Bow-Tie Patch Antenna with Different Shaped of Complementary Split Ring Resonator (SRR) Structures

Amier Hafizun Ab Rashid[1], Nornikman Hassan[2], Muhammad Syafiq Noor Azizi[2], Mohamad Hafize Ramli[2]
[1]*Kolej Komuniti Ledang, 84900 Tangkak, Johor Darul Ta'zim, Malaysia.*
[2]*Centre for Telecommunication Research and Innovation (CeTRI),*
Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
amier@kklej.edu.my

***Abstract*—In this paper, several shaped split ring resonator has been added to the bow-tie antenna design to improve it return loss or shifted the resonant frequency. Firstly, the design is started with the basic bow-tie patch antenna of Design A. Then, the single type of split ring resonator has been added to the bow-tie patch antenna. Six different shapes of single split ring resonator structures are designed in this work including circular SRR (Design Antenna B1), square SRR (Design Antenna B2), rhombic SRR (Design Antenna B3), spiral (Design Antenna B4), quadruple P-spiral SRR (Design Antenna B5) and Minkowski Island SRR (Design Antenna B6). Lastly, the bow-tie patch antenna with double ring split ring resonator (Design Antenna C) had been done. For Design Antenna C, it shows that with the addition of split ring resonator, the frequency has been shifted from 2.40 GHz to 2.332 GHz. The return loss of this antenna increased from – 20.160 dB to – 27.617 dB.**

***Index Terms*—Split Ring Resonator; Patch Antenna; Bow-tie; Resonant Frequency; Return Loss.**

I. Introduction

The structure of split ring resonator is a popular artificial magnetic material. This structure of split ring resonator consists of a pair of concentric ring shapes and it is made of resonant metallic elements. In the year of 2000, Smith [1] had been design a split ring resonator based on Pendry works [2]. Pendry had been claimed to have developed microstructured artificial materials exhibiting strange magnetic properties.

This split ring resonator structure is one of the popular techniques to improve the patch antenna design. Beside antenna, it also can be applied in numerous areas of telecommunication devices such as at microwave absorber, radio frequency (RF) filter, and oscillator [3-8]. The microstrip patches using FR-4 substrate is the basic antenna design that had been made-up because their low profiles, easy in fabricate in laboratory and also low in cost compare with Rogers and Taconic.

The main advantage of these split ring resonator structures is the miniaturization of the resonant particles. The enhancement of coupling between the individual rings can reduce the electrical size in split ring resonator [9]. Besides, [10] supported that the reduction of electrical size in split ring resonators can enhance the coupling between the individual rings.

II. Antenna Design

Firstly, the design is started with the basic bow-tie patch antenna of Design *A*. Then, the single type of split ring resonator had been added to the bow-tie patch antenna. Six different shapes of single split ring resonator structures that designed in this work are circular SRR (Design Antenna *B1*), square SRR (Design Antenna *B2*), rhombic SRR (Design Antenna *B3*), spiral (Design Antenna *B4*), quadruple P-spiral SRR (Design Antenna *B5*), and Minkowski Island SRR (Design Antenna *B6*). Lastly, the bow-tie patch antenna with double ring split ring resonator (Design Antenna C) had been done.

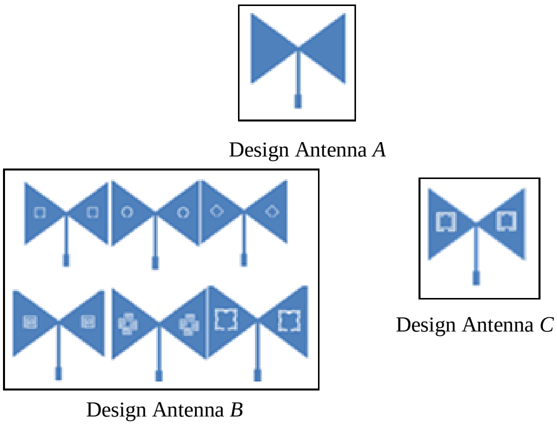
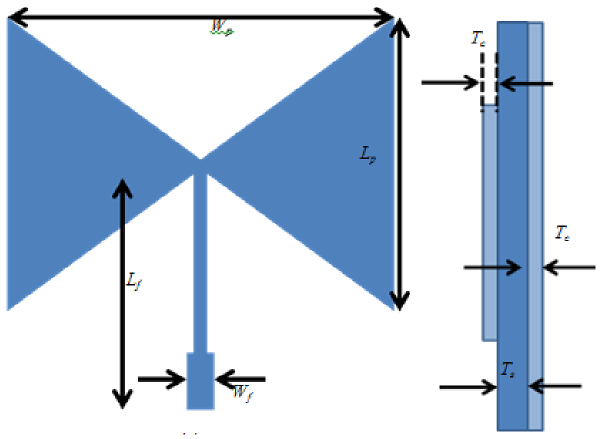


