Design A Quadband Frequencies Microstrip Patch Antenna with Double C-Shaped Slot

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***Abstract*—A quadband frequencies microstrip square patch antenna with double C-shaped slot at the patch is proposed in this paper. First, a rectangular shaped patch antenna is designed for 2.40 GHz frequency (WLAN application) with narrow bandwidth of 67 MHz (operate better than – 10 dB between 2.368 GHz and 2.435 GHz). Then, the double C-shaped slot had been embedded in the rectangular patch antenna. There are four stages of design (Design I, Design II, Design III and Design IV) with different dimensions of patch width and substrate width. This addition of this C-shaped slot had been producing a quadband frequency range of 2.40 GHz (2.368 GHz – 2.421 GHz), 5.0 GHz and 5.2 GHz (4.795 GHz - 5.333 GHz) and 5.6 GHz (5.521 GHz – 5.677 GHz). Parametric study with different dimension are also had been considered in Design III and Design IV.**

Keyword-patch antenna, C-shaped slot, return loss, gain, bandwidth

I. Introduction

Microstrip antenna or patch antenna type is the most common form of printed antennas. This antenna is low profile geometry, light weight and also low cost. The disadvantages of this type of antenna are low efficiency, low power-handling capability and also narrow frequency bandwidth. This type antenna consists of a metal patch on a substrate on the ground plane. Basically, the width of the patch is smaller than λ_0 while the length of the patch is in the range between $\lambda_0/3$ and $\lambda_0/2$.

Because of high demand in multiple application, the researcher had been introduced the technique to cater this problem. The antenna needed by the user must also easy to use, mobility and small in size. There are many methods has been approached to design the multiband antenna that can operate in many frequencies range. The example methods are Minkowski shaped patch [1], inverted F-shaped patch [2], slotted on the ground, slot on patch, fractal structure [3], defected ground plane [4], addition and changes of patch shape, hook-shaped [5] and shorting pin technique. The slot method for gain dual band can be existed by placing a single or multiple slots on the patch part (in front) or on the ground plane (bottom) or both. There are many researches that apply this method, for the examples are spiral slot [6], H-shaped slot [7], L-shaped slot [8], circular slot [9], slotted PIFA [10], CPW-fed slot [11] and slot loop [12].

In [13], the researcher had been designed a triple-band fork-shaped printed slot. The patch antenna design had been embedding a slot in the ground plane. An extra resonant band of 1.8 GHz (GSM application) is obtained by this elliptic shaped slot. In [14], a square patch microstrip antenna is designed to determine dual-band by embedding five asymmetrical slots on the patch plane. The basic patch antenna design with truncated corner had been operating at 2.5 GHz for lower band of WiMAX application while the five asymmetrical slots on the patch plane had been effect the better return loss on the high band of WiMAX application of 5.7 GHz. Both opposite truncated corners and asymmetrical slots are used to get the circular polarization by affecting the magnetic field around the slots.

A rectangular patch with dual operating frequency is designed in [15]. In this work, two narrow slots are etched on the rectangular patch to close. These slots are parallel to the radiating edges of the patch which closed to the minimum current location. The currents circulate around the slot and produce a secondary operating frequency and the upper frequency can be controlled by changing the slot length. Narrow slot that's embedded on patch is also one of the methods approached to determine multi-band antenna.

In [16], two narrow slots are embedded on E-shaped patch antenna that operate at 2.4 GHz, 5.4 GHz, and 5.8 GHz frequency ranges. The E shaped antenna is designed based on the dimension of rectangular patch size of the fist resonant frequency, and the slot loaded is providing an extra current path then, extra resonant frequency presets. The size of the current path which depends on the slot sizes affects the second and the third resonant frequency.

In this work, a double C-shaped slot had been embedded to investigate its effects on the return loss, resonant frequencies, bandwidth, radiation pattern and gain of the antenna. Parametric study with different dimension are also had been considered in Design III (A, B, C and D) and Design IV (A, and B).

II. ANTENNA DESIGN

This rectangular patch antenna design is focusing at frequency 2.4 GHz and 5.2 GHz because it is in the ISM band and it is one of the unlicensed bands. All of the designs are designed using the FR-4 board as the dielectric which has the dielectric constant, $_r$ equal to 4.4, tangent loss, tan δ equal to 0.019 and substrate thickness, *h* is 1.6 mm [17-20]. The patch and the ground plane consist of the conducting material which in this project, the material used is copper. The thickness of conducting plane (copper) is 0.035mm.

