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A Highly Miniaturized Multiband Microstrip Antenna for WiMAX and WLAN Applications

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ABSTRACT

This work presents a highly miniaturized multiband microstrip patch antenna for WiMAX and WLAN applications at 2.4 GHz, 3.6 GHz, 5.25 GHz and 5.725 GHz. The antenna is designed and simulated by using CST Microwave Studio® software. The substrate material is FR-4 with a dielectric constant, εr of 4.3, loss tangent, tan δ of 0.02 and thickness, h of 1.6 mm. Defected ground structure (DGS) is introduced by inserting two pairs of inverted-E shaped slots and a pair inverted-F shaped slots on the ground plane which play a huge role to miniaturize the size of the antenna. In this work, a simple rectangular patch is used as a radiating structure but with multiple slots introduced on it to generate multiband resonant frequencies of operation. Upon optimization, a H-shaped slot, inverted-U shaped slot and a vertical slot have been applied which dictate the production of multiband resonant frequencies for WiMAX and WLAN applications. The combination of slots on the rectangular radiating patch and DGS offers a good performance of the antenna in terms of size reduction, reflection coefficient, bandwidth and gain. The main contribution of this work is a highly miniaturized antenna with 15 × 15 mm2 in total dimension. The simulation results show convincing linear characteristics at WiMAX and WLAN frequency bands. From the results, the reflection coefficient, S11 at 2.4 GHz (WLAN band) is -11.097 dB with a bandwidth of 7.8 MHz, the S11 at 3.6 GHz (WiMAX band) is -23.402 dB with a bandwidth of 64.6 MHz, the S11 at 5.25 GHz (Lower WLAN band) is -16.747 dB with a bandwidth of 567.7 MHz and last but not least, the S11 at 5.725 GHz (Upper WLAN band) is -15.98 dB with a bandwidth of 215.9 MHz. Based on the results, it is safe to conclude that the proposed antenna in this work may be employed for WiMAX and WLAN applications.

1. Introduction

Nowadays, microstrip antennas play a huge role in realization of handheld devices due to their unique merits such as light in weight, compact size and ease of fabrication as mentioned in [1-3]. The efforts to reduce the size of microstrip antennas have been performed to achieve the miniaturization requirement of modern handheld devices but at the same time, able to support multiple wireless

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applications stated form previous studies [4,5]. Several methods have been introduced from previous studies such as by using a dielectric substrate with high permittivity [6], Defected Microstrip Structure (DMS) [7], and Defected Ground Structure (DGS) [8], only to name a few. DGS are slots that are compact in geometry and etched on the ground plane of the antenna [9]. DGS comprises of a single unit cell (single defect) or a number of periodic structures. The etching of DGS on the ground plane of an antenna perturbs the current length path which resulted in changes of effective capacitance and inductance, thereby resulting in antenna miniaturization [10].

The efforts to obtain multiband antennas have been proposed in the previous work with the implementation of a single and multiple slots on the radiating patch of the antenna in [11]. The slot can be of any shapes. For instance, it can be a U, V, L and T shape [12]. Wireless Local Area Network (WLAN) may be considered as a reliable communication solution. The most commonly used WLAN frequency bands include 2.4 – 2.483 GHz, 5.15 – 5.25 GHz and 5.725 – 5.825 GHz for the IEEE802.11a/b standards [13]. Worldwide Interoperability Microwave Access (WiMAX) is a wireless broadband internet technology that provide high speed over a wide area. IEEE802.16d/e was developed for WiMAX wireless communication with the frequency bands of 2.5 -2.7 GHz and 3.4 – 3.6 GHz [14]. At present, the development of antenna for wireless communication requires an antenna with more than one operating frequencies [15]. This is mainly because there are various wireless communication applications and the fact that telecommunication operates using different frequencies [16]. Moreover, there is a need for small and low profile antennas to support high mobility that is necessary for portable wireless communication devices [17]. Recently, authors in [18] proposed a defected ground structure (DGS) method to miniaturize the size of the antenna. The DGS is optimized with two sections of one cell of DGS and two cells of DGS. The simulated ground plane material is set as a metallic ground plane. In the absence of DGS, the antenna resonates at 5.7 GHz. Similarly, authors in [19] proposed the DGS method to miniaturize the size of antenna. The ground plane is etched with ten circular-shaped slots and improved through adding line and arms slots. The optimized design found in design D-4 with a reflection coefficient of -40 dB at 900 MHz frequency and -17 dB at 2.45 GHz frequency. Authors in [20] proposed design which has a dimension of 18×18 mm^2 and operates at 2.5 GHz (lower WiMAX), 3.47 GHz (middle WiMAX) and 5.75 GHz (WLAN), respectively. Miniaturization in the proposed design is accomplished by etching two novel cascaded E-type unit cell defected ground structure in conjunction with the F-shaped slot, and multiband operations are achieved by etching U- and H-shaped slots in the radiating monopole. The work in [21] proposed DGS and a single circular split ring resonator (SRR) to operates multiband operation from a miniaturized UWB antenna. In order to reconfigure the proposed UWB antenna to operate at 1.5 GHz (GPS), 3.5 GHz (WiMAX), 5.2 GHz and 5.8 GHz (WLAN) frequency bands, a slotted ground structure with metamaterial is used.

