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RF Energy Harvesting Study Using Various Metamaterial Patch Structure

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ABSTRACT

The E-field absorbance performance of various metamaterial absorber structure is presented. The study started from the simulation of various design patch of metamaterial absorber. The performances are measured from the reflection coefficient, percentage of absorption, value of E-field and the surface current for circle, square and hexagon patch design of metamaterial absorber. From the simulation, it is shown that the circle patch design shows the most reliable design for harvest energy with the absorption of 99.85% and highest E-field concentration of 2.07×10^5 V/m.

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1. INTRODUCTION

The In the past three decades, there are many wireless systems have been developed and widely used around the world. The wireless technology growing rapidly so that child now days already familiar with the device and application. There are examples of wireless technology such as cellular mobile radio, Wi-Fi systems, radio and television broadcasting systems [1]. These technologies required to radiate electromagnetic waves/energy into the air but a large amount of the energy is actually wasted [2]. For example, from 1 Watt energy transmit for television broadcasting, only 0.3 Watt power needed for a receiver to received the information. Thus, a large amount of energy is wasting around us. Thus the how to harvest and recycle electromagnetic wireless energy has become an increasingly interesting topic.

In RF energy harvesting field, a rectenna are widely used to capture RF energy. Rectenna is the combination of rectifier and antenna. The wireless energy is collected by the antenna and it is attached to rectifier diodes through a filter and matching circuit. When antenna received the wireless energy, the rectifying circuit will convert the energy into DC power. The low-pass filter will match the load with the rectifier and block the high-order harmonics generated by the diode in order to achieve high energy conversion efficiency which is the most important parameter of such a device [3].

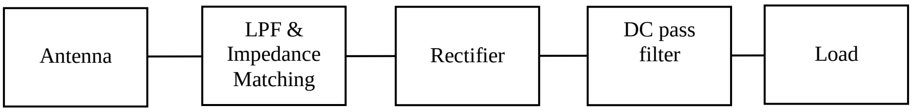


Figure 1. Block diagram of a rectenna with diode

Since the rectenna are commonly used as a technique to capture the RF energy, we proposed to use a metamaterial absorber as a platform to harvest the energy. The metamaterial absorber can absorb almost 100% of radiated frequency [4]. Once the radiated frequency through the metamaterial structure, the radiate energy trapped and disapoear at the substrate [5]. The idea is to harvest the energy that trapped inside the substrate.

There are several classes in metamaterial. In this study, we proposed the Split Ring Resonator (SRR) as a platform to harvest an energy. SRR is part of Single Negative Metamaterial [6]-[8]. In antenna field, one of the SRR usages is to enhance the performance of the patch antenna. The characteristic that SRR have to absorbs the electromagnetic wave make the propagation of electromagnetic wave more directional to the antenna. Since the energy was totally absorbing in the structure and disappear, the research comes out with the objective to harvest trapped energy inside the structure. This paper showed the process of identifying the performance and properties of absorber metamaterial structure.

2. RESEARCH METHOD

The research starts from the study the metamaterial performance of various design. The circle, square and hexagon shape of a patch has been proposed in this study. The designed frequency is decided at 1.3 GHz for all three designs. The operating frequency of 1.3GHz was decided due to the limitation of current measurement equipment. Current oscilloscope has a maximum measured frequency at 1.5 GHz. This oscilloscope used to measure the trapped energy between the gap of the structure which is identified has the highest energy trapped. The proposed of three design of patch is to determine either the shape of a patch will influence the performance of absorption the E-field.

