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# Design Coplanar Waveguide-fed Circular Patch Antenna with Edge Couple Split Ring Resonator Structure for Dual-band Application

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ABSTRACT

This paper proposes to fabricate a compact dual-band antenna which has the capability to work at two different operating frequencies. This project starts with the design of the basic structure coplanar waveguide-fed (CPW-fed) rectangular patch antenna to obtain the characteristic of the first desired frequency band. Then, an additional structure of edge couple split ring resonators (EC-SRR) is located at the center of the circular patch to obtain the second frequency band. In the simulation result, it shows that this antenna is radiating at 2.42 GHz and 5.01 GHz with a return loss of – 39.52 dB and – 14.64 dB respectively. The gains at both resonant frequencies are 2.29 dB and 3.22 dB.

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## INTRODUCTION

In this latest decade, a great evolution and advancement has been realized in the wireless telecommunication system. Besides that, the current market also demands for mobile and multi-functional devices. Thus, a smart antenna which plays an important role in transmitting and also receiving radio frequency (RF) signals in wireless system, also need to be small as well as to be able to work in various applications.

The common design of microstrip antenna consists of a metallic patch of copper on a grounded substrate. The metallic patch can be in many kinds of configuration such as rectangular, hexagonal shaped, circular, triangular, trapezium or oval shaped patch. Microstrip type antenna are popular for their low profile, suitable for planar and also for non-planar surfaces, and lastly low cost in fabrication stage. Right now, there are many types of substrate that suitable for printed microstrip antenna design such as FR-4, Roger Duroid, Taconic TLX and others. This substrate is required for giving mechanical strength to microstrip antenna.

There are several techniques used to design a multiband antenna, at the same time equipped with compact characteristic. They are fractal technique, meandering technique, modified ground plane technique as well as slot technique. Each technique has its own benefits and disadvantage of the multiband antenna design. Fractal geometry such as Koch curve (Ismahayati, A., *et al*., 2011; Karim, M.N.A., *et al*., 2008) and Sierpinski carpet structure (Soh, P.J., *et al*., 2012) with different iterative construction concept is one of the ways to design a multiband antenna. Fractal antennas show log periodic behavior that attributed to a similar scale factor of the antenna geometry (Saidatul, N.A., *et al*., 2009, Masri, T. *et al*., 2007). Meandering technique such as Minkowski and Minkowsi Island can be achieved by loading several meandering slits at the non-radiating edges of rectangular patch or at the boundary of circular patch such as in this paper (Ibrahim, M.I., *et al*., 2013, Majid, H.A., *et al*., 2013).

Ground plane modifying technique is also one of the popular techniques to obtain the multiband effect. The example techniques are ground plane aperture (GPA), ground plane lossy aperture (GPLA), and defected ground structure (DGS) (Zakaria, Z., *et al*., 2012). Coplanar waveguide or CPW is also one of the techniques to improve the performance of the patch antenna. The ground had been located surrounding in front side of the antenna but did not connect to the feedline. The example of CPW antenna research is in this paper (Alam, M.S., *et al*., 2013, Dagdeviren, B., *et al*., 2013). A compact multiband antenna also can be obtained by embedding suitable slots like rectangular, meander line, split ring resonator slot, and other structure in the radiating patch location (Mahatthanajatuphat, C., *et al*., 2007, Lee, E.C., *et al*., 2011, Radonic, V., *et al*., 2012).

There are few slot antenna designs for the bandwidth enhancement and also for size reduction functions

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have been wide studied such as in the papers (Noghabaie, *et al*., 2013, Aziz, *et al*., 2013). The slot antennas designed capability to exist the multiband and dual-band for the wireless communication system.

