Dual-band Stacked Patches Antenna Design with Three-Shaped Slots for GSM and WLAN Application

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***Abstract*—This paper presents a design of compact dual-band antenna for wireless telecommunication system. The operating antenna frequencies for this antenna are at ISM bands of 1.8 GHz of GSM and 5.2 GHz of WLAN applications. The designing process begins with a basic rectangular patch antenna with three shaped slots followed by the dual-band antenna with stacked patches. The antenna was designed by embedding a parasitic element with three-shaped slot structures. The design also used a triple layer with air gap (stacked patches) to enhance the gain of the antenna. Next, the optimum designs were simulated and measured and the results were compared to each other. The measurement results of this antenna showed a return loss of – 12.223 dB and - 11.904 dB at 1.81 GHz and 5.23 GHz of resonant frequencies and a performance of 3.01 dB and 1.76 dB, respectively.**

***Index Terms*—Dual-band; GSM; WLAN; Patch Antenna; Stacked Patches.**

I. INTRODUCTION

Having high capacity is very crucial in wireless communication as it is a requirement for future applications. This requirement is prior to the amount of data transferred by users, which nowadays has become very large. For example, in the early years, the data transferred consisted of a text or voice message only. However, as time goes by, users have demanded for a higher channel capacity to send a voice message with pictures, or a text with a video, or a text, picture, and video at the same time. These data require more capacity to be transferred. One of the main challenges in wireless communication is to gain high capacity in order to fulfill future application necessities. Thus, it is important to increase the amount of data transferred simultaneously.

Presently, many mobile communication systems use numerous frequency bands, such as GSM 900/1800/1900 bands (890-960 MHz and 1710-1990 MHz)[1-3]. Considering that a single antenna cannot function in all of these frequency bands of mobile communication, multiple different antennas that individually cover these bands should be used. Nevertheless, the usage of numerous antennas is typically limited by the capacity and cost constraints of the applications.

Due to these justifications, the current communication devices are becoming more portable and have the ability to support multi-applications, such as Bluetooth, WLAN [4-6], WiMAX, and many more. These applications use different operating frequencies in order to avoid interferences between them. The conventional way to support this demand is by placing two or more antennas with different resonant frequencies in the respective device. However, this method is clearly not efficient due to the difficulties in integrating two or more antennas as they are more likely going to couple with each other, causing degradation of the received or transmitted signals [7].

Placing two antennas in a device is found to trigger space issue since it is usually designed to be a portable device. In this context, placing multiple antennas will require more space. Hence, another way to support multi-frequency demand without facing any of those problems is by using multi-band antennas that consist of only one simple and efficient structure antenna that can support dual-frequency ranges

This is quite challenging as placing two antennas at a distance of half wavelength is necessary to achieve good isolation [8]. Furthermore, if the antennas are in a large size, more space will be required for the spacing and the antennas. Having large-sized antennas are not practical and inefficient.

In the paper of Nayari [9], the stacked patches with asymmetric U-Slots at the antenna had been identified as an effect to reflect the dual-band frequency band at 3.5 GHz for WiMAX and at 5.8 for HiperLAN application. In another paper, Zakaria [10] showed that the effect of stacked patches with circular polarization created two different frequencies at 2.45 GHz and 5.8 GHz.

There are several papers that show the effect of the reduced size in the slots at the patch antenna. These papers are [11] and [12]. Examples of the antenna gain increment by applying the stacked patched are in [13-14].

The air gap structure has the capability to enhance the gain of the antenna and increase the level of isolation. For example, in [15], the increment of the level of isolation is up to 1.5 times bigger than the antenna without a gap and the increment of gain from 3.12 dB (without gap) to 12.53 dB (with 10 mm gap).

In this work, a compact dual-band antenna has been designed using a parasitic element with three-shaped slot and stacked patches.

II. Antenna Design

The compact dual-band antenna was designed by combining two of the C-shaped slots and creating a slot that looks like the shape of number three.

