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Microstrip Patch Antenna with a Complementary Unit of Rhombic Split Ring Resonator (R-SRR) Structure

[1]Nornikman Hassan, [1]Badrul Hisham Ahmad, [1]Mohamad Zoinol Abidin Abd Aziz, [1]Zahriladha Zakaria, [1]Mohd Azlishah Othman, [1]Abdul Rani Othman, [2]Kamaruzaman Jusoff and [3]Zanariah Jano

[1]Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UteM), Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia
[2]Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[3]Centre for Languages and Human Development, Universiti Teknikal Malaysia Melaka (UteM), Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

Abstract: Hitherto, split ring resonator is becoming a popular structure in antenna design. The objective of this paper is to determine the effect of the rhombic complimentary split ring resonator structure (R-SRR) on microstrip patch antenna design. The basic microstrip patch antenna design is simulated in CST Microwave Studio simulation software. The findings show that the resonant frequency of this antenna is 2.40 GHz for Wireless Local Area Network (WLAN) application. The R-SRR structure has increased the gain and efficiency of microstrip patch antenna. Therefore, the users will get a better coverage of WLAN signal. The different number of split rings may offer attractive results in the future.

Key words: Split ring resonator % Microstrip antenna % Wireless Local Area Network

INTRODUCTION

In a telecommunication research area, patch antenna is popular because it is easy to fabricate. Wireless Local Area Network or WLAN is commonly used in the current technological applications and devices such as notebooks, laptops and mobile phones. An antenna is the device used for transmitting and receiving electromagnetic waves. Many types of patch antenna exist such as meander line [1], circular polarize [2], Minkowski [3], oval shaped [4]. Many researchers have improved the parameter results to produce better performance of the patch antenna design. The parameters which need improvements include return loss, gain, directivity and bandwidth. These improvements cover various shapes of antennas, additional special structures, attachment of RF components or integrated circuits into the patch antenna.

Metamaterial is the artificial substrate which is non-existence in the real world. Metamaterial is categorized as the structure which has simultaneously negative permeability and permittivity values. Many metamaterial structures have been proposed [7-10]. The structures include artificial magnetic conductor (AMC) [7], electromagnetic band gap (EBG) [8], split ring resonator (SRR) [9] and photonic band gap (PBG) [10].

These metamaterial structures are used in several applications such as microwave absorber [11], antennas [12], frequency selective surfaces (FSS) [13] and metamaterial filters [14]. Metamaterial structure such as split ring resonators (SRRs) design is used to produce the negative dielectric constant (permittivity) and negative permeability. This structure has been been initially discovered by Veselago [5]. Smith *et al.* [6] have fabricated the first artificial material.

Corresponding Author: Nornikman Hassan, Center for Telecommunication Research and Innovation, Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka(UTeM), Hang Tuah Jaya, 76100, Durian Tunggal Melaka, Malaysia.
Tel: +6013-2994949, E-mail: nornikman84@yahoo.com.

Their design depends on Pendry split ring resonator-based artificial negative magnetics permeability media.

There are many types of split ring resonator design such as edge coupled SRR (EC-SRR) [15], broadside-couple SRR (BC-SRR) [16], nonbianistropic SRR (NB-SRR) [17] and other SRR structures. This paper determines the effect of the rhombic complimentary split ring resonator structure (R-SRR) on microstrip patch antenna design.

MATERIALS AND METHODS

Rhombic SRR Design: There are many new shapes proposed in the literature. The popular shape is circular and square shape while the other shapes are rectangular, triangular, hexagonal, rhombic (diamond), oval, H-shaped, V-shaped and others. Different shape gives different result of the return loss and gain. Figure 1 shows the single unit of rhombic complimentary split ring resonator design. This structure is printed on the Roger RT/Duroid 5880 substrate with dielectric constant, g_r = 2.2. The thickness of the copper is 0.035 mm. Table 1 shows the dimension of the single unit of rhombic complimentary SRR. The size of the rhombic complimentary SRR structure is 3.93 mm width x 3.93 mm length. The dimension of the ring gap, W_s is 0.98 mm while the thickness of the ring, $T_{r\,=}$ 0.35 mm.

In this work, eight different variation patterns have been simulated to compare the return loss and gain performance between the normal patch and rhombic SRR patch antenna. The distance of the two rings is 10 mm while the ring width is 3.93 mm and the ring gap is 0.98 mm. These dimensions are similar to the single unit of rhombic SRR structure. Figure 2 shows the variation pattern of a single unit of the rhombic SRR.