Split ring resonator (SRR) structure is categorized as the left handed material (LHM) beside photonic band gap (PBG) (Goswani, K., *et al*., 2011), electronic band gap (EBG) (Kanso, A., *et al*., 2011) and also artificial magnetic conductor (AMC) (Abu, M., *et al*., 2010). The first structure of a split ring resonator design is a combination of wire and edge couple split ring resonator (EC-SRR) structure by (Pendry, J.B., *et al*., 2000) and (Smith, D.R., *et al*., 2000). This SRR has the capability to produce the negative dielectric constant (permittivity) and negative permeability in the patch antenna design. The other example of SRR antenna is in these papers: (Nikfalazar, M., *et al*., 2012, Pradeep, *et al*., 2011)

In this paper, the authors had been added the split ring resonator to investigate the effect of this structure on the rectangular patch antenna. The coplanar waveguide is used as the ground plane.

## *2. Antenna Design:*

This section shows the development stage of the CPW-fed circular patch antenna design with split ring resonator using CST Microwave Studio simulation software. Fig. 1 shows the schematic diagram of the coplanar waveguide-fed (CFW-fed) circular patch antenna with split ring resonator structure. This antenna used the CPW-fed as the ground plane. This CPW-fed is located at the border of the substrate. Table 1 shows the dimension of the CPW-fed circular patch antenna with SRR structure.

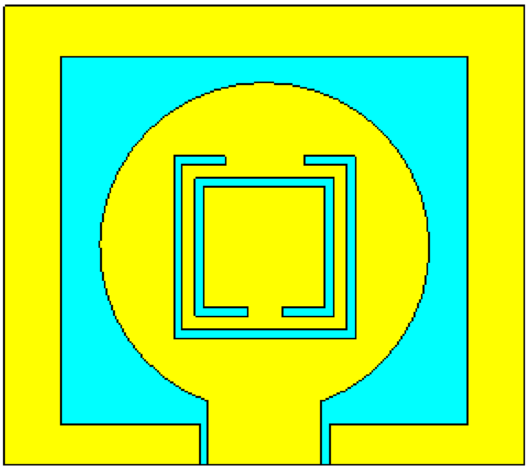

**Fig. 1:** Schematic diagram of CPW-fed circular patch antenna with edge couple split ring resonator structure (plan view)

**Table 1:** Dimension of CPW-Fed Circular Patch Antenna with Edge Couple Split Ring Resonator

| Part | Dimension (mm) |
|---|---|
| A | 60.0 |
| B | 53.0 |
| C | 46.9 |
| D | 42.5 |
| E | 13.0 |
| F | 9.00 |
| G | 16.0 |
| H | 4.00 |
| I | 21.0 |

The substrate dimension of the antenna is 60.0 mm width and 53.0 mm length with the substrate thickness of 1.635 mm. This antenna was designed using FR-4 substrates with dielectric constant of epsilon$_r$ = 4.3. This patch antenna is designed in circular shaped patch with split ring resonator structure at the center location. This circular patch is connected to the coaxial cable via the feedline. The edge couple split ring resonator is located at the center of the circular patch part. It contains of two same shape rings with different length and width. The outer edge couple split ring resonator structure is 21.0 mm width while the inner split ring resonator is only 16.0 mm width.

The compact dual-band circular patch antenna design with split ring resonator has been modified from Design A (basic design) to Design B (design with various shapes of SRR structure). At the first stage of designing a single band antenna, the basic CPW-fed circular patch antenna is designed by using microstrip line equations and parametric study to obtain the first operating frequency ranging from 2.4 GHz to 2.5 GHz. Fig. 2

(a) shows the basic structure of the circular patch antenna design that simulate in CST simulation software. Then, the rectangular U-shaped split ring resonator and double rectangular U-shaped split ring resonator structure had been incorporated in the basic circular patch antenna, shown in Fig. 2 (b) and Fig. 2 (c). Lastly, the proposed CPW-fed circular patch antenna with edge couple split ring resonator structure had been designed, shown in Fig. 2 (d). The rectangular slot at patch dimension at the patch antenna is 46.9 width x 42.5 mm length.