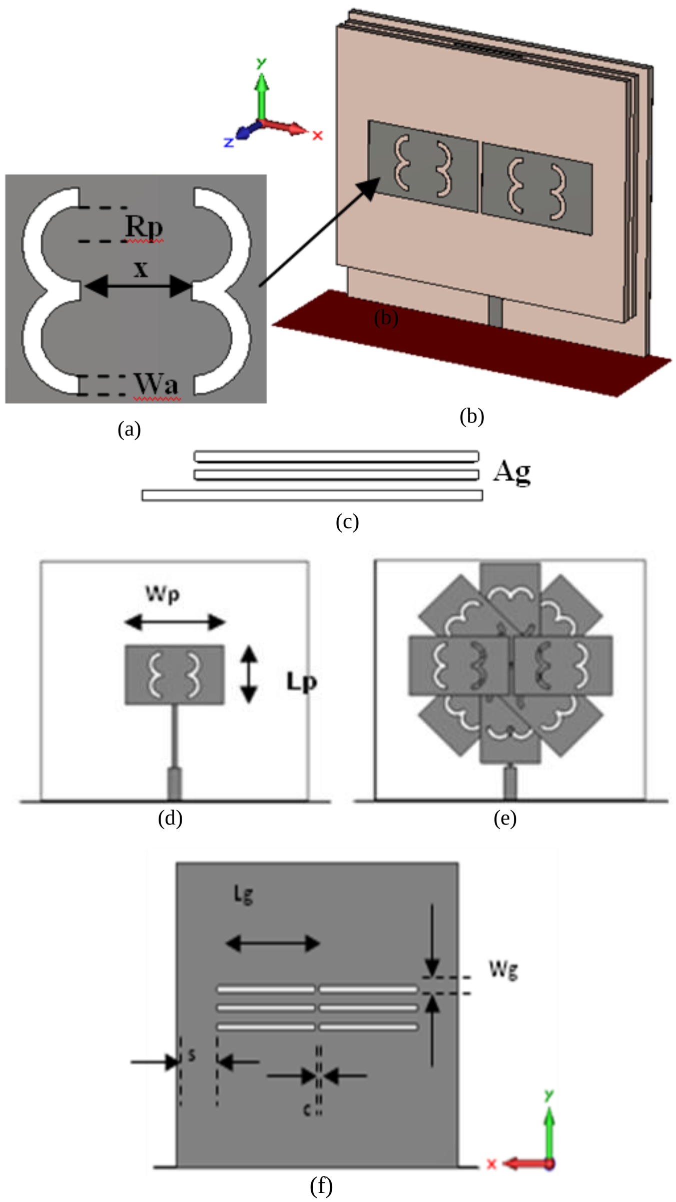


Figure 1: The dual-band antenna design, (a) three-shaped slots, (b) perspective view of the antenna, (c) side view that show three layer technique with air gap, (d) patch antenna (third layer), (e) The flower variation of the three-shaped slots (hidden substrate to show the variation), (f) ground plane with tri-slots

This design uses the dielectric and conductor material of FR-4 and copper respectively. Figure 1 displays the schematic diagram of the compact dual-band antenna, which contains three layers of FR-4 substrate, namely the lower substrate (containing the patch and the feedline of the antenna), middle substrate and upper substrate.

The dimension of the patch antenna, *Wp* is 23.05 mm width and *Lp* is 14 mm length. The addition of the three-shaped slot was effective in creating the dual-band resonant frequencies to the antenna. In addition, two main parameters were considered to provide the significant effects to the performance results at the patch antenna, which are the three-shaped slot width, *Wa* and the slot radius, *Rp*.

To further illustrate, the embedded tri-slots at the ground part, are effective to reduce the size of the antenna design. The optimized dimension width of the slot, *Wg* is 1 mm while the length, *Lg* is 21.83 mm. The basic rectangular antenna without slots has the dimension of 26.88 mm x 16 mm. With the addition of the three-shaped slots, it can be reduced to only 23.05 mm x 14 mm. The parameters that change the performance of the antenna are separated horizontally between the slots, *c* and slot width, *Wj*. The increase of the *c* and *Wj* dimension reduced the return loss of the second resonant frequencies. This technique can be done to control the needed resonant frequency at this point.