The design start from following the expression derived for resonant frequency by Pendry et al as follow [9]:

$$\omega_r = (3d/\pi^2 r)^{1/2}(c/r) \quad (1)$$

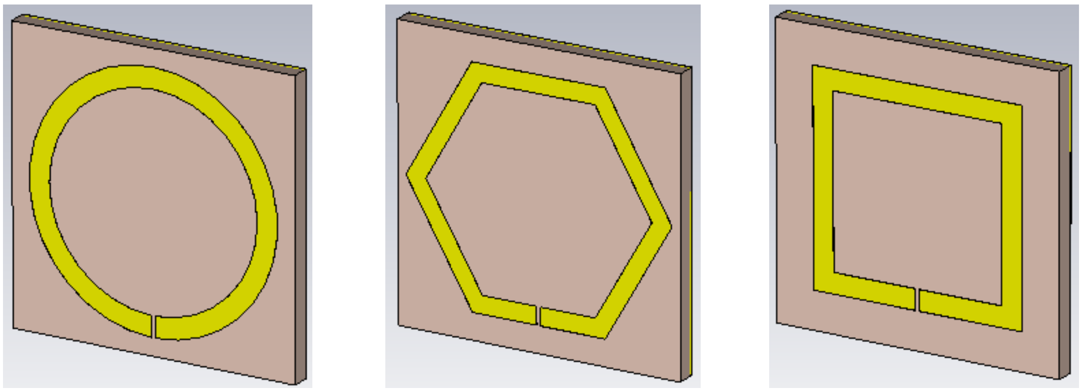
Where

$$d = r_{i1} - r_{e2} \quad (2)$$

$$r = (r_{i1} + r_{e2})/2 \quad (3)$$

The designed for the circle shape of split ring resonator by referring above equation. After adding the parameter value and get the dimension, the structures are designed and simulated by using CST software. The configuration of proposed structure based on metamaterial is shown in Figure 2. Figure 2(a) shows the proposed circle structure design, Figure 2(b) is proposed for hexagon design and Figure 2(c) for the proposed square design. The dielectric board is FR-4 lossy with epsilon 4.7 with thickness 4.8mm. The copper patch and ground plane thickness are 0.035mm. The simulation focus on the reflection phase, current surface and electric field (E-field) concentration result. All these results are compared to all design and to find which design will give the best outcome to harvest the trapped electromagnetic wave.

All three metamaterial designs already run and simulated by using CST software. To get the performance of a metamaterial absorber, the absorption can be calculated by using this formula; $A(\omega) = 1 - T(\omega) - R(\omega)$ where A(ω), T(ω) and R(ω) are the frequency dependent parameters which are absorbance, transmittance and reflectance respectively [10]. To obtain the perfect absorber, A(ω) supposedly equal to 1. Unfortunately, practically, this value impossible to obtain zero for both transmittance and reflectance. In metamaterial absorber field, researcher always assumes the transmittance are equally to zero, which there is no signal through pass the antenna because of the metal ground plane. The reflectance and transmittance value can be obtained from the simulation result. The relationship of the equation can be given by $R = |S11|^2$ and $T = |S21|^2$. Therefore, the absorption can be defined as $A(\omega) = 1 - |S11|^2 - |S21|^2$.



(a) (b) (c)

Figure 2. The configuration of metamaterial structure based on metamaterial (a) circle (b) hexagon and (c) square shape