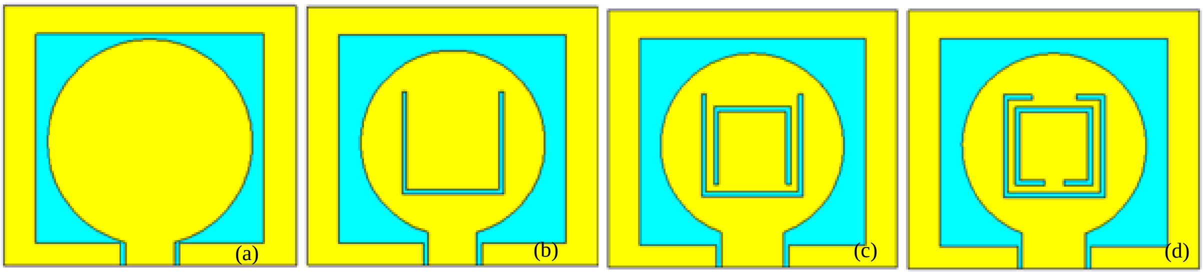

**Fig. 2:** Development stage of the CPW-fed circular patch antenna with split ring resonator structure (Plan view), (a) Design *A*, (b) Design *B* (*I*), (c) Design B (*II*), (d) Design B (*III*)

***Result:***

This section discussed all about the results obtained including the simulations and measurement result. Firstly, the result of different SRR design had been compared in Table 2. This stage is compared by simulating tool using CST Microwave Studio simulation software. This different SRR shaped had effect to give a different return loss performance and affect the location of the resonant frequency of the antenna.

**Table 2:** Comparison of Return Loss Performance for CPW-Fed Circular Patch Antenna With Different Shaped of Split Ring Resonator (Simulation)

| Antenna Parameter | Design *B(I)* | | Design *B(II)* | | Design *B(III)* | |
|---|---|---|---|---|---|---|
| Resonant frequency (GHz) | First resonant frequency | Second resonant frequency | First resonant frequency | Second resonant frequency | First resonant frequency | Second resonant frequency |
| | 2.45 | 5.21 | 2.44 | 5.20 | 2.42 | 5.01 |
| Return loss (dB) | - 23.351 | - 32.712 | - 10.533 | - 18.034 | - 39.523 | - 14.642 |

It shows that the Design B (*I*) had two resonant frequencies at 2.45 GHz and 5.21 GHz with – 23.351 dB and – 32.712 dB respectively. The Design B (*II*) shows the decreasing performance compared with Design *B* (*I*). At this stage, the return loss of the antenna is only – 10.533 dB and – 18.034 dB at 2.44 GHz and 5.20 GHz respectively.

Fig. 3 shows the return loss performance of the CPW-fed circular patch antenna with EC-SRR structure (Design B (III)). This antenna resonated at 2.42 GHz with – 39.523 dB and 5.01 GHz with – 14.642 dB of return loss. The first resonate frequency have the best return loss performance compared with the second resonate frequency but the second resonant frequency have wider bandwidth from 4.58 GHz to 5.47 GHz.