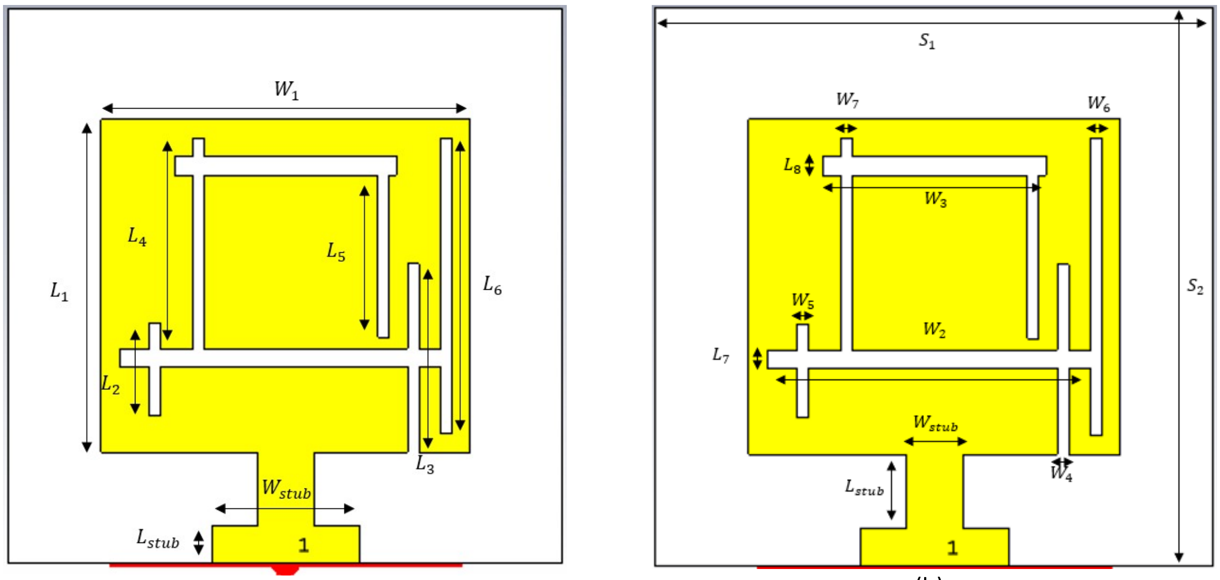
In this work, a miniaturized multiband microstrip antenna is proposed for wireless communication which operates at multiband resonant frequencies of 3.6 GHz, 5.25 GHz and 5.725 GHz for WiMAX and WLAN wireless communication applications. Defected ground structure (DGS) is chosen as the method to miniaturize the size of the antenna to cater for the demand of low profile antenna for ease of integration within the wireless communication device. The aim is to produce a highly miniaturized antenna with dimensions of less than 16×16 mm^2. In order to generate multiple resonant frequencies, slots are introduced on the radiating patch.

2. Antenna Design and Configuration

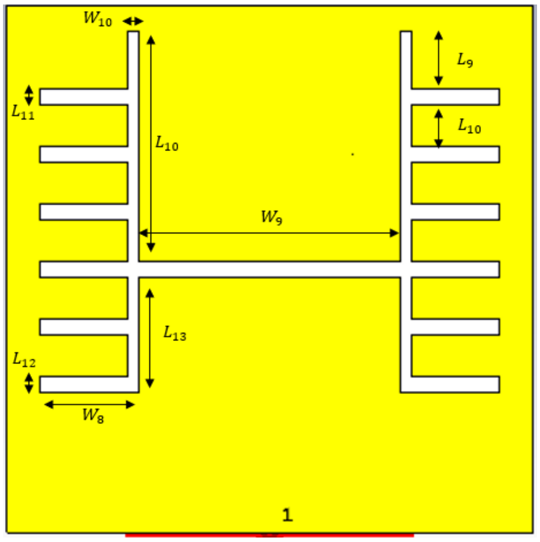
In this work, a microstrip patch antenna is selected to generate multiband operation frequencies. Then, three frequency band of applications are chosen which are the WiMAX and WLAN (Lower and

Upper bands) applications. The antenna has been designed and simulated by using CST Microwave Studio® software on a FR-4 substrate with a dielectric constant, ε_r of 4.3, loss tangent, tan δ of 0.02 and thickness, h of 1.6 mm. According to a recent study in [22], adding slots to the radiating structure results in increased compactness and bandwidth, as well as generating another resonant frequency. The linear characteristics of the multiband antenna are simulated to evaluate the performance of the antenna in terms of reflection coefficient, Voltage Standing Wave Ratio (VSWR), surface current distribution, radiation patterns and gain. The proposed antenna is further optimized to achieve the smallest dimensions other than maintaining a good antenna's performance.

