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A Metamaterial Based RF-Absorber Electronically Reconfigure for an Efficient DC-Low Power Generation

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***Abstract*—The number of split ring resonator (SRR) and complementary split ring resonator (CSRR) configurations which are considered as the popular metamaterial structures for energy harvesting applications have been investigated through the numerical computations. The study was performed for characterizing their electrical properties and the potential performance at certain application. The investigation results on the design of the double-T RF energy absorber exhibited an excellent electrical performance. The absorber could run in multiband frequencies and has large bandwidth. The desired absorber device has been optimized by altering the physical dimensions of the SRR and CSRR metamaterial structures. By etching the two SRR unit cells and six CSRR unit cells in the grounding area, the proposed absorber shows the great performance in terms of the return loss, gain, and bandwidth parameters. Also, the reconfigurable absorber design could be maximized for absorbing of the sustainable potential RF harvesting energy that both emitted from the licensed and unlicensed RF communication devices. The absorber covers the frequency spectra of GSM900 Band, GSM1800 Band, WiMAX Band, and ISM Band applications, respectively. This absorber is good for absorbing RF energy with a smaller physical size of 72.25% compared to the conventional designed one.**

***Keywords*—SRR, CSRR, energy harvesting, reconfigurable RF-absorber, multiband device**

I. INTRODUCTION

Nowadays, energy sources used such as hydropower, wind power, solar power, and other large energy sources have increased significantly in the society. Those energy sources become the main electrical power sources to supply for various modern technology applications. There is an interested profile of people demand to use mobile communication appliances anywhere and anytime. The utilization of the high power electrical sources for reliable charging of the low power consumption mobile device certainly inapplicable for a particular situation and location. Alternative electrical power production that is cheaper, flexible, compact, and not harmful to the environment is to use an energy harvesting system. Modification with this goal, many studies have been performed using potential environmental energy sources such as solar light/heat, environmental heat energy, electromagnetic waves, vibrations, and pressures. Those energy could be optimally converted into sufficient electrical energy for small power requirements [1].

Besides, the other main is to minimize dependence on battery and energy sources provided by the government. Then, this system does not require periodic maintenance so that it can function as an energy harvesting system for a long time as long as the energy source is available on site. In this paper, the double-T patch antenna method as an absorber with electromagnetic waves as its energy source has been investigated. Previously, energy harvesting has been done using electromagnetic waves [2,3]. Dimensions of patch antennas for energy harvesting applications which are generally still large are a challenge for researchers to be applied mobile. One technique to reduce the size of the antenna without reducing the results of the parameters obtained previously is the metamaterial.

The metamaterial is a composite structure that cannot be found in nature but can be engineered using existing structures so that it can improve the characteristics of electromagnetic waves [4]. Metamaterial has negative permittivity and permeability properties which are widely used in antenna design because it can miniaturize and work as a multiband antenna [5]. Metamaterial structures that are popular today especially for energy harvesting applications are split ring resonator (SRR) and complementary split ring resonator (CSRR). Patch antennas with SRR and CSRR structures can improve antenna performance characteristics such as bandwidth, gain, antenna, and other radiation patterns [6,7,8]. To maximize the RF absorber system, the authors reconfigured the proposed antenna using RF-PIN diodes. This technique can change the antenna's working frequency range and antenna radiation direction [9].

In this paper, antenna design and structure is optimized by comparing the performance of conventional antennas. The SRR and CSRR metamaterial structures are optimized to work at antenna operating frequencies. Then, the antenna performance analysis is proposed using the SRR and CSRR metamaterial structures and reconfigurable designs, respectively. The performance parameters of return loss, gain, and bandwidth shows good results for the proposed application. The antenna design and metamaterial structure have been investigated using CST Microwave Studio 2018 software.

