A Circularly Polarized Array Composed of Linear Polarized Microstrip Patches Fed by Metamaterial Transmission Line

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A CIRCULARLY POLARIZED ARRAY COMPOSED OF LINEAR POLARIZED MICROSTRIP PATCHES FED BY METAMATERIAL TRANSMISSION LINE

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Abstract—A novel single-feed circularly polarized antenna array is constructed by a 2×2 array of four square linear polarized microstrip patches with orthogonal orientation and phase shift of 90° in between. The sequential rotation and suitable phasing of linear polarized microstrip patches improve the radiation pattern symmetry and input impedance matching of the array antenna. A metamaterial transmission line is designed and applied to feeding the antenna array. The metamaterial transmission line works at its zeroth order resonant mode and there is no phase shift between its four output ports. A circularly polarized antenna array at 5.8 GHz is built and demonstrated, which is fed by the metamaterial transmission line. The antenna array is compact and the whole dimension is about $1.1\lambda_g^2$. The antenna gain reaches 9 dBi, and shows a good axial ratio. Experimental results and simulation agree well.

1. INTRODUCTION

Metamaterials are artificial periodic structures that exhibit specific electromagnetic properties not existing in nature [1–3]. Metamaterials exhibit simultaneously negative permittivity and permeability and have gained great interest in developing novel microwave/radio frequency devices and components [4–8]. Besides three- and two-dimensional metamaterials, an one-dimension approach is well-known as Composed Right/Left-Handed (CRLH) transmission line, which was presented and analyzed with transmission line theory by Itoh et al. Various applications based on CRLH transmission line in microwave

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fields, such as directional couplers, power dividers, diplexers, baluns, compact antennas, and so on, have been presented [9–15]. It is presented that CRLH transmission line phase-shifting lines can be applied to reducing the beam squint of series-fed antenna array [11].

Circularly polarized antennas find many applications in communication systems, and there are some research to improve their performance [16–23]. In this work, we have designed and realized a circularly polarized microstrip antenna array fed by a metamaterial feeding network, which is a CRLH TL and works as a series power divider. The microstrip antenna array is designed as sequential rotation elements with proper phasing among four patch antennas. The antenna array fed by CRLH transmission line is significantly more compact than its conventional equivalence. It shows that CRLH transmission lines have future applications in antenna arrays. The simulated and experimental results verify the usefulness of the circularly polarized antenna array structure for modern applications.

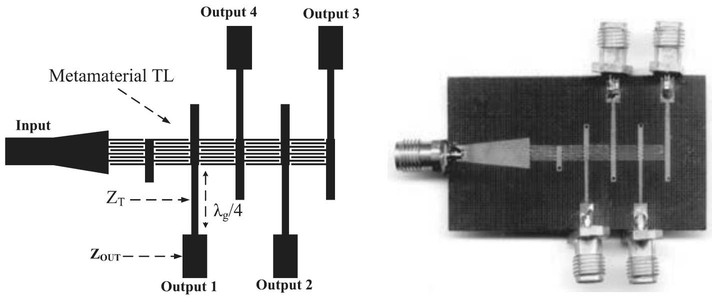
2. DESIGN AND REALIZATION

2.1. Series Power Divider

A CRLH transmission line unit can be usually implemented with microstrip lines, series lumped-capacitor and parallel lumped-inductor [9] or microstrip interdigital capacitor and shorted stub inductors grounded by vias [2]. This paper chooses the second structure to build a series 1 : 4 power divider as feeding network. The microstrip interdigital capacitors and shorted stub inductors are series and shunt resonators, once parasitic effects are taken into consideration. As we have discussed in [6], a CRLH transmission line is equivalent to the center part of a high order Chebyshev band-pass filter with low ripples. The series and shunt LC resonators have the same resonant frequency

$$\omega_{se} = \omega_{sh} = \omega_0 \tag{1}$$

where ω_{se} and ω_{sh} are the resonant frequency of the series and shunt LC resonators, respectively, and ω_0 is the center frequency of the band-pass filter. Equation (1) is also known as the balanced condition of a CRLH transmission line. Thus, at the center frequency ω_0, the series and shunt resonators are equivalent to short and open circuits, respectively, and all resonators are excited in phase. Then, the CRLH transmission line can work as a power divider at the center frequency ω_0. Compared with a series power divider employing conventional λ_g meander transmission lines to provide in-phase signals at the output ports, this structure maintains as compact as $\lambda_g/4$. The dimension is obviously diminished.



