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# A Compact Slot-Antenna with Tunable-Frequency for WLAN, WiMAX, LTE, and X-Band Applications

**Fouad Fertas[1, *], Mouloud Challal[1], and Khelil Fertas[2]**

**Abstract**—In this paper, a new monopole compact antenna with tunable frequency fed by a coplanar waveguide (CPW) for WiMAX, WLAN, LTE bands, and X-band satellite communication system is presented. This is achieved by adequate combination of a new radiating patch element along with slots and switches. The simulation and measurement results show that depending on ON/OFF states, the proposed reconfigurable antenna, printed on an FR4 substrate, can operate in four applicable frequency bands, i.e., [2.37–2.75 GHz], [3.15–4.08 GHz], [4.48–5.92 GHz], and [6.69–8.31 GHz]. Very interesting results for the reflection coefficient, current distribution, and radiation pattern of the antenna are presented and discussed. The measured results are in good agreement with the simulated ones.

## 1. INTRODUCTION

The fast expansion in modern communication systems has required antennas with multifunctional properties very necessary in today's technology to cover several applications such as WLAN, WiMAX, GSM, UMT, PCS, DCS, GPS, and LTE in a single structure [1–6]. This is because it is possible to dynamically change the properties and characteristics of the multifunctional antenna such as operating frequency/bandwidt, polarization, and radiation patter. One of the advantages of these antenna types is their ability to reconfigure in frequency [7–9], hence, providing additional devices flexibility and durability. In addition, the size and hardware complexity may also be minimized. Depending on the switching states, the operating frequencies can be exchanged between various services [10, 11]. All designed structures cited in [12–16] have been restricted to one and/or two frequency bands. For that, many strategies for independent control of one or more frequency bands in wide ranges have been proposed [17–19]. A dual-band reconfigurable antenna with wide tuning range of 2.02 GHz was proposed in [17]; however, a voltage of more than 30 V was required, and the designed structure had relatively large size ($150 \times 110\,\mathrm{mm}^2$. In [18], a relatively large size planar inverted-F antenna ($105 \times 30\,\mathrm{m}^2$) was proposed to control three frequency bands. A dual-band antenna was introduced in [19] using a square ring with a tunable lower resonant frequency and fixed upper frequency. All these techniques present drawbacks such as large size and small tuning range.

In this paper, a new shaped coplanar waveguide (CPW)-fed patch antenna along with slots and switches for [2.37–2.75 GHz], [3.15–4.08 GHz], [4.48–5.92 GHz], and [6.69–8.31 GHz] frequency bands is proposed and studied. The frequency bands are independently controlled by using ideal switches which are realized by copper strips or metal pins [20–23] ensuring the ON/OFF mode of tunability. The measured antenna offers acceptable results in terms of good reflection coefficient, gain, and radiation pattern. The experimental results demonstrate that the proposed antenna is appropriate for WLAN/WiMAX/LTE and X-band applications including both RX (7.25–7.75 GHz) and TX (7.9–8.4 GHz) bands [24–28].

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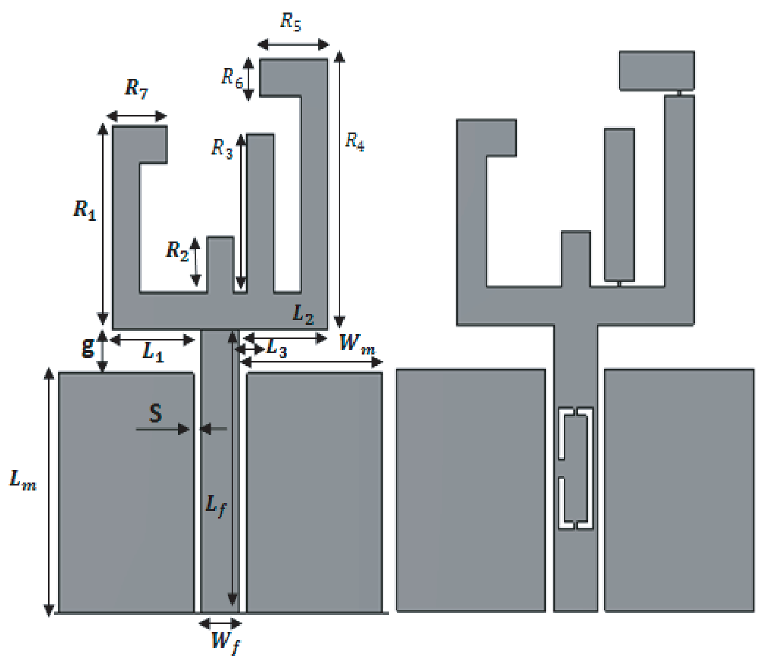
* Corresponding author: Fouad Fertas (f.fertas@univ-boumerdes.dz).
[1] Signals and Systems Laboratory, Institute of Electrical and Electronic Engineering, University M'hamed BOUGARA of Boumerdes, Algeria. [2] Ecole Nationale Polytechnique, Electronics Department, El-Harrach Algiers, Algeria.