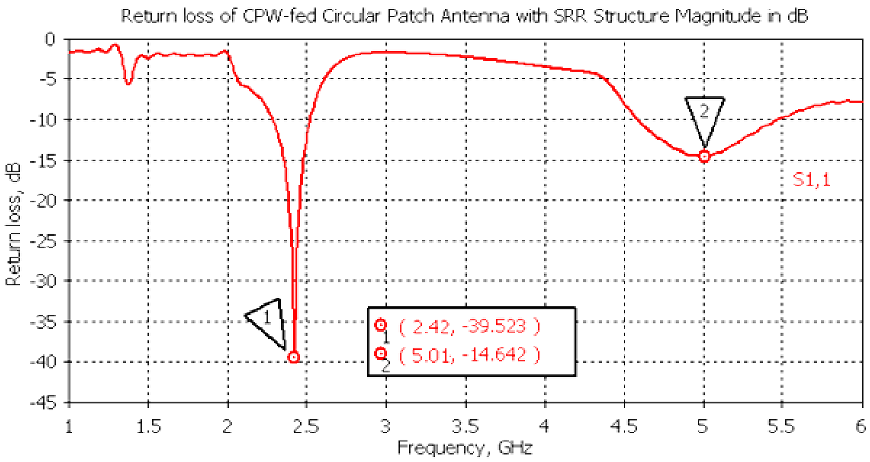

**Fig. 3:** Return loss of the CPW-fed circular patch antenna with split ring resonator structure

Fig. 4 shows the computed distribution current flow for the CPW-fed circular patch antenna with SEC-RR structure. It shows that at 2.42 GHz, the antenna had been resonating at two different parallel locations in the upper and lower part of the patch antenna. At 5.01 GHz, it shows that two main vertically directions at the patch antenna, mainly focusing on the northern side. It also has the radiation at southern part but in smaller scale.

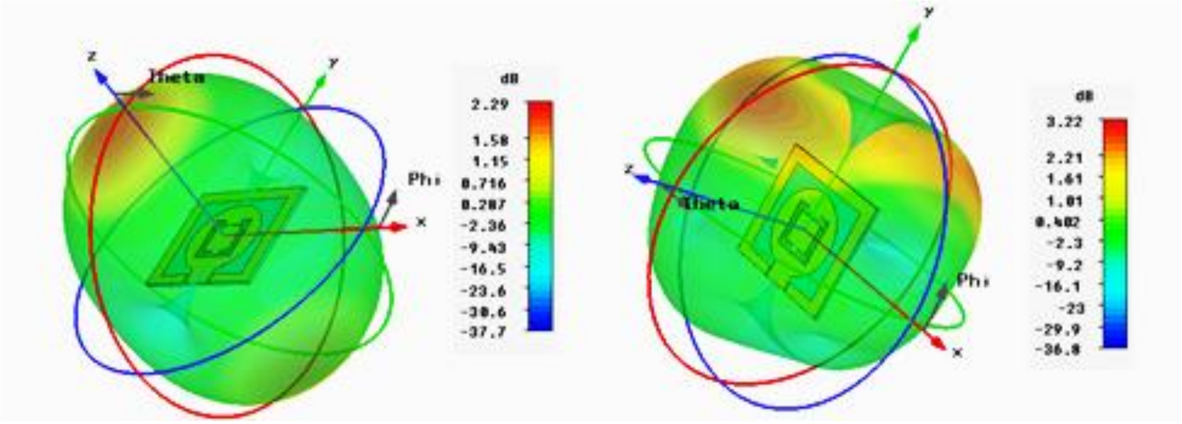

**Fig. 4:** Radiation pattern of the CPW-fed circular patch antenna with split ring resonator structure, (a) 2.42 GHz, (b) 5.01 GHz

Fig. 5 shows the 2D view of the radiation pattern of the CPW-fed circular patch antenna with SRR structure. At 2.42 GHz, the radiation pattern at phi = $0^0$ and at phi = 90° presents two main lobes of 8-like shaped radiation pattern. $0^0$ and $90^0$ shows only the small amount of angular width with 80.3 degree and 77.2 degree respectively. 5.01 GHz (phi = $0^0$), it shows that the four balance direction of X-shaped radiation pattern while at phi = $90^0$ it shows that the existing radiation pattern of butterflies shaped with two main lobes.