(a) (b)

Figure 1. Configuration of 1 : 4 series power divider.

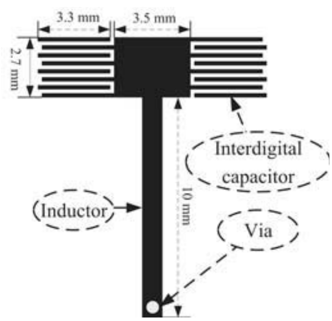


Figure 2. Unit cell of the CRLH transmission line used for parameter extraction.

Figure 1(a) shows the proposed metamaterial 1 : 4 power divider that provides equal power split to all four output ports based on the balanced condition of CRLH transmission line. The detailed design of a CRLH transmission line can be found in [9]. The CRLH transmission line operates at its zeroth order resonance, at which the guided wavelength reaches infinite [11]. Each output has no phase shift at the resonance frequency, and four outputs are virtually parallel connected to the input port. Thus, four quarter-wave transmission line impedance transformers are applied matching those outputs to the input. The characteristic impedance Z_T of the $\lambda_g/4$ transmission line is

$$Z_T = \sqrt{Z_{OUT} \times 4Z_{IN}} \tag{2}$$

where Z_{OUT} and Z_{IN} are the output and input impedances, respectively. When $Z_{OUT} = Z_{IN} = 50\,\Omega$ in normal case, it gives $Z_T = 100\,\Omega$. The parameter extraction was performed based on the unit cell in Figure 2 to verify performance of the CRLH transmission line.

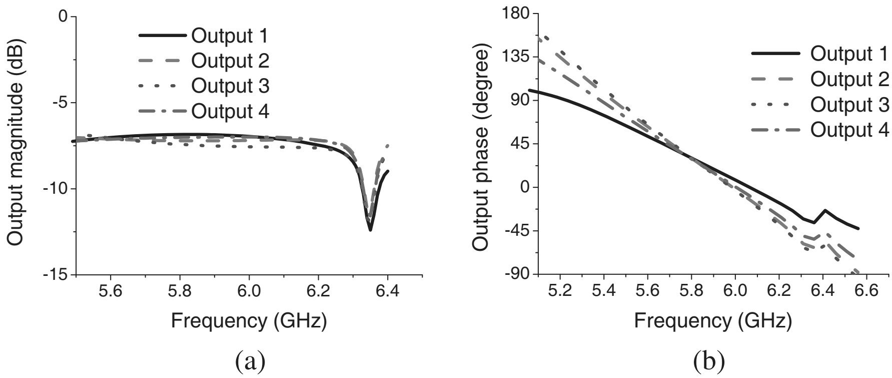


Figure 3. Simulated results. (a) Output magnitude. (b) Output phase.

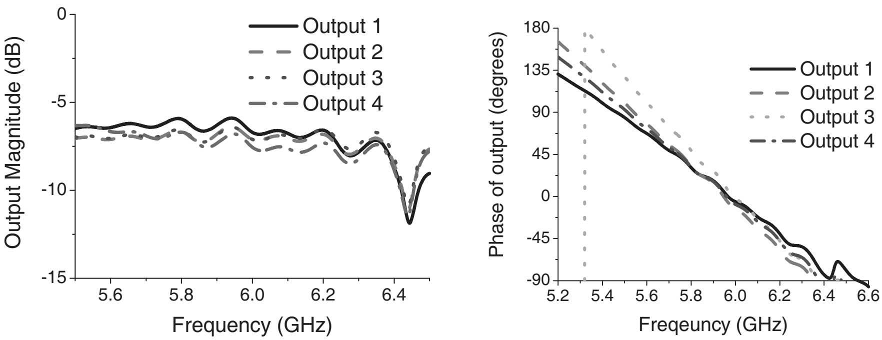
The power divider is fabricated on F4B-2 polytetrafluoroethylene substrate with thickness 1 mm and relative dielectric constant 2.65. The dielectric loss tangent is 0.001. Figure 1(b) shows the fabricated 1 : 4 power divider. A CRLH transmission line unit-cell is displayed in Figure 2, which includes series capacitors constructed by interdigital gaps and shunt inductors from short-ended lines. An interdigital capacitor contains four pairs of fingers with 0.18 mm both width and spacing. Figure 2 shows other dimensions of the unit cell.