The first design (Design I) is the basic rectangular patch antenna. This antenna is designed for 2.4 GHz resonant frequencies. This antenna will be used as the benchmark for the comparison with the enhance design. This antenna consists of three layers; patch, substrate, and the ground plane at the back.Figure 1 shows the schematic diagram of the rectangular patch antenna.

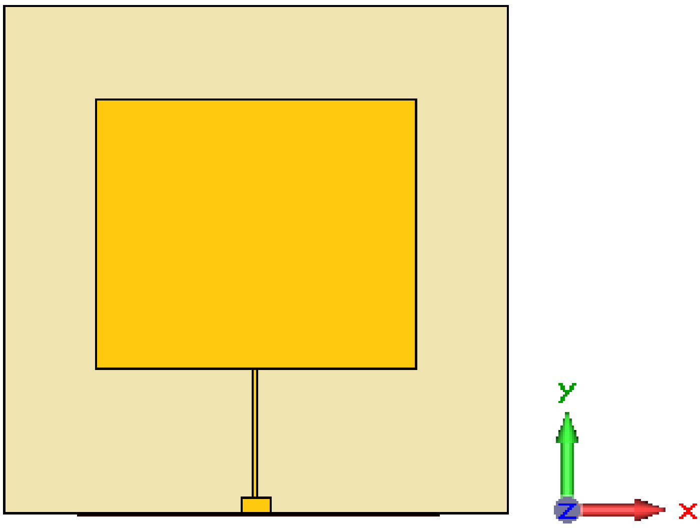

Figure 1: Schematic diagram of rectangular patch antenna

The dimensions of the patch of the antenna are the part that controls the designed frequency which by means the width, W and length, L of the patch is the parameters that depends on the resonant frequency of the design. Both W and L are determined by using calculations. The dimension of the antenna's patch is 34.50 mm x 29.31 mm. The feedline dimension is also determined by the calculation. The impedance of the feeding port used for this antenna is 50 Ω.

All C-Shaped Slot Antenna (Design II, Design III and Design IV) are similar shaped with the basic rectangular patch antenna. These patch antennas consist of the substrate (dielectric), and the ground plane and the material of each plane are also similar. There are many parameters that effect this C-shaped antenna such as slot width, slot radius, position of slots, the number of slots, and the separation between the slots.

The Design II structure of antenna's geometry is as shown in Figure 2(a). From the figure, there is a double C-shaped slot which create the additional of second frequency, then makes the antenna act as a dual-band antenna. Figure 2(b) shows the parametric study on the different patch width. Four different dimensions are considered in this parametric study is 31.50 mm for Design III(A), 29.54 mm for Design III(b), 28.56 mm for Design III(C) and 26.60 mm for Design III(D). Design IV in Figure 2(c) is an optimization step to get the right frequency bands. In this stage the antenna had been redesigned to the new patch width of 26.35 mm and new substrate width of 47 mm. Table 1 shows the comparative dimension (patch width and substrate width) of the various designs.