## 2. ANTENNA DESIGN

The proposed CPW-fed reconfigurable antenna configuration for WLAN, WiMAX, LTE, and X bands is shown in Figure 1, and Table 1 illustrates its physical dimensions. The antenna is printed on an FR-4 substrate with $\varepsilon_r$ of 4.3, $\tan\delta$ of 0.017, and thickness $h$ of 1.6 mm. The design process is based on a modified patch element with an inverted C-shaped slot in the feed line and ideal switches ("ON state" and "OFF state" assured respectively by the presence and absence of a copper bridge). On each side of the CPW feeding line, two finite ground planes with the same size of length $Lm$ and width $Wm$ are realized. The basic antenna (without slots and switches) resonates at 2.4 GHz, 3.5 GHz, and 5–6 GHz, and when introducing an inverted C-shaped slot in the feeding line, a further band (6.69–8.31 GHz) controlled by a single switch (denoted by $S_1$) is obtained. Moreover, two rectangular slots of $2 \times 0.5\,\text{mm}^2$ are cut away from the radiator so that to control the current path direction. They are replaced by switches $S_2$ and $S_3$ which are used to control two frequency bands 5–6 GHz and 2.44 GHz, respectively, as shown in Figure 2. During the design process, it has been found that the slot and switch



(a) (b)

**Figure 1.** Proposed monopole antenna, (a) base antenna and, (b) reconfigurable slot antenna.

**Table 1.** Antenna dimensions.

| Parameter | Value (mm) | Parameter | Value (mm) |
|---|---|---|---|
| $W_m$ | 10 | $R_6$ | 2 |
| $L_m$ | 13 | $R_7$ | 4 |
| $S$ | 2 | $L_1$ | 8 |
| $R_0$ | 2 | $L_2$ | 8 |
| $R_1$ | 9 | $L_3$ | 2 |
| $R_2$ | 3 | $g$ | 2.4 |
| $R_3$ | 8.5 | $S$ | 0.3 |
| $R_4$ | 12 | $P_1$ | 6 |
| $R_5$ | 3 | $P_2$ | 1 |