Figure 3 shows the simulated results by Zealand IE3D. There is a frequency, at which equal power split and in-phase to all four ports of the power divider, can be achieved. Figure 4 shows the measured results from an Agilent PNA 8362B vector network analyzer. It can be observed that the measured data matches the simulated data quite well.

As shown in the measured results, the magnitude difference between output ports is less than 1 dB from 5.6 GHz to 5.95 GHz, and the phase difference is less than 10° from 5.69 GHz to 5.92 GHz. The isolation between outputs is at the operational frequency. Although the performance of the metamaterial transmission line is not as good as a Wilkinson power divider, it is much compact than a Wilkinson type feeding network. The feeding network based on metamaterial transmission lines has potential applications in antenna arrays.

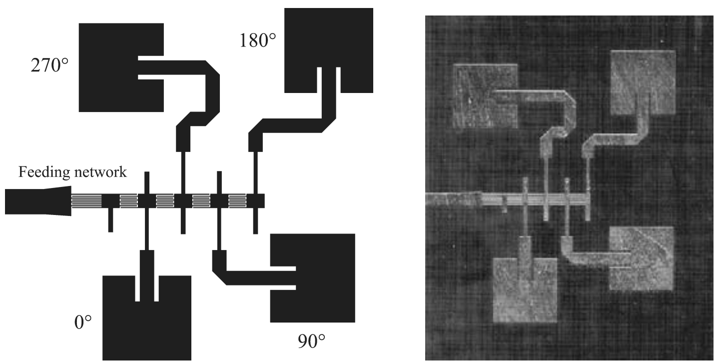
2.2. Circularly Polarized Antenna Array

Figure 5(a) shows the circularly polarized antenna array configuration of single-feed square elements with orthogonal orientation and phase difference of 90° between them to obtain circular polarization. The



(a) (b)

Figure 4. Measured results. (a) Magnitude. (b) Phase.



(a) (b)

Figure 5. Circularly polarized antenna with phase difference between elements (0°, 90°, 180°, 270°).

phase difference between these four elements could be arranged in (0°, 90°, 0°, 90°) or (0°, 90°, 180°, 270°) with alternative orientations [9]. We choose the latter configuration which gives better performance due to the cancelation of the undesired reflection and radiation from the 0° and 180° elements, and from the 90° and 270° elements, respectively. By arranging the four elements (0°, 90°, 180°, 270°) with different rotation directions, either the left-handed or right-handed circular polarization is obtained. Four square patch antennas are from conventional design. The antenna array is fabricated on F4B-2 substrate, as shown in Figure 5(b). Both length and width of a single patch are 15.8 mm, the insertion length of the feeding microstrip line is 5.4 mm, and the gaps between feeding line and the patch are 0.8 mm.

The simulation and measurement results of $|S_{11}|$ and Axial Ratio (AR) dependent on frequency, and the Right Hand Circular Polarized (RHCP) radiation patterns are shown in Figures 6(a), (b) and (c), respectively. The measured bandwidth (VSWR < 2) of this antenna array is 270 MHz, which is 4.7% of the center frequency 5.8 GHz. The antenna array is optimized for a reasonable bandwidth around the center frequency. As a result, there are two minimums of $|S_{11}|$ around 5.8 GHz. If it were optimized for a narrow band goal, $|S_{11}|$ at the center frequency would be much better. The axial ratio bandwidth of

