave

1. Introduction

A spiral antenna radiates a circularly polarized (CP) wave over a wide frequency range, compared with other antennas, such as the curl antenna [1] and the axial mode helical antenna [2][3]. In most cases the number of spiral arms is chosen to be two. The two arms are wound in either an equiangular shape [4] or an Archimedean shape [5]. When the two-arm spiral is excited in balanced mode, the maximum radiation occurs in two directions normal to the antenna plane [6]. This bi-directional beam is transformed into a unidirectional beam, subject to the requirement for high directivity, by backing the spiral with a conducting plane [7], as shown in Fig. 1(a).

Conventionally, the antenna height above the conducting plane in Fig. 1(a) is chosen to be one-quarter wavelength at the design frequency. As the antenna height is decreased (or as the frequency decreases), the radiation characteristics deteriorate. However, this deterioration is mitigated by terminating the antenna arms with resistive materials [5][8][9] [see Fig. 1(b)], which absorb currents reflected at the arm ends (in-coming currents flowing toward the feed point), thereby making the out-going currents (currents flowing from the feed point toward the arm ends) dominant.

In contrast to the backing by the conducting ground plane, use of an EBG reflector for spiral antennas has been discussed in [10]-[13]. Such a spiral antenna with an EBG reflector is designed by taking into account the mutual coupling between the antenna and the reflector. This mutual-coupling consideration leads to a modification of the EBG reflector [12][13]. It is found that the EBG reflector contributes to making the antenna height small, maintaining the inherent wideband characteristics.

It should be emphasized that each of the aforementioned spirals radiates a CP wave with one rotational sense, subject to the winding sense (either clockwise or counterclockwise). In other words, the spiral cannot radiate both a right-handed (RH) CP wave and a left-handed (LH) CP wave; the rotational sense is uniquely determined by the winding sense.

This paper presents a novel spiral antenna that radiates RH- and LH-CP waves. This antenna has one feed point and a small antenna height and is designated as the "electromagnetic metamaterial spiral antenna." For simplicity, an antenna with a single arm is chosen for this paper. The design process and the radiation characteristics are presented and discussed.

2. Configuration

Fig. 2 shows two spiral antennas. The single arm of the conventional spiral illustrated in Fig. 2(a), abbreviated as the C-SPA, is printed on a dielectric substrate (of thickness B and relative permittivity ε_r) and is backed by a ground plane. This arm is composed of M linear filaments, whose lengths are labelled L_1, L_2, …, L_{M-1}, L_M, starting from the innermost filament. The spiral is excited from its innermost point.

Fig. 2(b) illustrates a novel antenna, which is a modification of the C-SPA. The arm filaments are composed of numerous cells, each having a series capacitance C_L and a shunt inductance L_L. This antenna is designated as the electromagnetic metamaterial spiral (abbreviated as the EMM-SPA).

3. Discussion

The peripheral length of the EMM-SPA, defined as $4L_M$, is chosen to be more than one wavelength at a frequency of f_{bal}, where the band gap between LH operation and RH operation disappears (the balanced condition). The antenna design process is briefly summarized as follows. First, the scattering matrix elements [S] for an arm cell are determined under the condition that L_L and C_L are known. Second, the obtained scattering matrix elements are transformed into transmission matrix elements. Based on these results, the L_L and C_L are adjusted to meet the balanced condition at frequency f_{bal}.

We use the following parameters: (B, ε_r) = (1.6 mm, 2.6) for the substrate, f_{bal} = 3 GHz for the balanced-condition frequency, and $4L_M$ = 240 mm for the circumference. The radiation field components E_θ and E_ϕ are transformed into two CP wave components (an RH CP component E_R, and an LH CP component E_L) for evaluating the axial ratio.

Analysis reveals that an LH CP wave (E_L) dominates the radiation at a frequency f_{LH} ($< f_{bal}$), while an RH CP wave (E_R) dominates the radiation at f_{RH} ($> f_{bal}$). The frequency f_{LH} belongs to the frequency region for LH operation and f_{RH} belongs to the frequency region for RH operation. It is emphasized that the rotational sense of the radiation field at f_{LH} is opposite to that at f_{RH}.

Fig. 3 shows representative radiation patterns at f_{LH} and f_{RH} for the aforementioned CP radiation field. The axial ratio in the z direction (normal to the spiral plane) is less than 3 dB at f_{LH} and f_{RH}. The half-power beam width of the principal component at f_{LH} is wider than that at f_{RH}. As expected from Fig. 3, the gain at f_{RH} is larger than that at f_{LH}. Further analysis reveals that the VSWRs at f_{LH} and f_{RH} do not exceed 3, as desired.

4. Conclusions

We investigate a spiral antenna, designated as the EMM-SPA, which has a spiral arm composed of numerous cells, each having a capacitance C_L and an inductance L_L. The height of the spiral arm above the ground plane is chosen to be small (B = 1.6 mm). The EMM-SPA is excited at its innermost point, using a coaxial feed line. The C_L and L_L are adjusted such that a band-gap does not appear at the balanced condition frequency, f_{bal}.

The investigation reveals that the EMM-SPA radiates a dual-CP wave, whose rotational sense at f_{LH} (frequency below f_{bal}) is opposite to that at f_{RH} (frequency above f_{bal}). It also reveals that the gain at f_{RH} is larger than that at f_{LH}. The VSWRs at f_{LH} and f_{RH} are small (not exceeding 3), as desired.

