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Bandwidth Enhancement at Microstrip Patch Antenna using modified EC-SRR Structures

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Abstract

The research explores the effect of modified Edge Couple Split Ring Resonator (EC-SRR) on the wideband microstrip patch antenna. Firstly, there are three different size of the EC-SRR, namely larger EC-SRR, normal EC-SRR and smaller EC-SRR had been structured first before located into the patch antenna. After that, a simple microstrip patch antenna of Design A had been simulated using the CST Microwave Studio software. Then, the addition of different number of modified EC-SRR on the side and above side of the patch. Beside the basic design of Design A, three different stages of addition of SRR are considered in this research. Design B, Design C and Design D consist of SRR addition at the edges, sides and above of patch. The wideband antenna resonates between 2.08 GHz to 3.45 GHz of frequency with - 24.271 dB of return loss at resonant frequency of 3.11 GHz. At 2.4 GHz of WLAN application, the return loss is - 15.154 dB. Design D shows the increment of the bandwidth compare all designs with 1.372 GHz (from 2.077 GHz 3.449 GHz) compare with Design A with only 0.645 GHz (from 2.307 GHz to 2.952 GHz).

Keywords: split ring resonator, bandwidth enhancement, microstrip patch antenna, Wireless LAN, antenna gain, return loss

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1. Introduction

In current telecommunication situation, the antenna with wideband or multi-band effect are important for cater many users' demands. This is because of problem of size and the cost of production by using smaller substrate. For example, the important applications are like Wireless Local Area Network (WLAN) at 2.4 GHz [1] or 5.2 GHz and Worldwide Interoperability for Microwave Access (WiMAX) at 5.8 GHz [2] of frequency.

The printed patch antenna is a most used antenna types that applies the split ring resonator structure on its design. Printed antennas have become the preferred and popular solution in recent telecommunication systems.

In the recent finding, several enhanced methods are applied to create wideband or multiband effect to the patch antenna design. The first bandwidth enhancement method is single-feed compact cross-aperture coupled for circularly polarized microstrip antenna (CPMA), stated in [3]. This method effect to miniaturized size of the antenna (50mm × 50mm × 6.8mm) while improve the bandwidth to achieve between 1.88GHz and 2.11 GHz.

Yuan in his paper [4] had been achieved a wideband of 1.1 GHz and high-gain effect at 13 GHz of resonant frequency from the metamaterial added to the microstrip patch antenna. Wong in [5] had proposed a monopolar patch antenna that using a V-shaped slot for car-to-car (C2C) and wireless local area network for increase the bandwidth performance in the range between 4.82 GHz and

6.67 GHz of resonant frequencies.

In other paper, the stacked H-shaped shaped structure is effected to improve the gain and the bandwidth of the proposed antenna performance. In Liu paper [6], it stated that the bandwidth is enhanced from 0.65 % to 10.15 % while the gain is improved to 20 dB.

Xu in his paper [7] had been combine several techniques to widening the bandwidth of the proposed omnidirectional circularly polarized patch antenna. In his work, the antenna are designs with the combination method of L-shaped slots, a ground plane loaded a metal sleeve and a set of conductive vias. The bandwidth is improved in the range between 2.29 GHz and 2.51 GHz in the azimuthal plane. The other works on enhancement bandwidth performance in these several research papers [8-12].

The metamaterial or left-handed material (LHM) construction design is a non-natural material that can be originate in the nature or it is non-existence in actual environment. The term 'meta' is initiated from the Greek language of "μετα" that means beyond.

In detail, this split ring resonator is a fragment of the metamaterial structure has been a widespread topic for revisions and between researchers after year of 2000. In microwave investigation, the structure of split ring resonator has been practical in many designs. Beside antenna, this structure had been found in microwave filter, oscillator, amplifier, frequency selective surface (FSS), microwave absorber, and many others design.

Split ring resonator (SRR) structure is one the best candidate that can use in this difficulty, example in these

several papers [13-15]. The SRR is one of the popular metamaterial or left-handed material (LHM) beside electromagnetics band gap (EBG), photonic band gap (PBG), or artificial magnetic conductor (AMC) structure. This SRR also had probably to reduce the dimension of microstrip patch antenna. For example, in [16-18], the size reduction of the antenna after addition of SRR is 35 %, 21.9 % and 47 %, respectively.

