# Design of dual band slotted reconfigurable antenna using electronic switching circuit

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**ABSTRACT**

This paper proposes a dual band reconfigurable microstrip slotted antenna for supporting the wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) applications, providing coverage where both directive and omni-directive radiations are needed. The design consists of a feedline, a ground plane with two slots and two gaps between them to provide the switching capability and a 1.6 mm thick flame retardant 4 (FR4) substrate (dielectric constant Ɛ=4.3, loss tangent δ=0.019), modeling an antenna size of 30x35x1.6 $mm^3$. The EM simulation, which was carried out using the connected speech test (CST) studio suite 2017, generated dual wide bands of 40% (2-3 GHz) with -55 dB of $S_{11}$ and 24% (5.2-6.6 GHz) higher than its predecessors with lower complexity and -60 dB of $S_{11}$ in addition to the radiation pattern versatility while maintaining lower power consumption. Moreover, the antenna produced omnidirectional radiation patterns with over than 40% bandwith at 2.4 GHz and directional radiation patterns with 24% bandwith at the 5.8 GHz band. Furthermore, a comprehensive review of previously proposed designs has also been made and compared with current work.



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## 1. INTRODUCTION

In recent years, research in multiband antennas has gained a considerable interest due to their advantage in exploiting the unused frequency spectrum. Such antennas can be employed in various wireless applications. Configurable antennas, in particular, are under the spotlight of researchers with interest in electromagnetic spectrum usage. These antennas can be implemented using a variety of technologies, and the most trending type is the microstrip antennas justified by their low profile, light weight as well as their ability to produce multiple radiation bands [1]-[3]. The rising number of wireless devices is causing spectrum congestion which may increase collisions in the broadcasting channels. Antennas with reconfigurable structure offers an opportunity to modify them, enabling them to adapt with different frequencies by utilizing lumped elements including positive-intrinsic-negative (PIN) diodes. The idea is to manipulate the physical structure, such as the antenna length, which will shift the operating frequency to a lower or upper band depending on the configuration [4]. Moreover, this type of antennas are already employed in different applications including high range and close-range communications. Therefore, a switchable antenna provides more versatility, along with supporting vast wireless applications [5]-[7]. There is a variety of substrates that can be used to implement microstrip antennas, such as foam which has a positive impact on the antenna size reduction. Duroid is also popular for better performance since it delivers good gain with broad bandwidths [8]-[16]. Flame retardant 4 (FR4) on the other hand, is the most common of all since the fact it is inexpensive and provides significant mechanical properties, making it a suitable choice for manufacturing electronic components [17]-[21].

Several designs have been proposed over the last decade, with different implementation techniques and varied antenna properties, depending on the applications they support. The research in [22] has proposed a novel design of a microstrip antenna with a compact slotted configuration. To attain switching capabilities, a PIN diode was attached to the ground plane of the antenna. When the diode was turned on and off, it enabled the designed antenna to operate in the wireless local area network (WLAN) in one state and (WLAN, Bluetooth and worldwide interoperability for microwave access (WiMAX)) bands in the other state. The bluetooth, WiMAX and WLAN band frequencies range from 2.36 GHz to 2.5 GHz, 3.51 GHz to 3.79 GHz and 5.47 GHz to 5.98 GHz, respectively. Another study [23], has demonstrated a reconfigurable antenna design with a triple state with dual wide operating bands supporting the WLAN applications. The switching capability was achieved by using a PIN diode with triple state functionality that enabled the antenna to provide three difference frequency responses. The operating bandwidths were 2.4 to 2.6 GHz, 3.6 to 3.8 GHz and 5.45 to 5.8 GHz for bluetooth, WiMAX and WLAN applications respectively. Another antenna design was presented in [4] in which the antenna configuration utilizes a resonator with an H-shape radiator in addition to a double stub, as well as a double PIN-diode. Both of the stubs were placed in a symmetrical way on the top sides of the resonator connected to it using the PIN-diodes, thus enabling the antenna to operate in two bands. The first band was operating from 2.48 GHz to 2.53 GHz and the other band from 2.83 GHz to 2.85 GHz. The study of [24] illustrated its multimode monopole antenna design by switching the frequency response using PIN diodes, producing eight different bands. Three diodes were used for the switching purpose, thus causing a shift in the operating bands. By turning the diodes on and off, the antenna generated four modes, including bluetooth (2.4 GHz to 2.6 GHz) and WLAN (5.4 GHz to 5.6 GHz) bands. Moreover, the research of [25] has proposed a microstrip antenna design supporting WLAN and WiMAX applications operating in frequency ranges from 2.4 GHz to 2.45 GHz and 5.15 GHz to 5.35 GHz for WLAN and 3.3 GHz to 3.6 GHz for WiMAX. Numerous other research works [4], [22]-[26] proposed reconfigurable antennas generating dual and triple bands support for the 2.4, 3.5 and 5.5 GHz applications. In fact, there are designs that offered five band antennas such as [27].