Figure 1: The development stage of different types of bow-tie patch antenna design and bow-tie patch antenna integrated with several structures of split ring resonators

A. Bow-tie Microstrip Patch Antenna (Design Antenna A)

The basic design of the bow-tie patch antenna, Design Antenna *A*, is shown in Figure 2. This antenna was designed on the FR-4 substrate with dielectric constant εr = 4.3. The width-length of the board was 80 mm x 52 mm. The back side copper was printed on the ground of the FR-4. The aimed frequency of this antenna was at 2.4 GHz for WLAN application. The optimized dimension was based on the basic rectangular microstrip patch antenna design. It showed that the optimized dimension was 63.23 mm width x 46.8 mm length, with copper thickness of 0.035 mm, and substrate thickness of 1.6 mm. The loss tangent of this substrate was 0.019. Table 1 shows the dimension of the basic bow-tie microstrip patch antenna, Design Antenna *A*.



(a) (b)

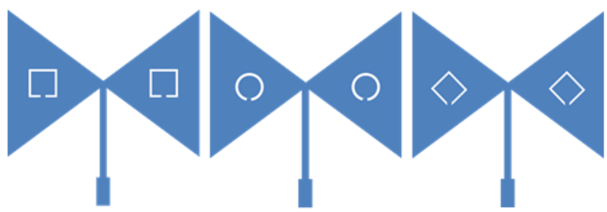
Figure 2: Bow-tie microstrip patch antenna, Design Antenna *A* (a) front view of the bow-tie patch shaped, and (b) side view with three layers of substrate and copper conductor

Table 1
The Dimension of The Basic Bow-Tie Microstrip Patch Antenna, Design Antenna *A*

Parameters of the antenna	Symbol	Optimized dimension (mm)
Patch width	W_p	63.23
Patch length	L_p	46.80
Feedline width	W_f	2.60
Feedline length	L_f	25.74
Copper thickness	T_c	0.035
Substrate thickness	T_s	1.60

B. Bow-tie Microstrip Patch Antenna with Single SRR (Design Antenna B)

Figure 3 shows three different single split ring resonators that were integrated with the bow-tie patch antenna. The dimension of all the split ring resonators was 5.0 mm length x 5.0 mm width for square (Design Antenna *B1*) and rhombic shapes (Design Antenna *B3*), while 5.0 mm in diameter for circular shape (Design Antenna *B2*). The split ring resonator gap for all shapes was 0.5 mm.



(a) (b) (c)

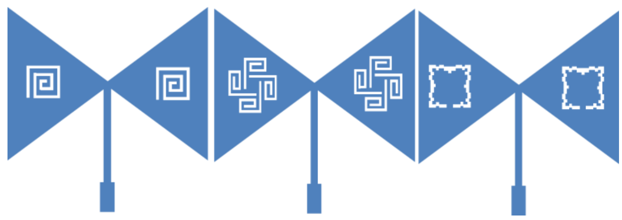
Figure 3: The bow-tie microstrip patch antenna with single split ring resonator structure, (a) square shaped split ring resonator, Design Antenna *B1*, (b) circular shaped split ring resonator, Design Antenna *B2*, and (c) rhombic shaped split ring resonator, Design Antenna *B3*

The location of the split ring resonator structure was at the center of the two triangular patches. Table 2 states the dimension of the microstrip patch antenna with different structures of the single split ring resonator, Design Antenna *B1*.

Table 2
The Dimension of The Bow-Tie Microstrip Patch Antenna with Different Structures in The Single Split Ring Resonators, Design Antenna *B*

Parameters of the antenna	Symbol	Optimized dimension (mm) at different SRRs		
		B1	*B2*	*B3*
SRR width	W_x	5.0	-	5.0
SRR length	L_x	5.0	-	5.0
SRR diameter	D_x	-	5.0	-
SRR gap	G_x	0.5	0.5	0.5

Figure 4 shows the folded split ring resonators that were integrated with the bow-tie microstrip patch antenna. Similar to the previous design, the dimension of all the folded split ring resonators was 5.0 mm length x 5.0 mm width. The split ring resonator gap for all shapes was 0.5 mm. The location of the spilt ring resonator structure was at the center of the two triangular patch of bow-tie.