Right now, it has many split ring resonator structures that have been use by numerous researchers such as edge couple split ring resonator (EC-SRR), broadside couple split ring resonator (BC-SRR), nonbianisotropic couple split ring resonator (NC-SRR), spiral resonator and others. Edge couple split ring resonator (EC-SRR) or sometimes called as double split ring resonator (D-SRR) is a most used split ring resonator structure that has been researched and designed. This edge couple split ring resonator structure consists of two similar split rings that are coupled to create strong distributed capacitance in the region between the rings, examples in [19-20]. The small gap between rings effect to produce a high capacitance value, which could reduce the value the resonance frequency of the antenna design. Ramakrishna in his paper stated that, the big gap in each ring evades the current from flowing around in a single ring, and the circuit is completed across the small capacitive gap between the two rings [21].

Pendry [22-23] introduced to have developed microstructured artificial materials exhibiting strange magnetic properties. In the theory by Veselago, this SRR design also is used to produce the negative dielectric constant (permittivity) and negative permeability [24]. From the previous work, it also have the capability to improve the gain performance, such as in this paper of [25-26].

Figure 1 shows the SRR structure and its equivalent circuit with basic SRR and compare with the complementary SRR structure.

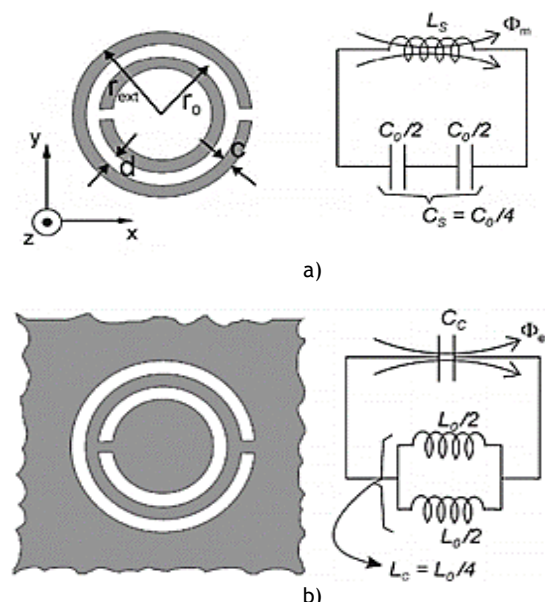


Figure 1. SRR structure and its equivalent circuit: (a) SRR, (b) Complementary SRR [27]

This two structures effect to create a different equivalent LC circuit.

The resonant frequency of the resonator structure, $f=1/(2\pi\sqrt{LC})$, can be obtain by deploying its structure

sizes. The modification in the inductance value of the resonator is correlated to the changes in the length of the resonator. Equally, the value of capacitance can be change by increasing or decreasing the ring gap of the split ring resonator.

There are several examples shows the improvement of bandwidth by adding the split ring resonator, such as by Patel [28]. By adding a multiple corrugated split ring resonator, he had a maximum of 420 MHz compared with the normal antenna which is only 230 MHz. In his paper, he also compared with a small 10 mm and larger 16 mm gap between ring. It shows that small ring gap of SRR have a better return loss as several frequencies. Beside that, the gain also improved from 6.2 dB to 7.0 dB.

In the fractal geometry theory, the size of each iteration stage design is different using the reducing scale for the structure. The different number of iterations can be done, but considering the compactness of fractal antenna [29-30].

In this work, the effect of embedded EC-SRR on microstrip patch antenna had been investigated. Four different stages of Design A, Design B, Design C and Design D are compared.

2. Materials and Methods

This section illustrates the split ring resonator structure. It also describes the dimension and configuration structure of the proposed microstrip patch antenna with split ring resonator structure.

The works start with the development of the split ring resonator structure. This structure will be located at the several locations in the antenna. Firstly, this structure had been design stand alone. There are three different size of the EC-SRR, namely larger EC-SRR, normal EC-SRR and smaller EC-SRR.

Figure 2 shows the modified Edge Couple split ring resonator (EC-SRR) structure.

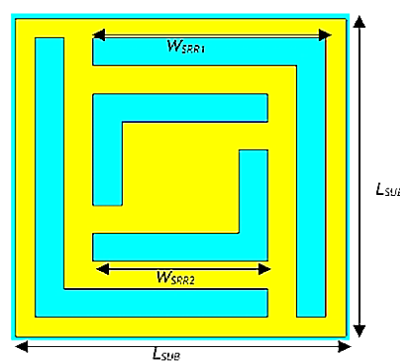


Figure 2. Modified Edge Couple split ring resonator (EC-SRR) structure (normal SRR dimension)

The dimension of the larger structure is 10.15 mm length (L_{SUB}) x 10.15 mm width (W_{SUB}) while the dimension of the normal EC-SRR and smaller EC-SRR is only 7.25 mm x 7.25 mm and 4.35 mm length x 4.35 mm length, respectively. The dimension of normal W_{SSR1} and W_{SSR2} is 5.45 mm and 3.65 mm, respectively. It had been different in size but remained the same design of L-shaped structure.

