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Single-Element ZOR Antenna with Circularly Polarization Using CRLH Transmission Line

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1. Introduction

Recently, antennas using metamaterials have been studied actively [1]. There have been many reports about leaky wave antennas using a composite right/left-handed transmission line (CRLH-TL), especially microstrip lines [2][3]. The features of this antenna are that, a wide range beam scanning can be achieved [4] and, a zeroth-order resonator (ZOR), whose phase and amplitude are constant along the line, can be constructed so that a small antenna that does not depend on its size can be fabricated [5]. Circularly polarized antennas using CRLH-TL, antennas using a phase shifter [6] or ground vias [7] have also been researched. On the other hand, we have previously proposed a new structure for a circularly polarized antenna, without using a phase shifter or a ground via. We confirmed the circular polarization operation by analysis [8] and experiments [9]. Our antenna is a leaky wave array antenna.

In this paper, we propose a single-element ZOR microstrip antenna with circularly polarization using CRLH-TL without a phase shifter. This antenna does not have ground vias, and can be produced easily and inexpensively. First, we describe the structure and the operation of the proposed antenna, and simulate the results of the generation of the circularly polarized waves. Next, we show the experimental results in detail.

2. Structure and operation of the antenna

The structure of the proposed circularly polarized single-element antenna using CRLH is shown in Fig. 1. This antenna, consisting of a series capacitor made up by the gap of the microstrip line, and shunt inductors made up by the lines leading to the open stub, is a CRLH-TL type antenna. The left line is an input line; the input impedance is set to 50 ohms. We employ a 0.8mm thick substrate with a relative permittivity of 2.2 and a loss tangent of 6×10^{-4}. The antenna has been simulated by using the FDTD method. The parameters used in the simulation are shown in Table 1.

The operation of the proposed antenna is shown in Fig. 2. The impedance of the larger patches is lower than the lines; these patches act as artificial ground. The arrow in Fig. 2 represents the electric current component. When the amplitude of the *y*-direction component (E) and the *x*-direction (E_c) into the artificial ground are equal, and the phase difference between the starting points is 90 degrees, the antenna operates as a circularly polarized one. Fig. 3 shows the approximate equivalent circuit of the antenna. The series gap and line represent the series capacitor C_L and the series inductor L_R. The branch lines leading to the artificial grounds represent the capacitors C_{R1}, C_{R2}, and the inductors L_{L1}, L_{L2}. The proposed antenna can be considered a zeroth-order CRLH-TL antenna because it contains series capacitance and shunt inductance. It is expected to operate as a circularly polarized wave in the vicinity of the shunt resonance frequency. The zeroth-order shunt resonance frequency f_{sh} can be expressed as follows:

$$f_{sh} = \frac{\omega_{sh}}{2\pi} = \frac{1}{2\pi\sqrt{\frac{L_{L1}L_{L2}}{L_{L1}+L_{L2}}(C_{R1}+C_{R2})}} \quad (1)$$

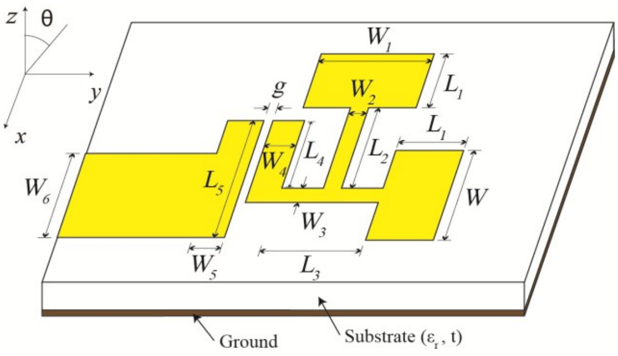


Figure 1: Structure of the proposed antenna.

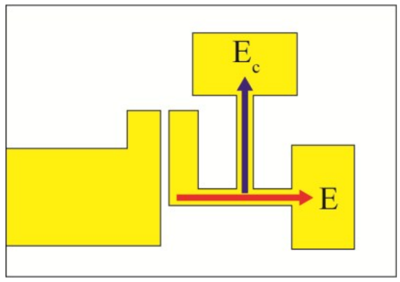


Figure 2: Operation of the antenna.

Table 1: Parameters of the antenna.

