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DOUBLE-SIDE RADIATING LEAKY-WAVE ANTENNA BASED ON COMPOSITE RIGHT/LEFT-HANDED COPLANAR-WAVEGUIDE

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Abstract—A double-side radiating leaky-wave antenna based on composite right/left-handed (CRLH) coplanar-waveguide (CPW) is proposed. Dispersion diagram of the unit cell is investigated, and balanced property is confirmed. Thus, the CRLH leaky-wave antenna can have backfire radiation due to the left-handed property of the CRLH structure and broadside radiation at the balancing frequency point. The measured results show that the proposed antenna can offer a scanning angle covering almost backfire-to-endfire directions.

1. INTRODUCTION

A Leaky-wave antenna is a radiating transmission line (TL) structure, either in uniform or periodic configurations, which have been widely studied and found a variety of applications [1]. However, only forward radiation can be obtained by conventional uniform leaky-wave antenna [2]. Although the periodic type leaky-wave antenna can produce backward radiation, its broadside radiation is restricted by the stopband between the forward and backward regions [3]. Composite right/left-handed (CRLH) metamaterials, which support the backward-wave propagation, have paved the road for novel perspectives of leaky-wave antennas [2]. When the balanced condition is satisfied, CRLH leaky-wave antennas can have improved broadside radiation. Then a continuously backfire-to-endfire beam steering can be achieved.

Since the CRLH metamaterials are introduced, various structures have been investigated, and many practical applications of CRLH

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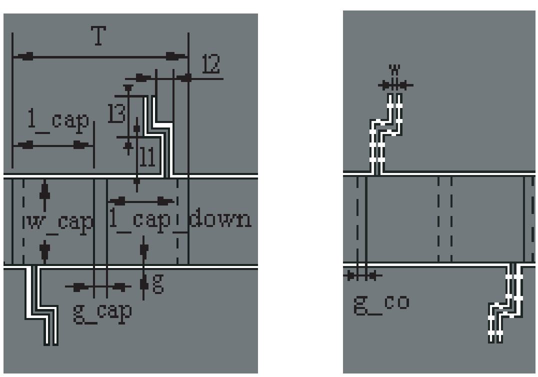
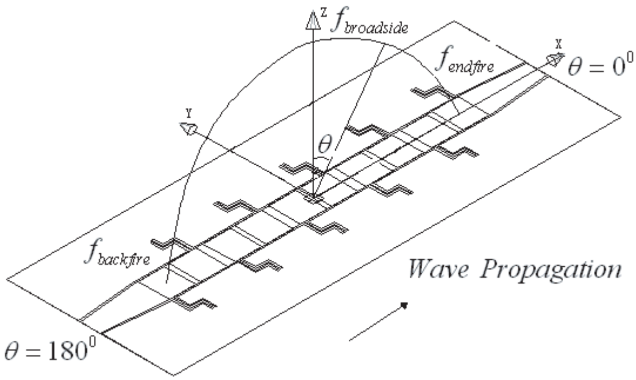
structures have been demonstrated [4–11], such as structures consisting of interdigital capacitor [4], wire bonded interdigital capacitor [5], gap capacitor [6], parallel-plate capacitor [7], etc. However, the interdigital capacitor is a multiconductor structure, and the resonances of the different modes appearing in the structure arise when more than three fingers are used. When the interdigital capacitor is used in a CRLH TL, those undesired resonances occur and prevent the line from propagating any signal at these frequencies [5]. The wire bonded interdigital capacitor can eliminate the resonances, but interconnecting the thin fingers with bonding wires makes it more difficult to fabricate. Usually, gap capacitor is very small, which leads to a large CRLH unit cell. Parallel-plate capacitor in [7] is a multilayered structure and is more difficult to fabricate than planar structure.

A CPW-based CRLH TL structure was proposed, which did not contain interdigital capacitor [12]. By introducing parallel-plate capacitors to enlarge the distributed series capacitance, the structure becomes compact. Furthermore, it could be easily implemented because of the planar structure. In this paper, a dispersion diagram of the unit cell is obtained, from which left- and right-handed bands and satisfied balanced condition are confirmed. The airline is also given to demonstrate the leaky-wave region. Then, a CRLH leaky-wave antenna using the novel structure is proposed. The backfire-to-endfire beam scanning performance is confirmed by measuring and comparing the radiation patterns at different frequencies.



(a) (b)



(c)

Figure 1. Unit cell of the CPW-based CRLH structure (a) Top view. (b) Bottom view. (c) Overall leaky-wave antenna prototype.

