A MONOFILAR SPIRAL ANTENNA ARRAY ABOVE AN EBG REFLECTOR

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1. Introduction

A two-arm spiral antenna with an EBG reflector has already been analyzed and effects of the presence of the EBG on the radiation characteristics have been revealed in [1]. The analysis in [1] is performed under the condition that the height from the surface of the EBG reflector to the spiral is extremely small (0.06 wavelength). It is found that the two-arm spiral successfully radiates a circularly polarized (CP) wave. Note that CP radiation is not obtained for the case where the spiral is located at such an extremely small height above a perfect electric conductor (PEC).

Based on the results in [1], this paper investigates a low-profile spiral array antenna with an EBG reflector. It is emphasized that the array element in this paper is composed of a single arm (a monofilar spiral), unlike the two-arm spiral in [1]. The number of spiral turns is small and hence the spiral can be called a *curl* antenna [2][3]. The monofilar spiral has the advantage that it is fed without balun circuits.

The finite-difference time-domain method (FDTDM) is used in the analysis. The radiation characteristics, including the radiation pattern, axial ratio, input impedance, and gain, are evaluated on the basis of the electric and magnetic fields obtained using the FDTDM. The frequency responses of these characteristics are presented and discussed.

2. Configuration

Fig. 1 shows the configuration of a monofilar spiral array antenna, where the array elements are spaced with distance d_x in the x-direction. Each array element is composed of one vertical filament and N horizontal filaments. The vertical filament length, called the antenna height, is h, the first horizontal filament length is s_1, the n-th ($n = 2, 3, \cdots, N-1$) horizontal filament length is defined as $s_n = 2(n-1)s_1$, and the last horizontal filament length is s_N. All the filaments have width w. The spiral is fed from the end point of the vertical filament by a coaxial line.

The array is backed by a mushroom-like EBG reflector, which is composed of $N_x \times N_y$ square patches, each with side length s_{patch} and shorted to a bottom conducting plate with a conducting pin. The substrate on which the patches are printed has relative permittivity ε_r and thickness B. The spacing between neighboring patches is denoted as δ_{patch}.

The following parameters are pre-selected and fixed throughout this paper: array spacing $d_x = 0.88\lambda_6$, height $h = 0.1\lambda_6$, first filament length $s_1 = 0.03\lambda_6$, number of filaments $N = 8$, filament width $w = 0.02\lambda_6$,

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number of patches (N_x , N_y) = (18, 6), patch side length $s_{patch} = 0.2\lambda_6$, relative permittivity $\varepsilon_r = 2.2$, thickness $B = 0.04\lambda_6$, and spacing $\delta_{patch} = 0.02\lambda_6$, where λ_6 is the free-space wavelength at a test frequency of 6 GHz. To simplify the discussion, only the last filament length s_N is varied subject to the objectives of the analysis.

3. Analysis and discussion

The antenna characteristics are obtained using the FDTDM. Yee's algorithm is adopted with Liao's second order absorbing boundary condition [4]. The antenna excitation at time t is modeled as a delta gap source of voltage $V_{in}(t)$, which is represented as a sine function modulated by a Gaussian function. The current along the antenna arm is obtained by integrating the magnetic field around the antenna arm. Using the obtained current, the input impedance Z_{in} is given as $Z_{in} = V_{in}(\omega)/I_{in}(\omega)$, where $V_{in}(\omega)$ and $I_{in}(\omega)$ are the Fourier transforms of the time-domain input voltage $V_{in}(t)$ and current $I_{in}(t)$, respectively. The radiation field (composed of a right-hand CP wave component E_R and a left-hand CP wave component E_L) is calculated using the equivalence principle [5], where the electric current density $\mathbf{J}_s(\omega)$ and the magnetic current density $\mathbf{M}_s(\omega)$ on a surface that encloses the antenna are used. From the radiation field components, the axial ratio is given as AR = Absolute value of $[(|E_R| + |E_L|)/(|E_R| - |E_L|)]$, and the gain for a right-hand CP wave is given as $G_R(\theta, \phi) = |E_R(R, \theta, \phi)|^2 R^2/30P_{in}$, where P_{in} is the power input to the antenna.

Before the array antenna is designed, the last filament length of the array element, s_N, is optimized for right hand CP wave radiation at 6 GHz. The best axial ratio is obtained when $s_N = 0.28\lambda_6$. In the following analysis, the last filament is fixed to be $s_N = 0.28\lambda_6$.

Fig. 2 shows the radiation pattern of a four-element array antenna at 6 GHz, where the radiation field is illustrated with two radiation field components E_R and E_L. As seen from the winding sense of the spiral in Fig. 1, the co-polarization radiation field component is E_R and the cross-polarization radiation field component is E_L. Fig. 2 clearly shows that array effects narrow the CP radiation beam; the half-power beam width (HPBW) of the array is calculated to be approximately 14 degrees. (Note that the HPBW of an array element is 68 degrees.)

Fig. 3 shows the axial ratio of the four-element array as a function of frequency. An axial ratio of less than 3 dB is obtained in the frequency range from 5.7 GHz to 6.5 GHz. The AR bandwidth for a 3-dB axial ratio criterion is calculated to be approximately 13% (Note that such a wide AR bandwidth is not obtained for the case where the EBG reflector is replaced with a perfect electric conductor with a small antenna height of $h = 0.1\lambda_6$). The gain within the AR bandwidth reaches a maximum value of approximately 15.4 dBi, which is approximately 6 dB higher than the gain of the array element.