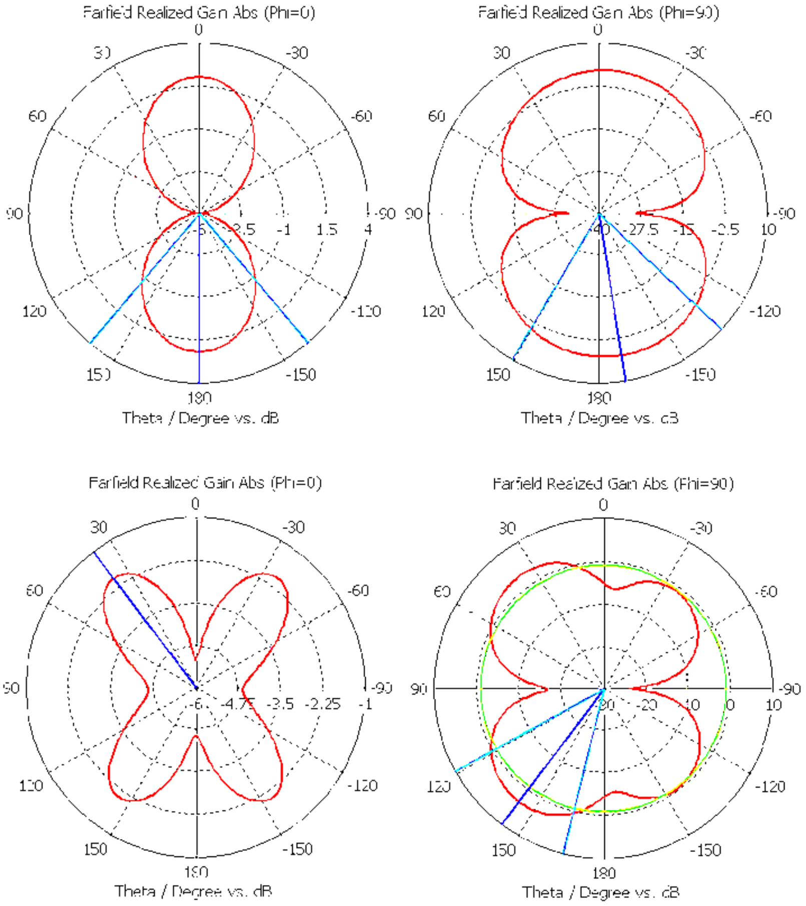

**Fig. 5:** Radiation pattern of the CPW-fed circular patch antenna with split ring resonator structure, (a) 2.42 GHz at $0^0$, (b) 2.42 GHz at $90^0$, (c) 5.01 GHz at $0^0$, (d) 5.01 GHz at $90^0$

Fig. 6 shows the computed distribution surface current of the antenna at 2.42 GHz and 5.01 GHz. Three main locations that effected most are at the split ring resonator, the border of the circular patch and at the feedline part. It shows that the 2.42 GHz and 5.01 GHz have the different phase of maximum current flow. The 2.42 GHz shows the maximum current flow at $0^0$, $135^0$ and $180^0$ while the 5.01 GHz effect at $0^0$ and $180^0$. From the figure also represent that the split ring resonator is mainly effected the 2.42 GHz of resonant frequency.

Fig. 7 represents the fabricated version of the CPW-fed circular patch antenna with SRR structure. This antenna had been fabricated using the FR-4 substrate with the same dimension as the simulation stage. This fabricated antenna is designed in the same dimension like the simulation version. This is for comparing the performance between two conditions.