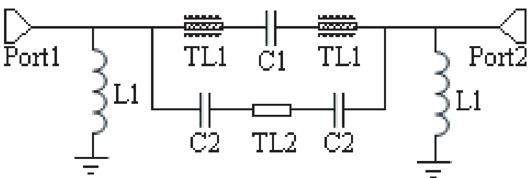


Figure 2. TL equivalent circuit of the unit cell.

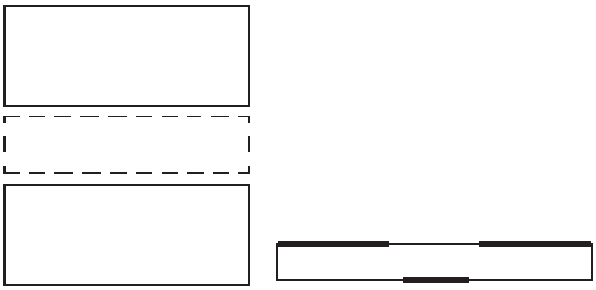
2. LEAKY-WAVE DISPERSION OF ONE PERIODIC STRUCTURE

The one periodic element of the proposed leaky-wave antenna is shown in Fig. 1. The equivalent circuit is shown in Fig. 2. The distributed gap capacitance is, in general, characterized to the circuit model with series capacitor C_1. Similarly, the parallel plate capacitors are modeled as the series capacitor C_2. The distributed inductive elements are modeled as the shunt inductance L_1. The CPW TL elements are modeled as TL_1. The TL composed of plate under the gap capacitor and the ground, which is shown in Fig. 3, is modeled as TL_2.

The $[ABCD]$ matrix of this unit cell is given by

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}_{unit} = \begin{pmatrix} 1+\frac{Y_1'}{Y_2'} & \frac{1}{Y_2'} \\ 2Y_1'+\frac{Y_1'2}{Y_2'} & 1+\frac{Y_1'}{Y_2'} \end{pmatrix}$$

where $Y_1' = \frac{1}{j\omega L_1}$ is the admittance of the shunt inductance L_1. Y_2' is



(a) Top view (b) Bottom view

Figure 3. TL_2 composed of a plate under the substrate and the ground.

the admittance of the series branches composed of TL_1, C_1 and TL_2, C_2, and it is given by

$$Y_2' = \frac{B_1C_1 - A_1D_1}{B_1} + \frac{B_2C_2 - A_2D_2}{B_2}$$

where

$$\begin{pmatrix} A_1 & B_1 \\ C_1 & D_1 \end{pmatrix} = \begin{pmatrix} \cos\beta_1 l_1 & jZ_1 \sin\beta_1 l_1 \\ jY_1 \sin\beta_1 l_1 & \cos\beta_1 l_1 \end{pmatrix} \begin{pmatrix} 1 & \frac{1}{j\omega C_1} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\beta_1 l_1 & jZ_1 \sin\beta_1 l_1 \\ jY_1 \sin\beta_1 l_1 & \cos\beta_1 l_1 \end{pmatrix}$$

$$\begin{pmatrix} A_2 & B_2 \\ C_2 & D_2 \end{pmatrix} = \begin{pmatrix} 1 & \frac{1}{j\omega C_2} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\beta_2 l_2 & jZ_2 \sin\beta_2 l_2 \\ jY_2 \sin\beta_2 l_2 & \cos\beta_2 l_2 \end{pmatrix} \begin{pmatrix} 1 & \frac{1}{j\omega C_2} \\ 0 & 1 \end{pmatrix}$$

where β_1 and β_2 are the phase constant of TL_1 and TL_2, respectively. β_2 can be calculated by EM simulator.

The corresponding S-parameters are then computed by

$$S_{11} = \frac{A + \frac{B}{Z_0} - CZ_0 - D}{A + \frac{B}{Z_0} + CZ_0 + D}$$

$$S_{21} = \frac{2(AD - BC)}{A + \frac{B}{Z_0} + CZ_0 + D}$$

The dispersion characteristic $\beta(\omega)$ is given by $|\beta p| = |\mathrm{Re}[\cos^{-1}(\frac{1-S_{11}S_{22}+S_{21}S_{12}}{2S_{21}})]|$, where p represents the total physical length of the TL. By the dispersion diagram, the balanced or unbalanced property could be identified.