Fig. 4 shows the input impedance Z_{in} (= $R_{in} + jX_{in}$) at element A as a function of frequency. It is found that the input impedance has a nearly constant value over a wide frequency band. From 5.5 GHz to 6.75 GHz, the resistive value R_{in} is approximately 98 ohms, and the reactive value X_{in} is approximately –39 ohms. This simplifies the design of the feed circuits. Note that the input impedance at elements B, C, and D is almost the same as that at element A.

5. Conclusion

An array antenna composed of monofilar spiral elements is presented. The array is backed by an EBG reflector, where the height of each array element above the surface of the EBG reflector is extremely small (0.06 wavelength). The array is analyzed using the FDTDM. The analysis of a four-element array shows that the frequency bandwidth for a 3-dB axial ratio criterion is approximately 13%. Within this AR frequency bandwidth, the input impedance shows a nearly constant value, and the gain reaches a maximum value of approximately 15.4 dBi, which is approximately 6 dB higher than the gain for the array element.

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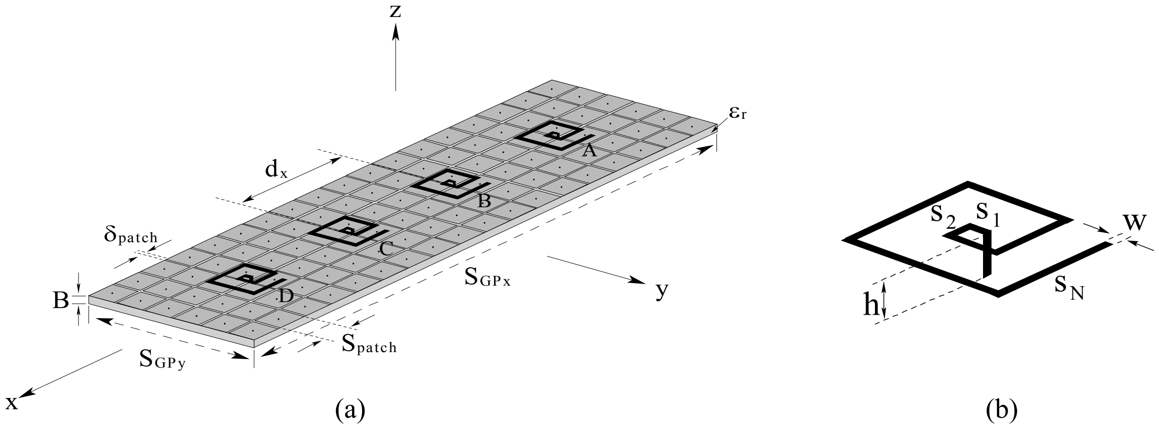

(a) (b)

Fig. 1. Monofilar spiral array antenna.

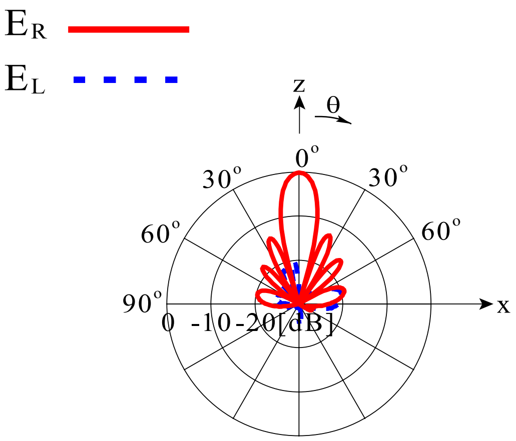

Fig. 2. Radiation pattern at 6 GHz.

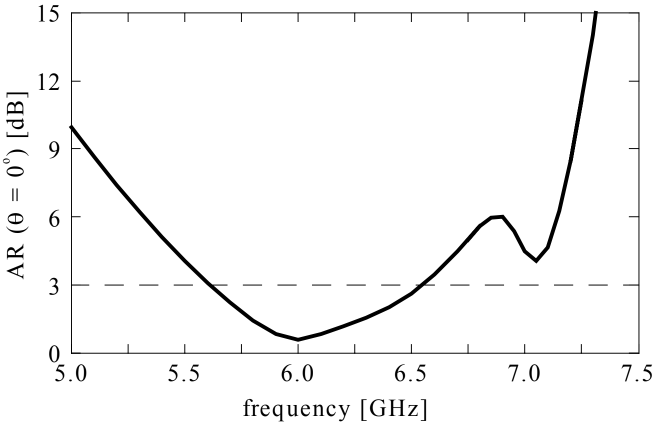

Fig. 3. Axial ratio as a function of frequency.

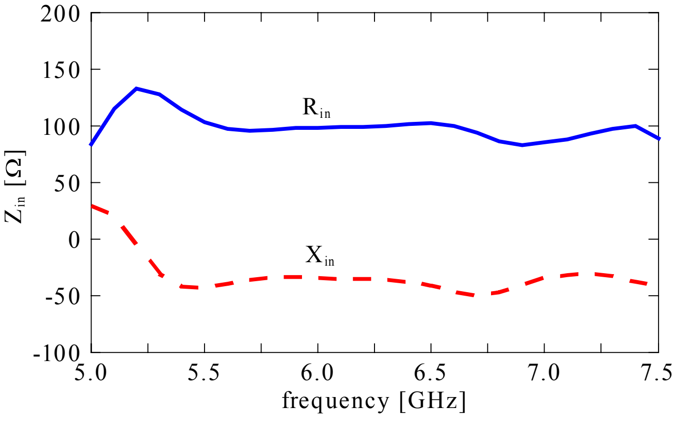

Fig. 4. Input impedance of element A as a function of frequency.