Antenna with Rhombic SRR Design: This design is simulated in CST Microwave Studio simulation software. This structure is printed on the Roger RT/Duroid 5880 substrate with dielectric constant g_r = 2.2. The dimension of the board is 60 mm width x 80 mm length. The ground plane is printed in the back side of the substrate with the dimension of 60 mm width x 80 mm length. A 50 S waveguide port is used to feed power into the radiator. Figure 3 shows the schematic diagram of the basic microstrip patch antenna design while Table 2 shows the dimension of the microstrip patch antenna design.

Figure 4 shows the location of the rhombic split ring resonator at the center of the patch antenna and is paralleled with the feed line of the patch antenna.

Table 1: The dimension of the single unit of rhombic SRR design

Part	Symbol	Dimension (mm)
Ring width	W_r	3.93
Ring gap	W_s	0.98
Thickness of ring	T_r	0.35

Table 2: Dimension of the normal and optimization dimension of patch antenna

	Dimension (mm)		
Symbol	Normal patch	Patch with rhombic SRR	Patch with rhombic SRR (optimization)
W_p	51.5	51.5	51.5
L_p	38.7	38.7	39.15
W_t	1	1	1
L_t	19	19	19
W_f	4.72	4.72	4.75
L_f	7.7	7.7	4

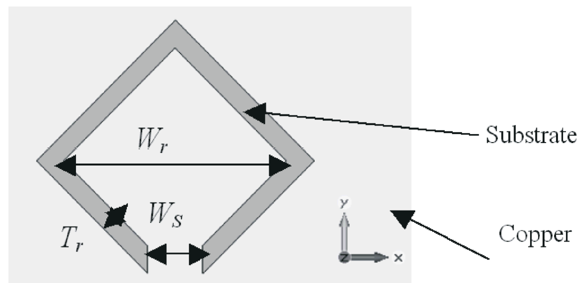

Fig. 1: Single rhombic complimentary split ring resonator structure on CST Microwave Studio. The green line is the RT/Duroid 5880 substrates

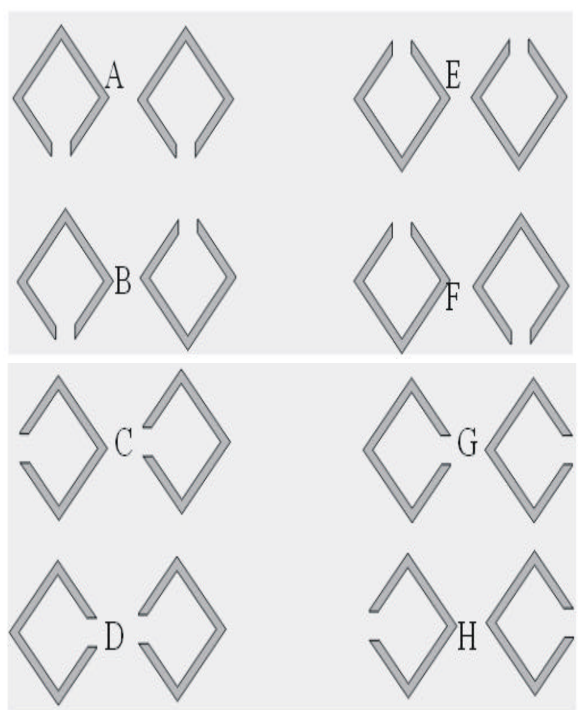

Fig. 2: Variation pattern of a single unit of rhombic SRR: (a) Pattern A, B, C and D. (b) Pattern E, F, G and H

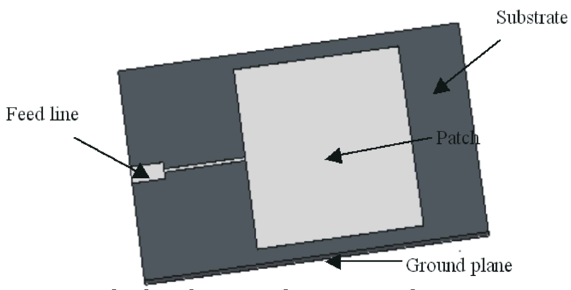

Fig. 3: Single rhombic complimentary split ring resonator structure on CST Microwave Studio