W_1	2.5 mm	W	2.5 mm
W_2	0.4 mm	L_1	1.5 mm
W_3	0.4 mm	L_2	2.24 mm
W_4	0.7 mm	L_3	2.24 mm
W_5	0.7 mm	L_4	2.08 mm
W_6	2.34 mm	L_5	3.25 mm

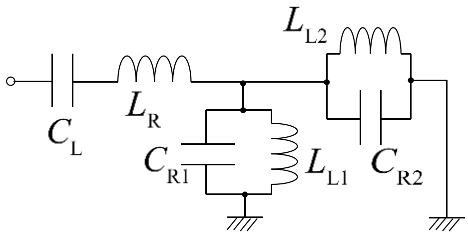


Figure 3: Equivalent circuit.

3. Calculation results

We calculated the radiation patterns using the parameters shown in Table 1. Figure 4 plots the *y*-*z* plane radiation pattern of the E-plane and cross polarization components. The frequency is 10.5 GHz. The radiation pattern is similar to that of the half-wave length dipole antenna, although with an asymmetric pattern. The amplitude ratio is 0.045 dB at 0 degrees, which is almost equal to the radiation intensity.

The frequency characteristics of the amplitude and phase difference are shown in Fig. 5 and Fig. 6, respectively. The axial ratio obtained from the amplitude and the phase difference is shown in Fig. 7. Because the amplitudes of E and E_c are equal in the vicinity of 10.5 GHz and the phase difference is 90 degrees, the axial ratio is 0.36 dB at 10.52 GHz. Therefore we can say that this antenna generates a circularly polarized wave.

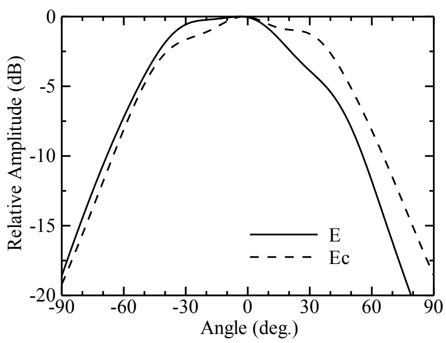


Figure 4: Radiation pattern. (10.5 GHz)

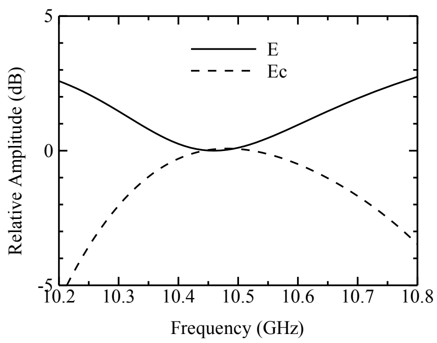


Figure 5: Amplitude.

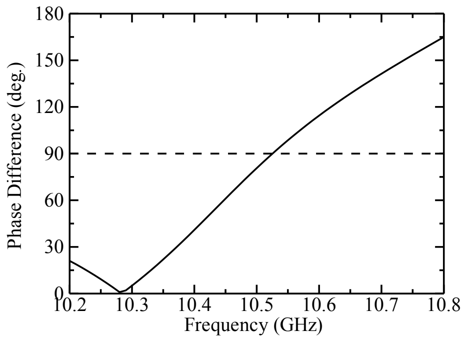


Figure 6: Phase difference.

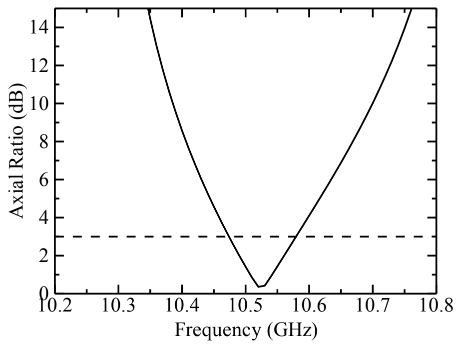


Figure 7: Axial ratio.

4. Experimental results

Firstly, we fabricated a CRLH antenna with the parameters employed in the analysis and measured the antenna pattern. The resonant frequency of the antenna is shifted to the low frequency side of 10.4 GHz, and the axial ratio is 4.2 dB, so the fabricated antenna did not generate a circularly polarized wave. This was caused by the fact that the E_c component is 3.8 dB greater than E as far as the amplitude ratio is concerned. Therefore, by increasing the width W of the artificial ground on the right side, because the C_{R2} from formula (1) becomes larger, we consider that the impedance Z= $1/j\omega C$ is decreased, and the current flow contributing to the E component is bigger. The shunt resonance frequency is also shifted to lower frequency.

