Circularly Polarized Microstrip Leaky Wave Antenna using Composite Right/Left-Handed Transmission Line

Yoshiki Mitsuhata, Ryo Osagawa, Kazuhiro Kitatani, and Yasuyuki Okamura
Graduate School of Engineering Science, Osaka University
1-3 Machikaneyama-cho, Toyonaka, Osaka, 560-8531, Japan
E-mail: mitsuhata@ec.ee.es.osaka-u.ac.jp

1. Introduction

Recently, researches for antennas with metamaterials have been studied actively [1-2]. A leaky wave antenna using a composite right/left handed (CRLH) concept has been investigated in particular. The CRLH leaky wave antennas with microstrip line [3-5] or rectangular waveguide [6] have been reported. The size of this type of antenna is smaller than that of the conventional antenna. In addition to this feature, this antenna can steer a beam direction from the backfire to the end-fire continuously by using peculiar characteristics in the CRLH region. The CRLH leaky wave antennas reported so far are mainly concerned with a linearly polarized operating; on the other hand, reports on circularly polarized antennas are very few. The circularly polarized antennas proposed so far employ mainly a phase shifter [7-8] to combine linearly polarized waves. The circularly polarized antenna is attractive in the deteriorated environment of the radio wave communications, and is useful for the sensor, radar, and mobile telecommunications as well.

In this paper, we propose a circularly polarized microstrip leaky wave antenna using a composite right/left-handed transmission line without a phase shifter. The specific characteristics of the circularly polarized wave have been confirmed by the simulation and the experiment. First, we refer to the structure and the operation of the proposed antenna. Secondly, we show the simulated results on the generation of the circularly polarized waves and its possible wide steering. Finally, we exhibit the experimental results in detail.

2. Structure and operation of an antenna

The structure of the proposed CRLH antenna and the coordinates are shown in Fig. 1. The antenna consists of series capacitors, parallel inductors, and open stub without vias. We apply a signal from the left edge and attach a resistance of 50 ohms to the right edge. This antenna is composed of 10 unit cells and an overall dimension is 60mm×40mm. We employ a 0.8mm thick substrate with a relative permittivity of 2.2 and a loss tangent of 6×10^{-4}. The unit cell is aligned with a space (S) of 3.85 mm. A part of capacitor is a transmission line with a length (L_4), which is separated with a gap (g) of 0.2 mm. A part of inductor is a transmission line with a length (L_2) of 2.25 mm. The antenna has been simulated by using Ansoft HFSS, which employs a finite element method (FEM). Parameters used in the simulation are shown in Table 1.

The operation of proposed antenna is shown in Fig. 2. The arrow in this figure shows an electric current component. In the unit cell, the electric current components are cancelled in the two capacitors. Therefore, the components of *y*-direction and *x*-direction, which are shown as a thick line, exist. The starting points of the components of *y*-direction and *x*-direction differ, which gives the different phase in the orthogonal directions, and as a result, the operation of circularly polarized wave can be expected. The unit cell is designed to equalize amplitudes of the *y*-direction component (E) and the *x*-direction component (Ec) in Fig. 2. The equivalent circuit of the unit cell is shown in Fig. 3. The series elements in the unit cell are the capacitor C_L and the inductor L_R. The parallel elements are the inductor L_L, the virtual ground capacitor C_g, and the parasitic capacitor C_R .Therefore, the proposed antenna can be considered as a CRLH transmission line without vias.

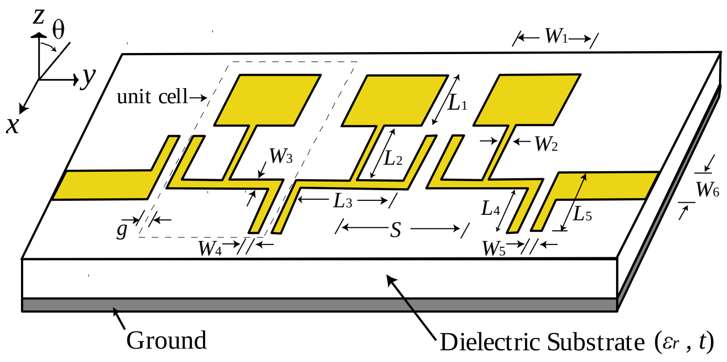


Figure 1: Structure of the proposed antenna.

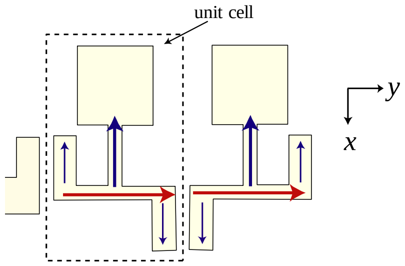


Figure 2: Operation of the antenna.