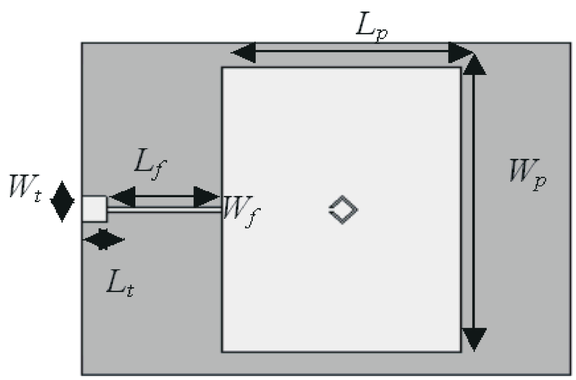

Fig. 4: Microstrip patch antenna with rhombic SRR structure

The dimension of this SRR antenna is similar to the normal patch antenna design. Table 3 shows the comparison of dimension between normal patch antennas and patch antenna with rhombic SRR structure. From the theory, we know that the rhombic SRR will increase the gain performance of the antenna. It also shifts the targeting frequency of the return loss result to other range of frequency. Hence, the antenna dimension (especially the length of the feed line) must be optimized to locate the targeting frequency and targeting 50 S of impedance matching. Table 2 represents the optimization dimension of the patch antenna design with the rhombic SRR structure compared to the normal patch antenna design. The incorporation of the rhombic SRR structure can minimize the microstrip patch antenna design.

RESULTS AND DISCUSSION

The parameters which are analyzed include the effect of the rhombic SRR structure on patch antenna design, different distance between two rhombic SRR structures, different size of rhombic SRR structures and different variation patterns of rhombic SRR structures. The return loss of normal patch antenna (without SRR structure) is shown in Figure 5. The resonant frequency of this design is at 2.40 GHz with - 32.846 dB of return loss. The - 10 dB bandwidth of this design is at the frequency between 2.374 GHz and 2.425 GHz.

Figure 6 and Table 3 represent the comparison of return loss performance between the normal patch antenna and rhombic SRR patch antenna. The gain of the patch antenna is increased by incorporating the single unit of rhombic SRR structure.

The new gain of the patch antenna with the rhombic SRR indicates 6.372 dB, an improvement of 0.038 dB. The SRR structure affects the targeting frequency of 2.40 GHz for this design. The SRR structure is shifted by 22 MHz of the frequency in the 2.422 GHz. After the antenna dimension optimization (redesign) is performed, the frequency is located at the 2.40 GHz. With the optimization process for the patch antenna, the gain of the antenna is increased from 6.372 dB to 6.402 dB. Figure 7 shows a comparison of the 3D return loss of the antenna design.

Figure 8 shows the return loss of the patch antenna with the different distance between two SRR structures. The different dimension between the two SRR does not give any effect to the frequency location and the-10 dB bandwidth. All design acquire the same resonant frequency that is 2.396 GHz. It only affects the return loss and gain performance result. Hence, the best return loss is shown by 30 mm distance with - 31.795 dB. The highest gain is 15 mm distance with 6.372 dB. Table 4 shows the comparison return loss, bandwidth and gain results of the different distances between the two SRR structures.

Figure 9 and Table 5 show the effect of the rhombic SRR size on the return loss of the patch antenna. Four different sizes used are 2.45 mm, 3.68 mm, 4.91 mm and 6.13 mm. The larger rhombic SRR size gives the highest return loss performance result with - 35.639 dB but does not give the highest gain. An antenna with the 2.45 mm of rhombic SRR size with 6.495 dB shows the highest gain. The rhombic SRR size affects the location of the resonant frequency. For example, the resonant frequency of 2.45 mm rhombic SRR is 2.398 GHz.

Different variation pattern also affects the performance of the patch antenna. Figure 10 and Table 6 show that Pattern *A* and *B* give the best gain results with 6.372 dB while Pattern *C* and Pattern *D* score poorly with only 6.310 dB. All SRR patterns show the same resonant frequency and bandwidth that is 2.396 GHz and 51 MHz. Table 6 shows that the best return loss is shown by Pattern *D* with - 32.200 dB compared to Pattern *A* with only - 30.026 dB.