Initially, a rectangular patch microstrip antenna with microstrip feed line is designed based on the calculation method to operate at 2.4 GHz as the fundamental frequency (for WLAN application). One of the methods to improve the reflection coefficient is by using a stub which will increase the impedance matching. Thus, a stub is introduced at the base of the microstrip feed line. The introduction of a pair of inverted-E shaped defected ground structure (DGS) allows the size reduction of the proposed antenna. Another pair of DGS shaped inverted-E is duplicated on top of the current pair to observe reduction in antenna's length. In addition, a pair of inverted-F shaped is introduced on top of the two pairs of DGS structures to further miniaturize the antenna size. The introduction of horizontal dipole as a single slot connecting the two pairs of inverted-E shaped with additional pair of inverted-F shaped DGS on the ground plane also allows the size reduction of the microstrip patch antenna. The optimized dimensions of slots on the radiating structure consist of a combination of H-shaped slot, inverted U-shaped slot and a single vertical slot Figure 1 shows the configuration and geometries of the proposed multiband microstrip antenna in this work for WiMAX and WLAN applications. For simplicity, the top view is divided into two parts as can be seen in Figure 1(a) and (b). Table 1, on the other hand, lists the final dimensions of the antenna.



(a) (b)



(c)

Fig. 1. Final antenna design – A highly miniaturized multiband microstrip antenna for WiMAX and WLAN applications; (a) Top view – 1 (b) Top view – 2 (b) Bottom view

Table 1
Final dimensions of the highly miniaturized multiband microstrip antenna for WiMAX and WLAN applications

Parameter	Size (mm)	Parameter	Size (mm)	Parameter	Size (mm)	Parameter	Size (mm)
L_1	9	L_8	0.5	W_1	10	W_8	3
L_2	3	L_9	1.75	W_2	8.7	W_9	8
L_3	5.6	L_{10}	7	W_3	6.7	W_{10}	0.3
L_4	5.7	L_{11}	0.5	W_4	0.3	W_{stub}	3
L_5	4.2	L_{12}	0.5	W_5	0.5	S_1	15
L_6	9	L_{13}	3.5	W_6	0.3	S_2	15
L_7	0.5	L_{stub}	1	W_7	0.3		

3. Analysis of Results

Simulated reflection coefficient of the optimized stub of miniaturized rectangular patch microstrip antenna with a combination of H-shaped slot, inverted U-shaped slot and a single vertical slot is shown in Figure 2. From the figure, it can be observed that the S_{11} at 2.4 GHz increases to -11.097 dB which is the result of optimizing the size of the stub. The bandwidth has been calculated at -10 dB line for each resonant frequency which are 7.8 MHz (at 2.4 GHz for WLAN band), 64.6 MHz (at 3.6 GHz for WiMAX band), 567.7 MHz (at 5.25 GHz for Lower WLAN band) and 215.9 MHz (at 5.75 GHz for Upper WLAN band).

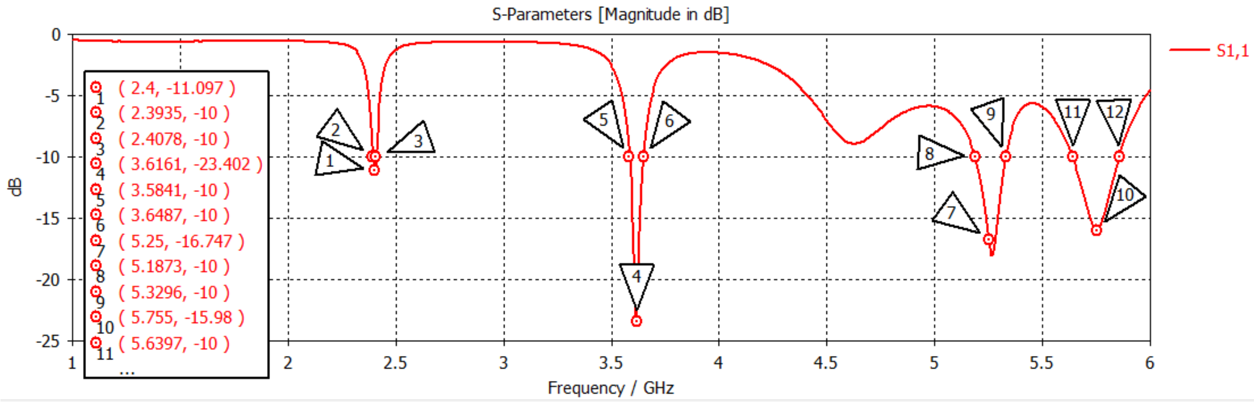


Fig. 2. Simulated reflection coefficient of the multiband microstrip antenna at 2.4 GHz for WLAN band, 3.6 GHz for WiMAX band, 5.25 GHz for Lower WLAN band and 5.75 GHz for Upper WLAN band

An important criterion for assessing an antenna's performance is VSWR. It measures the amount that the antenna and transmission line match up and shows how much radio waves are reflected back to their source. A low VSWR value shows that most of the radio waves are being transmitted, whereas a high VSWR value indicates that a significant amount of power is being reflected, which results in signal loss and degradation according to a recent study in [23]. Figure 3 shows the simulated Voltage Standing Wave Ratio (VSWR) of the proposed antenna. From the figure, the VSWR of the proposed antenna is less than 2.0 for all resonant frequencies which implies that the antenna shall operate within the WiMAX and WLAN frequency bands.