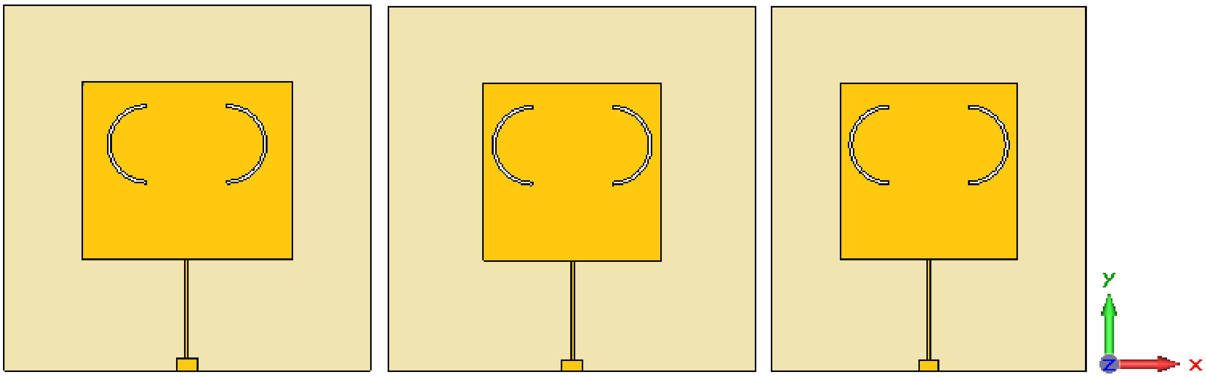

Figure 2: Schematic diagram of the rectangular patch antenna with C-shaped slot (a) Design II, (b) Design III(ID), (c) Design IV(B)

Table 1: Different patch width and substrate width of the rectangular patch antenna

Design	Patch Width	Substrate Width
I	34.50	55.00
II	31.50	55.00
III(A)	31.50	55.00
III(B)	29.54	55.50
III(C)	28.56	55.00
III(D)	26.60	55.00
IV(A)	26.60	47.00
IV(B)	26.35	47.00

III. Result

Figure 3(a) shows the return loss of the rectangular patch antenna (Design I). It shows that this antenna operates in the frequency range between 2.368 GHz and 2.435 GHz with a narrow bandwidth of 67 MHz. This antenna creates only a single resonant frequency of this antenna is at 2.404 GHz. The gain of this antenna is 3.357 dB. Table 2 shows the resonant frequency, return loss, bandwidth, and gain result performance of the Design I and Design II.

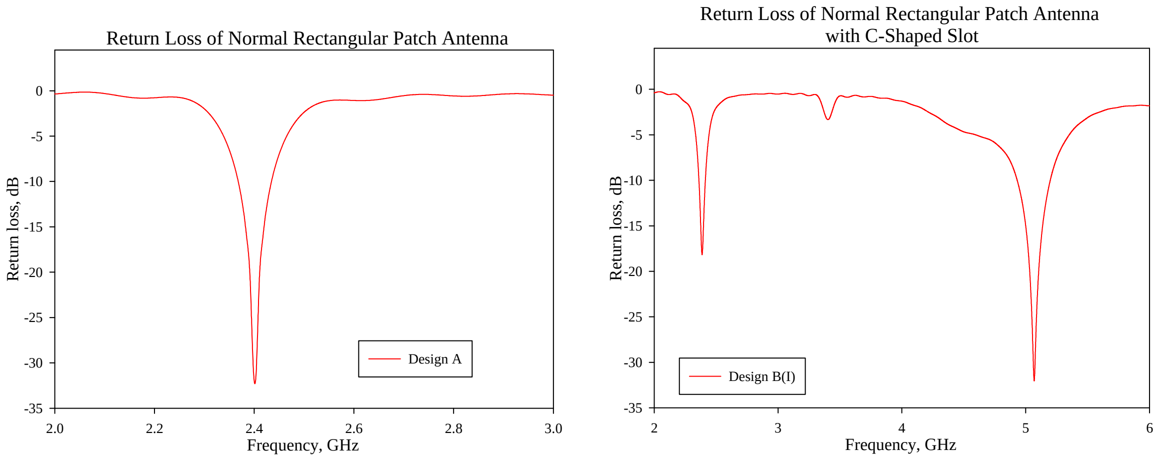

Fig. 3

Figure 3: Return loss result (a) normal rectangular patch antenna (Design I), (b) rectangular patch antenna with C-shaped slot (Design II)

Table 2: Resonant frequency, return loss, bandwidth, and gain result performance of the Design I and Design II

Design	Resonant frequency	Return loss	Bandwidth (MHz), Frequency range (GHz)	Gain
I	2.404	- 30.974	67, 2.368 – 2.435	3.357
II	2.386	- 18.176	52, 2.313 – 2.413	3.751
	5.068	- 32.025	267, 4.931 – 5.198	2.971

Figure 3 (b) represents the return loss performance of the rectangular patch antenna with C-shaped slot antenna (Design II). The first resonant frequency of this antenna is shifted from 2.404 GHz to 2.386 GHz. This C-shaped slot are effect to create another resonant frequency in the 5.068 GHz of frequency (second resonant frequency). The return loss for first resonant is – 18.176 dB while in resonant frequency is – 32.025 dB. The gain of this antenna is 3.751 dB for first resonant frequency and 2.971 dB for the second resonant band.