Table 1: Parameters of the antenna (unit: mm).

W_1	1.75	W_6	1.5
W_2	0.375	L_1	1.5
W_3	0.375	L_2	2.25
W_4	0.7	L_3	2.26
W_5	0.7	L_4	3.25

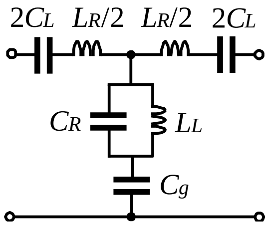


Figure 3: Equivalent-circuit model for unit cell.

3. Calculation results

The radiation patterns of the unit cell calculated by HFSS are shown in Fig. 4. The frequency was 11.8 GHz. θ was defined the angle measured from the z-axis in the y-z plane (θ = -90 degrees, θ=0 degree, and θ=90 degrees correspond to the backward endfire, the broadside, and the forward endfire, respectively). The patterns of E component and Ec component are shown in Fig. 4 (a). The peak amplitude was corresponding in the direction of five degrees. The radiation characteristics for the circularly polarized wave are shown in Fig. 4 (b). LHCP (Left-Handed Circularly Polarized) wave level is less than -26.3 dB comparing with RHCP (Right-Handed Circularly Polarized) wave level. Therefore, the unit cell operates as an antenna for the RHCP wave.

The dispersion characteristics of the unit cell are shown in Fig. 5. In the figure, β is a phase constant. β is set to be 0 at the frequency (f_0) of 12.06 GHz. When the frequency decreases from f_0, the CRLH transmission line operates as left-handed in the region of β<0. On the other hand, the transmission line operates as right-handed in the region of β>0 over f_0. An air line represents the relation of $\omega = +\beta c_0$. Radiation occurs in the region of $\beta < k_0$, where k_0 is a free-space wave number. Therefore, the radiation can be expected in the region from 11.5 GHz to 13.1 GHz. The beam scanning angle θ of the antenna can be expressed in terms of β of the CRLH transmission line as follows:

$$\theta = \sin^{-1}\frac{\beta}{k_0} \qquad (1)$$

Expression (1) indicates that the beam direction can be varied by changing the frequency. β varies quickly with the frequency in the left-handed region. On the other hand, β changes slowly with the frequency in the right-handed region.

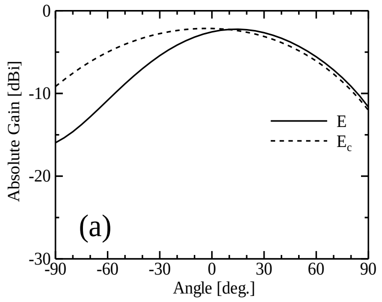


Figure 4: Radiation pattern of the unit cell.

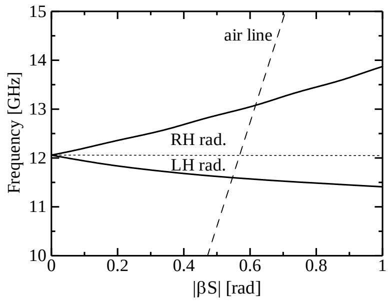


Figure 5: Dispersion diagram.

4. Experimental results

Figure 6 shows a photograph of the fabricated CRLH leaky wave antenna. The antenna parameters are the same as used in the simulation. The input and output portions of the antenna were joined in each with a SMA connector. The matched termination was attached to the connector at the output. The radiation characteristics of the antenna were measured in an anechoic camber. Experimental results of the radiation pattern in the *y*-*z* plane at three kinds of frequencies are shown in Fig. 7. Figs. 7 (a), (b), and (c) corresponded to at 11.5 GHz, 11.9 GHz, and 12.6 GHz, respectively. A solid and dotted line are for the RHCP and LHCP waves, respectively. The antenna radiated to the backward (-32.5 deg.) at 11.5 GHz for the RHCP wave. The frequency, which operates as a broadside antenna, was 11.9 GHz. The main beam direction changed from the backward to the forward (29 deg.) at 12.6 GHz. This antenna operates as a beam scanning antenna. The main beam direction levels of cross-polarization for the three frequencies measured were -10.2 dB, -11.0 dB, and -15.5dB, respectively.

The beam direction as a function of frequency is shown in Fig. 8. The axial ratio via frequency is shown in Fig. 9. Antenna gain frequency characteristics are shown in Fig. 10.