II. ANTENNA DESIGN AND STRUCTURE

In this section, the optimization of the dimensions of the double-T microstrip antenna is carried out to work at the 2.4 GHz operating frequency as the reference antenna of the proposed antenna design. The width and length of the antenna dimensions are 193.5 mm and 129 mm with a thickness of 35µm copper material. The patch of the double-T antenna is simulated using FR-4 substrate ($\varepsilon_r = 4.5$, and $\tan \delta = 0.02$) with a thickness of 1.6 mm as shown in figure 1. This double-T

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patch antenna uses a feed line technique with 50Ω impedance normalization and dimensions the width and length of the feed line are 3,008 mm and 67 mm, respectively.

The dimensions of conventional antennas can be seen in Table 1. Simulation results of the return loss (S_{11} <-10 dB) of conventional antennas can be seen in figure 2. These antennas can work at frequencies 0.9 GHz (0.84 - 0.97 GHz) and 2.4 GHz (2.39 - 2.51 GHz) with a gain of 1.8 and 4, respectively.

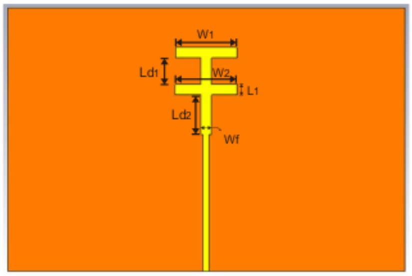

Fig. 1. Conventional antenna design

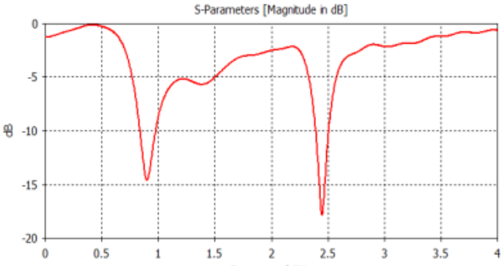

Fig. 2. S_{11} of the conventional antenna operates at 0.9 GHz and 2.4 GHz

TABLE I. VALUE OF THE CONVENTIONAL ANTENNA DIMENSIONS

Parameter	W_1	W_2	W_f	L_1	L_{d1}	L_{d2}
Value (mm)	29.8	30.2	5.2	5.2	12.9	19.4

The SRR and CSRR metamaterial structures on the antenna ground side are optimized by equations (1) - (5) to operation same frequency as conventional antennas which are 2.4 GHz [10].

$$L_{SRR} = \frac{\mu_0}{2}\frac{l_{savg}}{4} 4.86\left(ln\frac{0.98}{\rho} + 1.84\rho\right) \tag{1}$$

$$\rho = \left[\frac{(N-1)(d+g_3)}{[l_{ring} - (N-1)(d+g_3)]}\right] \tag{2}$$

$$C_{SRR} = \frac{N-1}{2}[2l_{ring} - (2N-1)(d+g_3)]C_o \tag{3}$$

$$C_o = \varepsilon_{ro}\varepsilon_r(h,d,g_3)\frac{K\sqrt{(1-k_1^2)}}{K(k_1)} \tag{4}$$

$$f_r = \frac{1}{2\pi\sqrt{L_{SRR}C_{SRR}}} \tag{5}$$

Where μ_0 is the permeability of free space $(4\pi\, x\, 10^{-7})$, $l_{savg} = 4[l_{ring} - (N-1)(d+g_3)]$, and $k_1 = \left[\frac{g_3/2}{(d+g_3/2)}\right]$. Then, N is the number of rings, d is the width of the ring, l_{ring} is the length of the inner ring, g_3 is the space between the rings, ε_o dielectric value of the constant air, and k_1 is the elliptic integral. Using the equation, the optimization of the SRR and CSRR structures obtained the dimension values in figure 3(a) and figure 3(b) as well as Table 2.

