A Small Complementary Split Ring Resonator Loaded Circularly Polarized Patch Antenna

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Abstract— **Size reduction of patch antennas by loading them with complementary split ring resonators (CSRRs) has been recently demonstrated for linearly polarized radiators. This paper demonstrates that the design approach can be extended for circularly polarized radiation by employing multiple CSRRs under the patch to generate a 90^0 rotationally symmetric antenna structure. It is also shown that, in this antenna configuration, the radiation efficiency becomes strongly dependent on the size of the ground plane that carries the CSRR metallization. To further miniaturize the antenna size without affecting its radiation efficiency, we develop a new antenna structure in which the CSRRs are formed within a truncated ground plane loaded with vertical inductive pins. The antenna operates at 2.24GHz with peak broadside realized RHCP gain of 3dB, corresponding to 75% radiation efficiency.**

I. Introduction

Microstrip patch antennas are attractive for their robust performance, low profile, and relatively inexpensive manufacturing costs. However, patch antennas typically employ a large size that limits their use in various wireless applications. It is not therefore surprising to see a vast majority of miniaturization techniques being pursued for their size reduction. Commonly employed techniques such as shorting pins [1], slot based reactive loadings [2], and high contrast permittivity substrates [3] are known to result in low radiation efficiency and in some cases increased fabrication costs. To address these drawbacks, an alternative miniaturization technique utilizing a complementary split ring resonator (CSRR) under the patch antenna metallization was recently proposed [4]. In this paper, we extend this approach to realize a circularly polarized patch antenna by employing multiple CSRRs under the patch to generate a 90^0 rotationally symmetric antenna structure. We demonstrate that, in this antenna configuration, the radiation efficiency becomes strongly dependent on the size of the ground plane that carries the CSRR metallization. To further miniaturize the antenna size without affecting its radiation efficiency, we also develop a new antenna structure in which the CSRRs are formed within a truncated ground plane loaded with vertical inductive pins.

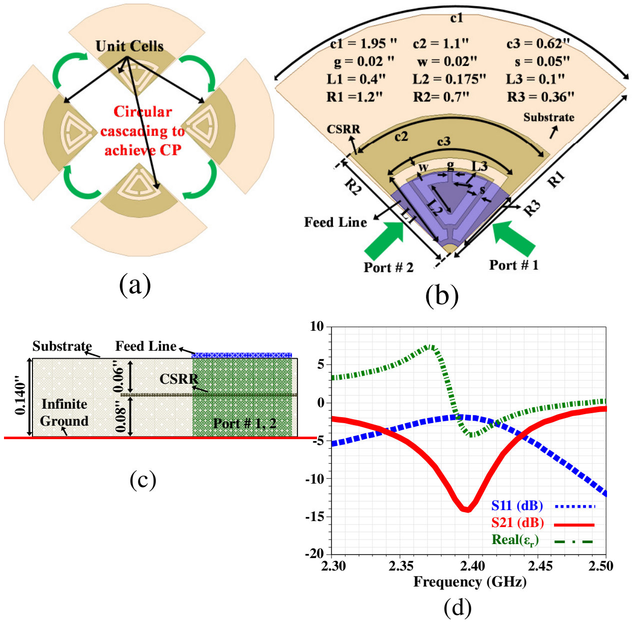


Fig. 1: (a) Circularly cascading 4 unit cells to form a 90^0 rotationally symmetric antenna structure; (b) CSRR unit cell layout with corresponding dimensions; (c) Substrate stack-up for the unit cell and antenna; (d) Simulated S-parameters and extracted permittivity (ε_r) of the unit cell.

II. CSRR Unit Cell Design

It is well known that an antenna exhibiting 90^0 rotationally symmetry can provide a circularly polarized radiation. To accomplish this, the proposed antenna layout consists of four CSRRs as shown in Fig. 1(a). Similar to the design approach suggested in [4], the dimensions of the unit cell were adjusted as in Fig. 1(b) to achieve a negative permittivity response at the desired frequency of 2.4GHz by employing parametric simulations (throughout this paper, Ansys HFSSv14 is utilized as the full wave EM modeller). Fig. 1(c) depicts the side view of the unit cell consisting of two substrate layers of Rogers RT/Duroid (ε_r =2.2, tanδ = 0.0009). The CSRR and patch metallizations were over the 80mil and 60mil thick substrates, respectively. In the antenna configuration, the top layer was also utilized to carry the feed line. The radii of the

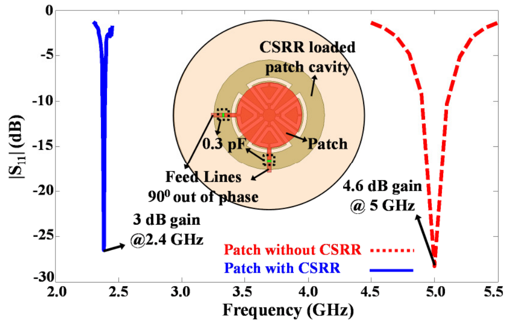


Fig. 2: Simulated return loss of patch antenna with and without the CSRRs.

