Metamaterial Based Patch Antenna with Broad Bandwidth and Simple Structures

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Abstract— A patch antenna based on metamaterials of composite split-ring-resonators (CSRRs) and strip gaps is presented. The antenna is constructed by using CSRR structures in forms of circular rings on the patch and employing strip gaps on the ground plane. The signal is fed by a common microstrip line that connects the patch and the input port. The antenna is based on a simple structure of an only one-layer substrate. Rogers RO4350 ($\varepsilon_r = 3.66$) is preferred as the dielectric material of the substrate. The antenna has a compact footprint that is only $0.408\lambda_0 \times 0.357\lambda_0$ at the lowest operating frequency of 1.7 GHz. The antenna could operate over two bands that are from 1.70 GHz to 2.98 GHz and from 3.99 GHz to 5.34 GHz. The CSRR and strip gaps are combined with the patch and ground to broaden its operating frequencies as well as to enhance its radiation performance via their coupling with the substrate in a different way. The measured impedance of the antenna shows a smooth variation in the vicinity of 50 Ω over the operating bands. This smooth variation enables the antenna to have broad bandwidth. Additionally, its radiation performance is kept favorable with a peak gain of 6.04 dB. The performances of the antenna were characterized computationally and verified experimentally. Good agreements between the simulations and measurements were observed convincing that the antenna could operate over wide bandwidths and radiate effectively with its simple structure and compact size. The presented design is favorable for its broadband as well as good radiation performance with a simple structure that is comprised of only one layer substrate. The antenna is promising for broadband applications that require the operating bands of WCDMA (1920–2170 MHz), WiMAX (2500–2690 MHz), Bluetooth (2400–2480 MHz) or Wibro (2300–2390 MHz).

1. INTRODUCTION

The metamaterial inspired patch antenna is a promising field of research for its favorable characteristics like multi-band operation, miniaturization, controllable radiation properties, etc.. Base on these advantages, metamaterial antennas have found their applications in a wide spectrum of industries, such as the WCDMA operating at 1.92–2.17 GHz, the WiMAX operating at 3.30–3.70 GHz, the Bluetooth operating at 2.40–2.48 GHz and the wireless broadband (Wibro) operating at 2.30–2.39 GHz [1, 2]. However, there are still several aspects of metamaterial antennas that need to be improved, such as their relatively complicated structures and low antenna gain.

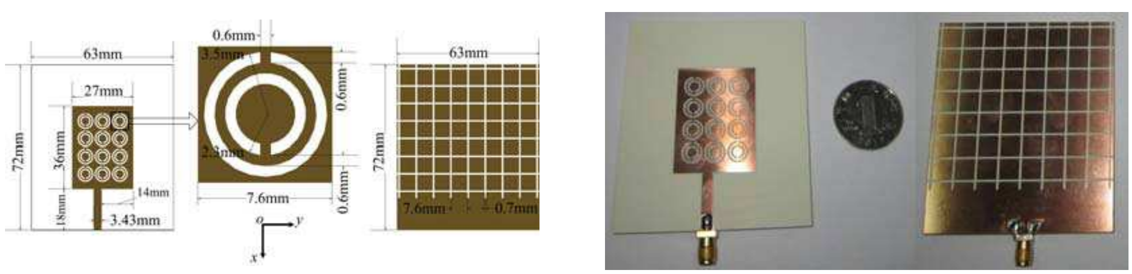
To improve the performance of metamaterial antennas, several novel structures of metamaterials, like the CSRR, the reactive impedance surface (RIS), the partial reflective surface (PRS), the mushroom like electromagnetic band-gap (EBG) structures etc., are emerging in recent years [3–7]. The CSRR structures etched on the patch along with the substrate and the ground plane can be modeled as a LC circuit with left-handed material (LHM) properties. They could resonant at lower frequencies leading to effects of miniaturization and multi-band operation [3]. In order to further enhance the gain and extend the bandwidth of metamaterial antennas, the RIS structure embedded in the substrate or the chiral patterns placed over the patch were proposed [4, 8]. In the recently published works on metamaterial antennas, a RIS like pattern was etched on the ground with a only one-layer substrate and metamaterial inspired structures were being etched on the patch of the same antenna [9–12]. This type of metamaterial inspired antennas gave out a good example of extending the bandwidth while keeping the radiation performance acceptable. Something worth to be improved might be that the operation frequencies of these antennas are relatively high (all above 3 GHz). This is not so favorable for applications at lower frequencies, like WCDMA, Bluetooth, or Wibro.

From a practical point of view, it might be desirable to shift the operating frequency of the antenna in [9] to a lower band while keeping its broadband and favorable radiation performances. In this letter, a metamaterial inspired antenna is presented with the desirable characteristics aforementioned. It was constructed by using the CSRR structure in forms of circular rings on the patch and employing the strip gaps on the ground plane. The antenna is broadband at lower frequencies and has a simple structure with a one-layer substrate. The radiation performances of the antenna are also kept desirable over its operating bands.