The air gap technique at the substrate layers functioned to increase the gain performance of the antenna. In the last design, it had a 3.0 mm, which was the maximum increment of the gain. Compared with the no air gap (*Ag* = 0 mm), the gain of the antenna increased when *Ag* = 1 mm and 2 mm, while it reduced its performance, if the *Ag* = 4 mm.

It shows that the basic rectangular antenna achieved the resonant frequency at 1.8 GHz with a return loss of – 20.15 dB and 1.235 GHz of the antenna gain. This basic antenna reflects a single frequency band only in comparison to the proposed antenna. Table I describes the optimized dimension of the compact dual-band antenna.

Table 1
Optimized dimension of design

Parameter	Dimension (mm)
Patch width, *Wp*	23.05
Patch length, *Lp*	14
Three-shaped slot width, *Wa*	0.5
Three-shaped slot radius, *Rp*	2.6
Ground slot width, *Wg*	1.0
Ground slot length, *Lg*	21.83
Distance between patch slots, *x*	3.0
Distance between groud slots, *c*	1.0
Distance slot from edge, *s*	9.2
Air gap between layer, *Ag*	3.0

III. Result

Figure 2 presents the return-loss performance of the dual band antenna. It signifies that this antenna is operating at two different resonant frequencies of 1.83 dB and 5.2 dB with - 12.011 dB and - 12.433 dB for the simulation, while 1.81 dB and 5.23 dB with – 12.223 dB and - 11.904 dB for the measurement. There are notches at 3.41 dB (simulation) and 3.43 dB (measurement). However, this design could not be counted because it did not reach the requirement of – 10 dB of the return-loss performance. The return losses at these two points were marked at only - 6.02 dB and - 5.27 dB, respectively.

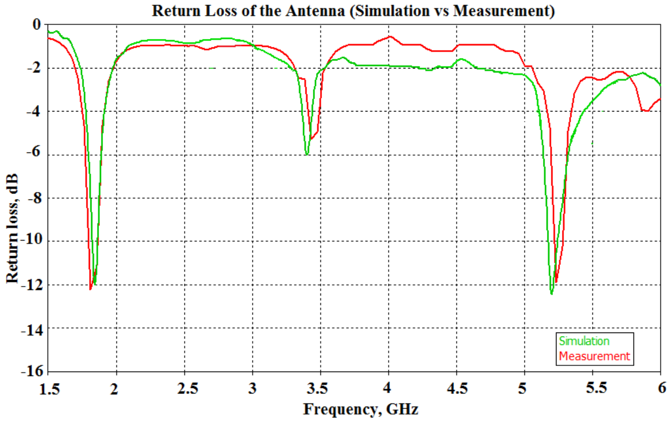
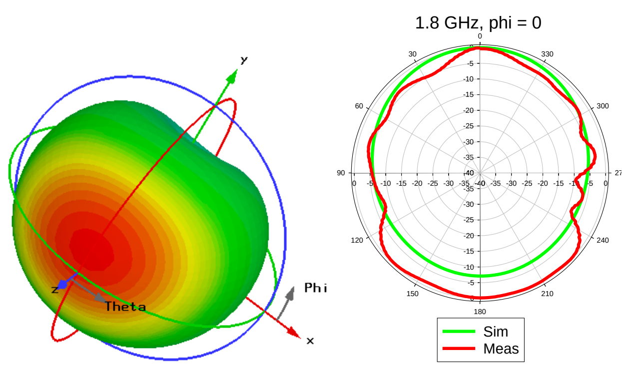


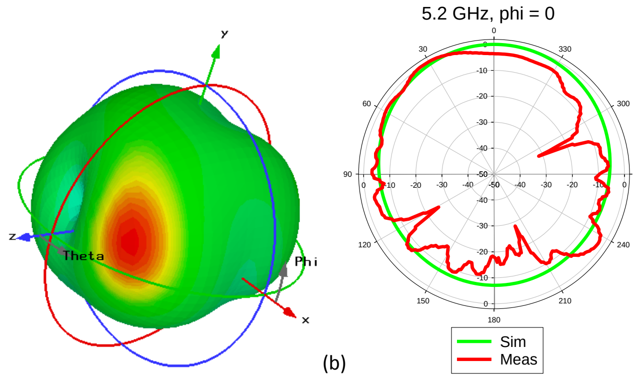
Figure 2: Return-loss performance of the dual-band antenna (simulation and measurement).