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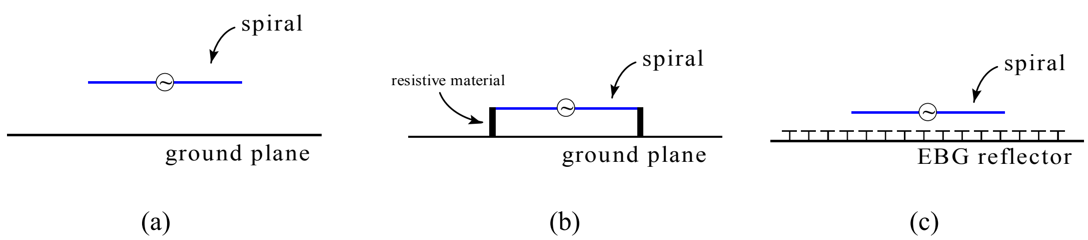

Figure 1: Spiral antennas.

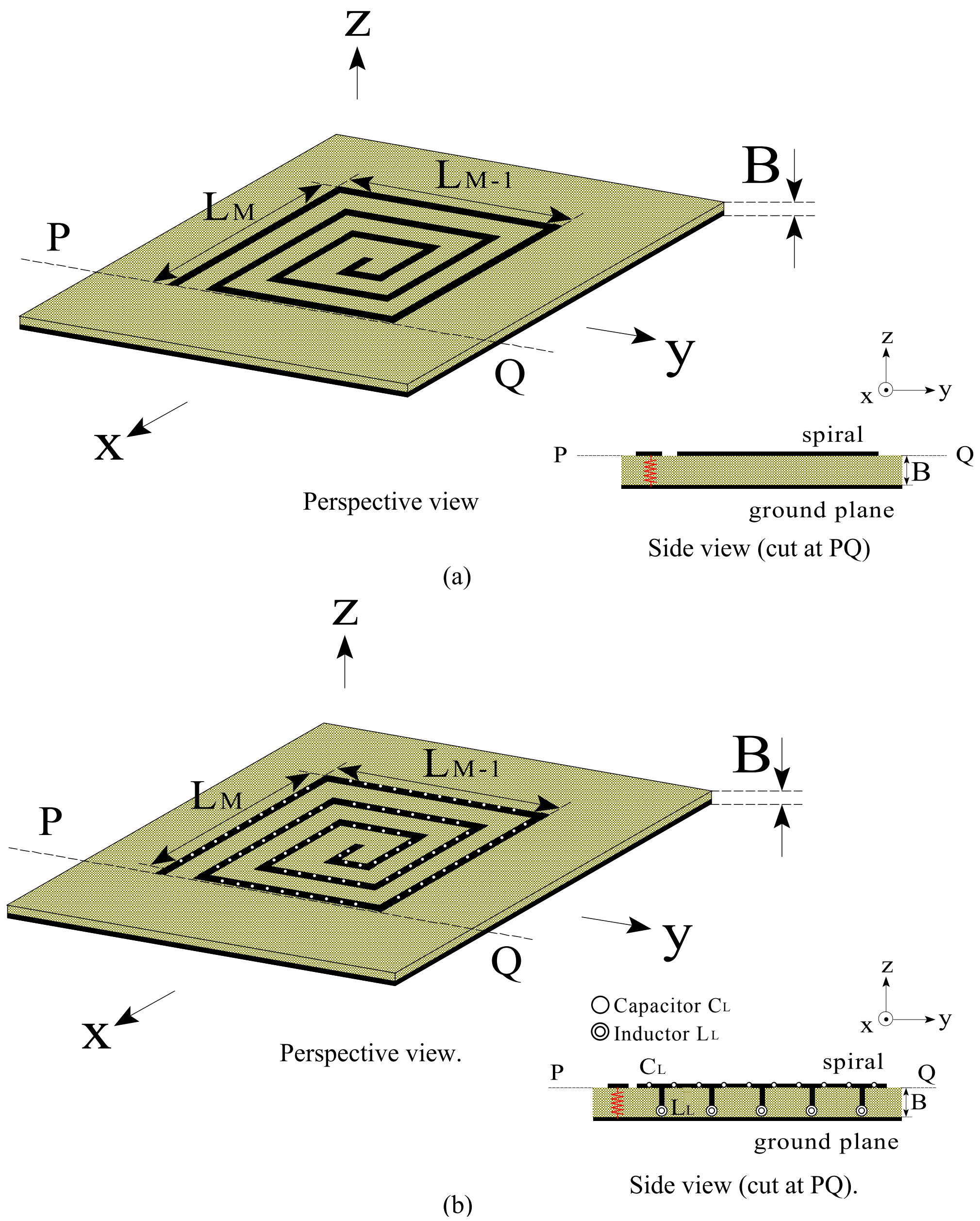

Figure 2: Spiral antenna. (a) C-SPA. (b) EMM-SPA.

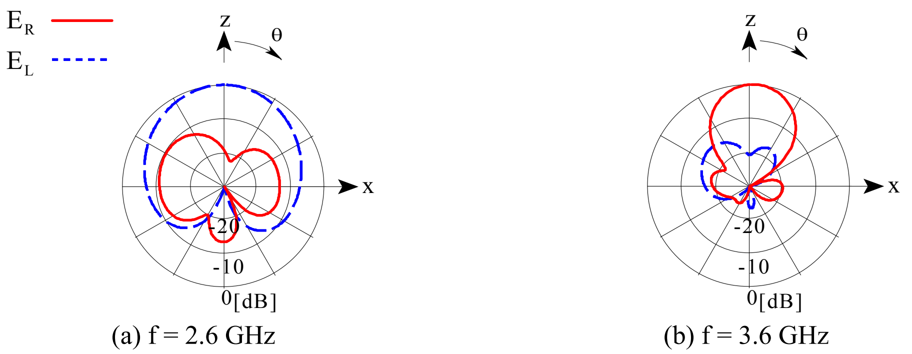

Figure 3: Radiation patterns for the EMM-SPA at f_{LH} (a) and f_{RH} (b).