2. STRUCTURES AND RESULTS

The antenna based on LHM patterns is proposed. To achieve broadband and simple-structure properties, the configuration of the two antennas is based on an original one-layer patch antenna. It was constructed by employing CSRRs on the patch and etching strip gaps on the ground. The antenna is excited by a microstrip that connects the patch and the input port. The LHM patterns of CSRR and strip gaps are combined with the patch and ground to broaden its operating frequencies as well as enhance its radiation performance via their coupling with the substrate in a different way. The left-handed properties of these patterns have been verified in [12] and thus will not be further discussed. Their performances are characterized computationally and verified experimentally. Their broadband and simple-structure characteristics will be demonstrated as follows.

The structure of the antenna is shown in Fig. 1. In order to extend the operating frequencies, several metamaterial inspired patterns, the CSRRs, were arranged and etched on the patch. Another kind of metamaterial inspired structure, the strip gaps, was also employed on the ground plane to enhance the radiation performance as well as broaden the bandwidth of the antenna. It should be noted that there are some main differences between the antenna presented here and the one in [9]. Firstly, the dimensions of the patch were adjusted larger and then optimized so that the operating band could be shifted towards lower frequencies than those in [9] (above 5.3 GHz). In addition, the metamaterial structures employed on the patch are changed from periodic gaps to CSRRs of circular shapes. The unit cell of the CSRR is shown in Fig. 1(a). It is formed by two isolated concentric circular slots oppositely oriented. The fabricated antenna is shown in Fig. 1(c). The permittivity of the substrate is $\varepsilon_r = 3.66$ (Rogers RO4350). The thickness of the substrate is chosen to be as small as 1.524 mm. The overall antenna volume is only $0.408\lambda_0 \times 0.357\lambda_0 \times 0.0086\lambda_0$ at the lowest operating frequency of 1.7 GHz.



(a) Top view (b) Bottom view (c) Fabricated antenna

Figure 1: Structure of the antenna.

The reflection coefficient of the antenna is shown in Fig. 2. It can be seen that the two main bandwidths where the reflection coefficients are below -10 dB are located from 1.70 GHz to 2.98 GHz and from 3.99 GHz to 5.34 GHz. The corresponding two relative bandwidths are 75% at 1.70 GHz and 34% at 3.99 GHz, respectively. The reflection coefficient is also compared with that of the original antenna with the same dimensions excepting that the patch and ground are intact. The reflection coefficient performance of the proposed antenna is significantly improved according to Fig. 2. This demonstrates that the CSRRs and strip gaps employed here can affect the resonance of the antenna and extend its bandwidth by a large scale.

The impedance characteristics of the antenna are also shown in Fig. 3. According to the figure, there are several resonant frequencies where the imaginary part of the impedance is crossing zero. This has an effect of maintaining the real part of the impedance close to 50 Ω at the same frequencies. The operating bands of the metamaterial inspired antenna are thus successfully extended by introducing these resonant frequencies.

The radiation property of the antenna was measured in terms of its radiation patterns. Two frequencies, 1.8 GHz and 4.2 GHz, were randomly chosen to verify the radiation performance of the antenna. The three-dimensional gain patterns are shown in Fig. 4(a) and Fig. 4(b) in the dB scale. The patterns of the XOY and XOZ planes at 1.8 GHz and 4.2 GHz are also plotted in Fig. 4(c) and Fig. 4(d) in the dB scale, respectively. It should be noted that the antenna tends to radiate in

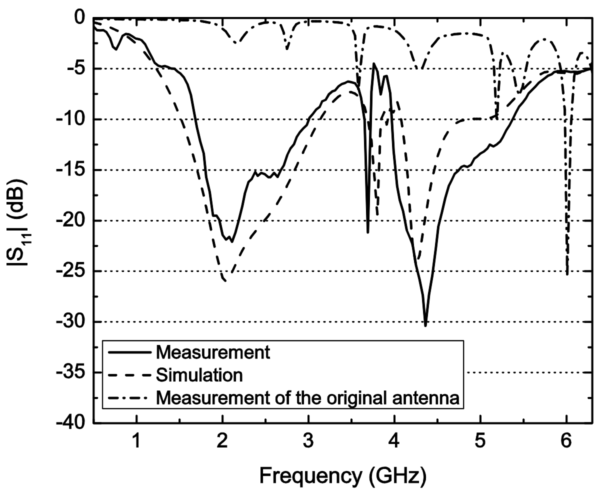


Figure 2: Reflection coefficients.