Table 1 shows the dimension of for larger, normal, and smaller modified Edge Couple split ring resonator (EC-SRR) structure.

Table 1. Dimension of modified Edge Couple split ring resonator (EC-SRR) structure (larger, normal and smaller EC-SRR dimension)

Parameter	Code	Dimension (mm)		
		Larger	Normal	Smaller
Substrate length	L_{SUB}	10.15	7.25	4.35
Substrate width	W_{SUB}	10.15	7.25	4.35
SRR width 1	W_{SSR1}	7.65	5.45	3.25
SRR width 2	W_{SSR2}	5.15	3.65	2.15

After the design of SRR stand-alone structure had been done, it goes to design a patch antenna with split ring resonator.

Figure 3 represents the proposed wideband patch antenna with modified Edge Couple split ring resonator (EC-SRR) structure.

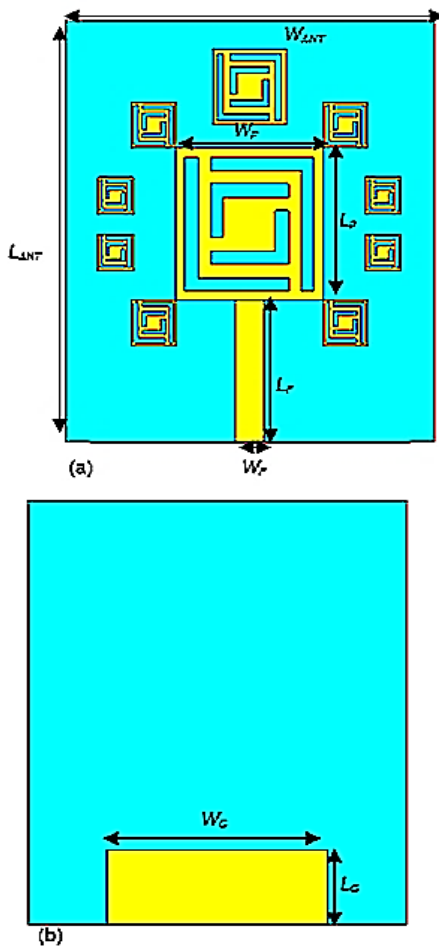


Figure 3. Wideband patch antenna with modified Edge Couple split ring resonator (EC-SRR) structure, (a) front view - patch part, (b) back view - ground part

This proposed antenna is designed on a FR-4 substrate with dielectric constant, ϵ_r of 4.3. The substrate dimension is 36.0 mm width x 40.0 mm length with thickness of this antenna is 1.6 mm and copper thickness of 0.035 mm. These copper plates are located at the top and the bottom (ground) of the substrate. The patch, feedline and ground plane dimension are 14.4 mm width x 14.4 mm length, 2.8 mm width x 13.5 mm length, 21.0 mm width x 7.0 mm length, respectively.

In this patch antenna, three different size of the EC-SRR structures are located at different place at the front part of the antenna. The larger EC-SRR is located above

of the patch structure while smaller and normal EC-SRR structures is located at the side and edge of the patch, respectively.

The cut-off ground type effect to increase the frequency bandwidth of the antenna.

Table 2 shows the several parameter dimensions (in mm) of wideband patch antenna with modified Edge Couple split ring resonator (EC-SRR).

Table 2. Dimension of wideband patch antenna with modified Edge Couple split ring resonator (EC-SRR) structure

Parameter	Code	Dimension (mm)
Patch antenna substrate width	W_{ANT}	36.0
Patch antenna substrate length	L_{ANT}	40.0
Patch antenna width	W_P	14.4
Patch antenna length	L_P	14.4
Feed line width	W_F	2.8
Feed line length	L_F	13.5
Ground width	W_G	21.0
Ground length	L_G	7.0

In this work, four different stages of Design A, Design B, Design C and Design D are simulated in this work.

Figure 4 shows the different stage of antenna design from basic (Design A) to antenna with SRR (Design D).