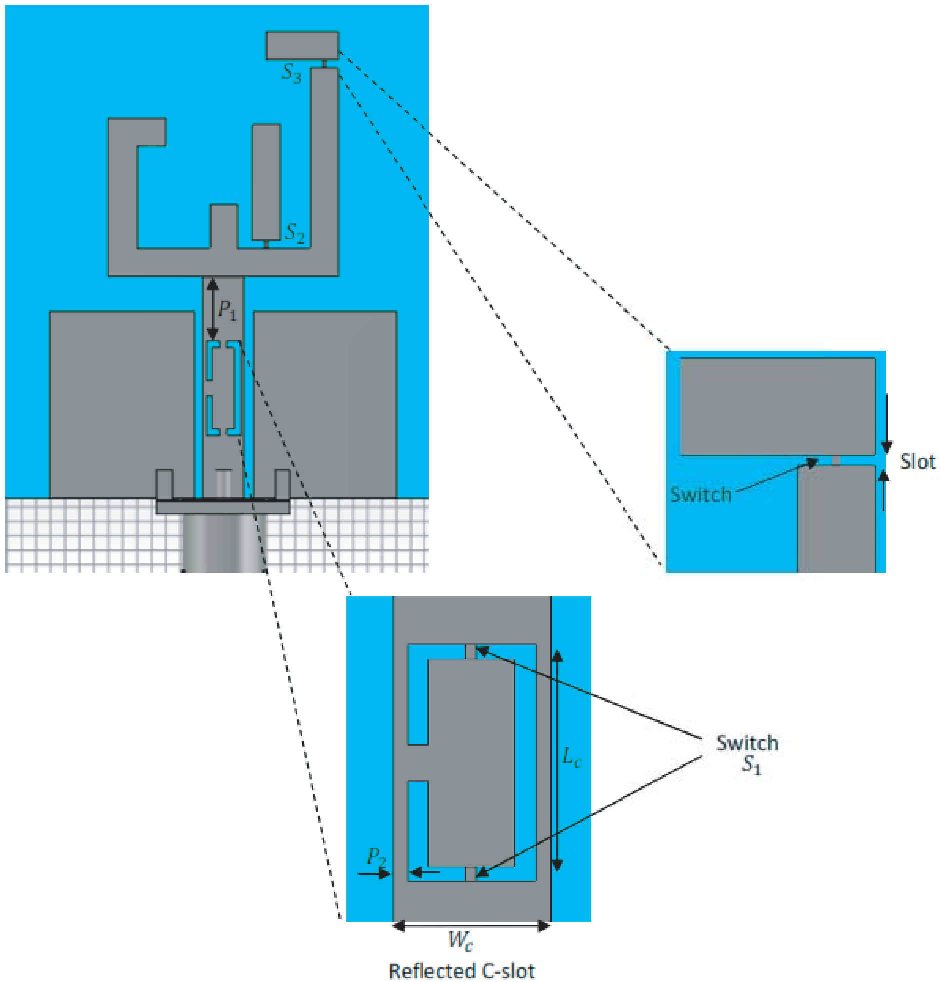



**Figure 2.** Antenna with slots and switches.

approach used in this research enables the antenna response to obtain an additional frequency band and offer the possibility to control three frequency bands according to the application's requirements.

## 3. RESULTS AND DISCUSSION

In this section, we will highlight the antenna behavior in a tunable mode. To design the antenna with multiple bands operations, independent frequency control is desirable. Achieving this operation is very challenging. More often, when one parameter is changed, all the frequency bands are affected, and the antenna needs to be completely re-optimized. The designed antenna shape has to be significantly changed, causing a lot of inconvenience in designing wireless devices.

To better understand the antenna operating mechanism, the surface current distributions of the whole antenna at four different frequencies are given in Figure 3. It can be clearly seen from the figure that $R1$ and $L1$ have a similar effect among the four frequencies with varying levels from one frequency band to another. At the first resonant frequency, the current is mostly concentrated in the arms of dimensions $R4$ and $L2$; consequently, the 2.44 GHz can be controlled by changing one of the two parameters $R4$ or $L2$. At the second resonant frequency, the current is more concentrated in the arms of dimensions $R1$ and $L1$ and in the feed line; hence, this second frequency can be controlled by the length of the feed line as well as parameters $R1$ and $L1$. At the third resonant frequency, the current is more concentrated on the feed line and the arm of dimensions $R3$ and $L3$, so that the frequency can be