Despite the good results these proposed designs have achieved in terms of some antenna properties, they still could not provide a significant improvement in the bandwidth. The wideband antennas have the ability to cover different standardized applications and deliver more versatility than the regular multiband antennas [28]. Additionally, there are some scenarios where directive antennas are appreciated, attached to the ceiling or hanged on the wall to cover dead zones where an omnidirectional antenna could be wasting radio frequency (RF) energy in undesired directions [29]. This paper presents a dual band switchable antenna with omnidirectional at 2.4 GHz and directional at 5.8 GHz. The design can support the WLAN (2.4G and 5G) as well as the WiMAX frequencies while [30] uses a switching circuit within a band reject filter to achieve switching circuitry in microwave to switch between band stop filter and all pass filter, in this work, a noval modified design based on that proposed by [18] is introduced throught using a series of single pole single throw (SPST) switches to produce 5 GHz frequency response operation without using extra circuitry to enable and disable 5 GHz response as well as to enhance the antenna radiation pattern.

## 2. ANTENNA DESIGN

There is a variety of substrates that can be used to implement microstrip antennas such as foam, duroid and flame retardant 4 (FR4), with each having its own pros and cons as discussed earlier.

### 2.1. Antenna theory

The antenna design equations that have been used for calculating the dimensions of the antenna from (1) to (4) as appeared in [31].

$$W = \frac{\lambda_o}{f_o\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

$$\epsilon_{reff} = \frac{(\epsilon_r+1)}{2} + \frac{(\epsilon_r+1)}{2}[1+12\frac{h}{w}]^{-1/2} \quad (2)$$

$$L = \frac{\lambda_o}{f_o\sqrt{\epsilon_{reff}}} - 2\Delta L \quad (3)$$

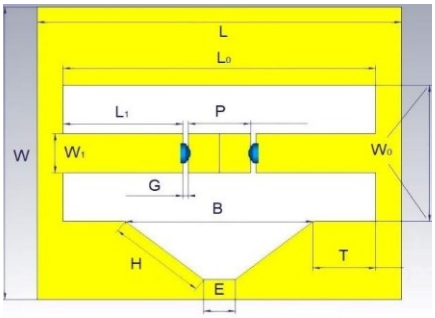
$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

$$f = \frac{c}{4L1\cdot\sqrt{\epsilon}} \quad (5)$$

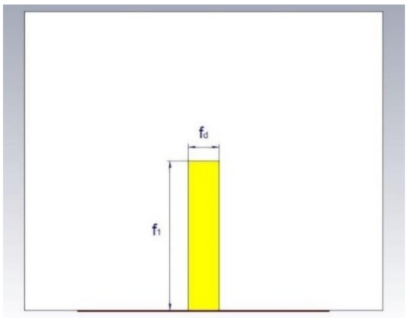
$$\epsilon = \frac{(\epsilon_r+1)}{2} \quad (6)$$

The designed antenna as shown in Figure 1 was rendered using the connected speech test (CST) studio 2017 computer aided design software. It consists of an FR4 substrate with a dielectric constant of 4.3 along with a loss tangent of 0.019. The ground plane is 35 mm wide, 30 mm long and 1.6 mm thick. On the other hand, a feed line of 50 ohms is placed on the back of the other side to be connected to the sub miniature version A (SMA).