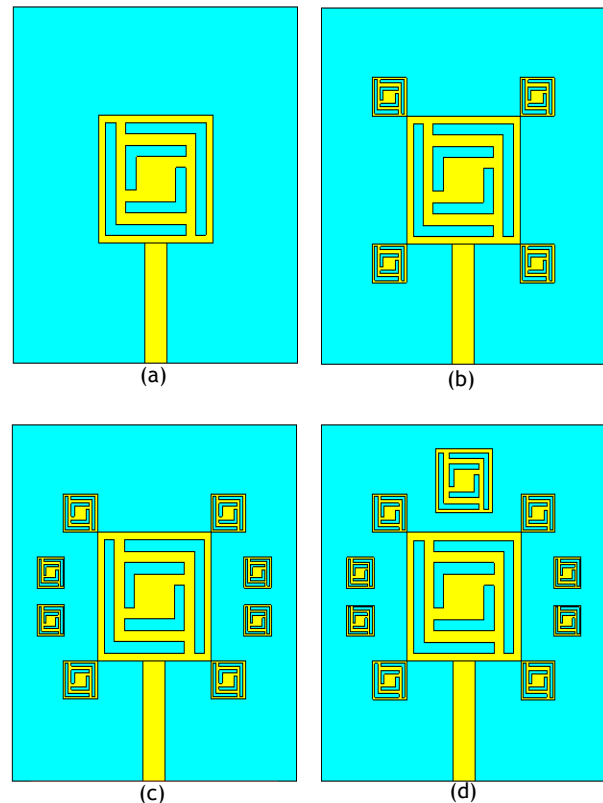


Figure 4. Different stage of microstrip patch antenna design with EC-SRR structure, (a) Design A - basic patch, (b) Design B - added EC-SRR at the edges, (c) Design C - added EC-SRR at the sides, (d) Design D - added EC-SRR at the above

Design a) consist only the patch antenna with L-shaped slotted, while Design b), Design c) and Design d) have the addition of the SRR structures at the edges, left and right sides and the above of the patch, respectively.

This different location and size had been effect to the location of the resonant frequency of the antenna.

The numbers of EC-SRR of each design is four, eight and nine EC-SRR structures.

3. Results & Discussion

This section describes the result performance of the proposed antenna. The important parameters that are considered in this work are resonant frequency (in GHz), return loss (in dB), bandwidth (in GHz), and the gain (in dB). Beside that, radiation pattern and surface current of the proposed microstrip patch antenna also had been shown.

Figure 5 and Table 3 show return loss performance of the different stage of antenna design (Design a)-Design d)).

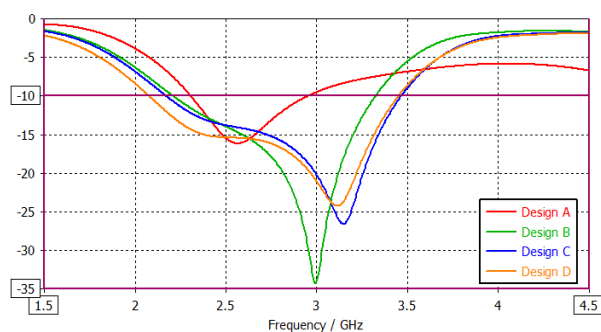


Figure 5. Return loss performance of the different stage of antenna design (Design a)-Design d))

Table 3. Return loss at resonant frequency and at 2.4 GHz

Design	Return loss		Bandwidth, frequency range
	At resonant frequency, return loss	Return loss at 2.4 GHz	
a)	2.56 GHz, -16.156 dB	2.4 GHz, -12.753 dB	0.514 GHz (2.464 GHz-2.978 GHz)
b)	2.996 GHz, -34.316 dB	2.4 GHz, -12.848 dB	1.067 GHz (2.214 GHz-3.281 GHz)
c)	3.164 GHz, -26.597 dB	2.4 GHz, -13.226 dB	1.289 GHz (2.198 GHz-3.487 GHz)
d)	3.112 GHz, -24.271 dB	2.4 GHz, -15.154 dB	1.394 GHz (2.097 GHz-3.491 GHz)

For Design a), it shows that the return loss of -16.156 dB at 2.56 GHz; Design a) antenna has a narrow bandwidth of 0.514 GHz between 2.464 GHz and 2.978 GHz. Compared with the basic rectangular antenna in [x], it had been shifted from 2.4 GHz, effected by the L-slotted shaped at the patch antenna. At 2.4 GHz for Design a), the return loss is -12.753 dB

For Design b), the EC-SRR structures is located at the edge part of the patch. It creates new resonant frequency, but in the graph, we cannot have seen it has two resonant frequency. This because, this two-resonant frequency had combines to create a wider bandwidth. In this case, the bandwidth is 1.067 GHz, covers from 2.214 GHz to 3.281 GHz with resonant frequency at 2.996 GHz with

return loss of -34.316 dB. At 2.4 GHz, the return loss achieves -12.848 dB.