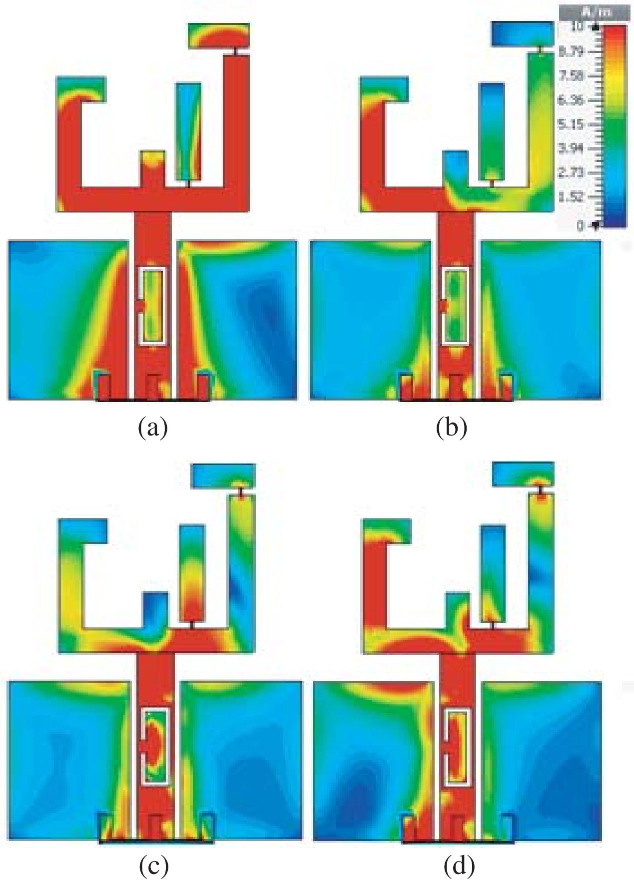



**Figure 3.** Surface current distributions at four different frequencies: (a) 2.44 GHz, (b) 3.5 GHz, (c) 5.6 GHz, (d) 7.2 GHz. CASE: $S_1$ OFF, $S_2$ ON and $S_3$ ON.

controlled by the length of the feed line as well as parameters $R3$ or $L3$. Concerning the fourth resonant frequency, the current is mostly concentrated on the feeding line as well as $L2$, while this resonant frequency can be controlled by adjusting either parameter $L2$ or the feeding line. Cutting slots on an antenna feeding line can change the current path and so can be used to generate one or more bands. We have in our case inserted an inverted C-slot to interrupt the current in this zone, and as a consequence, we recover the frequency 7.2 GHz. Without the inverted C-slot, the antenna has only one main current feeding line direction. However, in the presence of the inverted C-slot, the current path in feeding line is troubled. To have the desired frequency, only the inverted C-slot dimensions and its position in the feeding line must be taken into consideration.

The design process is based on the modified patch element with an inverted C-shaped slot in the feed line and switches (which are realized with ideal switches to ensure the ON/OFF tuning mode). Adding an inverted C-shaped slot in the feeding line makes the antenna response goes from three bands to four frequency bands; three of them can be managed independently, using only three RF switches. Two switches located in the inverted C-slot, as shown in Figure 2, act as a single switch $S_1$, i.e., both have a single state either ON or OFF and are responsible for the control of the fourth frequency centered at 7.2 GHz. The state ON allows the frequency band 7.2 GHz to be rejected; otherwise, when the switch is OFF, the antenna radiates again at 7.2 GHz. Two other switches $S_2$ and $S_3$ are mounted in the radiating element as shown in Figure 2. Switch $S_2$ controls the frequency band 5–6 GHz, while switch $S_3$ is used for controlling independent 2.44 GHz frequency band.