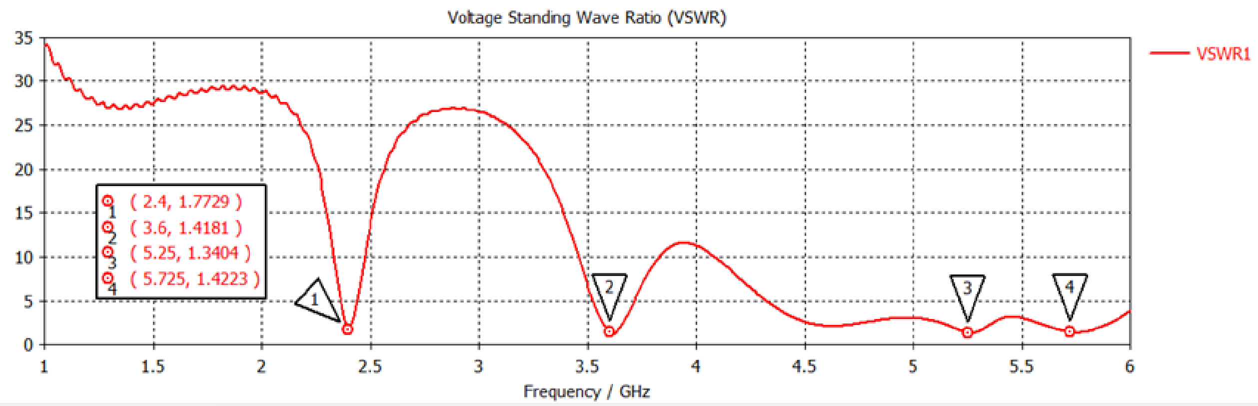


Fig. 3. VSWR of the highly miniaturized multiband microstrip antenna for WiMAX and WLAN applications

Figure 4 shows the surface current distribution of the proposed antenna. From Figure 4(a), maximum surface current is seen to concentrated around the edges of inverted-U shaped slot at 2.4 GHz which implies that the slot is responsible to generate that particular resonant frequency for WLAN band. From Figure 4(b), maximum current can be observed to be concentrated around the edges of two vertical slots on the right-hand side of the patch. These show that the two vertical slots are responsible in radiating electromagnetic waves from the antenna at 3.6 GHz for WiMAX band. As can be seen from Figure 4(c), maximum current is concentrated around the edges of a vertical slot at the right-hand side of the patch which dictates the production of 5.25 GHz for lower WLAN band. Last but not least, maximum surface current in Figure 4(d) is concentrated around the edges of T-shaped slot at the bottom left-hand side of the patch which is responsible to produce the 5.725 GHz for upper WLAN band. These findings are consistent with the theoretical background given in the previous work in [24], which states that the frequency of operation is affected by the length of the current path on the patch. The longer the current path travels on the radiating structure of any antennas, the lower the frequency of operation, and vice versa.