Table 3: Dimension of the normal patch and the optimization dimension of patch antenna

Antenna design	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_1-f_2 (GHz)	Gain (dB)
Normal patch	2.400	- 32.846	51 (2.374 - 2.425)	6.334
Rhombic SRR	2.422	- 24.029	53 (2.396 - 2.449)	6.372
Rhombic SRR (redesign)	2.400	- 26.883	51 (2.374 - 2.425)	6.402

Table 4: Return loss of patch antenna with different distance between two SRR structures

Distance between two SRR structure	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_1-f_2 (GHz)	Gain (dB)
10 mm	2.396	- 30.595	52 (2.370 - 2.422)	6.323
15 mm	2.396	- 30.026	52 (2.370 - 2.422)	6.372
20 mm	2.396	- 31.736	52 (2.370 - 2.422)	6.366
30 mm	2.396	- 31.795	52 (2.370 - 2.422)	6.367

Table 5: The return loss of patch antenna with different size of SRR structure

SRR size (mm)	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_1-f_2 (GHz)	Gain (dB)
2.45	2.398	- 29.167	50 (2.374 - 2.424)	6.495
3.68	2.398	- 33.895	52 (2.373 - 2.425)	6.321
4.91	2.396	- 30.026	52 (2.370 - 2.422)	6.372
6.13	2.390	- 35.639	51 (2.365 - 2.416)	6.334

Table 6: The return loss of patch antenna for Pattern A to Pattern D

SRR pattern	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_1-f_2 (GHz)	Gain (dB)
A	2.396	- 30.026	52 (2.370 - 2.422)	6.372
B	2.396	- 31.902	52 (2.371 - 2.423)	6.310
C	2.396	- 30.091	52 (2.370 - 2.422)	6.372
D	2.396	- 32.200	52 (2.371 - 2.423)	6.310

Table 7: The return loss of patch antenna for Pattern E to Pattern H

SRR pattern	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_1-f_2 (GHz)	Gain (dB)
E	2.398	- 31.418	51 (2.373 - 2.424)	6.381
F	2.398	- 32.613	51 (2.374 - 2.425)	6.323
G	2.398	- 31.378	51 (2.373 - 2.424)	6.371
H	2.398	- 32.417	51 (2.373 - 2.424)	6.379

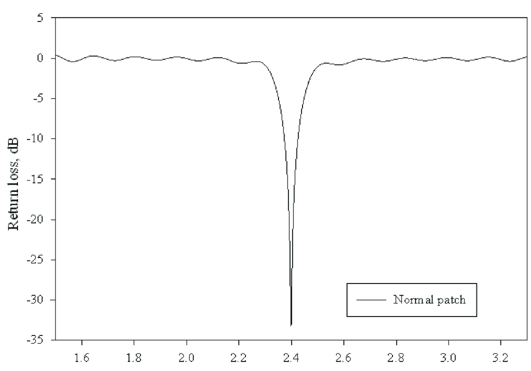

Fig. 5: Return loss of single rhombic R-SRR antenna

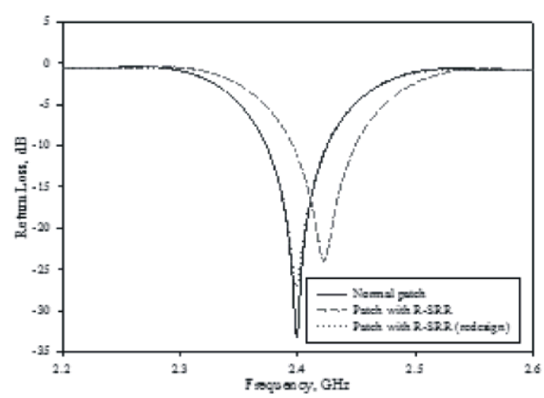

Fig. 6: Return loss of Single R-SRR antenna

Figure 10 and Table 7 show the effect of the different variation patterns of rhombic SRR on the return loss of the absorber. Four patterns analyzed are Pattern *E*, Pattern *F*, Pattern *G* and Pattern *H*. The higher gain performance is shown by Pattern *E* with 6.381 dB while the worst gain performance is shown by Pattern *F* with only 6.323 dB.