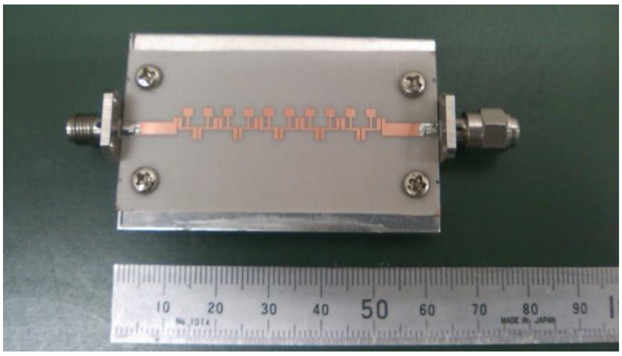
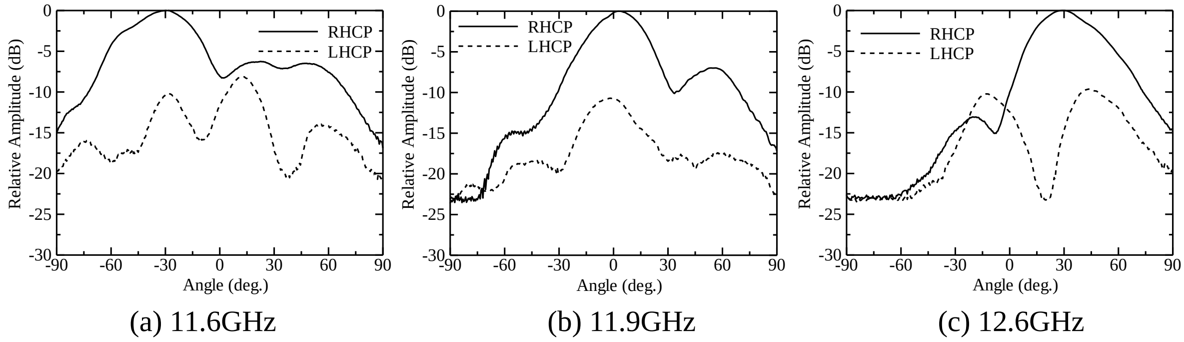


Figure 6: Photograph of fabricated antenna.



(a) 11.6GHz (b) 11.9GHz (c) 12.6GHz

Figure 7: Radiation pattern of measured results.

The frequencies are varied in the range from 11.5GHz to 13GHz. The dotted line represents simulated results. In the Fig. 8, the main beam directions were -30 degrees and +50 degrees at 11.5 GHz and 13.0 GHz, respectively. Thus, the main beam direction is able to continuously scan from -30 degrees to +50 degrees with frequency. The experimental results were a little different from the simulated results, but the tendency is similar. With the axial ratio in Fig. 9, the minimum axial ratio was 1.43 dB and the 3dB bandwidth was 700MHz. The frequency of the minimum axial ratio moves to the high frequency from the calculated one. The maximum and minimum antenna gains in the measurement were 7.28 dBi at 12.3 GHz and 3.32 dBi at 11.5GHz, respectively. The measured results agree with the simulation in the frequency range from 11.7 GHz to 12.3 GHz.

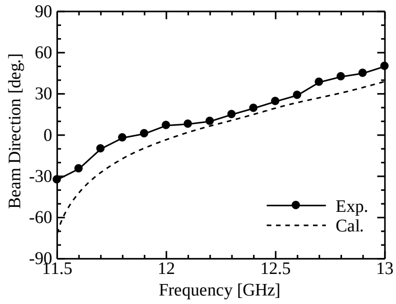


Figure 8: Beam direction.

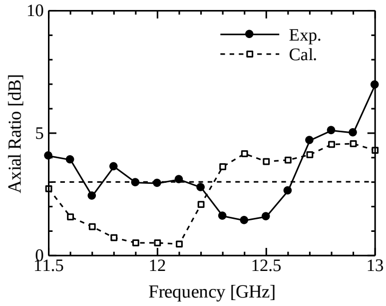


Figure 9: Axial ratio.

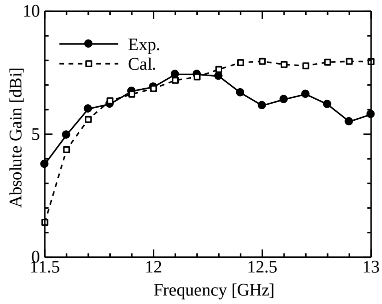


Figure 10: Antenna gain.

5. Conclusion

This paper presents a circularly polarized microstrip leaky wave antenna using a CRLH transmission line without a phase shifter. At first, we referred to the structure and the operation of the proposed antenna, and designed the antenna under simulated results on one unit cell. Secondly, we measured various characteristics of the fabricated antenna in X-band. As a result, the beam scanning range of 80 degrees was achieved in the region from the forward to the backward. The measured minimum axial ratio was 1.43dB. We are now planning to improve the axial ratio of the antenna in a wide frequency range.

Acknowledgments

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