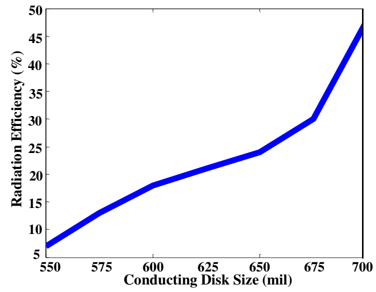
substrates were selected as1200mil and the substrates were backed by an infinite ground plane. In order to predict the resonance frequency, equivalent material parameters were extracted from the simulated S-parameters of the unit cell [5]. As shown in Fig. 1(d), a sharp stop band associated with the presence of negative permittivity was observed at the desired resonance frequency of 2.4GHz for the selected unit cell dimensions.

III. CSSR Loaded Circularly Polarized Patch Antenna

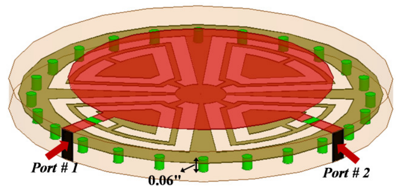
Fig. 2 depicts the complete CSRR loaded circularly polarized patch antenna obtained by circularly cascading the unit cells. As expected, a broadside radiation is observed at 2.4GHz that is associated with the unit cell resonances. The antenna was fed by two 50Ω microstrip lines that are excited by 90^0 out of phase to achieve the circularly polarized radiation. For impedance matching purposes, a series capacitance of 0.3pF was employed at the input feed lines. The traditional patch antenna formed on the top surface of the substrate stack-up resonates at 5GHz, implying about ~50% footprint miniaturization within the presence of CSRRs. However, there is an inherent drop in S11<-10dB bandwidth associated with this antenna miniaturization. Specifically, the bandwidth is 0.8% for the CSRR loaded patch antenna. It exhibits a simulated realized gain of 3 dB with 48% radiation efficiency. The antenna metallization footprint is 1400mil (λ_0/3.5 @ 2.4GHz) in diameter. If the ground plane size of the CSRR is ignored, the footprint is 880mil (λ_0/5.6 @ 2.4GHz) in diameter. Therefore, reducing the ground plane size is necessary for fully realizing the miniaturization advantages offered by this antenna design technique.

IV. Pin Loaded CSRRs For Reduced Substrate Size

Although the antenna developed in the previous section has a small footprint, its overall size is dominated by the size of the substrate and conducting disk around the CSRRs. Hence, it is important to understand the performance of the antenna when its substrate size is reduced down to merely fit the antenna metallization. To investigate this scenario, we first gradually reduced the radius of the conducting disk around the CSRRs from 700mils to 550mil in steps of 25mils without changing any other antenna dimensions. As shown in Fig. 3(a),



(a)

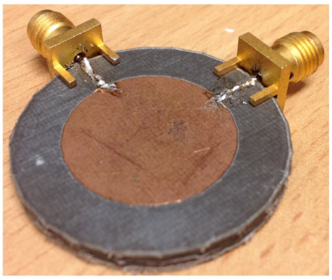


(b)

Fig. 3: (a) Effect of reducing the radius of the conducting disk around the CSRRs on radiation efficiency; (b) The reduced substrate size antenna configuration with pin loaded CSRRs

this modification is accompanied with a significant drop in radiation efficiency from 48% to 7%. Following this, we have also reduced down the radius of the substrate from 1200mil to 600mil (in steps of 100mil) while keeping the radius of the conducting disk fixed at 550mil. This modification degraded the radiation efficiency of the antenna further down to 5%. The drop in radiation efficiency due to the size reduction of the conducting disk and substrate can be attributed to increase in resonant current densities that in turn contribute to an enhanced ohmic loss. To overcome this, we have utilized a volumetric inductive loading approach that was presented in our recent work [6]. Fig. 3(b) depicts the antenna configuration with reduced conducting disk and substrate size when it is volumetrically loaded with pins that are 31mil in diameter and 60mil in length. The pins are electrically connected to the conducting disk and do not touch the ground plane. The simulated results demonstrate that the radiation efficiency of the pin loaded antenna increases from 7% to %75. Also, there is a drop in resonance frequency from 2.4GHz to 2.24GHz within the presence of the pins. The computed broadside realized peak gain is 3dB at 2.24GHz. In addition, the corresponding cross-polarization levels are well below -10dB below the peak gain, rendering axial ratio <1.5dB. Fig. 4 shows a fabricated antenna prototype that is measured to perform with -9dB return loss at 2.44GHz. The gain and radiation pattern measurement with improved matching is under progress and will be presented at conference. To estimate the amount of miniaturization achieved by reducing the size of the conducting disk and substrate, a conventional patch antenna with identical 550mil radius was modelled over the identical substrate material. Based on the simulated performance, the conventional patch antenna resonates at 4.8GHz. Hence, the pin loaded CSRRs

(a)



(b)

Fig. 4: Fabricated prototype of the pin loaded CSRR based circularly polarized antenna: (a) CSRR metallization layer; (b) complete assembly

lead to a 50% electrically small antenna as compared to its traditional counterpart.

V. CONCLUDING REMARKS

A small circularly polarized patch antenna is developed by employing multiple CSRRs under the patch to generate a 90^0 rotationally symmetric antenna structure. It was also shown that, in this antenna configuration, the radiation efficiency becomes strongly dependent on the size of the ground plane that carries the CSRR metallization. Further miniaturization without affecting the radiation efficiency is possible by resorting to CSRRs formed within a truncated ground plane loaded with vertical inductive pins. The operational principles of pin loading will be further discussed in the conference along with several experimental verifications.

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