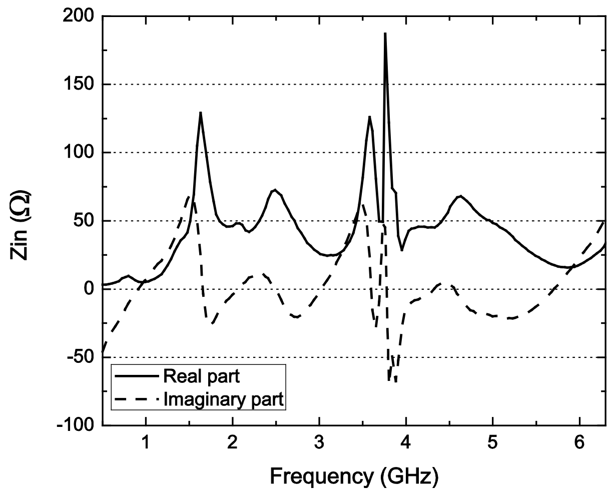
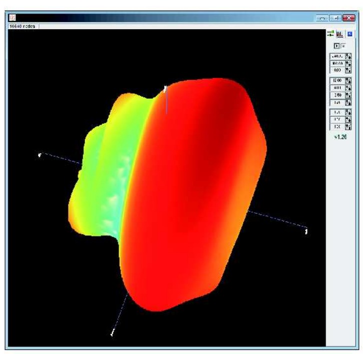
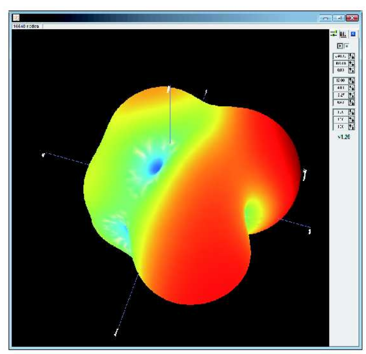


Figure 3: Measured impedance.

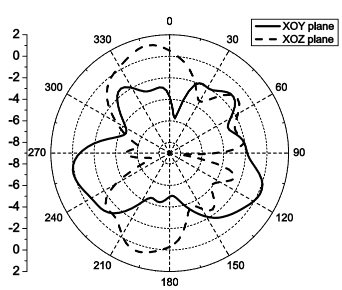
the vertical direction of the antenna at 1.8 GHz, which is similar to a dipole antenna that is placed along the x axis. The radiation pattern at 4.2 GHz has two main lobs in the XOY plane and one main lobe in the XOZ plane. This demonstrates that the metamaterial structure employed on the ground is capable of changing the radiation pattern of the patch. The position of the antenna could be adjusted so that the antenna is feasible for radiating or receiving signals in the desired direction.



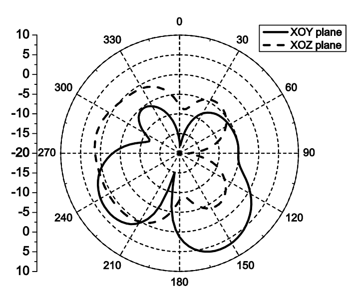
(a) 3D gain pattern at 1.8 GHz



(b) 3D gain pattern at 4.2 GHz



(c) *XOY* and *XOZ* planes at 1.8 GHz



(d) *XOY* and *XOZ* planes at 4.2 GHz

Figure 4: Measured radiation patterns.

The radiation gain of the antenna was simulated and shown in Fig. 5. It can be seen that the antenna has a peak gain of 6.04 dB at 3.58 GHz. In Fig. 5, it could also be observed that the gain is above 2 dB over the frequency range of 1.7 GHz–5.8 GHz. However, the gain value below 3 GHz is lower than that above 3 GHz. This gain degradation may be due to a stronger ohmic loss of the

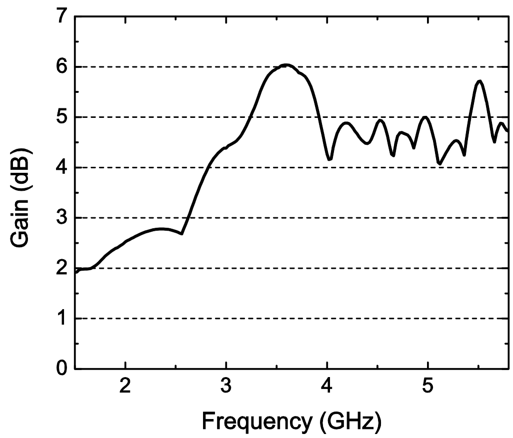


Figure 5: Simulated maximum gain.

antenna below 3 GHz. Nevertheless, Fig. 5 demonstrates that the antenna could radiate effectively over a wide band. This is quite favorable for such a patch antenna with broadband and simple structure characteristics.

3. CONCLUSION

The metamaterial inspired antenna with broadband and simple-structure characteristics is presented in this paper. The configuration of the antenna are based on the one-layer patch antenna with a compact footprint of $0.408\lambda_0 \times 0.357\lambda_0$ at the lowest operating frequency of 1.7 GHz. The CSRRs were employed on the patch and the strip gaps were etched on the ground. The dimension and substrate parameters of the antenna were adjusted and optimized to shift the operating frequencies towards relatively low bands that are from 1.70 GHz to 2.98 GHz and from 3.99 GHz to 5.34 GHz. The relative bandwidths of the antenna are 75% at 1.70 GHz and 34% at 3.99 GHz, respectively. The radiation gain is favorable over the operating bands with a simulated peak gain of 6.04 dB at 3.58 GHz. We find out that the antenna keeps the radiation performance favorable with such simple structures and compact sizes. The newly designed antenna is applicable for a wide spectrum of applications like WCDMA, WiMAX, Bluetooth and Wibro.

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