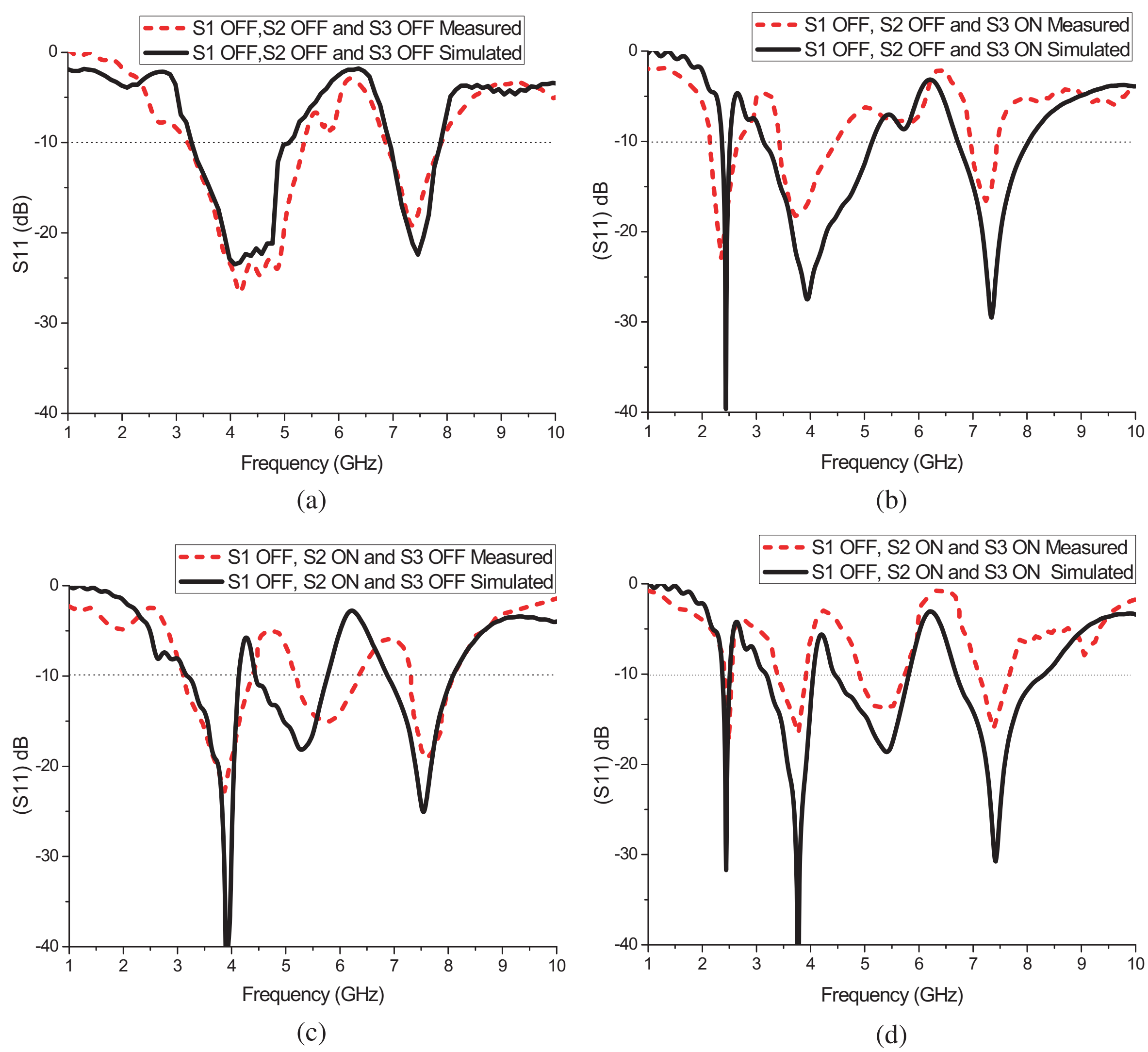
For the proposed antenna, there are eight possible switching scenarios which are summarized in Table 2. As seen in this table, the first, sixth, and seventh cases provide single band notched characteristics at 7.2 GHz, 2.44 GHz, and 5–6 GHz, respectively. The characteristic of dual notch band

**Table 2.** Different switching cases.

| Case | Notch bands (GHz) | $S_1$ | $S_2$ | $S_3$ |
|---|---|---|---|---|
| 1 | 7.2 | ON | ON | ON |
| 2 | 2.44 and 5–6 | ON | ON | OFF |
| 3 | 5–6 and 7.2 | ON | OFF | ON |
| 4 | 2.44, 5–6 and 7.2 | ON | OFF | OFF |
| 5 | None (four bands) | OFF | ON | ON |
| 6 | 2.44 | OFF | ON | OFF |
| 7 | 5–6 | OFF | OFF | ON |
| 8 | 2.44 and 5–6 | OFF | OFF | OFF |

is achieved in the second, third, and eighth cases for the frequency bands (2.44 GHz, 5–6 GHz), (5–6 GHz, 7.2 GHz), and (2.44 GHz, 5–6 GHz), respectively. The triple band-notched characteristic is obtained in the fourth case at 2.44 GHz, 5–6 GHz, and 7.2 GHz. Finally, the fifth case (where no band notches exist) shows the presence of the four bands.