There are a couple of slots etched on the ground plane with two 0.5 mm gaps in between them, cutting a strip of 6 mm long and 4 mm wide. The upper slot has a length of 30 mm and a width of 5 mm, while the lower slot is shaped like a strip line with a length of 30 mm punched in the ground plane, attached to a trapezoid slot having two 9.6 mm tilted sides as well as a 3 mm lower side, both etched back to back. The distance between the trapezoid edges is 18 mm while the sharp edge of the trapezoid slot is distant from the side edge by 6 mm. Moreover, the distance between the far edges of the slots is 14 mm. On the other hand, based on [32] conclusion the antenna feed gap affecting the bandwidth, therefor the feedline is placed on the other side of the antenna, facing the trapezoid lower side with a length and width of 15 mm 3 mm, respectively. As seen in Table 1 that shows the summery of dimenssions of the proposed antenna.




(a)




(b)

Figure 1. These figures are (a) ground plane, (b) front plane. The structure of the ground plane and the front plane of the designed antenna

Table 1. Designed antenna dimensions

| Parameters | Value (mm) |
|---|---|
| L | 35 |
| W | 30 |
| L1 | 11.5 |
| W1 | 4 |
| Lo | 30 |
| Wo | 14 |
| fd | 3 |
| f1 | 15 |
| G | 0.5 |
| T | 6 |
| P | 6 |
| E | 3 |

### 2.2. Switching circuit

As stated in [33] the change in geometry of shapes can result in energy gain, the proposed design based on manipulating with ground shape geometry. The gaps between the slots are not just regular gaps, each one is connected with a series SPST switching circuit. It was substituted by a special diode circuit using the CST lumped element tool, recognized by two blue pins, one in each gap. The components used in the switching circuit include three 1nF capacitors, two 30nH inductors and a proper dendritic cells (DC) bias as illustrated in Figure 2. Each PIN diode has an equivalent circuit consisting of an inductor connected in series with a resistor and a capacitor which are connected in parallel, based on the BAP65-02 model. These components govern the operating frequency of the designed antenna. The inductance value is 0.6nH while the resistance and capacitance values are 1 ohm and 0.65µF, respectively.

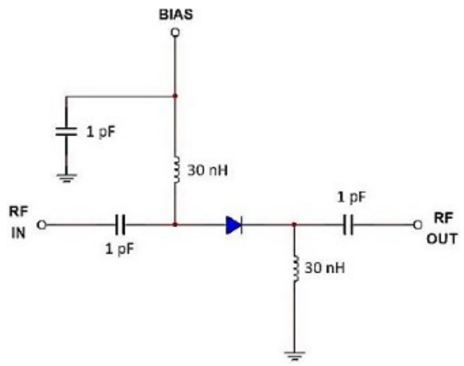



Figure 2. The SPST switch circuit

## 3. RESULTS AND ANALYSIS

The antenna implementation and simulations were carried our using the CST Studio Suite 3D EM simulation and analysis software 2017. The simulation results showed a change antenna responses with change of PIN diode status, see Table 2.

Table 2. Designed antenna performance

| Diodes State | Frequencies (GHz) | Bandwidths (GHz) | Radiation Efficiency |
|---|---|---|---|
| OFF | 2.4/5.8 | 2-3 GHz/3.6-3.8 | 80% |
| ON | 5.8 | 5.2-6.6 | 95% |

### 3.1. Frequency response

The resultant return loss is shown in Figure 3. As illustrated, when the switching diodes are OFF, only one band (5.2 GHz to 6. 6GHz) is generated, thus covering a bandwidth of 1.3 GHz (24%). On the other hand, when the switching diodes are ON, the gain of -10 dB was attained from the bandwidths ranging from 2 GHz to 3 GHz (40%) and from 5.2 GHz to 6.6 GHz (24%), supporting both of the WLAN and WiMAX bands. The dual bands are generated due to the effect of the etched slots on the ground plane, the slot with the tilted lines is causing a significant resonance in addition to its effect on the impedance matching.

