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A COMPACT SPLIT RING RESONATOR ANTENNA FOR WIRELESS COMMUNICATION SYSTEMS

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Abstract—In this paper, we report a new design of a compact antenna based on the use of split ring resonator (SRR). The designed antenna consists of two SRRs, with the same geometrical parameters, printed symmetrically on both sides of the dielectric substrate. Excitation of the SRR element is performed by adequately placing the access microstrip lines with respect to the confinement plane of the split rings. The resonance frequency of the antenna is essentially defined by geometrical parameters of the SRR, which makes it suitable for a broad range of applications spanning from mobile terminals to WLAN and WPAN systems. The final result is low profile, and can be easily integrated with other RF front-end circuits in a PCB.

1. INTRODUCTION

The arrival of metamaterials, artificial media constructed from subwavelength periodic unit structures that are compactly crowded into an effective material, opens the way to observe some interesting properties that cannot be observed in natural materials, notably,

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negative refractive index for which the permittivity and permeability are simultaneously negative, and furthermore lead to potential applications, many of which were considered impossible in the past. These include, for example, perfect lensing [1], invisibility cloaking [2] and miniaturizing microwave devices [3].

One of the most important elements of metamaterials is the split ring resonator [4], proposed for the first time by Pendry et al. in 1999, to achieve a negative permeability in a certain frequency range, and later used for the first experimental realization of left-handed metamaterials [5]. According to [9], SRR can be excited by a time-varying external magnetic field component of normal direction of the resonator. This small particle can behaves as an LC resonator with a resonant frequency

$$\omega_0 = \sqrt{\frac{2}{L_s C_0}} \tag{1}$$

where C_0 is the per unit length capacitance between the inner and outer rings, L_s is the self-inductance of the SRR. The most attractive feature of this element is its ability to exhibit a quasi-static resonant frequency at wavelengths that are much larger than its own size. Thus, the application of SRR for designing small antennas for RF and wireless communication systems is of great interest. Yang et al. proposed a compact UWB using an individual split ring resonator [6] and Alici et al. used a split ring resonator excited by a monopole antenna [7]. In [8], a loaded split ring antenna over an artificial magnetic conductor (AMC) is introduced. However, the first proposed design looks like a ring antenna and not exploits the sub-wavelength feature of the SRR. Furthermore, the second design excites the quasi-static resonance but this configuration cannot be easily integrated with other RF front-end circuits in a PCB. In the third design [8] the authors use an AMC over the antenna to increase the gain from −1.24 dBi to 1.6 dBi. However, they use a complicated feeding technique which consists of a microstrip line over a tapered ground plane.

In this paper, a compact antenna based on split ring resonator with a simple feeding technique, was designed, fabricated, and measured. The proposed antenna consists of two split ring resonators printed symmetrically on both sides of the dielectric substrate and excited by a 50-Ω microstrip line. To have a good impedance matching, the microstrip line was placed at the edge of the SRR.

2. ANTENNA CONFIGURATION AND DESIGN

The geometry of the proposed antenna is shown in Figure 1, in which the unit of dimension is expressed in mm. This antenna is composed of two split ring resonators printed symmetrically on different sides of the dielectric substrate, which is an Arlon with permittivity $\varepsilon_r = 2.43$ and the thickness of the substrate is 0.49 mm. The antenna is fed by a paired microstrip line with a fixed width $w_f = 1.4\,\mathrm{mm}$ to achieve 50-Ω impedance. Notice that the bottom microstrip line acts a ground plane. The dimensions of the SRR used in this design, as shown in Figure 1(c), are: the outer radius is 3.5 mm, the widths of splits and the gap between inner and outer rings is 0.4 mm, and the width of metals is 1 mm. These parameters give a theoretical quasi-static resonance frequency of about 5 GHz, in accordance with the theory developed in [9]. The overall size of the antenna is $20 \times 20\,\mathrm{mm}^2$. In order to quantitatively study the proposed antenna characteristics, a frequency domain solver within the commercial software package CST Microwave Studio was used to obtain numerical results.

For the proposed antenna, the microstrip line position plays an important role in impedance matching. Indeed, in microstrip structures, SRR has to be close to microstrip line to guarantee efficient magnetic coupling. Thus, by carefully selecting the optimal position of the microstrip line placed at a distance g away from the SRR centre, a good impedance matching can be achieved. This optimal position was choosing through a number of simulations not show here. It is found that among the examined cases, the one with $g = 3.65\,\mathrm{mm}$ meet the 10-dB return loss requirements, thus a good impedance matching. The other detailed dimensions of the proposed antenna are shown in Figure 1.