Secondly, we change the antenna size from W = 2.5 mm to 3.1 mm. Fig. 8 shows a photograph of the antenna fabricated with W = 3.1 mm. The measurement results of the frequency characteristics about radiation and axial ratio are shown in Fig. 9 and Fig. 10, respectively. We obtained an axial ratio of 1.9 dB in the broadside direction at 10.30 GHz, which is sufficient the circularly polarized wave operation. At this time, the absolute gain was -2.4 dBi and the return loss was -3.8 dB. Fig. 10 shows the frequency characteristics of the axial ratio. As mentioned above, shunt resonance frequency has been moved to the low frequency. The minimum axial ratio was also moved to the low frequency. The size of the antenna is $0.18\lambda_0 \times 0.15\lambda_0$ at W = 3.1 mm. Because the entire surface of the artificial ground does not contribute to the radiation of radio waves, the actual size of the antenna is smaller, so we consider that the absolute gain is low.

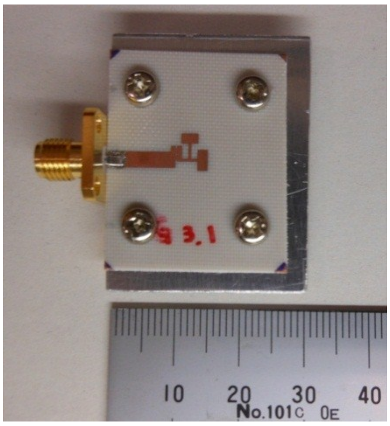


Figure 8: Photograph of the fabricated antenna.

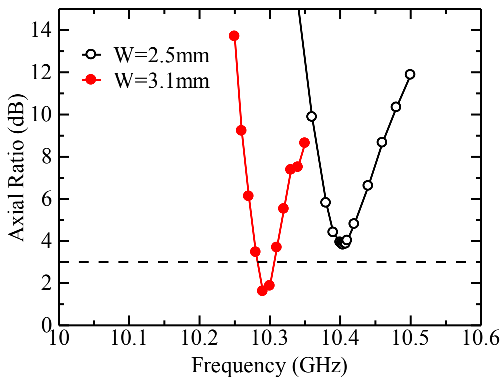
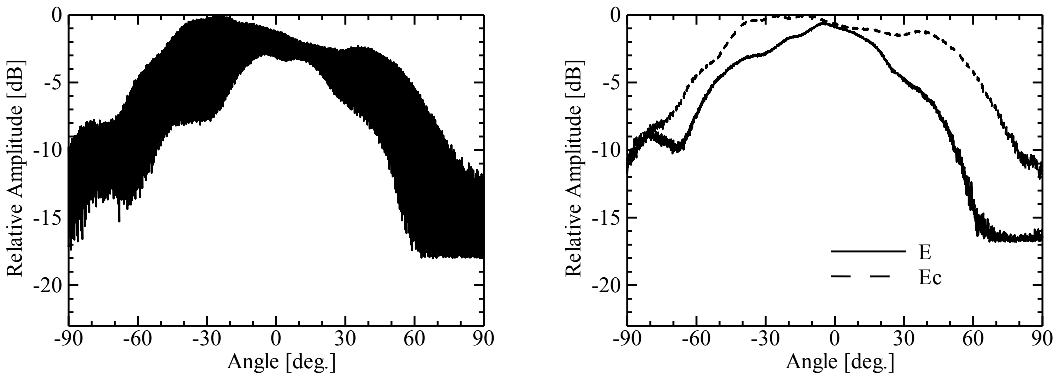


Figure 9: Axial ratio.



(a) Axial ratio (b) Amplitude

Figure 10: Radiation pattern of W=3.1 mm. (10.30GHz)

5. Conclusion

In this paper, we proposed a simple and small circularly polarized single-element ZOR antenna using CRLH-TL. First, we discussed the structure and the circular polarization principle of the antenna, and confirmed by the simulation that the antenna operated as a circularly polarized antenna. Next, based on the analysis, it was confirmed that we can obtain an axial ratio of 1.9 dB at 10.30 GHz by changing the width of the artificial ground. In our future work, we are planning to improve the return loss.

Acknowledgments

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