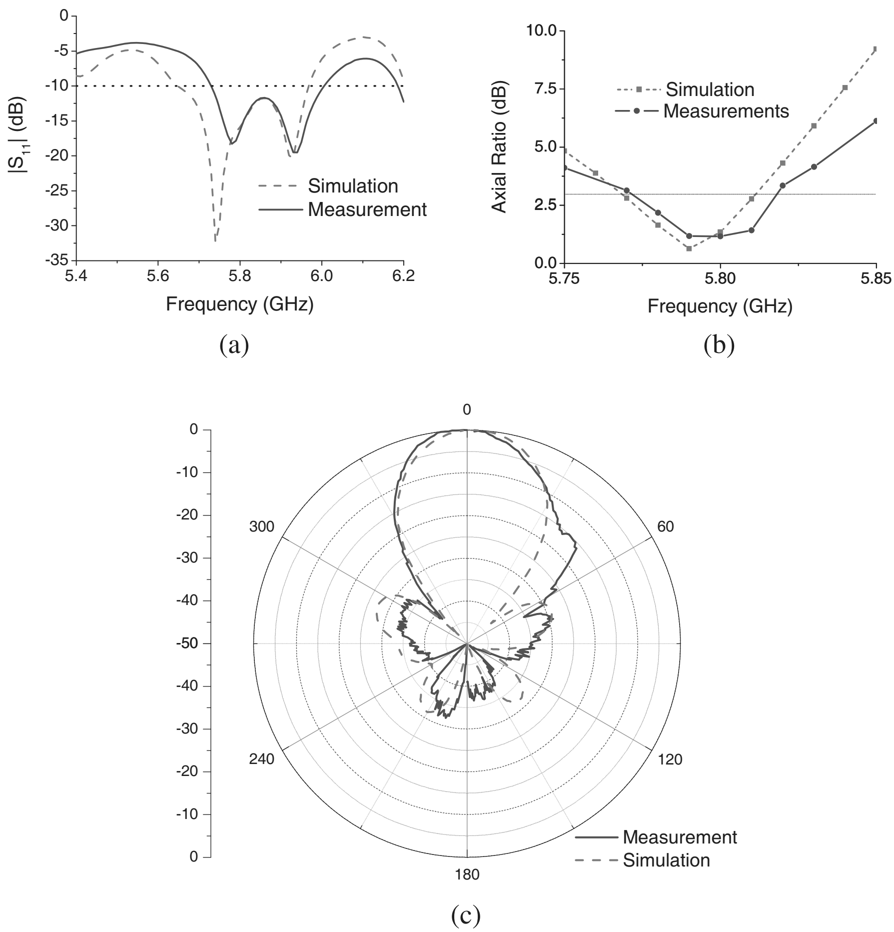


Figure 6. The simulated and measured results (a) S-parameter; (b) Axial ratio; (c) RHCP radiation pattern.

the antenna array is 50 MHz (AR < 3 dB), and the axial ratio is 1.16 dB at the center frequency. The gain of the antenna array is 9 dBi, and the measured and simulated patterns are show in Figure 6(c). The pattern is slightly not symmetrical due to the feeding network and the unsymmetrical configuration.

3. CONCLUSION

A sequentially rotated circularly polarized microstrip patch antenna array has been presented. The antenna array contains 2×2 linear polarized microstrip patch antenna and uses metamaterial power divider as a feeding network. The metamaterial power divider operates at its zeroth order resonance to feed four antennas separately. It is a compact and easy-to-build circularly polarized antenna array by using a metamaterial transmission line as its feeding network. The measured and simulated results agree well with each other. Metamaterial transmission lines show potential applications in antenna feeding networks for building compact antenna arrays.

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REFERENCES

1. Veselago, V. G., "The electrodynamics of substances with simultaneously negative values of ε and μ," *Soviet Physics Uspekhi*, Vol. 10, No. 4, 509–514, Jan. 1968.
2. Grzegorczyk, T. M. and J. A. Kong, "Review of left-handed metamaterials: Evolution from theoretical and numerical studies to potential applications," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 14, 2053–2064, 2006.
3. Lai, A., C. Caloz, and T. Itoh, "Composite right/left-handed transmission line metamaterials," *IEEE Microwave Magazine*, Vol. 5, No. 3, 34–50, Sep. 2004.
4. Liu, C. and W. Menzel, "Broadband via-free microstrip balun using metamaterial transmission lines," *IEEE Microwave & Wireless Components Letters*, Vol. 18, No. 7, 437–439, Jul. 2008
5. Wang, W., C. Liu, L. Yan, and K. Huang, "A novel power divider based on dual-composite right/left handed transmission

line," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 8–9, 1173–1180, 2009.