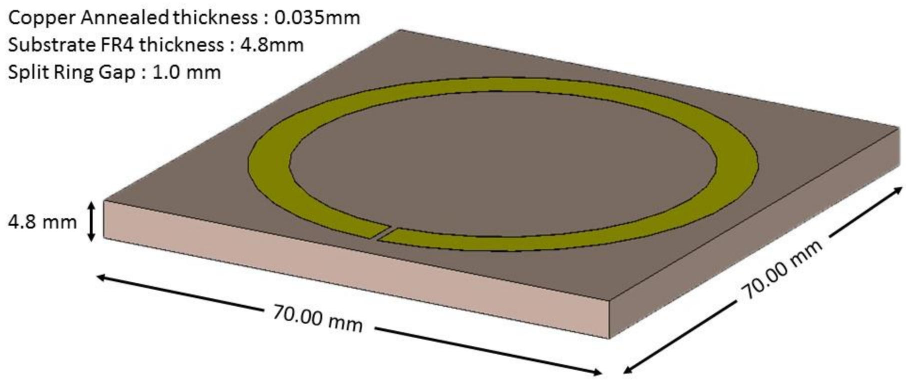
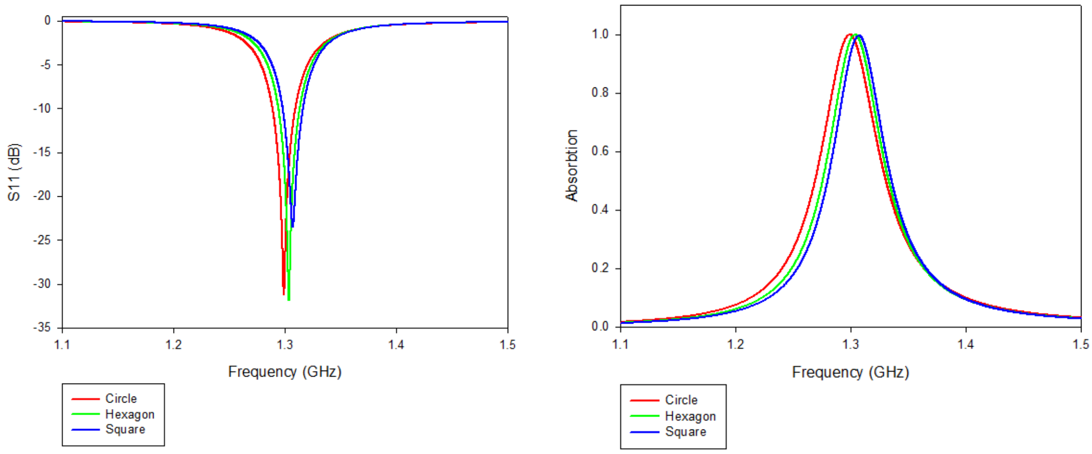


Figure 3. Dimension of Split Ring Resonator

3. RESULTS AND ANALYSIS

As we can see the Figure 4(a) show the reflection coefficient for each structure. At 1.3GHz, all three structure have a good result of the reflection coefficient and it's operating well to absorb the 1.3GHz signal. To get the result, the value of S21 is equal to zero for all frequency range between 1.1GHz to 1.5GHz due to the full ground plane effect.

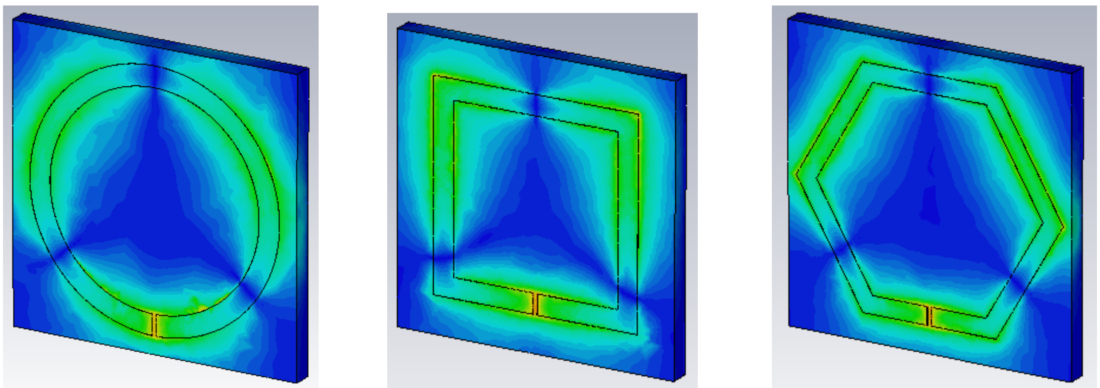
The Figure 4(b) shows the result of absorption for all metamaterial patch design. At 1.3GHz, the circle patch showed the highest absorption percentage, which is 99.85%, followed by the hexagon and square patch metamaterial, 98.26% and 93.38% respectively. By referring to absorption result, the circle patch metamaterial has absorbed the highest amount of electromagnetic wave, contribute to the highest energy trapped inside the structure.