From the parametric study of the ground slots for the width dimension, *Ws*, further structure from the edge can affect the increase of the resonant frequency. However, the return loss increased as the distances of the ground slots from the edge, s of the antenna increased. As the ground slot became wider, the resonance frequency decreased. For instance, the parametric study of three-shaped slot width, *Wa* started with 0.5 mm until it reached an equal size to 2.0 mm. This justifies that as three-shaped slot width increases, the second resonant frequency also increases, with a contrary to the return loss that decreases as the slots get wider. This also means that the second resonant frequency will be increased as the three-shaped slot radius, *Rp* increases.

With reference to Figure 3, the polar plot radiation pattern performance (simulation versus measurement) of the dual-band antenna is explained in detail. At 1.8 GHz, the simulation of the radiation pattern of the antenna showed a figure of an oval shape, while the measured radiation pattern looked more like a circular shape. Further, at 5.2 GHz, the radiation pattern showed a circular-like shape for the simulation, while the measurement looked like the shape of a number eight (8). In this scenario, the gain increased after the three layers of FR-4 substrate with the three-shaped slots structure.



(a)



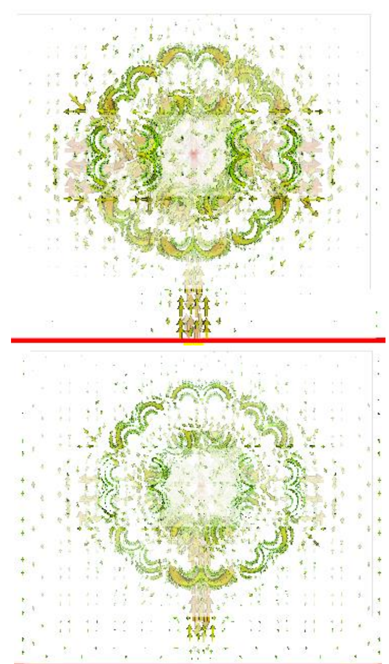
(b)

Figure 3: Radiation pattern performance (simulation vs measurement) of the dual-band antenna, (a) at 1.8 GHz, (b) at 5.2 GHz

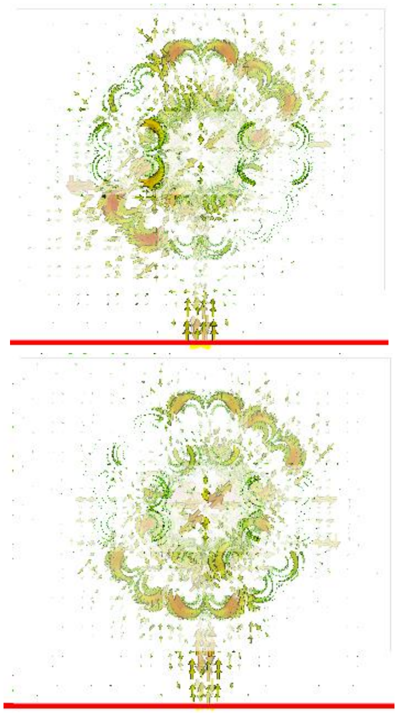
The gain of this antenna was 3.211 dB at 1.83 GHz and 1.874 dB at 5.2 for simulation. For the measurement results, the gain performance showed 3.045 dB at 1.81 GHz and 1.65 dB at 5.23 GHz. It showed that the gain capacity at 1.8 GHz of the proposed had been improved compared with the basic antenna from 1.235 GHz to 3.211 dB.

Based on the parametric study, the increment of the air gap between substrate layers, *Ag* has the tendency to increase the gain to the antenna but it also reduces the return-loss performance.

The analysis continues with the identification of the current surface of the dual band antenna at two different current phases of 0^0 and $90^{0,}$ as shown in Figure 4. Both resonant frequencies of 1.8 GHz and 5.2 GHz were found to have high current densities at the parasitic element with the three-shaped slots structure. It can be concluded that the wanted frequencies of these two frequencies can be control at this part of the patch antenna.



