A Novel Circularly-Polarized Microstrip Antenna by Coupled Resonators

Jia-Xiang Hao
Department of Electrical and Computer Engineering
University of Macau
Macau, China
yc27456@um.edu.mo

Lei Zhu
Department of Electrical and Computer Engineering
University of Macau
Macau, China
leizhu@um.edu.mo

***Abstract*—This paper proposes a circularly-polarized (CP) antenna through coupling effects. By orthogonally arranging the short-circuited (open-circuited) ends of two identical λ/4 short-circuited microstrip line (MS-L) resonators to each other, the CP radiation by magnetic(electric) coupling can be produced. Then, for improving the peak gain and the axial ratio bandwidth (ARBW), a binary array comprising of an electrically coupled (EC) pair and a magnetically coupled (MC) pair of resonators is presented. Then the array is fabricated, and an excellent agreement between the experiment and simulation results is validated.**

Keywords—Coupled resonators, phase difference, electric coupling, magnetic coupling, circular polarization.

I. Introduction

Compared to linearly-polarized (LP) antennas, circularly-polarized (CP) antennas have received more attentions due to their lower polarization deflection loss and anti-environmental impact [1]. The CP patch antennas [2]–[4] is credited for being lightweight, compact, and easy to conform to objects.

Mutual couplings have been employed to develop several circularly polarized (CP) patch antennas. However, comprehensive studies on these coupling effects remain limited. To address this issue, a method leveraging the coupling mechanism is proposed. A 90° phase difference was achieved between two perpendicular λ/2 slots that were magnetically coupled (MC) as described in [5]. This resulted in a CP slot antenna with a gain of 3.5 dBic and an axial ratio bandwidth (ARBW) of 4.7%. Additionally, a CP antenna was realized in [6] by electrically coupling (EC) two perpendicular λ/2 patches. Nevertheless, the design flexibility for achieving the desired CP rotation is constrained by the fact that conventional λ/2 resonators can only facilitate one type of coupling (either EC or MC) in edge-to-edge configurations.

This paper employs a pair of λ/4 microstrip line (MS-L) resonators to achieve CP radiation. One end of the resonator is loaded with a shorting pin, while the other end is open-circuited, as illustrated in Fig. 1(a). By orthogonally spacing the same ends, either EC or MC, the desired CP rotation can be achieved. Then a binary array consisting of an EC pair and a MC pair is proposed to not only expand the antenna's axial ratio bandwidth (ARBW) to five times its original value, reaching 1.7%, but also to increase the gain to 5 dBic compared to a single pair.

II. Woking Mechanism

A. Analyses of a pair of Coupled Resonators

As illustrated in Fig. 1(b) and (c), a pair of resonators are coupled at their opened (shorted) ends to produce EC(MC). To elucidate the operational principle, equivalent circuit models comprising a λ/4 transmission line and a shunt conductance is developed. As shown in Fig. 1(d) and (e). A $K(J)$-inverter is employed to represent the MC(EC) [7]. The

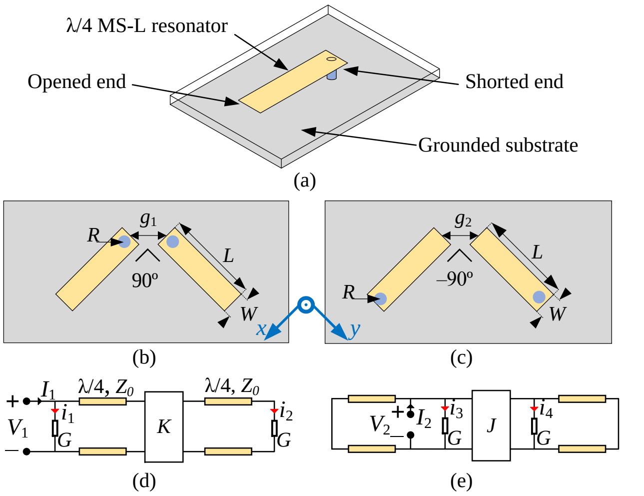

Fig. 1. (a) The proposed λ/4 microstrip line resonator. (b) The MC and (c) the EC resonators with their corresponding equivalent circuit model (d) and (e).