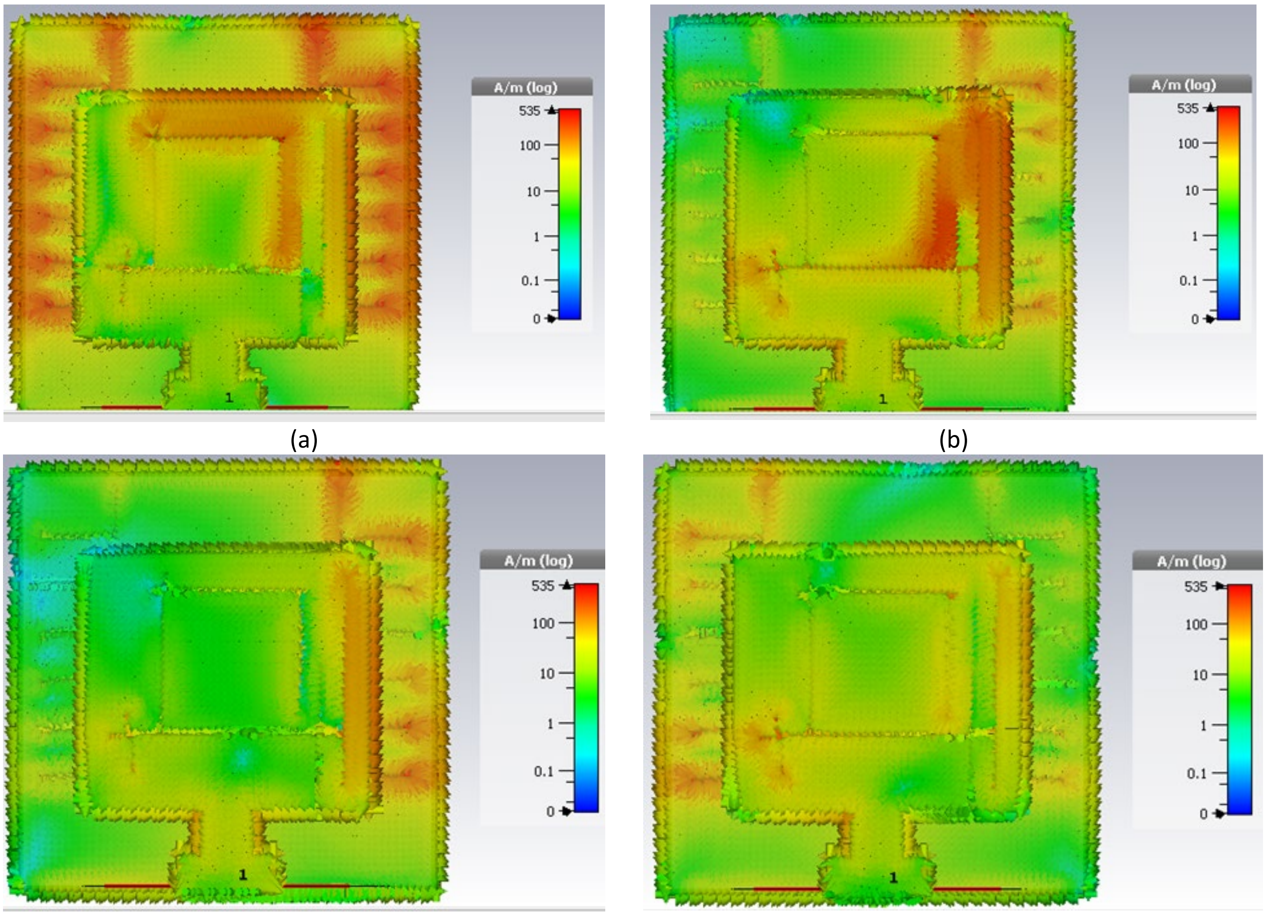
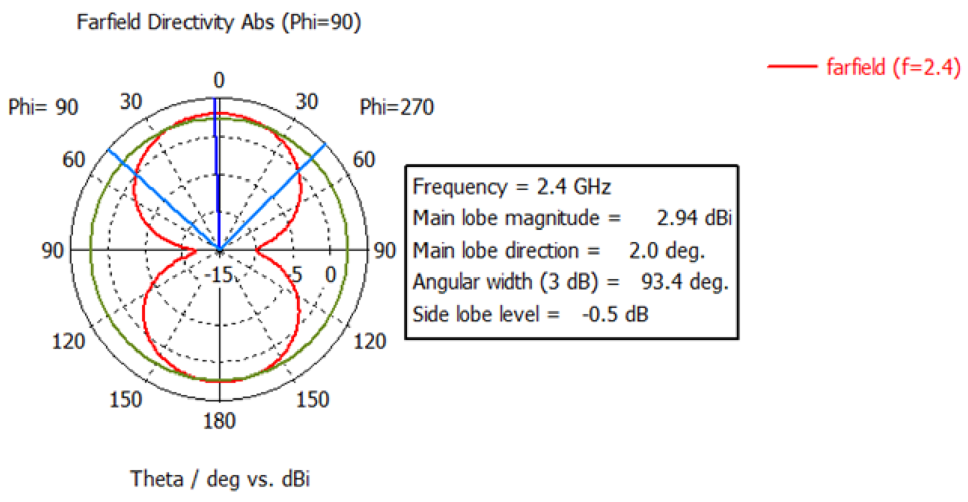


Fig. 4. Surface current distribution of the proposed antenna at (a) 2.4 GHz (b) 3.6 GHz (c) 5.25 GHz (d) 5.725 GHz

Figure 5 shows the radiation patterns of the proposed antenna at 2.4 GHz. From the figure, the radiation pattern of the antenna is bidirectional in the *E*-plane and omnidirectional in the *H*-plane as predicted.



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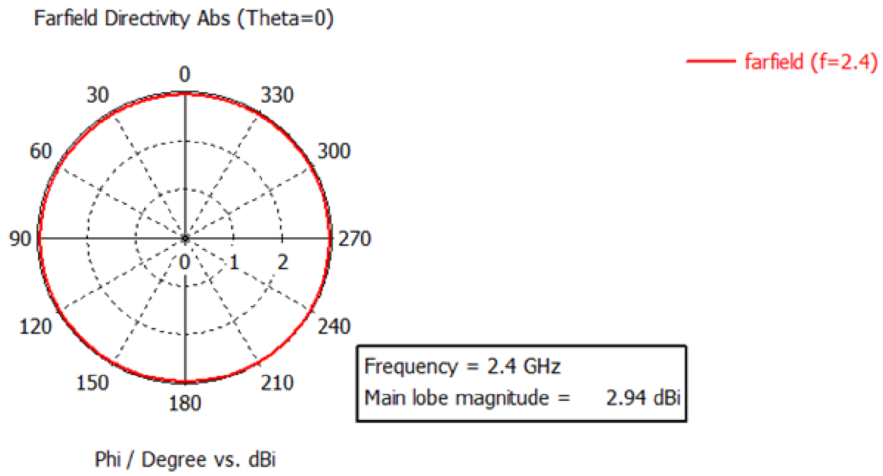
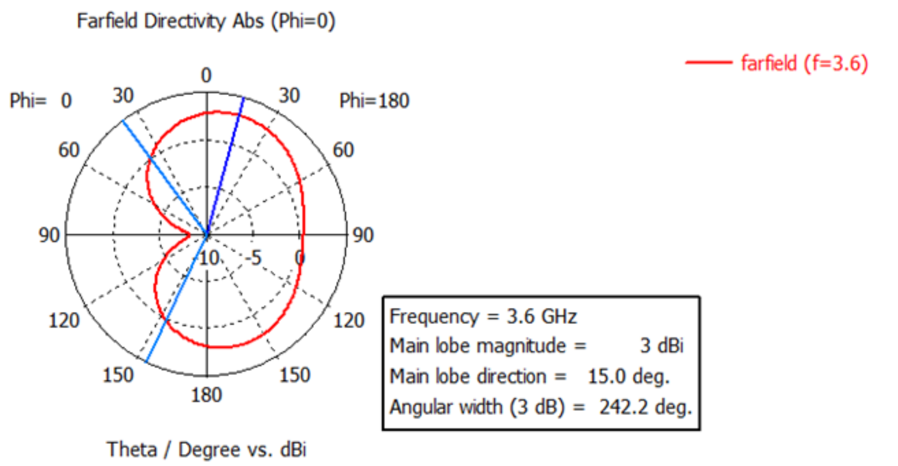