(a)



(b)

Figure 4: Surface current of the dual band antenna, (a) first resonant frequency at 1.8 GHz, current phase = 0^0 and 90^0 (b) second resonant frequency at 5.2 GHz, current phase = 0^0 and 90^0

It also shows that the current density concentrates at the feedline location of the antenna. This indicates that there is a higher current density at the lower part of the FR-4substrate as opposed to the middle and upper layers of the FR-4 substrate. This is led by the location of the lower substrate, which contains the patch antenna connected to the SMA connector via the feedline structure.

Figure 5 shows the surface current of the upper part of the parasitic element with three-shaped slot at the patch antenna for resonant frequency of 1.8 GHz at different phase = 0^0, 90^0, 135^0, and 180^0. It shows that the current is focusing at the three-shaped slot with numerous volumes at the edge of the parasitic element.

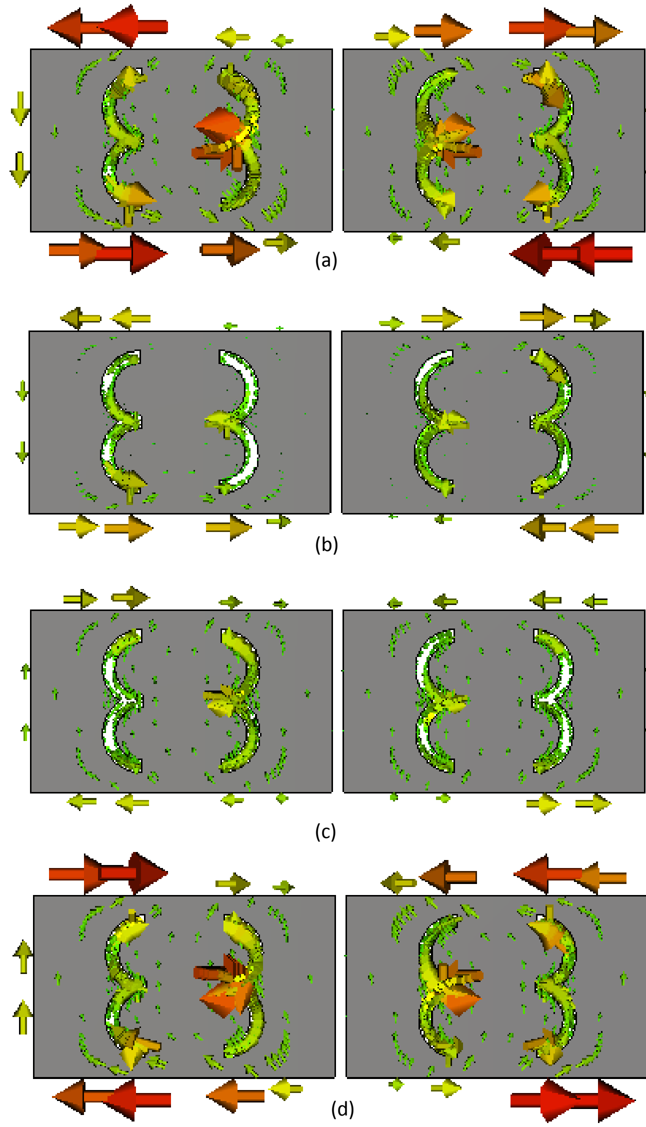


Figure 5: Surface current of upper part of the parasitic element with three-shaped slot at the patch antenna for resonant frequency of 1.8 GHz at different phase, (a) phase = 0^0, (b) phase = 90^0 (c) phase = 135^0, (d) phase = 180^0

Figure 6 shows the surface current at the ground plane of the antenna for resonant frequency of 1.8 GHz at different phase = 0^0, 90^0, 135^0, and 180^0. The surface current is focusing at the gap between the slots.