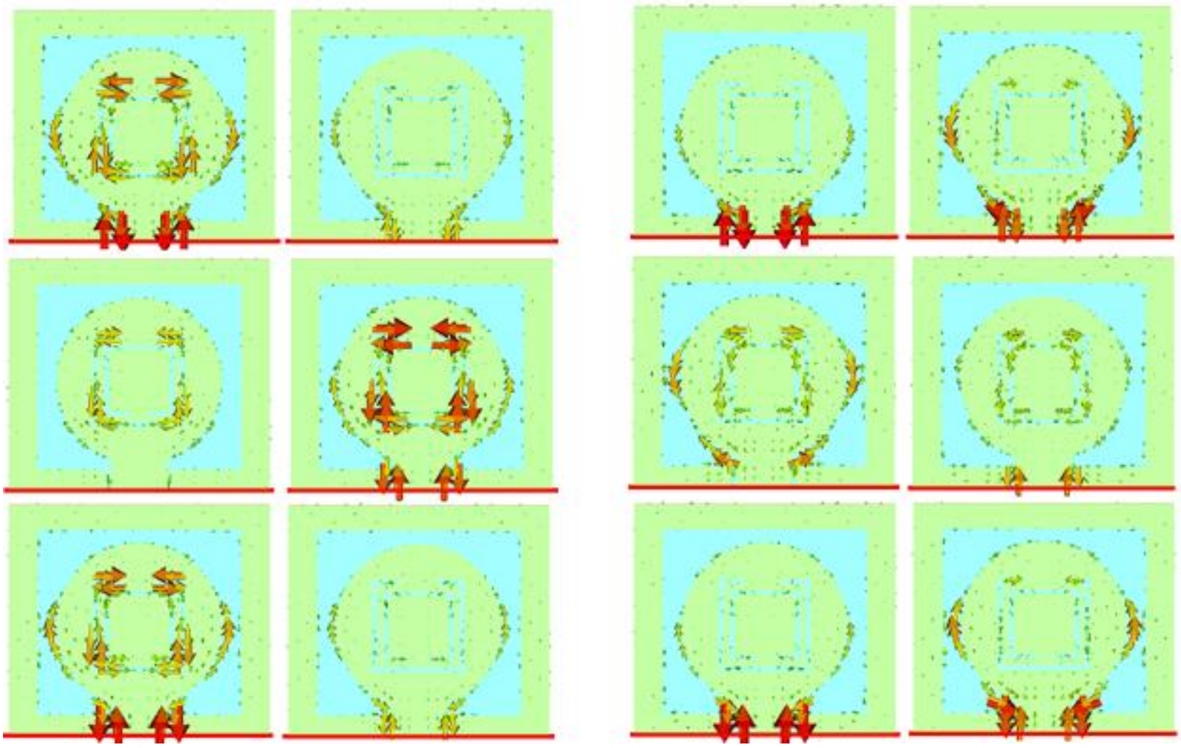

**Fig. 6:** Computed distribution surface current of the CPW-fed circular antenna with split ring resonator structure at 2.42 GHz with a different phase, (a) $0^0$, (b) $45^0$, (c) $90^0$, (d) $135^0$, (e) $180^0$, and (f) $225^0$. Computed distribution surface current of the CPW-fed circular patch antenna with split ring resonator structure at 5.01 GHz with a different phase, (g) $0^0$, (h) $45^0$, (i) $90^0$, (j) $135^0$, (k) $180^0$, and (l) $225^0$

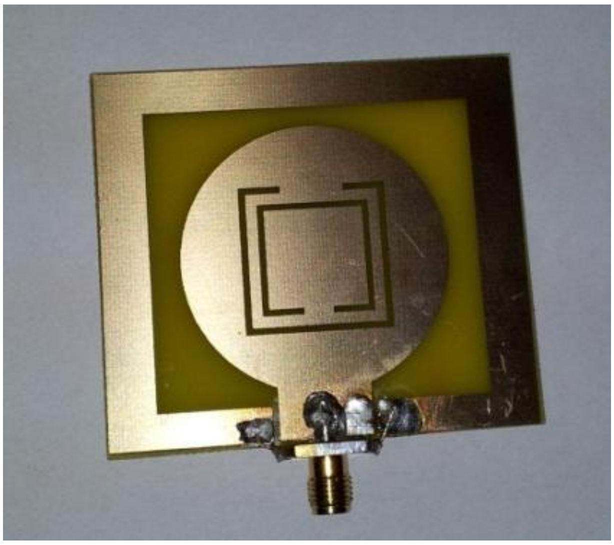

**Fig. 7:** Fabricated version of the CPW-fed circular patch antenna with split ring resonator structure

Fig. 8 shows the graph of the simulation and measurement result of return loss. The measurement result displays the first operating frequency from 2.17 GHz to 2.45 GHz and the second operating frequency is from 4.35 GHz to 6.24 GHz. The measurement result is shifted a little towards the left but it is still considered acceptable. Theoretically, a fabricated antenna which has exactly same dimension with the simulated design should give the same result as simulated result. Thus, the difference in simulated and measurement result may be caused by fabrication defect. Table 3 shows the comparison result between simulation and measurement. The first resonate frequency is 2.28 GHz while the second resonates frequency is 5.01 GHz.