These entire four patterns show the same resonant frequency result that is 2.398 GHz but is located differently for Pattern *A*, Pattern *B*, Pattern *C* and Pattern *D*. Pattern *F* scores the best return loss performance with - 32.613 dB followed by Pattern *E* and Pattern *H* with - 32.418 dB and - 32.417 dB. The worst return loss is

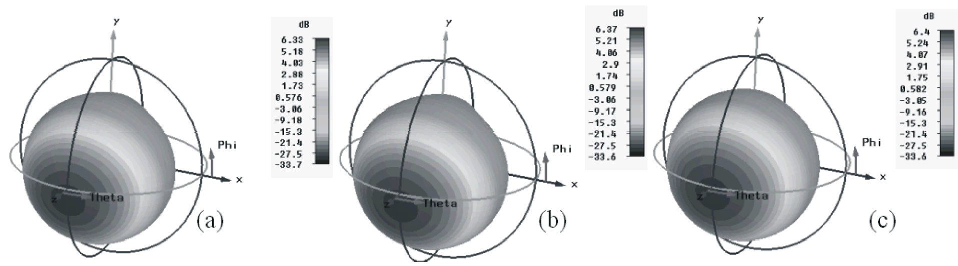

Fig. 7: The 3D return loss of the antenna: (a) Normal patch antenna, (b) Rhombic SRR antenna, (c) Optimization design of rhombic SRR antenna

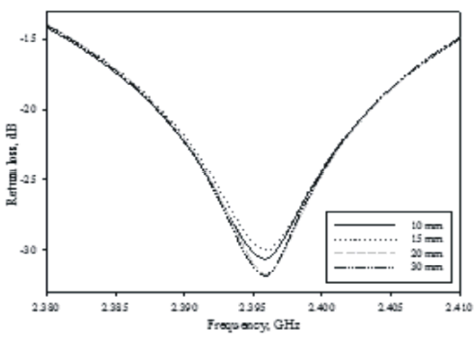

Fig. 8: The return loss of patch antenna with different distance between two SRR structures

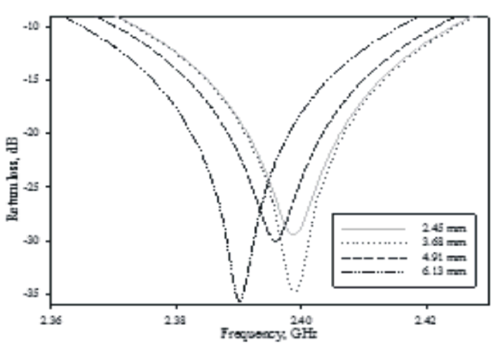

Fig. 9: The return loss of patch antenna with different size of SRR structure

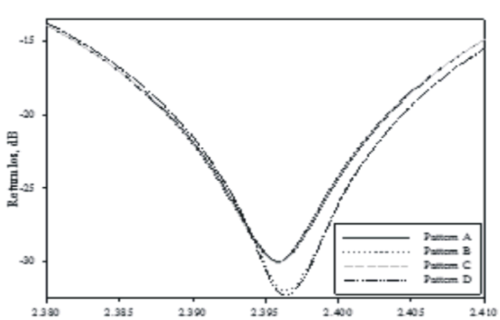

Fig. 10: The return loss of patch antenna for Pattern E to Patern H

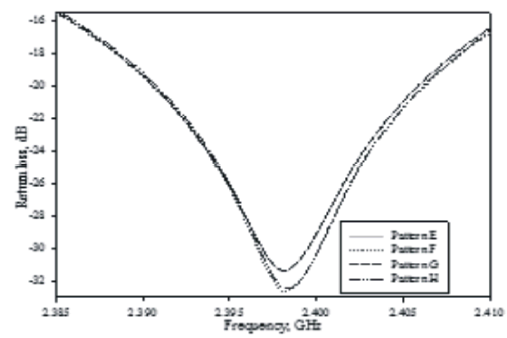

Fig. 10: The return loss of patch antenna for Pattern A to Pattern D

shown by Pattern *G* with only - 31.378 dB. All variation patterns (Pattern *A* to Pattern *H*) show the same - 10 dB bandwidth to 51 MHz of frequency range. Overall, different variation patterns do not affect the - 10 dB bandwidth but only shift the frequency into the new resonant point.

CONCLUSION

From the simulation work in CST Microwave Studio simulation software, the rhombic split ring resonator (R-SRR) has improved the gain of the microstrip patch antenna design. The incorporation of the rhombic split ring resonator structure affects the resonant frequency of the microstrip patch antenna design. The frequency is shifted in the range of 0.02-0.22 Ghz to another location depending on size, pattern and distance between two split rings. The increment of gain does not significantly gives impact to the increment of return loss at the resonant frequency. When the gain is increased, the return loss will decrease and vice versa. The findings are beneficial for end users in which they will get a better coverage of WLAN signal. Future research suggested that the microstrip patch antenna can be improved by adding the

N-number rings and the array split ring resonator structures or defining the new shape design of the split ring resonator structure.

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