Figure 4 shows the parametric study of return loss for a rectangular patch antenna with C-shaped slot (Design III). The parametric study that consider in this graph is the different path width. The first graph shows the return loss in the frequency range between 2.0 GHz and 6.0 GHz while the second graph focusing on the second resonant frequency (frequency between 4.6 GHz and 6.0 GHz).

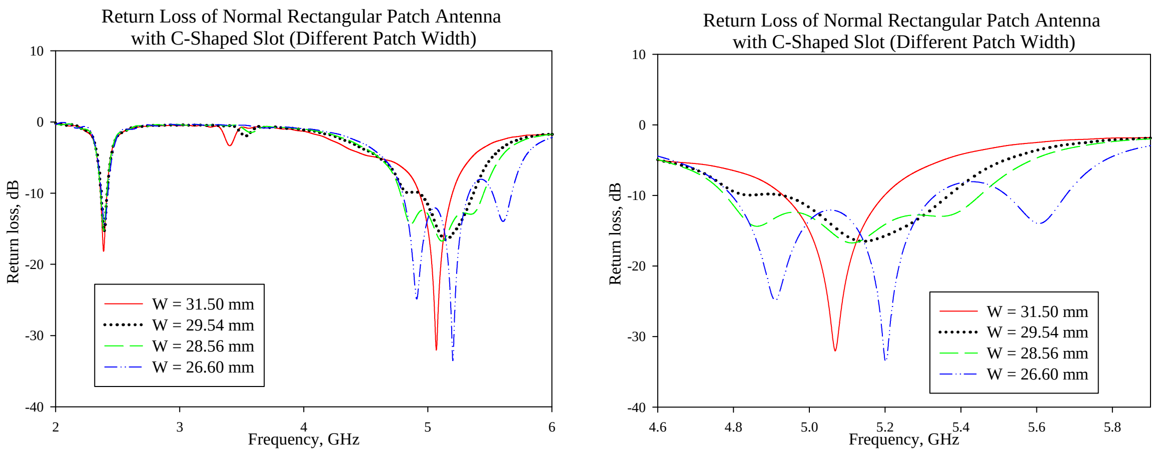

Figure 4: Return loss of rectangular patch antenna with C-shaped slot (different patch width), (a) 2.0 GHz to 6.0 GHz range, (b) 4.6 GHz to 6 GHz range

Table 3: Resonant frequency, return loss, bandwidth, and gain result performance of rectangular patch antenna with C-shaped slot Design III

Design, width (mm)	Resonant frequency	Return loss	Bandwidth	Gain
III(A), 31.50	2.386	- 18.176	52, 2.313 – 2.413	3.751
	5.068	- 32.025	267, 4.931 – 5.198	2.971
III(B), 29.54	2.392	- 15.374	50, 2.365 – 2.415	3.415
	5.146	- 16.495	438, 4.930 – 5.368	3.548
III(C), 28.56	2.386	- 15.241	51, 2.362 – 2.413	3.251
	4.858	- 14.349	671, 4.778 – 5.450	2.359
	5.110	- 16.727		4.215
	5.356	- 12.942		1.369
III(D), 26.60	2.392	- 14.470	53, 2.368 - 2.421	2.672
	4.912	- 24.852	538,4.795 - 5.333	3.917
	5.200	- 33.344		4.294
	5.608	- 13.969	156, 5.521 - 5.677	0.163

It shows that in Table 3, width = 31.50 mm had been creates two resonant frequencies, width = 29.54 mm create two resonant frequencies, width = 28.56 mm create four resonant frequencies while width = 26.60 mm had been creates four resonant frequencies. The first resonant frequency bandwidth for all dimensions stated a nearly same of result, achieve only a narrow bandwidth (operate between 50 MHz and 53 MHz). The significant resonant frequency shifted is shown at second, third and fourth resonant frequency.

The best return loss at the first resonant frequency are shown by Design III(A) with - 18.176 dB at resonant frequency of 2.386 GHz while the worst shown the Design III(D) with only – 14.470 dB at resonant frequency of 2.392 GHz. The wide bandwidth is shown by Design III(C) with 671 MHz (frequency between 4.778 GHz and 5.450 GHz).The best gain performance is achieved by the third resonant frequency of Design III(C) with 4.215 dB while the worst is achieved by the fourth resonant frequency of Design III(D) with only 0.163 dB.