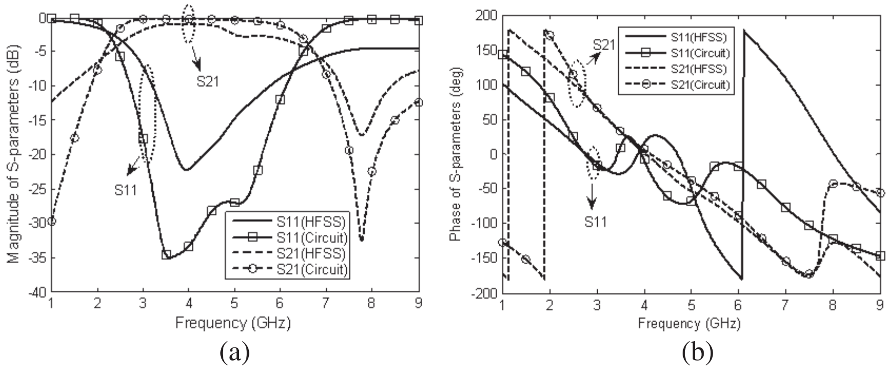


Figure 4. S-parameters of the unit cell. (a) Magnitude. (b) Phase.

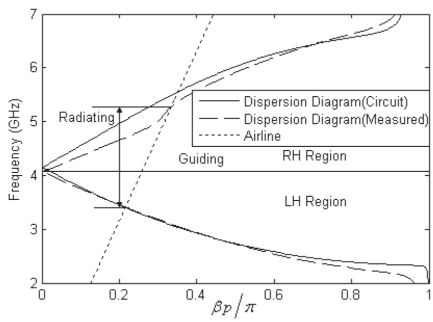


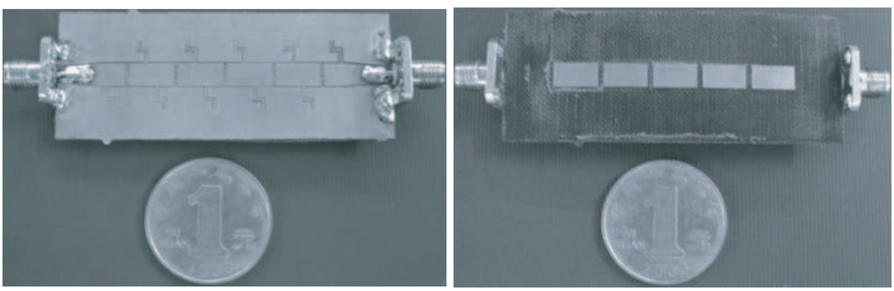
Figure 5. Dispersion diagram of the CRLH unit cell.

By the guidance of the equivalent circuit, a balanced CRLH TL structure is proposed. The dimensions of the structure are finalized using Ansoft HFSS simulation tools: $T = 9.5\,\text{mm}$, $l_1 = 2.22\,\text{mm}$, $l_2 = 1.64\,\text{mm}$, $l_3 = 2.36\,\text{mm}$, $w = 0.3\,\text{mm}$, $g = 0.22\,\text{mm}$, $l\_cap = 4.4\,\text{mm}$, $w\_cap = 4.6\,\text{mm}$, $g\_cap = 0.7\,\text{mm}$, $g\_co = 0.4\,\text{mm}$. The ε_r and height of the substrate are 2.55 and 0.8 mm, respectively. The corresponding L-C parameters are: $C_1 = 0.07\,\text{pF}$, $C_2 = 1.05\,\text{pF}$, $L_1 = 2.35\,\text{nH}$. The magnitude and phase of the S-parameters are shown in Fig. 4. Although resistances are not included in the circuit, the circuit theory can illustrate the tendency and can be used to be guidance to the design of the model.

Besides the dispersion diagram according to circuit theory, the measured dispersion diagram is shown in Fig. 5 to confirm the balanced condition. The two diagrams agree well. It can be seen that the balancing point locates at about 4.07 GHz. Two regions are divided by the airline: The radiating region above the line and the guiding region below the airline. The radiating region is from about 3.37 GHz to 5.3 GHz.