TABLE II. OPTIMIZATION OF SRR AND CSRR METAMATERIAL STRUCTURE DIMENSIONS

Parameter	**Value of metamaterial structure (mm)**	
	SRR	***CSRR***
W	8	15
f	0.5	1
s	0.8	2.5
g	0.5	0.5

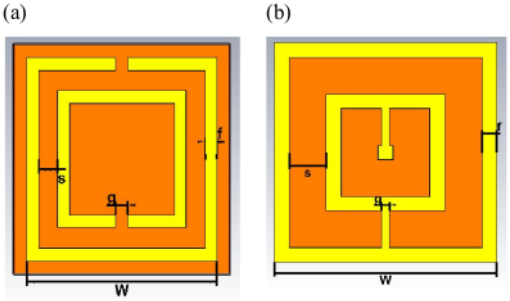

Fig. 3. Metamaterial structure (a) SRR, and (b) CSRR

III. RESULT AND DISCUSSIONS

In this section, optimization of the antenna dimensions after the metamaterial structure is added to the antenna ground plane. The proposed antenna design can be seen in figure 4. The shape and dimensions of the patch are made almost similar to conventional antennas so that performance comparisons can be seen between the two. However, the size of the antenna after the addition of the metamaterial structure decreases to 72.25% from the size of the conventional antenna without changing the desired performance parameters ie width and length respectively 41.63 mm and 129 mm. Two SRR structures and six CSRR structures are placed in the proposed ground antenna plane. The proposed antenna design can be seen in figure 4. The parameters analyzed are return loss, bandwidth and gain of the proposed antenna. The S_{11} compared of proposed antenna can be seen in figure 5.

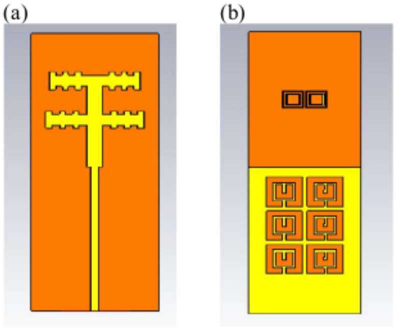

Fig. 4. Proposed antenna (a) Top view, and (b) Bottom view

A. Proposed Antenna with SRR and CSRR Structure

In this section, the antenna performance analyzed is by placing the SRR and CSRR structures in the ground plane (see Figure 4). This antenna can operates in three frequency ranges 0.88 - 1.05 GHz (BW = 0.17 GHz), 2.42 - 2.56 GHz (BW = 0.14 GHz) and 2.76 - 2.8 GHz (BW = 0.04 GHz). The gain of this antenna at the working frequency of 0.915, 2.4 and 2.77 is 1.45, 1.7 and 0.7, respectively.

B. Proposed Antenna Without CSRR

In this section, the antenna performance analyzed is by removing the CSRR structure. This antenna operates in two frequency ranges 0.85 - 1.06 GHz (BW = 0.21 GHz), and 2.16 - 2.24 GHz (BW = 0.08 GHz). The gain of this antenna at the working frequency of 0.915 and 2.5 respectively is 1.56 and 2.62.

C. Proposed Antenna Without SRR

In this section, the antenna performance analyzed is by removing the SRR structure and the CSRR structure remaining in the ground plane. This antenna operates in two frequency ranges namely 0.88 - 1.05 GHz (BW = 0.17 GHz), and 2.35 - 2.56 GHz (BW = 0.21 GHz). The gain of this antenna at the working frequency of 0.915 and 2.5 respectively is 1.43 and 2.4.

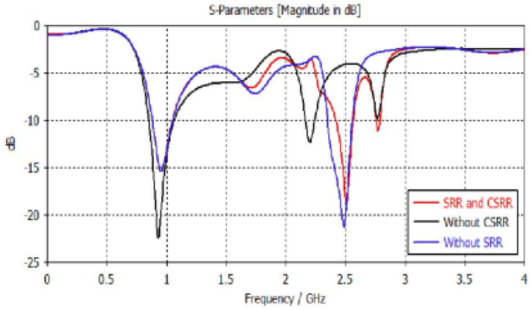

Fig. 5. The S_{11} compared of proposed antenna

D. Reconfigurable Antenna Design

In this section, to maximize the absorbance of electromagnetic waves around, the reconfigurable technique is performed. Three conditions of the antenna have been investigated namely antenna with SRR and CSRR structure, antenna without CSRR structure, and antenna without SRR structure. The reconfigurable technique uses RF-PIN diode on the side of the antenna patch as shown in figure 6. This RF-PIN diode is adjusted until two ON and OFF conditions occur.