(a) (b)

Figure 4. The result of (a) reflection coefficient and (b) absorption for three designs

The performance of metamaterial absorber continued studied from the electric field perspective. Figure 5 below showed the electric field concentration at operating frequency 1.3GHz. The electric field clearly concentrates at the gap of each structure. The E-field density for all the patch design are more likely the same if compared to the highest amplitude phase but it's different to their values. Circle patch absorber is shown the highest value of the electric field which is 2.07 × 10^5 V/m, following by hexagon patch design and square patch design, which both are 1.27 × 10^5 V/m and 1.07 × 10^5 V/m respectively. On E-field side, the circle patch design gives the highest value of E-field inside the structure.

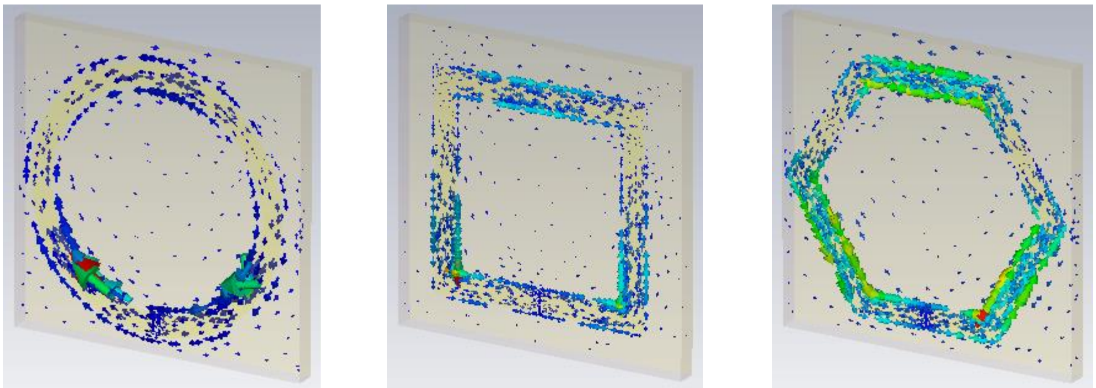


(a) (b) (c)

Figure 5. Electric field concentration at operating frequency 1.3GHz for (a) circle, (b) square and (c)hexagon patch design antenna

Figure 6 shows the current distribution for simulated metamaterial absorber with various patch design. To harvest the trapped electromagnetic energy inside the absorber, the concentration of surface current at one point is the most reliable. The concept is to make all the energy focus only one area, which here at the split / gap area. When all the energy concentrated in one area, this area is the peak energy and it is the best location to harvest energy.

As shown in Figure 6(a), the surface current more concentrate at one point only, make it the design is more reliable to harvest energy. For hexagon patch design as shown in Figure 6(b), the absorption electromagnetic wave has several places of surface current density. This condition makes the trapped energy will more disappear in several areas due to the dielectric losses or known as volume losses. Hexagon patch design also showed the same characteristic same as square, which gives the lower value of trapped energy inside the structure.



(a) (b) (c)

Figure 6. Surface current distribution at operating frequency 1.3GHz for (a) circle, (b) square and (c) hexagon patch design antenna

This section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2],[5]. The discussion can be made in several sub-chapters.

4. CONCLUSION

The simulation result showed that the circle patch antenna has the highest reliability to harvest energy. With the absorption of 99.85% and have reflection coefficient at -32dB, it copes with other two patch designs, square and hexagon. The research will continue by fabricating the circle patch antenna and measure the performance of the structure.

Table 1. Comparison of simulation for all three patch design for metamaterial absorber

	Circle	Hexagon	Square
Reflection Coefficient	-32 dB	-33 dB	-25 dB
Absorption	99.85 %	98.26 %	93.38 %
Electric Field	2.07×10^5 V/m	1.27×10^5 V/m	1.07×10^5 V/m

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