Figure 5 shows the return loss of the Design IV with two different patch dimension – Design IV(A) and Design IV(B). Table 4 represents the resonant frequency, return loss, bandwidth, and gain result performance of the rectangular patch antenna with C-shaped slot (Design IV). This optimization size of the antenna had been done to shift back to the wanted resonant frequency. From the graph, it shows that both two designs had been created four different resonant frequencies. The Design IV(A) are resonating at 2.392 GHz, 4.912 GHz, 5.182 GHz and 5.596 GHz while Design IV(B) resonate at 2.398 GHz, 4.918 GHz, 5.200 GHz and 5.632 GHz. The best return loss is shown by the third resonant frequency in Design IV(A) with – 33.471 dB at 5.182 GHz while the worst return loss had been shown by the fourth resonant frequency of – 14.077 dB at 5.632 GHz.

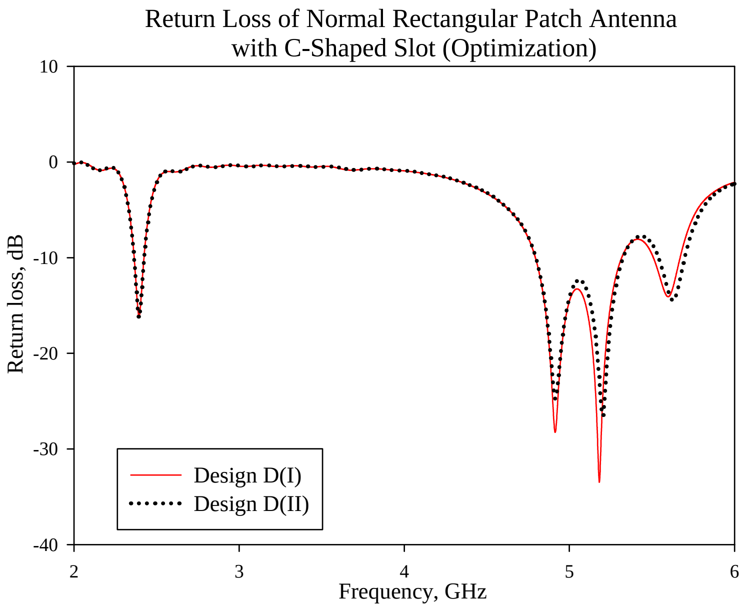

Figure 5: Return loss of rectangular patch antenna with C-shaped slot (Design D)

Table 4: Resonant frequency, return loss, bandwidth, and gain result performance of rectangular patch antenna with C-shaped slot (Design IV)

Design, width (mm)	Resonant frequency	Return loss	Bandwidth	Gain
IV(A)	2.392	- 16.072	59, 2.365 – 2.424	2.702
	4.912	- 28.203	524, 4.793 – 5.317	3.830
	5.182	- 33.471		4.155
	5.596	- 14.077	162, 5.509 – 5.670	0.462
IV(B)	2.398	- 16.183	61, 2.365 – 2.426	2.616
	4.918	- 24.715	529, 4.797 – 5.698	3.863
	5.200	- 26.542		4.165
	5.632	- 14.415	159, 5.540 – 5.698	0.309

Figure 6 shows the 3D radiation pattern of the C-shaped slot antenna – Design IV(B). The best gain performance in Design IV is achieved by the second resonant frequency of Design IV(B) with 4.165 dB while the worst is achieved by the fourth resonant frequency of Design IV(B) with only 0.309 dB.