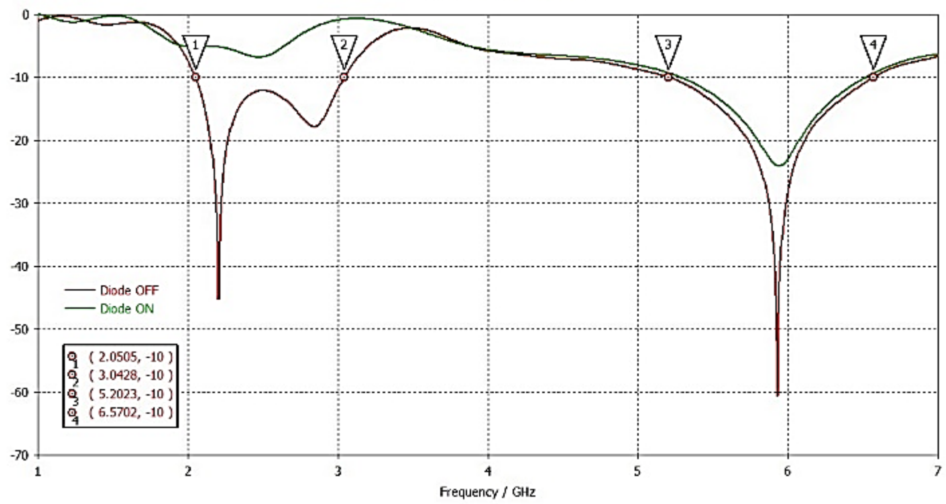
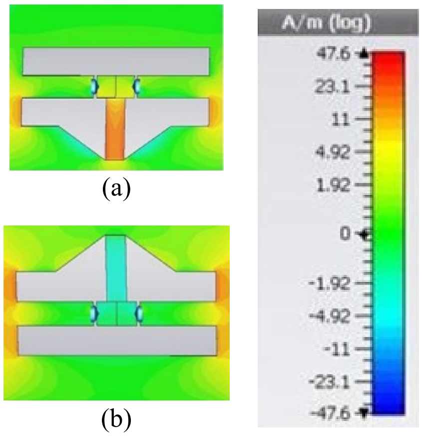



Figure 3. Simulated return loss of the designed antenna

### 3.2. Currents flow

Figure 4 shows the current flow at both operating bands. When the diodes are on, currents flow through the feedline and around the edges of the upper and lower slots, causing the propagation of the 2.4 GHz and 5.8 GHz bands. Turning the diodes off makes the currents to flow around the edges of the lower slot and through the feedline, generating the 5.8 GHz band only.

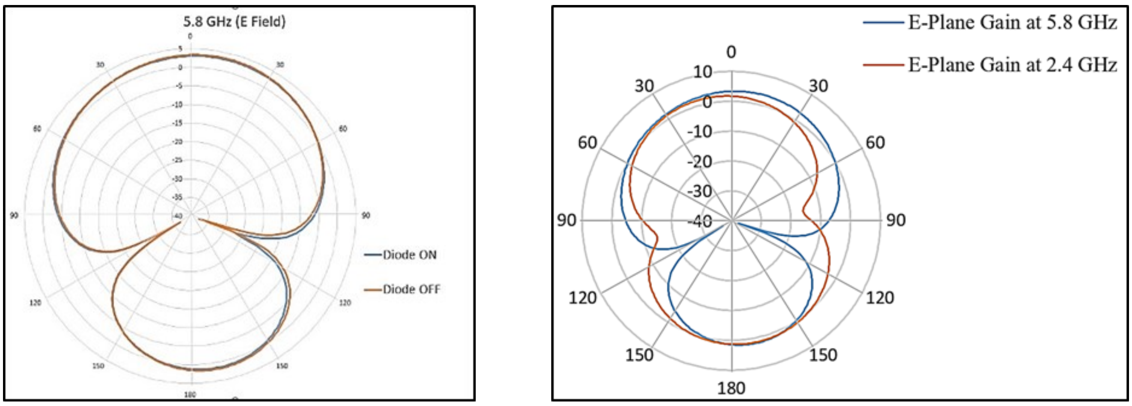



(a) (b)

Figure 4. These figures are (a) 2.4 GHz with 5.8 GHz, (b) 5.8 GHz. The currents flow of the designed antenna

### 3.3. Radiation pattern

Figure 5 shows the omnidirectional radiation patterns of the antenna at the 2.4 GHz band with 80% radiation efficiency with main and back lobes direction towards 15° and 115° degrees respectively. Furtherly, the antenna radiation patterns at the 5.8 GHz band showed 95% radiation efficiency and the main lobe which had higher power density than the back lobe, was radiating in the 12° direction, while the back-lobe's direction was at 118°.