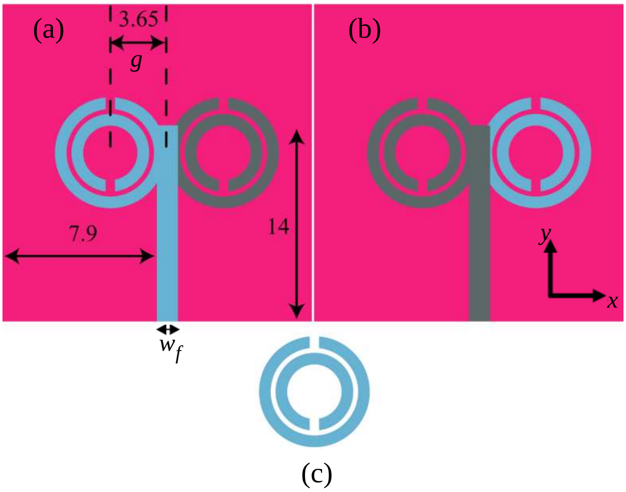


Figure 1. Configuration of the proposed antenna. (a) Top layer, (b) bottom layer, and (c) split ring resonator (SRR).

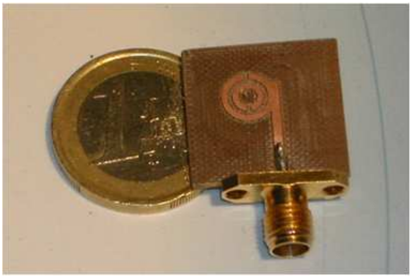


Figure 2. Photo of the constructed design prototype.

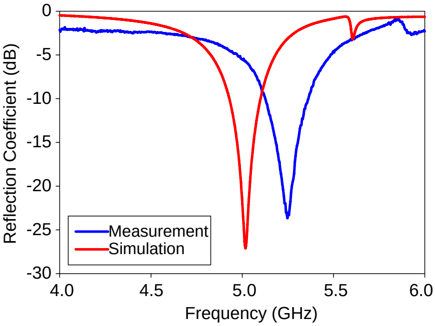


Figure 3. Simulated and measured transmission coefficient S_{11} of the proposed compact antenna.

3. SIMUALTED AND MEASURED RESULTS

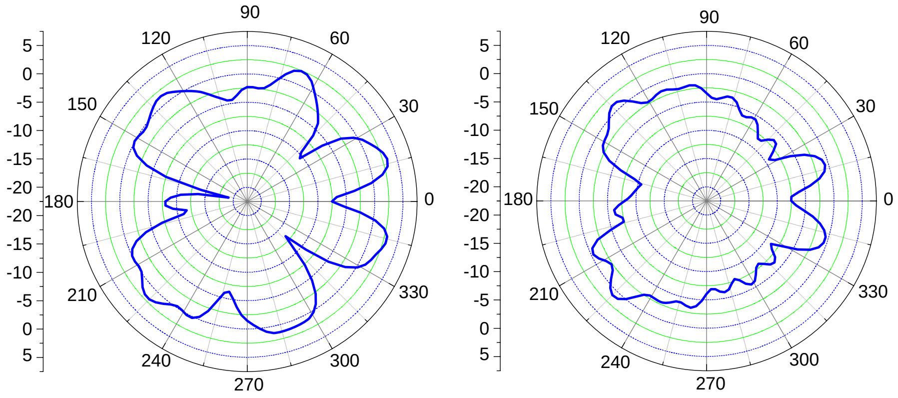
Based on the design and dimensions of the thereof described in the above paragraph, a prototype of the proposed antenna has been fabricated (see Figure 2) using an LPKF Protomat S100 mill/drill unit and experimentally analyzed using a Wiltron 360B vector analyzer to verify the obtained simulation results. The simulated and measured results of the compact proposed antenna are presented in Figure 3. It shows that the resonance frequency of the proposed antenna is very close to the quasi static resonance of the SRR. The difference between simulation and measurement results, in the order of 4% of the frequency of operation is given by tolerances in the dielectric permittivity of the substrate as well as by tolerances in the fabrication process.

The measured results agree well with the simulated predictions and show a bandwidth of 230 MHz ranging from 5.13 GHz to 5.36 GHz with a reflection coefficient less than −10 dB, which is equivalent to 4.38% fractional bandwidth. In order to realize the effect of the bottom structure which consists of a microstrip line and the SRR, we have performed other simulations (not shown here). We found that the quasi static resonance disappears when removing the bottom SRR, which means that it helps for the matching process.

It is worthwhile to mention that the resonance of the proposed antenna can be tuned by varying the geometrical parameters of the SRR. Therefore, the proposed antenna can be readily re-designed in order to meet easily different wireless communications system standards. Besides this merit, both individual split ring resonators can be designed with different geometrical parameters to have a dual band antenna. That is a topic for further study.