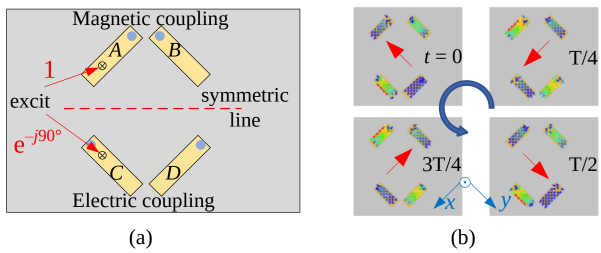

Fig. 2. (a)The geometry of proposed binary array and (b)the current distributions of this array at 3.55 GHz.

radiation from the open-circuited end is modeled by the shunt conductance G. Thus the currents through each conductance can be analyzed to discuss the power distribution across the two conductances. The currents $i_1(i_3)$ on the conductance G (active resonator) and $i_2(i_4)$ on the conductance G (parasitic resonator) can be inferred by multiplying the ABCD matrices of those circuits: $i_2/i_1 = -j\left(K/GZ_0^2\right)$; $i_4/i_3 = j(J/G)$.

As shown in above equations, the –90° (90°) phase difference is validated between $i_2(i_4)$ and $i_1(i_3)$. Therefore, $|i_2/i_1|$ ($|i_4/i_3|$) = 1 should be the remaining requirement for the CP radiation. The expression for the $K(J)$-inverter can then be determined: $K = GZ_0^2$; $J = G$.

B. Desesign of a Binary Array

A binary array with two λ/4 pairs can be arranged in a compact mirror-symmetric configuration, leveraging the flexibility of using either EC or MC, as illustrated in Fig. 2(a). The parasitic resonator B and active resonator C are y-polarized, while the active resonator A and parasitic resonator D are x-polarized. Due to MC, the radiation from B holds a phase difference of -90° relative to A. Conversely, due to EC, the phase in D is +90° ahead of that in C. For verification, HFSS is used to simulate this array with ideal excitations (equal in amplitude but with a 90° phase difference). Fig. 2(b)

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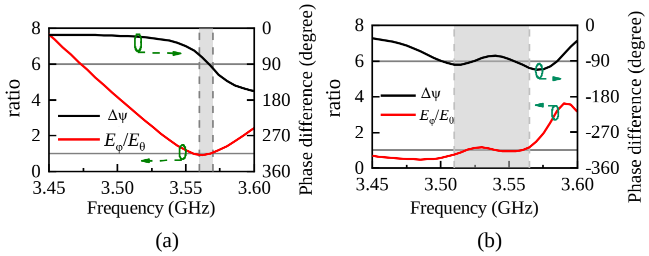

Fig. 3. Simulated magnitude of electric field and the phase difference versus frequency of (a) the electrically coupled antenna, and (b) the binary array.

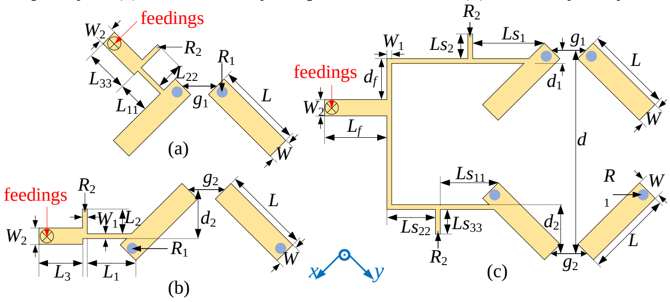

Fig. 4. The geometry of the proposed (a) magnetically coupled antenna, (b) electrically coupled antenna and (c) binary array.

Dimensional Parameters(unit: mm): W: 5, L: 13.5, g_1: 10, d_1: 4.4, g_2: 5.6, Ls_2: 4.1, R_1: 1.5, R_2: 0.2, L_{11}:16.5, L_{22}:5.6, L_{33}:9, df:10.6, W_1:0.8, Ls_1:17.5, W_2:3.4, Lf:6.8, L_1:19.2, L_2:7.6, L_3:20.2, d:40, d_2:7.1, Ls_{22}:2.6, Ls_{11}:19.2.