Figure 4 shows the simulated and measured return losses for different cases. From Figure 4, a good agreement between the measured and simulated results is observed. The slight variation between



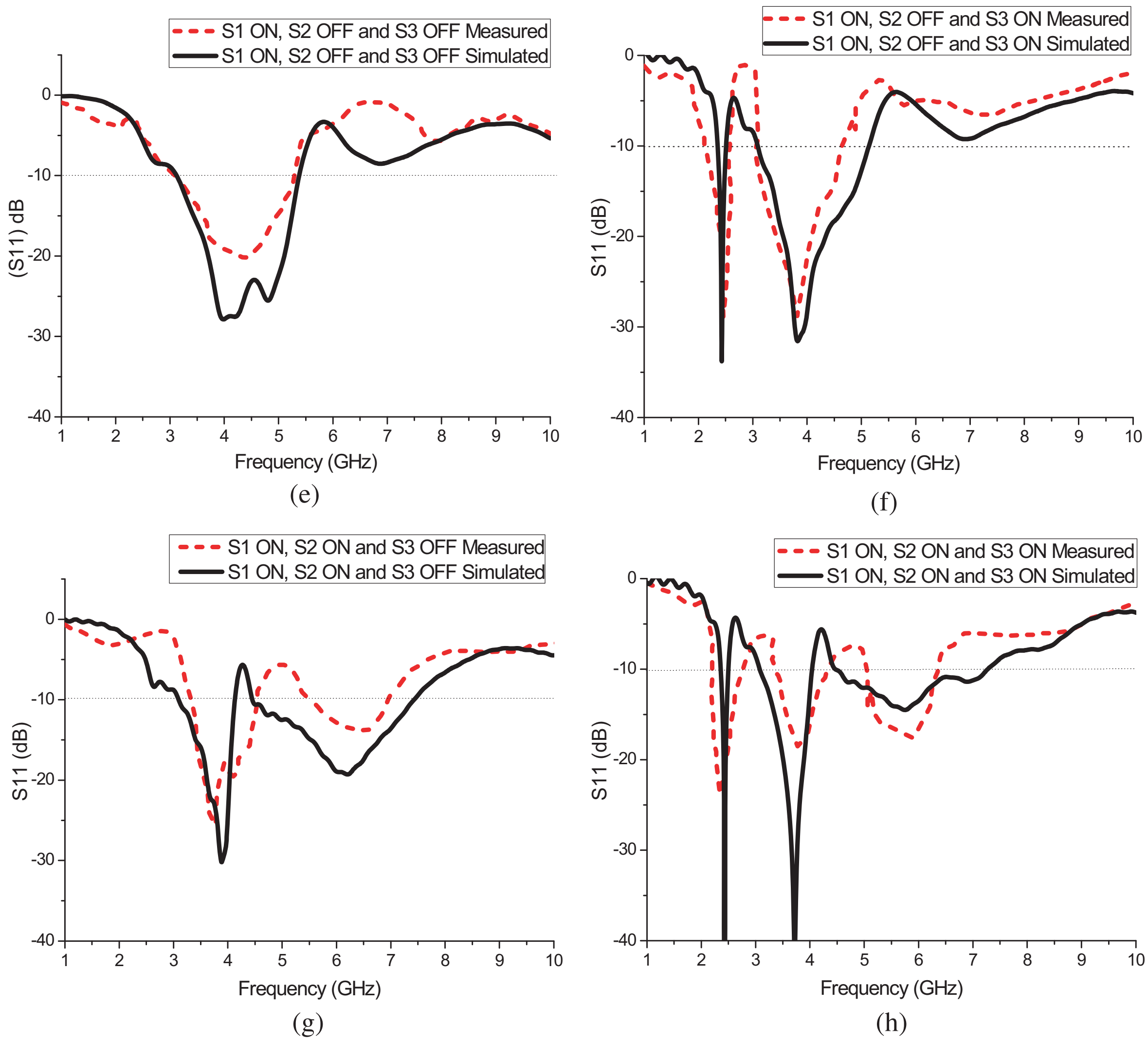



**Figure 4.** Simulated and measured S11 versus frequency of proposed antenna in (a) $S_1$ OFF $S_2$ OFF $S_3$ OFF, (b) $S_1$ OFF $S_2$ OFF $S_3$ ON, (c) $S_1$ OFF $S_2$ ON $S_3$ OFF, (d) $S_1$ OFF $S_2$ ON $S_3$ ON, (e) $S_1$ ON $S_2$ OFF $S_3$ OFF, (f) $S_1$ ON $S_2$ OFF $S_3$ ON, (g) $S_1$ ON $S_2$ ON $S_3$ OFF, (h) $S_1$ ON $S_2$ ON $S_3$ ON.

the measurement and simulation results is attributed to various factors such as the substrate dielectric constant, fabrication accuracies, and the quality of SMA connectors. In addition, the figure shows that the antenna operates at the diverse desired frequency bands, according to the selected switches, allocated to the WLAN, WiMAX, LTE, and X-band applications.