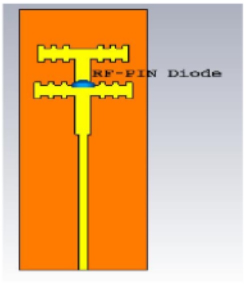

Fig. 6. The reconfigurable antenna design uses RF-PIN diode with ON and OFF conditions

1) Antenna with SRR and CSRR structure: In figure 7, the working frequency range of the antenna switches during OFF conditions, namely 1.83 - 2.07 GHz (BW = 0.24 GHz) and 2.42 - 2.56 GHz (BW = 0.14 GHz).

2) Antenna without CSRR structure: In figure 8, the working frequency range of the antenna switches during OFF conditions ie 1.02 - 1.3 GHz (BW = 0.28 GHz) and 1.67 - 1.99 GHz (BW = 0.32 GHz).

3) Antenna without SRR structure: In figure 9, the working frequency range of the antenna switches during OFF conditions, namely 1.83 - 2.07 GHz (BW = 0.24 GHz) and 2.42 - 2.56 GHz (BW = 0.14 GHz).

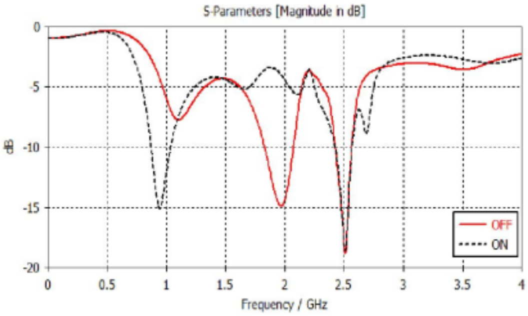

Fig. 7. The S_{11} of reconfigurable proposed antenna with SRR and CSRR structure

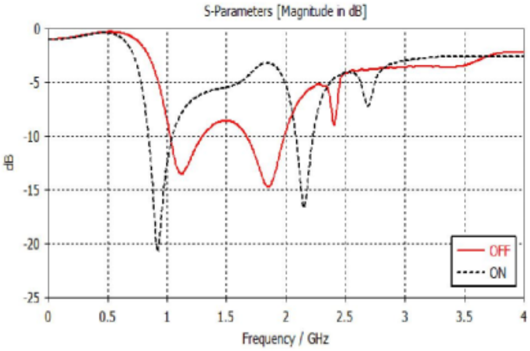

Fig. 8. The S_{11} of reconfigurable proposed antenna without CSRR structure

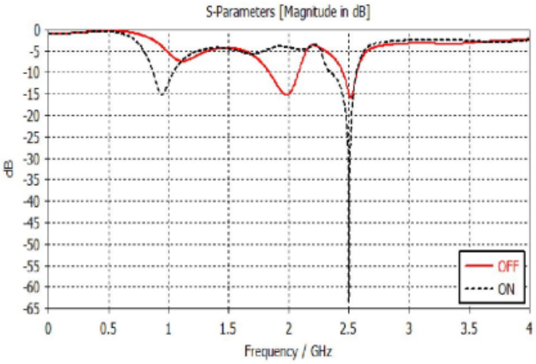

Fig. 9. The S_{11} of reconfigurable proposed antenna without SRR structure

IV. CONCLUSIONS

Optimization and numerical computation of both conventional and proposed antennas (to act as the absorber parts), as well as the SRR and CSRR metamaterial structures, have been carried out. The number of SRR metamaterial structures as many as 2 unit cells and CSRR as many as 6 unit cells show good performance with an increase in the value of return loss, gain, and bandwidth and can be applied as an RF absorber. Besides, this antenna is more compact 72.25% than the size of conventional antennas so that it is easily applied as an RF absorber for mobile applications. Reconfigurable techniques to maximize the energy of electromagnetic waves can be used as a source of electricity, showing good results too. Thus, the antenna system is enable to absorb electromagnetic waves from a certain direction and frequency to obtain the maximum power. In future work, this antenna can be fabricated and integrated with rectifier and multiplier systems so that the output of energy harvesting can be maximized.

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