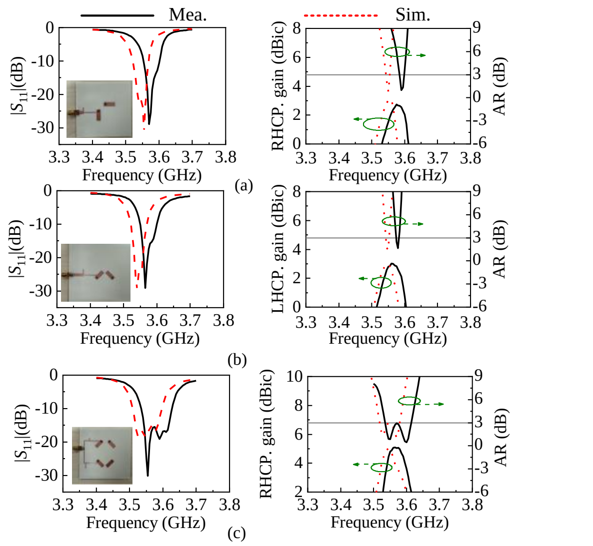

Fig. 5. The reflection coefficients, the AR responses and the maximum gain of the presented (a) magnetically coupled antenna, (b) the electrically coupled antenna and (c) the dual symmetric binary array.

shows the current distributions in this array. The counterclockwise rotation of the currents indicates that this binary array can effectively achieve right-hand circularly polarized (RHCP) radiation.

To demonstrate the array's performance in improving ARBW, two orthogonal components of the electric field, E_θ and E_φ, and their phase difference $\Delta\psi$ (ψ (E_θ) – ψ (E_φ)), are simulated at the broadside. Also, the EC pair are also simulated for comparison. As shown in Fig. 3, the array exhibits a broader ARBW compared to the single-pair antenna.

III. Experimental Results

In Fig. 4, a RHCP antenna with MC, a LHCP antenna with EC and a RHCP array were fabricated by a Rogers RO4003C substrate with a thickness of h = 1.524 mm. As illustrated in Fig. 9 and Fig.10, excluding a 1% variation in the working band, an excellent agreement is validated between the

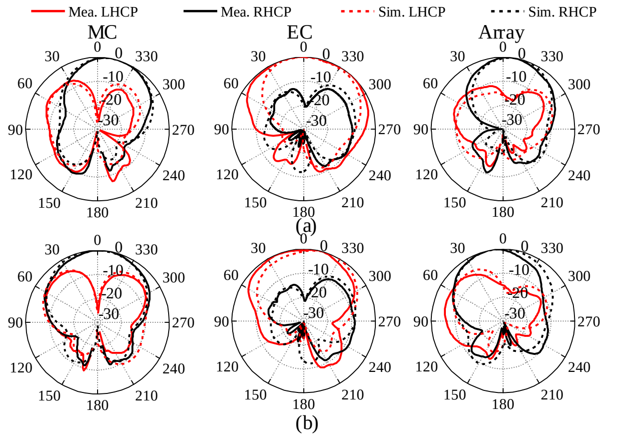

Fig. 6. The normalized radiation patterns of the magnetically coupled, electrically coupled and the binary array antennas in (a)xz- and (b)yz-plane.

experiment and simulation results. For these single pairs, an average gain of approximately 3 dBic is observed. According to the results of the binary array, a maximum gain of 5 dBic can be achieved. Also, the array's ARBW is 5 times larger than that of a single pair, extending to 80 MHz.

IV. Conclusion

A method by utilizing coupling effects between two identical λ/4 patches is proposed. EC (MC) can be achieved through short-circuited(open-circuited) end coupling to attain the desired CP rotation. Compared to λ/2 length pairs, the proposed λ/4 length patch pairs are nearly half the size. Finally, a binary array with a compact mirror-symmetric configuration is constructed. This array has demonstrated significant potential for enhancing antenna gain and improving axial ratio bandwidth (ARBW).

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