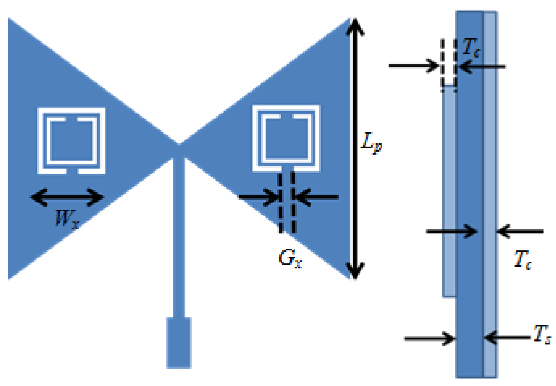


(a) (b) (c)

Figure 4: The bow-tie microstrip patch antenna with folded split ring resonator structure. (a) Spiral shaped split ring resonator, Design Antenna *B4*, (b) quadruple P-spiral split ring resonator, Design Antenna *B5* (c) Minkowski Island split ring resonator, Design Antenna *B6*

C. Bow-tie Microstrip Patch Antenna with Double SRR (Design Antenna Q2)

Figure 5 shows the edge couple split ring resonator that was integrated at the bow-tie microstrip patch antenna. The dimension of all split ring resonator was 5.0 mm length x 5.0 mm width on the outer ring, while 4.5 mm length x 4.5 mm width on the inner ring. The split ring resonator gap for all shapes was 0.5 mm. The location of the spilt ring resonator structure was at the center of the two triangular patch of bow-tie. Table 3 shows the dimension of the microstrip patch antenna with different structures of the enhanced split ring resonators.



(a) (b)

Figure 5: Bow-tie microstrip patch antenna with double square split ring resonator, Design Antenna *Q2-i* (a) front view of bow-tie patch shaped, (b) side view with three layers of substrate and copper conductor

Table 3
The Dimension of The Bow-Tie Microstrip Patch Antenna with Different Structures of The Double Square Split Ring Resonators, Design Antenna *C*

Parameters of the antenna	Symbol	Dimension
SRR width	W_x	5.0
SRR length	L_x	5.0
SRR diameter	D_x	-
SRR gap	G_x	0.5

III. Result and Discussion

This segment displays the numerous simulated and measured performance results of the bow-tie microstrip patch antenna with different SRR structure. The result of resonant frequency, return loss, bandwidth and antenna gain are presented.

Figure 6 represent the return loss of basic bow-tie microstrip patch antenna, Design Antenna *A* in CST Microwave Studio simulation software. The resonant frequency, f_r for this antenna was 2.404 GHz with - 20.160 dB of return loss performance. The value of f_{Low} = 2.372 GHz, while f_{High} = 2.436 GHz. The bandwidth of 64 MHz for this bow-tie microstrip patch antenna, Design Antenna *A* type, was a narrow bandwidth. Table 4 represents the performance of parameter for the basic bow-tie microstrip patch antenna, Design Antenna.

Figure 7 represents the performance of return loss for the bow-tie microstrip patch antenna with different shapes of single split ring resonator structures. From observation, it showed that the addition of split ring resonator shifted the frequency to lower than 2.40 GHz. It also decreased the return loss compared to the normal patch antenna design. For example, square S-SRR, circular S-SRR, and rhombic S-SRR had resonant frequencies of 2.338 GHz, 2.362 GHz, and 2.338 GHz with – 13.866 dB, - 16.403 dB, and – 16.952 dB respectively. Table 5 shows the comparison of different parameters between the basic patch antenna and the single split ring resonator patch antenna.

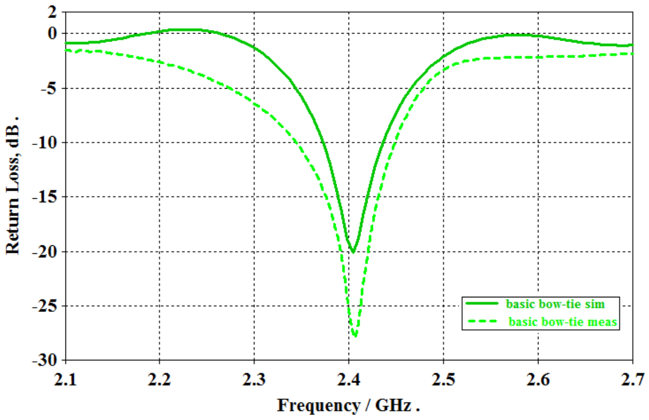


Figure 6: Return loss performance of the basic bow-tie microstrip patch antenna, Design Antenna *Q* (simulation and measurement)