(b)

Fig. 5. Radiation patterns of the proposed antenna at 2.4 GHz in the (a) *E*-plane (b) *H*-plane

Figure 6 shows the radiation patterns of the proposed antenna at 3.6 GHz. The radiation pattern in the *E*-plane is almost bidirectional but with a null only at 90° while maintaining an omnidirectional pattern in the *H*-plane.



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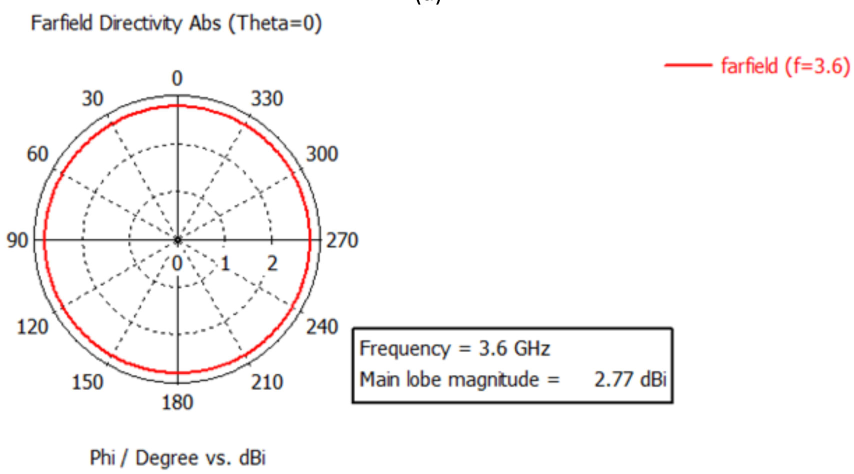
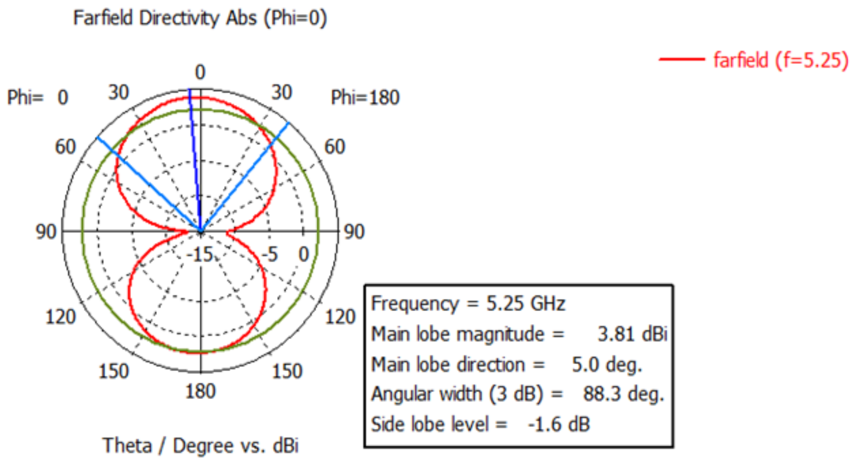


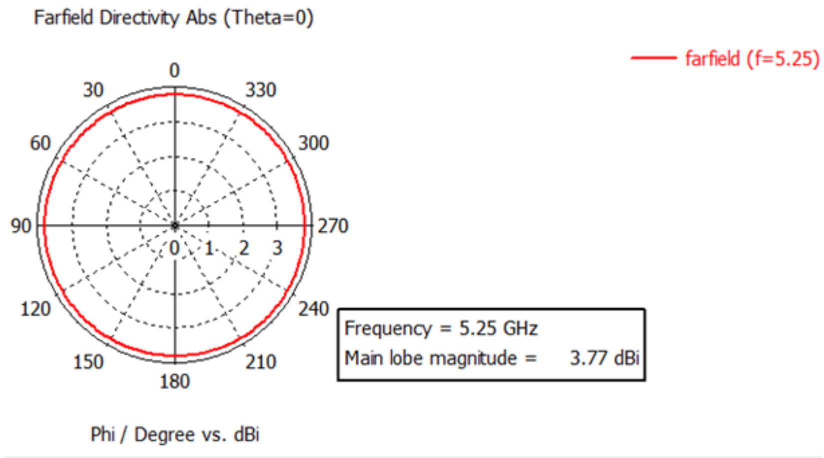
(b)

Fig. 6. Radiation patterns of the proposed antenna at 3.6 GHz in the (a) *E*-plane (b) *H*-plane

Figure 7 shows the radiation patterns of the proposed antenna at 5.25 GHz. From the figure, a bidirectional and omnidirectional pattern can be observed in the *E*-plane and *H*-plane as predicted.



