A Circularly-Polarized Microstrip Antenna Fed by Composite Right/Left-handed Quadrature Power Splitter

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Abstract

A circularly-polarized (CP) microstrip antenna (MSA) fed by composite right/left-handed (CRLH) quadrature power splitter (QPS) is developed and experimentally demonstrated in this paper. Instead of using the conventional branch-line coupler to provide dual feeding inputs, two adjacent edges of the square path are fed by two outputs of the CRLH QPS for CP performance improvement. The developed CRLH QPS has an 84.2% quadrature phase bandwidth within ±5° phase variation and an amplitude imbalance of 0.45 dB over the frequency range of 1.1-2.7 GHz. As the CRLH QPS is treated as a feeding circuitry, and then applied to implement the CP MSA, one can achieve a 67.8 % return loss bandwidth and a 12.8 % axial-ratio bandwidth.

1. Introduction

RECENTLY, circularly-polarized (CP) microstrip antennas (MSAs) are extensively utilized for mobile, satellite and military applications due to the advantages of low cost, light weight, low-profile, and easy fabrication and integration with radio-frequency front-end circuits.

The CP MSA can be implemented by a radiating patch with a singly-fed or dual-fed excitation circuitry [1]. As considering the bandwidth improvement, the dual-fed CP MSAs excited by two quadrature outputs of the branch-line coupler (BLC) [2] are usually employed to yield the right-handed (RH) or left-handed (LH) CP wave. This feeding technique is also applied to implement the dielectric resonator antenna for the AR enhancement [3]. In addition, the sequentially rotated technique [4] can be applied to broader the AR bandwidth, but it occupies a large antenna size.

The CP MSA fed by the BLC is conventionally implemented as shown in Fig. 1 (a). The BLC is treated as a polarizer to provide two signals with equal amplitudes and a quadrature phase difference. As two adjacent edges of the square patch antenna are fed by two outputs of the BLC, one can achieve a CP MSA. The antenna configuration shown in Fig. 1 (a) gives the RHCP, and can then switches to the LHCP as the other input port is excited. Since the CP is mainly caused by two equal excitations with quadrature phase, the performance of the CP antenna significantly depends on the characteristics of the polarizer, namely BLC. However, the conventional BLC just can provide limited quadrature-phase and amplitude-imbalance bandwidths. One can not effectively achieve the CP MSA with the wider RL and AR bandwidth.

In recent years, based on novel properties of the composite right/left-handed (CRLH) TL [5], microwave components with abilities to equally divide power and provide a specified phase difference, such as baluns [6], quadrature power splitters (QPS) [7], and microstrip-to-CPS transition [8], have been developed to enhance the bandwidth and reduce the circuit size. Moreover, the CRLH balun and microstrip-to-CPS transition are treated as feeding circuits to implement the loop antenna [6] and Quasi-Yagi antenna [8], respectively. The improvement of the antenna performance has been experimentally demonstrated.

In this paper, a CRLH QPS [7] is implemented to have a broadband quadrature phase bandwidth and a moderate amplitude imbalance. Instead of the BLC, the CRLH QPS is integrated with a square patch antenna to realize the CP MSA as shown in Fig. 1 (b). Compared with the conventional CP MSA with the BLC, the CP MSA with the QPS improves the RL and AR bandwidths, and also alleviates the radiation pattern tilt caused by the amplitude imbalance between the BLC outputs.

2. Composite Right/Left-Handed Quadrature Power Splitter

The QPS is mainly realized by a Wilkinson power divider whose two outputs are respectively connected with a well-synthesized CRLH TL and a conventional microstrip (MS) as shown in Fig. 2. [7] In order to obtain a broadband quadrature phase difference between two output ports of the developed QPS, the CRLH TL should be synthesized to have the same curve slope of the phase response as that of the MS. As shown in Fig. 2, the FR4 substrate with 1.5-mm thickness and the dielectric constant of 4.3 is employed to fabricate the developed QPS. In addition, the LH section in the CRLH TL is realized by Murata 0603 (1.6 mm×0.8 mm) chip inductors and capacitors. It is cascaded by two T-networks with L=12.1 nH (a series of 3.9 nH and 8.2 nH inductors) and C=5 pF. The folded MS is utilized to provide the same feeding position as that given by the CRLH TL. The measured S-parameters in this letter are carried out by the Anritsu 37347C vector network analyzer.