Table 4
The Performance of Parameter For The Basic Bow-Tie Microstrip Patch Antenna, Design Antenna *A* (Simulation And Measurement)

Antenna	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_{High} - f_{Low} (GHz)	Gain (dB)
A (sim)	2.404	- 20.160	64, 2.372 – 2.436	4.780
A (meas)	2.406	- 27.945	94, 2.346 – 2.440	2.978

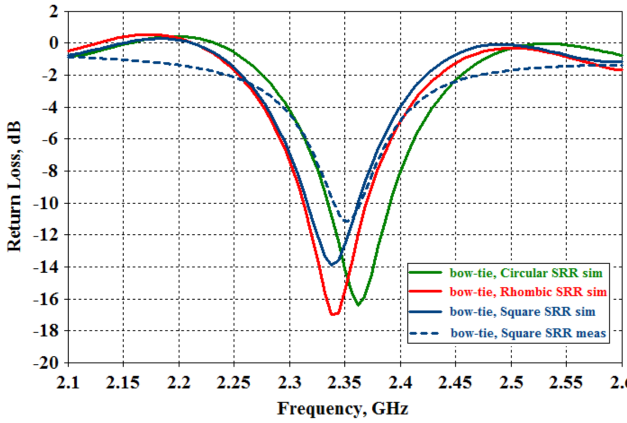


Figure 7: Return loss in dB for the bow-tie microstrip patch antenna with several single split ring resonators, Design Antenna *B1*(simulation and measurement)

Figure 8 represents the performance of return loss for the bow-tie microstrip patch antenna with folded shapes of single split ring resonator structures. The graph shows that the addition of these three split ring resonator shifted the frequency to lower than 2.40 GHz. It also decreased the return loss compared to the normal patch antenna design. It showed that the spiral split ring resonator, quadruple P-spiral split ring resonator, and Minkowski Island had resonant frequencies of 2.320 GHz, 2.320 GHz, and 2.332 GHz with – 20.160 dB, - 15.470 dB, and – 12.114 dB respectively. Table 6 shows the comparison of different parameters between the basic patch antenna and the bow-tie patch antenna with enhanced split ring resonator.

Table 5
Comparison of Different Parameters for Bow-Tie Microstrip Patch Antenna with Different Single Split Ring Resonator Structures (Simulation and Measurement)

Single SRR shape	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_{High} - f_{Low} (GHz)	Gain (dB)
A	2.404	- 20.160	64, 2.372 – 2.436	4.780
B1 (Sim)	2.338	- 13.866	46 , 2.316 – 2.362	4.87
B1 (Mea)	2.352	- 11.148	31, 2.338 – 2.369	2.45
B2	2.362	- 16.403	56 ,2.335 – 2.391	4.81
B3	2.338	- 16.952	57 , 2.313 – 2.370	4.79

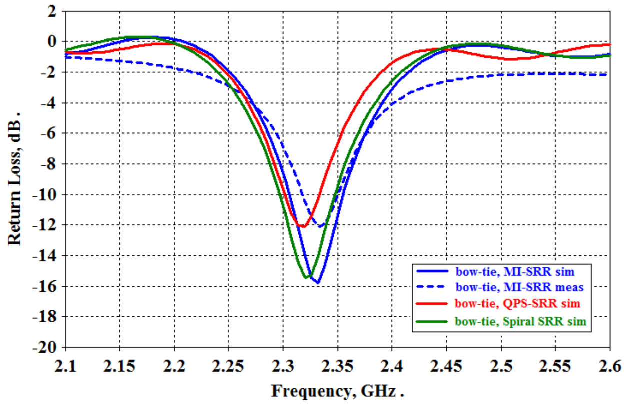


Figure 8: Return loss in dB for the bow-tie microstrip patch antenna with the folded split ring resonator structures (simulation and measurement)

Table 6
Comparison of Different Parameters for Bow-Tie Microstrip Patch Antenna with Different Folded Split Ring Resonator Structures

Antenna type	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_{High} - f_{Low} (GHz)	Gain (dB)
A	2.404	- 20.160	64, 2.372 – 2.436	4.780
B4	2.320	- 15.470	48, 2.300 – 2.348	5.16
B5	2.320	- 12.114	31, 2.302 – 2.333	4.82
B6 (sim)	2.332	- 15.774	49, 2.306 2.355	4.56
B6 (meas)	2.334	- 12.061	32, 2.319 – 2.351	2.981

Figure 9 represents the performance of return loss for the bow-tie microstrip patch antenna with double square split ring resonator, Design Antenna *C*. The graph shows that the addition of split ring resonator shifted the frequency from 2.40 GHz to 2.332 GHz. The return loss of this antenna increased from – 20.160 dB to – 27.617 dB. Table 7 shows the comparison of different parameters between the basic patch antenna and the bow-tie patch antenna with double square split ring resonator, Design Antenna *C*.