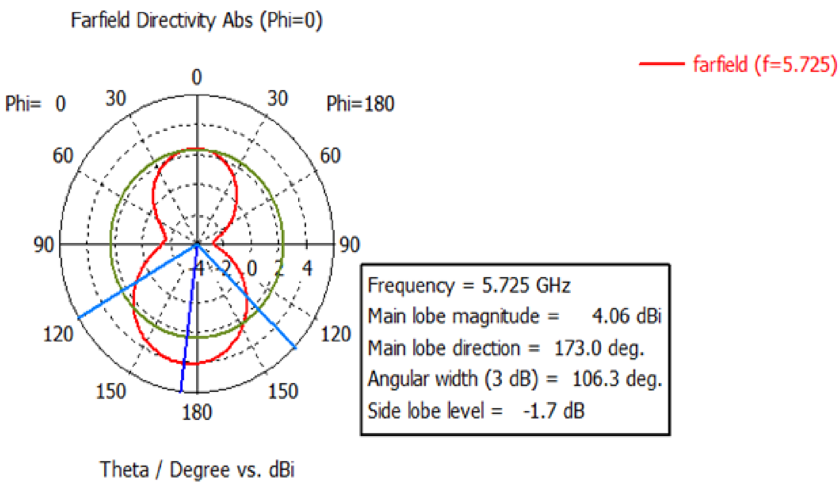
(a)



(b)

Fig. 7. Radiation patterns of the proposed antenna at 5.25 GHz in the; (a) *E*-plane (b) *H*-plane

Figure 8 shows the radiation patterns of the proposed antenna at 5.725 GHz. Similarly, the antenna produces a bidirectional and omnidirectional pattern in the *E*-plane and *H*-plane.



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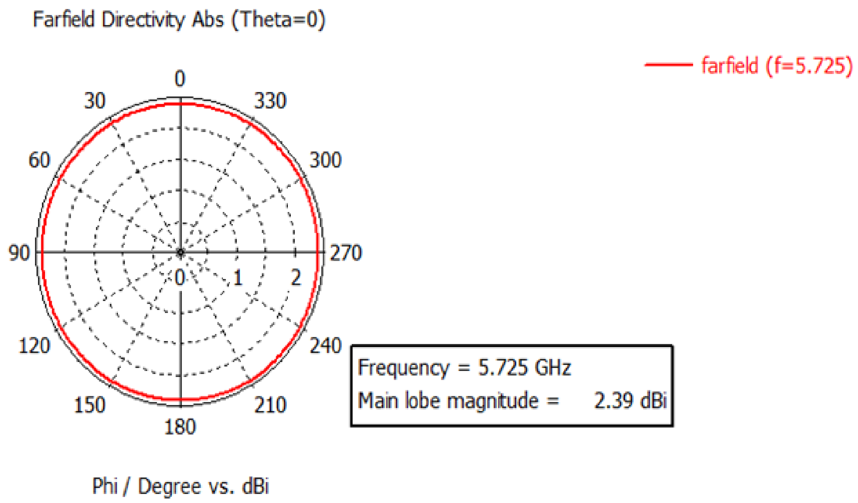
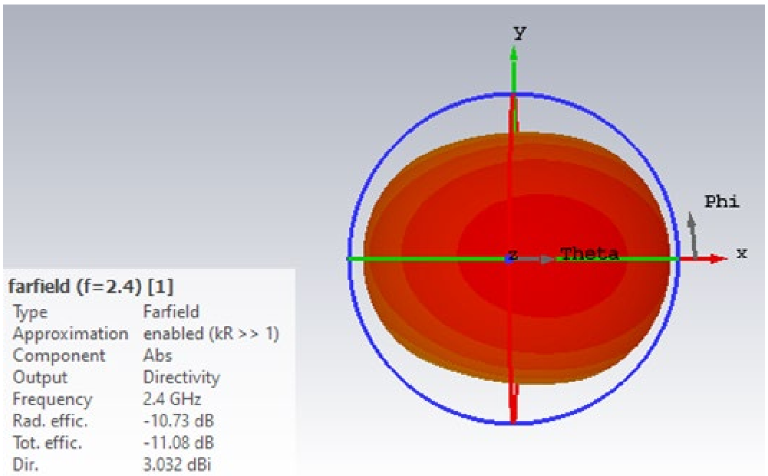


(b)

Fig. 8. Radiation patterns of the proposed antenna at 5.725 GHz in the (a) *E*-plane (b) *H*-plane

Figure 9 shows the gain of the proposed antenna at 2.4 GHz, 3.6 GHz, 5.25 GHz and 5.725 GHz. From the figure, it is observed that at 2.4 GHz, the gain, G is 3.032 dBi. The gain increases to 3.332 dBi at 3.6 GHz and further increases to 3.815 dBi and 4.062 dBi at 5.25 GHz and 5.725 GHz, respectively.