For the same concept with the Design b), the Design c) is the same design with addition of smaller size of EC-SRR at the left and right of the patch antenna. It effects to shift the resonant frequency from 2.996 GHz to 3.164 GHz and effect to increase the bandwidth from 1.067 GHz to 1.289 GHz. At 3.164 GHz, the return loss is -26.597 dB while for 2.4 GHz, its only shows -13.226 dB.

For the last Design d), the addition of the larger sizes of the EC-SRR had been increase the bandwidth of this antenna to 1.394 GHz, covers from 2.097 GHz to 3.491 GHz. At this point, it shows that the resonant frequency at 3.112 GHz with return loss of -24.271 dB. At 2.4 GHz, it shows the return loss only -15.154 dB. So, after all design had been done, it shows that the improvement of bandwidth from the Design A to Design D by 0.514 GHz to 1.394 GHz, with the improvement of 0.880 GHz.

Table 4 shows the bandwidth performance of different design at resonant frequency. From the graph, it shows that the Design d) had the wider bandwidth of 1.372 GHz between 2.077 GHz and 3.449 GHz

Table 4. Bandwidth performance of different design at resonant frequency

Design	Bandwidth, start and stop bandwidth
a)	0.645 GHz, (2.307 GHz-2.952 GHz)
b)	1.114 GHz, (2.209 GHz-3.323 GHz)
c)	1.294 GHz, (2.170 GHz-3.464 GHz)
d)	1.372 GHz, (2.077 GHz-3.449 GHz)

It shows that the addition of the SRR had been increase the bandwidth of the patch antenna. It also improves the return loss at 2.4 GHz of the antenna in the small volume after the addition of the SRR. The return loss at 2.4 GHz for Design d) is -15.154 dB while for Design a) is -12.753 dB.

Figure 6 shows the return loss performance of Design d).

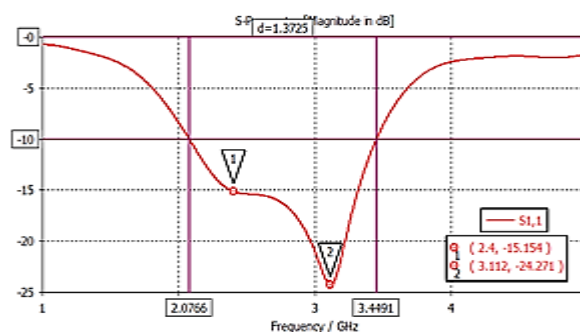


Figure 6. Return loss performance of Design D with resonant frequency at 3.112 GHz and at 2.4 GHz

Figure 7 represents the radiation pattern for antenna of Design D at two different frequencies of 3.112 GHz and at 2.4 GHz.