The simulated and measured radiation patterns of the proposed antenna at four distinct frequencies of 2.44, 3.5, 5, and 7.2 GHz for the case where $S_1$, $S_2$, and $S_3$ are OFF, ON, and ON, respectively, in the $E$-and $H$-planes are shown in Figure 5. It can be seen from Figure 5 that the simulated radiation patterns are nearly in agreement with the corresponding measured ones. Furthermore, the antenna shows nearly bidirectional and almost omnidirectional radiation patterns in the $E$-and $H$-planes, respectively. The maximum gain is approximately 1.59 dBi, 2.39 dBi, 3.32 dBi, and 4.58 dBi at 2.44 GHz, 3.5 GHz, 5.6 GHz, and 7.2 GHz, respectively.

Figure 6 depicts the group delay. From this figure, the group delay has very little variations across the operating band within a range of 1 ns, but at the notch frequencies, the group delay has very sharp changes. The antenna prototype is fabricated and tested. A photograph of the fabricated antenna is shown in Figure 7.

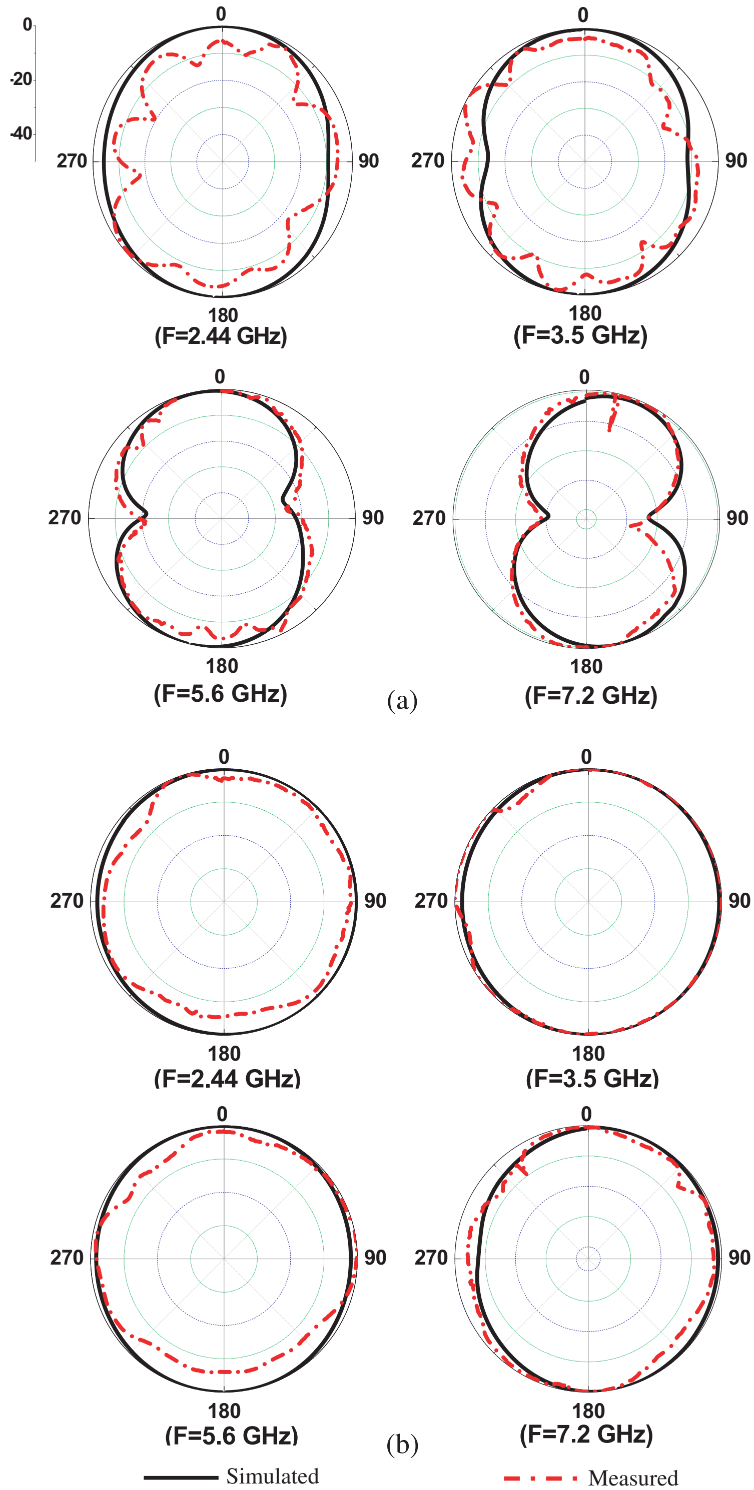



**Figure 5.** Measured and simulated radiation patterns, (a) in $H$-plane and, (b) in $E$-plane at frequencies 2.44, 3.5, 5.6 and, 7.2 GHz. Case where $S_1$, $S_2$ and $S_3$ are OFF, ON, ON, respectively.

A comparative study of the proposed antenna performances with similar antennas published in recent literature is illustrated in Table 3. One can see that the proposed antenna has advantages like compact size with fewer switches to control more bands over previous reference designs.

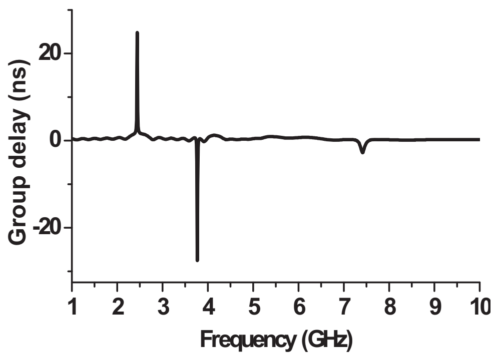