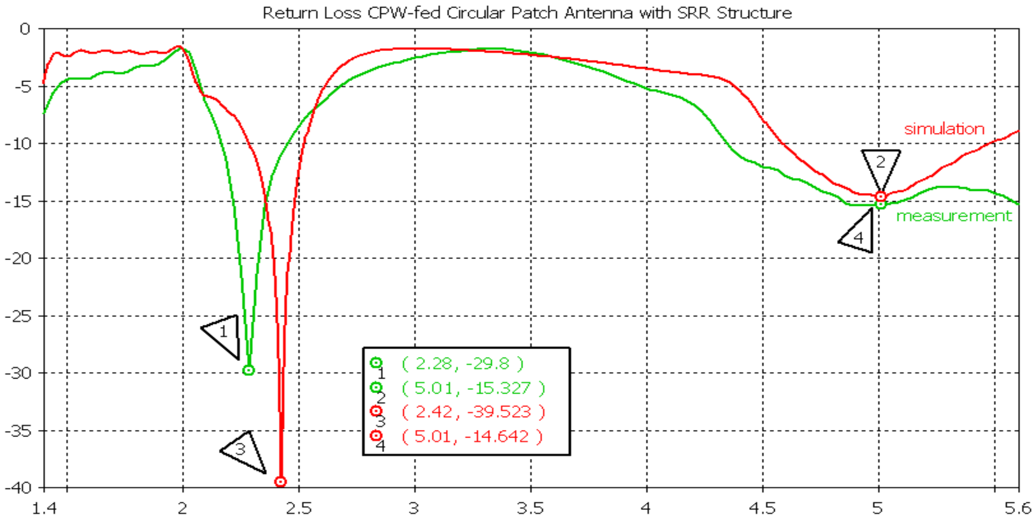

**Fig. 8:** Return loss comparison between simulation and measurement of the CPW-fed circular patch antenna with split ring resonator structure

**Table 3:** Return Loss Comparison between Simulation and Measurement f the CPW-Fed Circular Patch Antenna with Split Ring Resonator Structure

| | First resonant frequency (GHz) | Return loss (dB) | Second resonant frequency (GHz) | Return loss (dB) |
|---|---|---|---|---|
| Simulation | 2.42 | - 39.530 | 5.01 | - 14.642 |
| Measurement | 2.28 | - 29.800 | 5.01 | - 15.327 |

In this project, a compact multiband antenna has been successfully designed. However, there are still potential of improvement which can be applied to this design. In terms of the gain of an antenna, it may be able to further enhance by using techniques such as using air gap for stacking patch, increasing the substrate thickness, and designing array antenna. Besides improving the gain, the number of available frequency bands can also be increased. The higher number of available frequency bands indicates that the number of applications which can be operated with the antenna increases as well.

The design antenna potentially can be integrated with the other devices to form a complete radio frequency front-end transceiver system. The example devices can include in this system are switch (Shairi, N.A., *et al.*, 2013), amplifier (Othman, A.R., *et al.*, 2007), and also the devices like microwave filters (Zahari, M.K., *et al.*, 2012, Ahmad, B.H., *et al.*, 2013, Zakaria, Z., *et al.*, 2013).

## *Conclusion:*

From the simulation work in CST Microwave Studio simulation software and the measurement work in the laboratory, the CPW-fed circular patch antenna with SRR structure had been proposed. It shows that, this antenna had been operating at two different resonant frequencies at 2.42 GHz and 5.01 GHz for simulation and 2.28 GHz and 5.01 GHz for measurement. The second resonant frequency has wider bandwidth but have lower return loss performance compare to the first resonant frequency.

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