(a) (b)

Figure 5. These figures are (a) radiation pattern of 5.8 GHz, (b) radiation patterns at 2.4 GHz & 5.8 GHz. The radiation patterns of the proposed antenna

As illustrated in Table 3, the proposed antenna is similar to the design of [18] in terms of the size. Additionally, the antenna operates in two wide bandwidths, wider than the reference designs in support for the WiMAX and WLAN applications while successfully achieving the highest bandwidth percentages. Moreover, the proposed antenna has been distinguished for producing two types of radiation patterns, an omni-directional patter at the 2.4 GHz band and a directional pattern in the 5.8 GHz band. As shown in Table 3 all previous designs were producing a uni-directional radiation patterns while this design produce a multi-directional patterns at the same time with different.

Table 3. Comparing the proposed antenna with other dual reconfigurable microstrip slot antennas

| Reference | Size ($mm^3$) | Bandwidth (GHz) | Radiation Patterns | Bandwidth Percentage % |
|---|---|---|---|---|
| [4] | 20 x 20 x 1.6 | 2.4-2.6, 3.6-3.8, 5.4-6.1 | Omni | 8, 5.4, 12 |
| [10] | 22 x 95 x 22 | 2.25-2.4, 3-3.3, 4.3-4.7 | Omni | 6, 9.5, 8.9 |
| [18] | 35 x 30 x 1.6 | 2.4-3, 3.25-3.68, 4.9-6.2 | Omni | 22.2, 12.3, 23.2 |
| [22] | 40 x 35 x 1.6 | 2.4-2.6, 3-4.5, 5-5.5 | Omni | 13.5, 35.7, 9.94 |
| [34] | 77 x 135 x 0.6 | 1.57-2.15, 2.13-3.0, 3.2-3.4, 5.2-5.8, 6.3-6.8, 8.3-8.9, 9-9.6, 12.03-13.14 | Omni | 31, 34, 8, 11, 7, 7, 6, 9 |
| [35] | 58 x 48 x 0.8 | 2.4- 2.35, 2.3-2.5, 2.11-2.35 | Omni | 7, 8, 11 |
| [36] | 37.8 x 27.1 x 1.6 | 3.20 - 3.67, 4.32 - 5.81 3.32 - 3.55, 5.46 - 6.51 3.18 - 11.72, 3.18 - 12.2 | Omni | 14, 29, 7, 18, 115, 117 |
| [37] | 20 × 45 × 1.5 | Narrow bands | Omni | - |
| [38] | 31 x 31 x 3.15 | 3.5 - 3.7 | Directional | 2.1 |
| [39] | 36 x 72 x 1.6 | 1.49 - 1.8, 5.4 - 5.6 | | 19, 4 |
| This work | 35 x 30 x 1.6 | 2-3, 5.2-6.6 | Omni, Dir | 40, 24 |

## 4. CONCLUSION

The paper has proposed a dual band switchable antenna for supporting the Wi-Fi and WiMAX applications. Several proposed antennas have been reviewed and compared to this work, where all of them have lower bandwith and single radiation pattern, only one design has very large bandwith with omni-directional radiation pattern shape. The designed antenna was implemented to achieve a switching capability using a special diode circuit called the series SPST switch which was substituted using an equivalent CST lumped elements circuit. The simulation of the antenna design has shown good results in terms of bandwidth, suitable for the WLAN and WiMAX applications. Adding to the above, the simulation has produced omnidirectional radiation patterns at the WiMAX band and directional radiation patterns at the WLAN band, thus achieving radiation pattern versatility.

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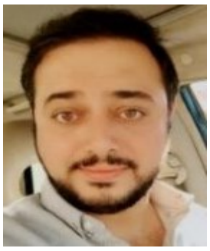

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