**Figure 6.** The group delay.

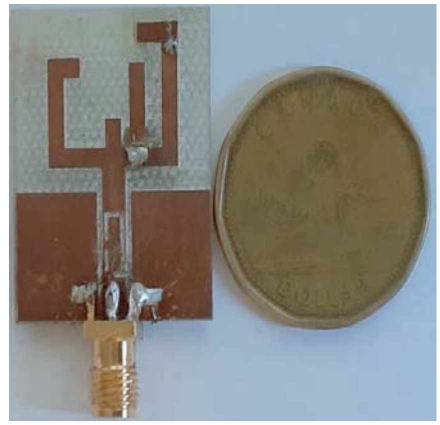


**Figure 7.** Photograph of the fabricated antenna prototype.

**Table 3.** Comparison with previously published works.

| References | Number of switches | Number of bands | Size (mm$^2$) | Size ($\lambda^2$) | Size reduction (%) | Publication years | Substrate materials |
|---|---|---|---|---|---|---|---|
| [21] | 4 | 3 | $32 \times 82$ | 0.168 | 42.6 | 2017 | FR4 |
| [26] | 4 | 3 | $80 \times 30$ | 0.154 | 46.6 | 2018 | FR4 |
| [27] | 2 | 2 | $39.3 \times 51$ | 0.37 | 26.9 | 2017 | AgHT-4 |
| [28] | 7 | 2 | $84 \times 84$ | 0.45 | 15.86 | 2018 | FR4 |
| [29] | 2 | 2 | $33 \times 34$ | 0.11 | 115.8 | 2017 | Rogers Duroid 5880 |
| This work | 3 | 4 | $24 \times 29$ | 0.044 | 160.7 | 2020 | FR4 |

## 4. CONCLUSION

A new multiband microstrip monopole antenna with tunable frequency band has been designed and tested experimentally. Three ideal switches ensuring the ON/OFF mode of tunability are used to control the antenna operating mode. The proposed antenna can be used to cover 2400–2484 MHz for WLAN/ISM bands, 2400–2500 MHz for Bluetooth band, 2484–2491 MHz for Global star satellite phone uplink, 5250–5850 MHz for WiMAX band, 5725–5825 MHz for WLAN band, and 7.25–8.4 GHz for X-Band satellite applications. The proposed antenna has been prototyped and tested, and a good agreement has been observed between the simulated and measured return losses. Appreciable gain and radiation characteristics have been observed over the entire operating range.

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