6. Liu, C. and W. Menzel, "On the relation between a negative refractive index transmission line and Chebyshev filters," *The 37th European Microwave Conference (EuMC 2007)*, 704–707, Munich, Germany, Oct. 8–12, 2007.
7. Yang, T., C. Liu, L. Yan, and K. Huang, "A compact dual-band power divider using planar artificial transmission lines for GSM/DCS applications," *Progress In Electromagnetics Research Letters*, Vol. 10, 185–191, 2009.
8. Liu, C.-Y, Q.-X. Chu, and J.-Q. Huang, "Double-side radiating leaky-wave antenna based on composite right/left-handed coplanar-waveguide," *Progress In Electromagnetics Research Letters*, Vol. 14, 11–19, 2010.
9. Caloz, C. and T. Itoh, "Transmission line approach of left-handed (LH) materials and microstrip implementation of an artificial LH transmission line," *IEEE Trans. Antenna Propagat.*, Vol. 52, No. 5, 1159–1166, May 2004.
10. Caloz, C. and T. Itoh, "Metamaterial-based electronically controlled transmission-line structure as a novel leaky-wave antenna with tunable radiation angle and beam width," *IEEE Trans. Microwave Theory Tech.*, Vol. 53, No. 1, 161–182, Jan. 2005.
11. Huang, W., C. Liu, L. Yan, and K. Huang, "A miniaturized dual-band power divider with harmonic suppression for GSM applications," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 1, 81–91, 2010.
12. Li, Y., Q. Zhu, Y. Yan, S.-J. Xu, and B. Zhou, "Design of a $1 * 20$ series feed network with composite right/left-handed transmission line," *Progress In Electromagnetics Research*, Vol. 89, 311–324, 2009.
13. Lai, A., K. Leong, and T. Itoh, "A novel N-port series divider using infinite wavelength phenomena," *2005 IEEE MTT-S International Microwave Symposium Digest*, Jun. 12–17, 2005.
14. Qiang, L., H. Lu, W. Zhao, J.-K. Wang, and B. Liu, "Simplified extended composite right/left-handed transmission line structure for dual-band applications," *Progress In Electromagnetics Research Letters*, Vol. 15, 137–144, 2010.
15. Monti, G., R. de Paolis, and L. Tarricone, "Design of a 3-state reconfigurable CRLH transmission line based on MEMS switches," *Progress In Electromagnetics Research*, Vol. 95, 283–297, 2009.

16. Chang, T. N., M. C. Wu, and J.-M. Lin, "Gain enhancement for circularly polarized microstrip patch antenna," *Progress In Electromagnetics Research B*, Vol. 17, 275–292, 2009
17. Deng, J.-Y., Y.-Z. Yin, Y.-H. Huang, J. Ma, and Q.-Z. Liu, "Compact circularly polarized microstrip antenna with wide beamwidth for compass satellite service," *Progress In Electromagnetics Research Letters*, Vol. 11, 113–118, 2009.
18. Heidari, A. A., M. Heyrani, and M. Nakhkash, "A dual-band circularly polarized stub loaded microstrip patch antenna for GPS applications," *Progress In Electromagnetics Research*, Vol. 92, 195–208, 2009.
19. Chang, T. N. and J.-H. Jiang, "Enhance gain and bandwidth of circularly polarized microstrip patch antenna using gap-coupled method," *Progress In Electromagnetics Research*, Vol. 96, 127–139, 2009.
20. Chen, J., G. Fu, G.-D. Wu, and S.-X. Gong, "Broadband circularly polarized combinatorial slot antenna," *Journal of Electromagnetic Waves and Applications,* Vol. 23, No. 16, 2127–2134, 2009.
21. Lai, C.-H., T.-R. Chen, and T.-Y. Han, "Circularly-polarized reconfigurable microstrip antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 2–3, 195–201, 2009.
22. Hong, T., L.-T. Jiang, Y.-X. Xu, S.-X. Gong, and W. Jiang, "Radiation and scattering analysis of a novel circularly polarized slot antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 13, 1709–1720, 2010.
23. Ooi, T. S., S. K. B. A. Rahim, and B. P. Koh, "2.45 GHz and 5.8 GHz compact dual-band circularly polarized patch antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 11–12, 473–1482, 2010.