The measured transmission coefficients S_{21} and S_{31} of the developed QPS are shown in Fig. 3. For comparison, the results of the conventional BLC are also given. It demonstrates that the LH section realized by chip components does not lead to the significant degradation of the transmission performance. As considering $90° \pm 5°$ phase difference ($\angle S_{31} - \angle S_{21}$), the frequency range is from 1.1 GHz to 2.7 GHz with an 84.2 % relative bandwidth. While over the same frequency range (1.1-2.7GHz), the maximum output imbalance ($|S_{31}| - |S_{21}|$) is about 0.45 dB. The BLC gives $90° \pm 5°$ phase difference and 1.38 dB amplitude imbalance over frequency range of 1.73 GHz-2.46GHz with a 34.8 % relative bandwidth.

3. Circular-Polarized Microstrip Antennas Fed by CRLH QPS

According to the configuration of CP MSA shown in Fig. 1 (b), the CP MSA fed by the CRLH QPS is fabricated as shown in Fig. 4 (a). It consists of a CRLH QPS, quarter-wave transformer and a square patch, and can generate the RHCP wave. Moreover, the impedance transformer and the square patch are designed at 2 GHz. Via the quarter-wave transformer, the output impedance of the QPS matches to the impedance of the edge-fed square patch.

For performance comparison, the CP MSA fed by the BLC is also fabricated as shown in Fig. 4 (b), and one of input ports isterminated by a 50 Ω load for the RHCP. Except the QPS and BLC, the MSAs shown in Fig. 4 (a) and (b) have the same dimensions of the square patch and the transformer.

Measured return losses of two CP MSAs are shown in Fig. 5. The CP MSA fed by the QPS has the return loss greater than -10 dB over the frequency range of 1.22 GHz-2.47 GHz with a 67.8 % relative RL bandwidth, whereas the CP MSA fed by the BLC gives 45.9 % RL bandwidth (1.61 GHz-2.57 GHz). Figure 6 shows the ARs of the CP MSAs fed by the QPS and BLC in the broadside direction. The measurement frequency is swept from 1.7 GHz to 1.9 GHz. The CP MSA fed by the QPS obtains the AR of less than 3 dB from 1.76 GHz to 2 GHz with a 12.8 % relative AR bandwidth, whereas the CP MSA fed by the BLC has a 7.25 % relative AR bandwidth (1.86 GHz-2.0 GHz). The RL and AR bandwidths are effectively improved as the BLC adopted in conventional CP MSA configuration is replaced by the broadband QPS.

For radiation measurement, figure 7 presents the normalized far-field radiation pattern for RHCP and LHCP at 2GHz in the *x-z* plane defined in Fig. 4. It can be observed that the cross-polarization level is larger than 25 dB in the broadside direction for two MSAs. Furthermore, there is a 5° main beam tilt in the measured radiation pattern of the MSA fed by the BLC. It is because the amplitude imbalance of the BLC reaches 0.55 dB at 2 GHz as shown in Fig. 3. In addition, since the dielectric loss ($\tan\delta = 0.02$) of the FR4 substrate degrades the effective radiation power, the relatively lower antenna gain is achieved than that of the MSA using the lossless substrate. The MSA fed by the CRLH QPS gives the antenna gain of 1.5 dBi at 2GHz, while the MSA fed by the BLC obtains the antenna gain of about 0.38 dBi.

4. Conclusions

In this paper, a CP MSA fed by the CRLH QPS is implemented and verified. A broadband QPS is developed in Section 2 using the CRLH TL. In order to illustrate the effectiveness of using the CRLH QPS as a feeding circuitry for the CP MSA, a CP MSA fed by the BLC is also fabricated, and then compared with the CP MSA fed by the CRLH QPS. The results shown in Section 3 demonstrate that the MSA fed by the QPS can effectively improve the RL and AR bandwidths, alleviate the main beam tilt of the radiation pattern, and enhance the antenna gain.

Acknowledgments

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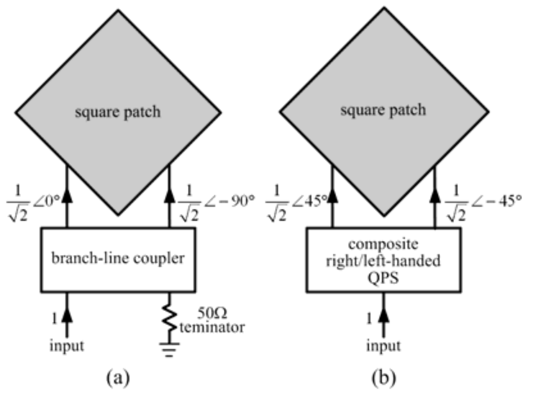

Fig. 1. Circular-polarized patch antenna fed by (a) brach-line coupler and (b) the metamaterial-based QPS.