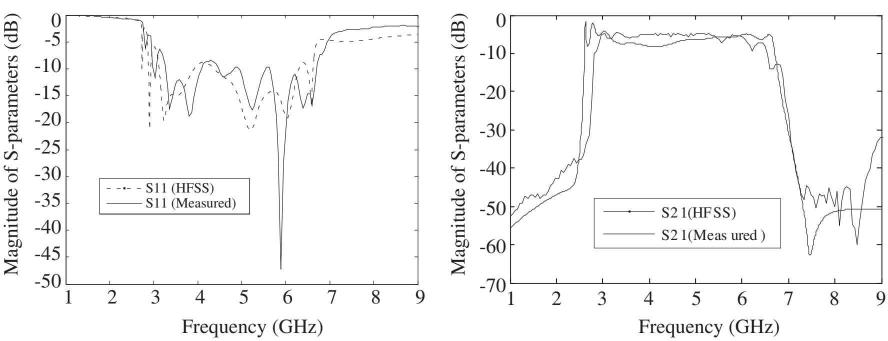
3. DOUBLE-SIDE RADIATING LEAKY-WAVE ANTENNA

A double-side radiating leaky-wave antenna, whose photograph is shown in Fig. 6, is fabricated. It has 5 proposed CRLH unit cells. Fig. 7 shows the measured and simulated S-parameters of this leaky-wave antenna, which show good consistency. A return loss below -10 dB in the band of interest (from 3.37 GHz to 5.3 GHz) is achieved.



(a) (b)

Figure 6. The fabricated leaky-wave antenna. (a) Top view. (b) Bottom view.



(a) (b)

Figure 7. Measured and simulated S-parameters of the leaky-wave antenna. (a) S_{11}, (b) S_{21}.

In Fig. 8, the measured radiation patterns at 3.4, 4.08 and 5.3 GHz are shown. From the radiation patterns, which are measured at outdoors, a backfire-to-endfire beam steering is shown. The beam angle θ is taken from the backward, broadside to the forward direction, and the angles at the above-mentioned frequencies are about 150°, 87°, and 65°, respectively.

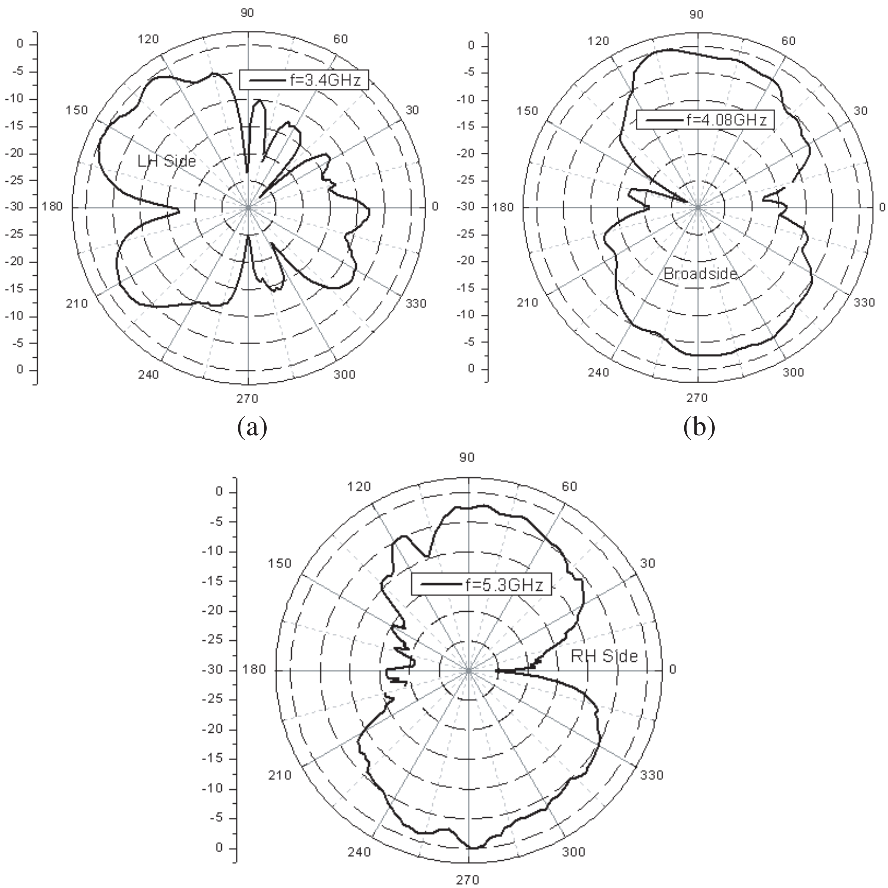


Figure 8. Measured antenna radiation patterns. (a) X-Z plane in the LH region. (b) Broadside radiation in the X-Z plane. (c) X-Z plane in the RH region.

4. CONCLUSION

A double-side radiating leaky-wave antenna is proposed. It is constructed with a CPW-based CRLH structure. The measured double-side radiating patterns are given. The results show that the proposed antenna can offer a scanning angle covering almost backfire-to-endfire directions.

ACKNOWLEDGMENT

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