To demonstrate the performance of the proposed antenna in free space, its radiation patterns (2D and 3D) have been measured. These measurements are obtained using the reliable Satimo StarLab anechoic chamber which is a near-field measurement instrument. The measured far-field *E*-plane and *H*-plane radiation patterns at the resonance frequency are presented in Figure 4, whereas Figure 5 displays the measured 3D radiation pattern. It is observed that *E*-plane radiation pattern is seen to be stronger for most directions, with an overall radiation pattern compatible with mobile wireless devices.

A more insightful understanding of the compact SRR antenna behaviour can be obtained by analyzing the current density



(a) (b)

Figure 4. Measured 2-D radiation pattern at the resonance frequency. (a) *E*-plane and (b) *H*-plane.

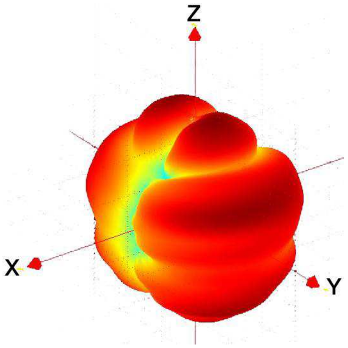


Figure 5. Measured 3-D radiation pattern at the resonance frequency.

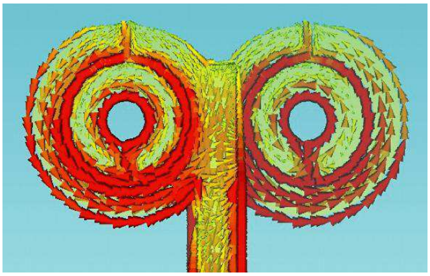
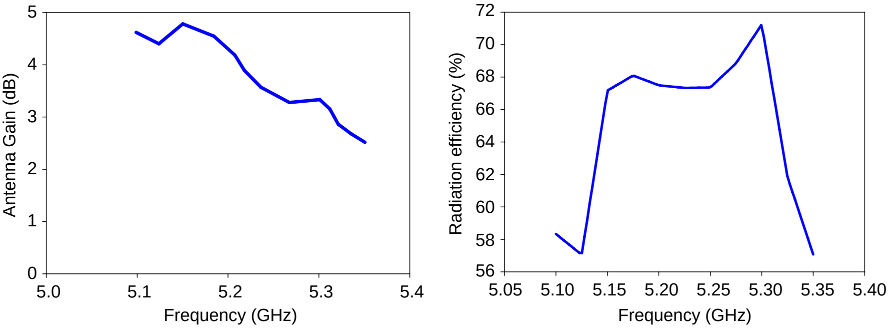


Figure 6. Simulated current distribution results of the proposed antenna: Direction of the current flow.



(a) (b)

Figure 7. Measured gain and radiation efficiency across the resonance frequency for the proposed antenna. (a) Measured gain and (b) measured radiation efficiency.

distribution on SRR. Figure 6 shows the simulated current distribution of the proposed SRR antenna, at the resonance frequency. It is clearly seen that the induced current density circulates in the same direction in both rings, having as result opposite charges at the facing sides of the outer and inner ring, thus a capacitor is formed between the rings and its capacitance is added to that given by the gap of the outer ring.

This suggests that the antenna size can be further miniaturized since the SRR resonance frequency can be tuned by increasing the capacitance between the inner and outer rings. This can be done either with physically altering the ring shape or by simply loading lumped elements. Note that this method has been proved by the authors in [7]. The measured peak gain around the resonance frequency is shown in Figure 7(a). The maximal measured gain is approximately 4.77 dB.

Finally, from the measured results shown in Figure 7(b), it is found that the radiation efficiency at the resonance frequency is around 71.25%. To the best of our knowledge, the obtained measured gain and radiation efficiency are much higher than the ones previously presented in [7, 8]. This is due to the fact that lumped elements are avoided in our design which can decrease the gain. Furthermore, the currents on upper and lower SRRs circulate in the same direction (Figure 6) which produce a strong radiation patterns.

4. CONCLUSIONS

In this work, a compact antenna based on split ring resonator and using a simple and effective feeding technique is presented. By properly choosing the location of the feed line, the proposed antenna achieved a bandwidth of 4.38%. Furthermore, the experiment shows that this antenna has a maximum gain peak of 4.77 dB and 71.25% radiation efficiency at resonance frequency. The proposed antenna can be designed to meet different wireless communication systems just by tuning the geometrical parameters of the SRR. It has a simple configuration, low profile, and can be easily integrated with other RF front-end circuits in a PCB, leading to a low cost competitive design.

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The authors wish to dedicate this work to the memory of Professor Mario Sorolla.

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