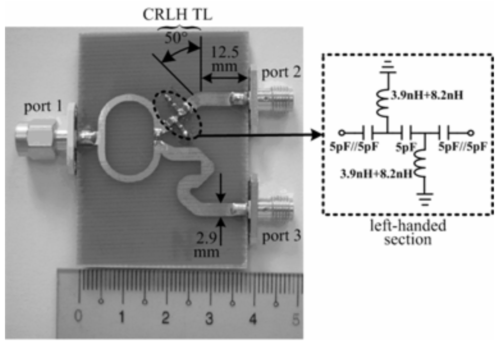

Fig. 2. Photograph of the developed CRLH quadrature power splitter.

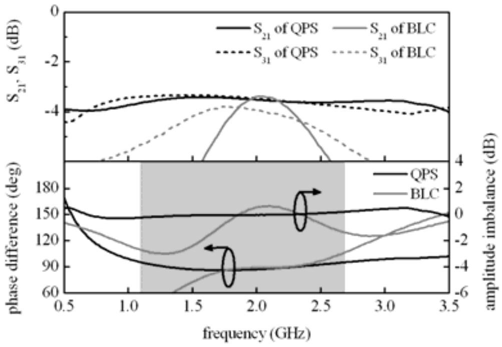

Fig. 3. Measured results of the phase difference and amplitude imbalance between two output ports of the QPS.

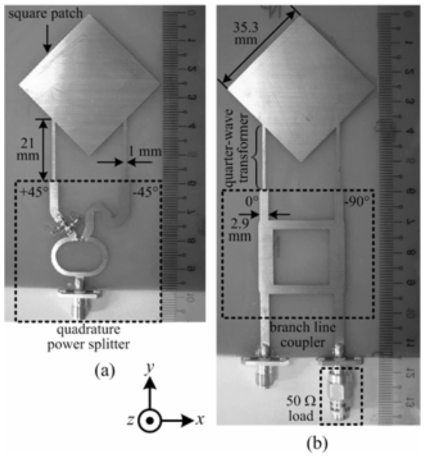

Fig. 4. The circularly-polarized microstrip antennas fed by the (a) CRLH QPS and (b) BLC.

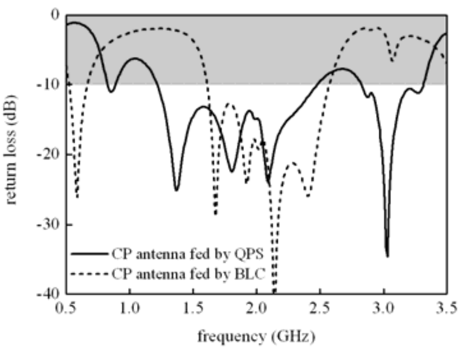

Fig. 5. Measured return losses of the CP MSAs fed by QPS and BLC.

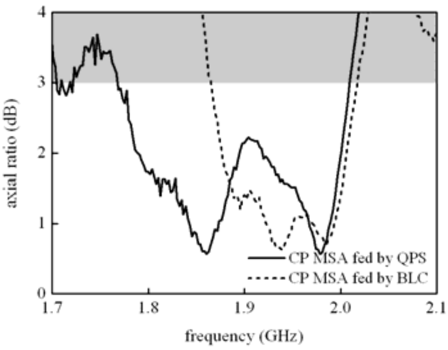

Fig. 6. Measured axial ratios of the CP MSAs fed by QPS and BLC.

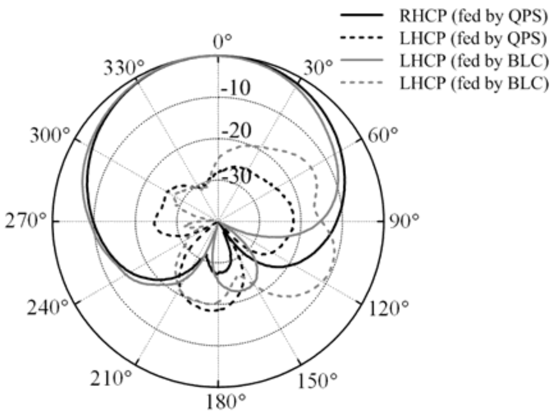

Fig. 7. Measured radiation patterns of the CP MSAs fed by QPS and BLC.