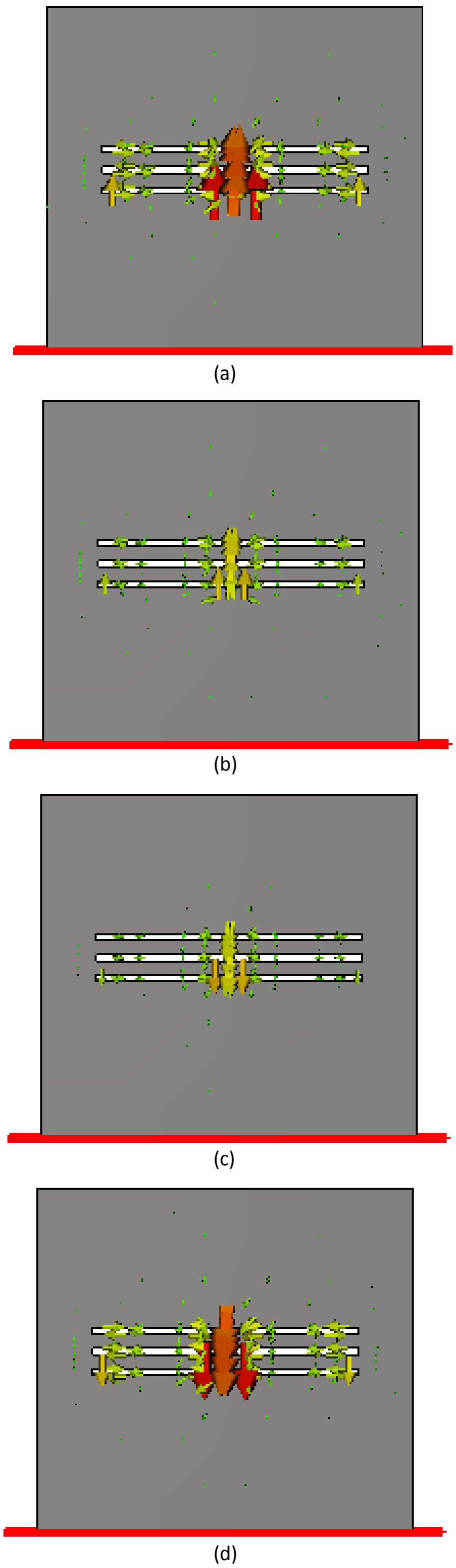


Figure 6: Surface current of the ground plane patch antenna for resonant frequency of 1.8 GHz at different phase, (a) phase = 0^0, (b) phase = 90^0 (c) phase = 135^0, (d) phase = 180^0

Table 2 shows the parameters for the dual band antenna (measurement) of resonant frequency, return loss, bandwidth and gain. The first resonant frequency showed 3.045 dB of gain compared with the second of 1.65 dB only. A dual band antenna, using triple layers of FR-4 substrate with air gap and parasitic element with three-shaped slots were proposed at two different frequencies of 1.8 GHz and 5.2 GHz. The measurements of the return-loss performance of this proposed antenna were 1.81 dB and 5.23 dB with – 12.223 and - 11.904 dB.

Table 2
Measurement results performance for dual band antenna

Parameter	Frequency band	
	Band 1	Band 2
Target resonant frequency (GHz)	1.8	5.2
Resonant frequency (GHz)	1.81	5.23
Return Loss (dB)	– 12.223	- 11.904
Bandwidth (MHz)	73	71
Gain (dB)	3.045	1.65

IV. CONCLUSION

In comparison to the basic rectangular patch antenna, this proposed antenna was designed to create a dual band antenna. This proposed antenna used triple layers of FR-4 substrate with air gap (stacked patches) and parasitic element with three-shaped slots was proposed at two different frequencies, namely 1.8 GHz and 5.2 GHz. The effect of return loss measurements of the proposed antenna was at the frequencies of 1.81 GHz and 5.23 GHz with the return loss of – 12.223 and - 11.904 dB, respectively. The simulation and measurement results show acceptable performance between them. There are many parameters that can be considered to control the required first and second resonant frequencies of the proposed antenna. The air gap between stacked patches, *Ag* can control the gain performance of the antenna, while the horizontal separation between the slots, *c* and slot width, *Wj* dimension reduce the return loss of the second resonant frequencies.

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