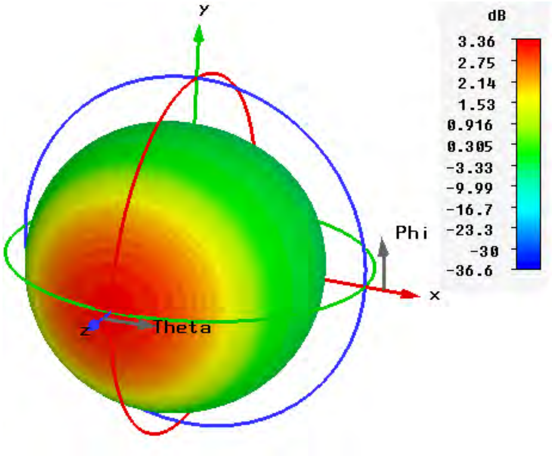

Figure 6: 3D radiation pattern of rectangular patch antenna with C-shaped slot of Design IV(B)

Figure 7 shows the surface current of the rectangular patch antenna with C-shaped slot of Design IV(B). At the first resonant of 2.398 GHz, it shows that the current flow are focusing at the C-shaped slot structure. There are also a little current flow effect at the feedline and also at the outer border of the patch antenna part. The current flow is more larger at the second resonant of 4.918 GHz comparing with the first resonant frequency. The feedline also shows significant effect to the surface current. At a third resonant frequency of 5.200 GHz and fourth resonant frequency of 5.632 also shown the same effect like the first resonant frequency.

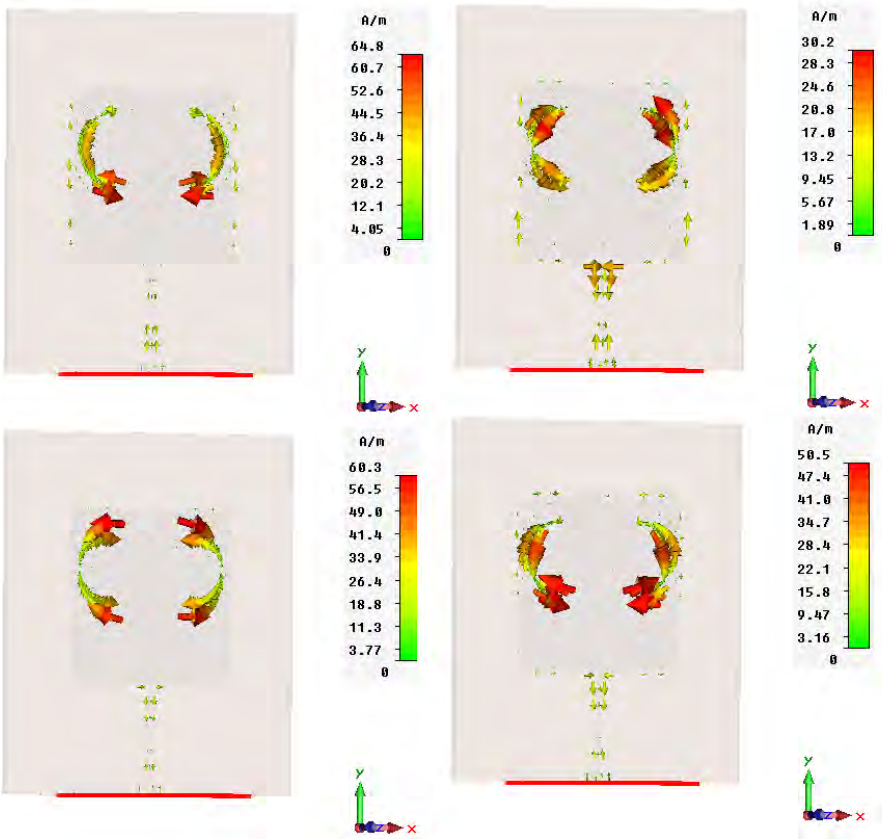

Figure 7: 3D radiation pattern of rectangular patch antenna with C-shaped slot of Design IV(B); (a) at 2.398 GHz, (b) at 4.918 GHz, (c) at 5.200 GHz, (d) at 5.632 dB.

The proposed antenna design can be integrated with RF transmitter and RF receiver [21-22] to form a complete WLAN front-end system. This rectangular antenna also had been potential to enhance its performance by adding the split ring resonator into the patch part of the antenna [23-24].

IV. CONCLUSION

The rectangular antenna without any slot structure (Design I) only operates in the single resonanct frequency. By the comparison in terms of all three design (Design II, Design III and Design IV), it shows that all three antennas with C-shaped slot design can perform a dual band or four band antenna. The patch size of Design *D* the smallest compared to the rectangular patch antenna (reduced size of 34.73 %).

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