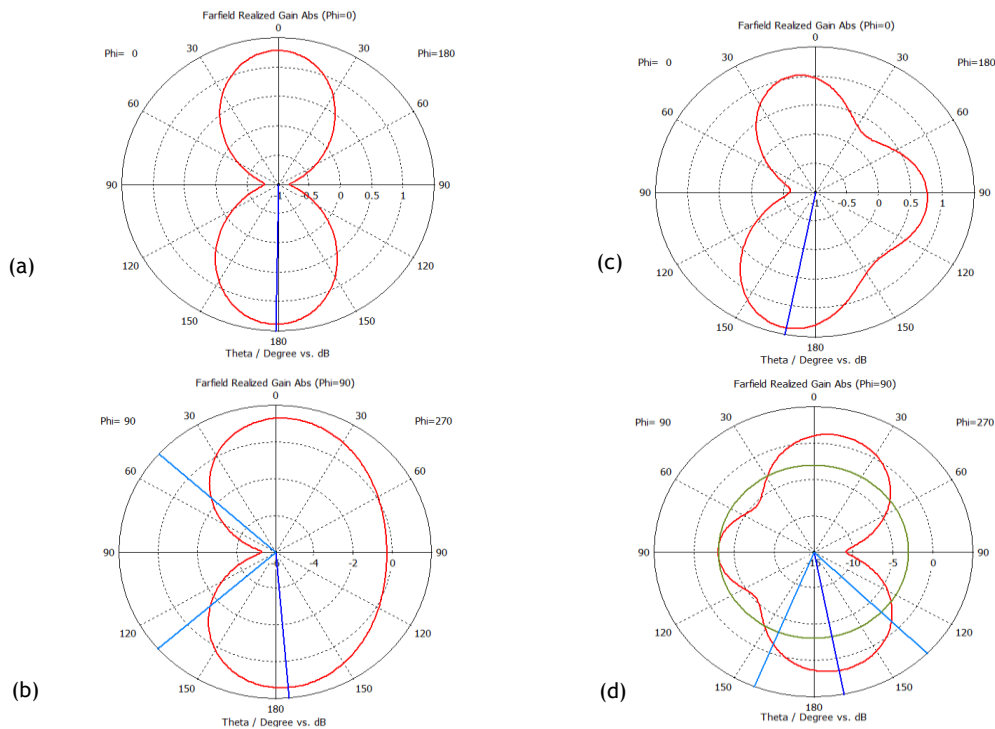


Figure 7. Radiation pattern of the proposed antenna at 3.112 GHz and 2.4 GHz of frequency at different phase, (a) 3.112 GHz, 00, (b) 3.112 GHz, 900, (c) 2.4 GHz, 00, and (d) 2.4 GHz, 90⁰

For the 3.112 GHz, the antenna effect o gives a eight-shaped and kidney shaped for 0⁰ and 90⁰, respectively. While the other two radiation pattern at 2.4 GHz shows the love-like shaped for both 0⁰ and 90⁰, respectively.

Figure 8 shows surface current distribution of the proposed antenna at 2.4 GHz of frequency at four different phases of 0⁰, 45⁰, 90⁰, and 135⁰.

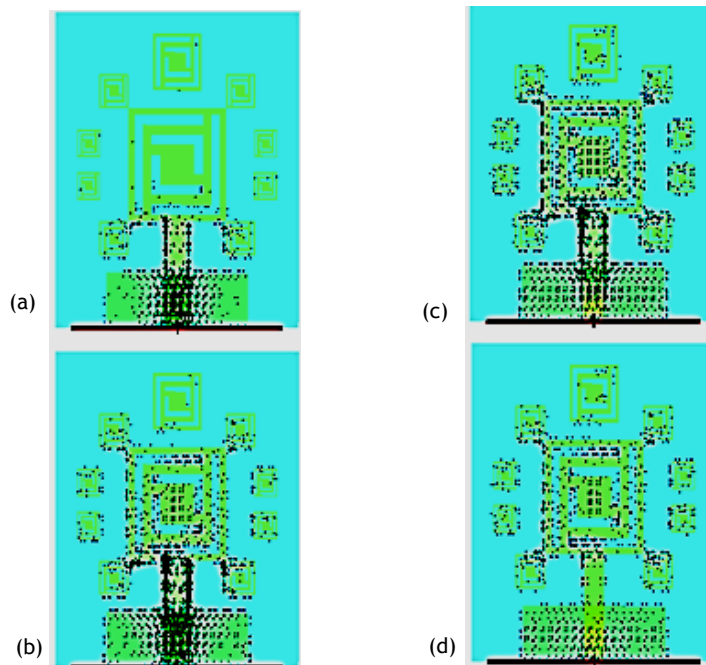


Figure 8. Surface current distribution of the proposed antenna at 2.4 GHz of frequency at different phase, (a) 0⁰, (b) 45⁰, (c) 90⁰, and (d) 135⁰

For 2.4 GHz, the main contribution at the feedline and also at the patch antenna.

4. Conclusions

After simulation work done, it shows that the patch antenna bandwidth had been enhanced by the addition of

the modified EC-SRR. An improvement of the bandwidth is 727 MHz, increase from 0.645 GHz (Design a)) to 1.372 GHz (Design d)).

The antenna of Design a) achieved a bandwidth of 0.514 GHz in the range between 2.464 GHz and 2.978 GHz, while Design d) effect of bandwidth of 1.394 GHz between

2.097 GHz and 3.491 GHz. The return loss also increases but not gives the significant effect to the antenna design.

For Design a), the antenna radiates at resonant frequency of 2.56 GHz with return loss of -16.156 dB, while for Design d), it radiates at resonant frequency of 3.112 GHz with return loss of -24.271 dB.

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Biography



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