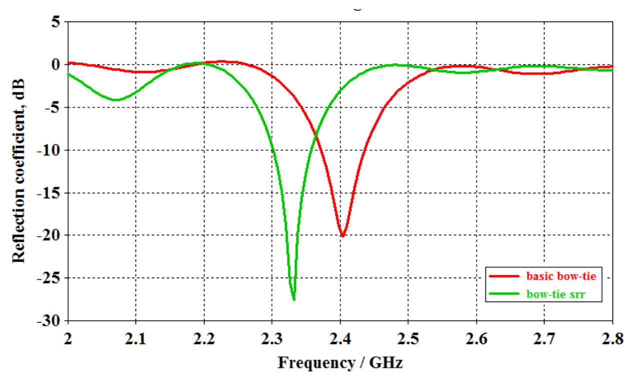
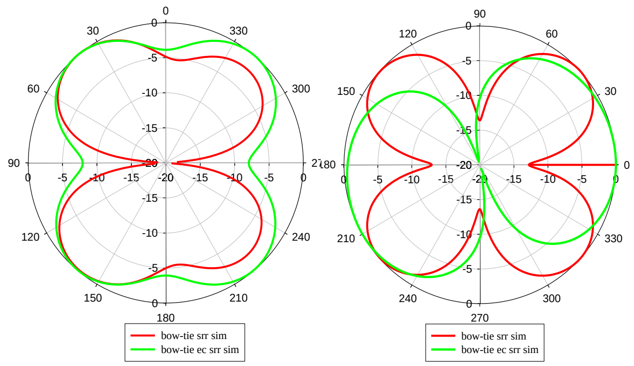


Figure 9: Return loss in dB of the bow-tie microstrip patch antenna with double square split ring resonator, Design Antenna *C*

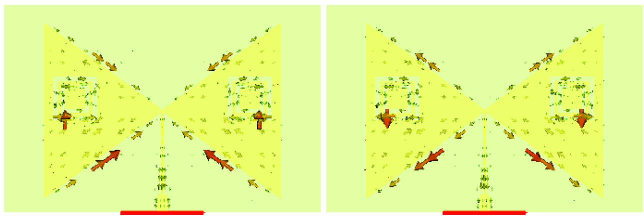
Figure 10 (a) compares the radiation pattern for the bow-tie microstrip patch antenna with double square split ring resonator, Design Antenna *C*. The addition of the split ring resonator structure did not change the shape of the radiation. This split ring resonator microstrip patch antenna showed bigger butterfly-like shape of radiation pattern compared to the basic bow-tie antenna. Figure 10 (b) represents the computed distribution surface current of the bow-tie microstrip patch antenna with double square split ring resonator structure at 0^0. From the figure, it shows that the surface current was concentrated on both split ring resonator structures.

Table 7
Comparison of Different Parameters Between the Basic Bow-Tie Microstrip Patch Antenna, Design Antenna *A*, and the Bow-Tie Microstrip Patch Antenna with Double Square Split Ring Resonator Structure

Antenna type	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (MHz), f_{High} - f_{Low} (GHz)	Gain (dB)
A	2.404	- 20.160	64 , 2.372 – 2.436	4.78
C	2.332	- 27.617	57 , 2.301 – 2.358	4.4



(a)



(b)

Figure 10: (a) The radiation pattern of the bow-tie microstrip patch antenna with edge double square ring resonator, Design Antenna *C*, and (b) Surface current of bow-tie microstrip patch antenna with double square split ring resonator structures, at 0^0 and 180^0

IV. Conclusion

After simulation work done in CST Microwave Studio simulation software, it represent that the split ring resonator had been effected the several parameter of the microstrip patch antenna. The resonant frequency of the antenna can be considered using different dimension of the length, width and the location of the split ring resonator structure. The reflection loss can be shifted to the lower frequency to support the smaller size of the bow-tie antenna after the addition of the split ring resonator.

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