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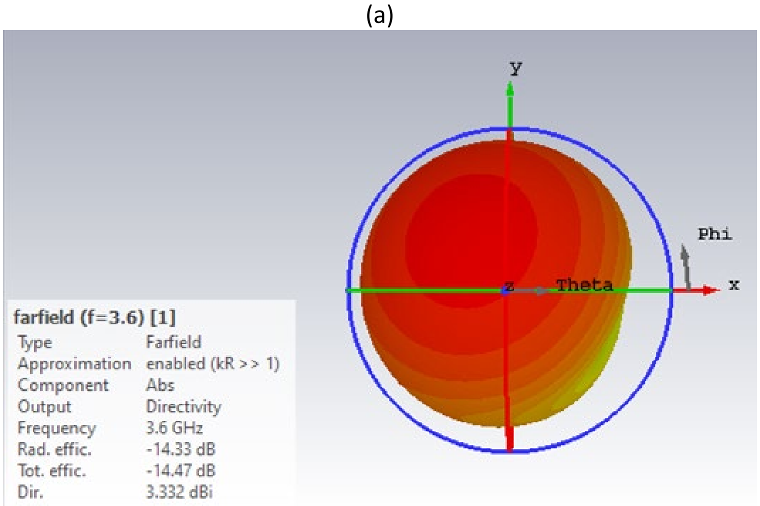

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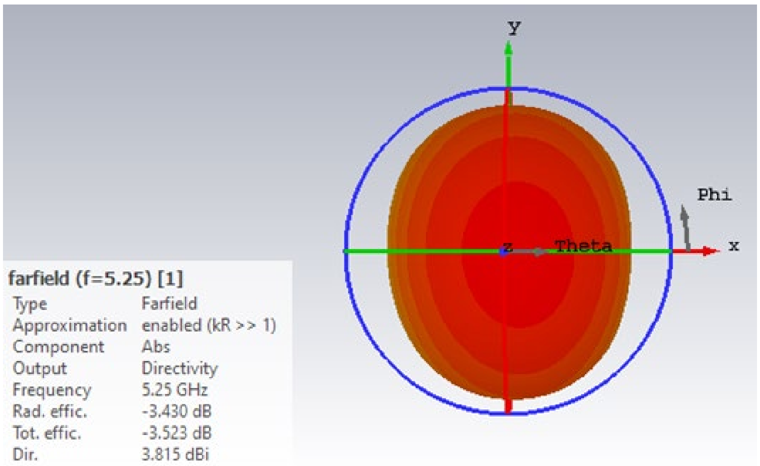

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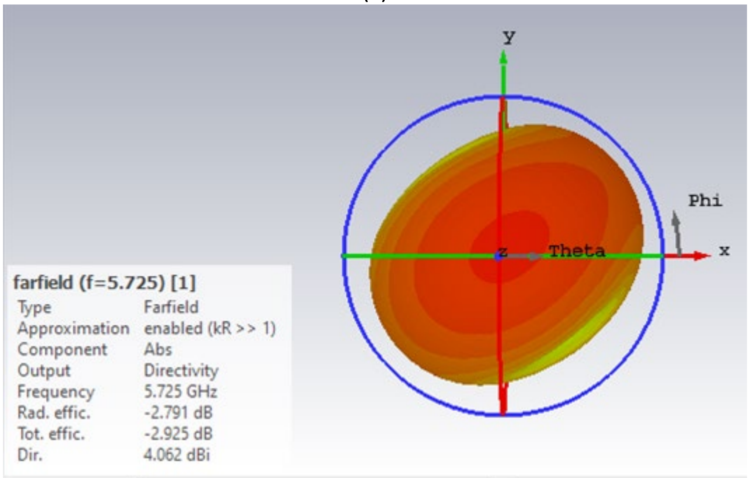

(d)

Fig. 9. Gain of the proposed antenna for WiMAX and WLAN applications at (a) 2.4 GHz (b) 3.6 GHz (c) 5.25 GHz (d) 5.725 GHz

4. Conclusion

In this work, a highly miniaturized multiband microstrip antenna for WiMAX and WLAN applications is proposed. The size is the antenna is highly compact with 15 × 15 mm^2 which is the main contribution of the work. This can be attributed to the introduction of DGS on the ground plane which is one of the techniques for miniaturization of antennas. The antenna has been designed and simulated by using CST Microwave Studio® software on a FR-4 substrate with a dielectric constant, ε_r of 4.3, loss tangent, tan δ of 0.02 and thickness, h of 1.6 mm. The linear characteristics of the antenna are observed in terms of size, reflection coefficient, bandwidth and gain. Upon optimization, a H-shaped slot, inverted-U shaped slot and a vertical slot have been introduced on the radiating patch of the antenna to generate multiple resonant frequencies. The simulation results of the antenna reveal a quadruple-band resonant frequencies at 2.4 GHz (WLAN band), 3.6 GHz (WiMAX band), 5.25 GHz (Lower WLAN band) and 5.725 GHz (Upper WLAN band) with reflection coefficients, S_{11} of -11.097 dB (bandwidth of 7.8 MHz), -23.402 dB (bandwidth of 64.6 MHz), -16.747 dB (bandwidth of 567.7 MHz) and -15.98 dB (bandwidth of 215.9 MHz), respectively. The antenna gain, G at each resonant frequency is also simulated and computed at 3.032 dBi, 3.332 dBi, 3.815 dBi and 4.062 dBi, respectively. Based on the results, it is evident that the proposed antenna in this work might be useful for WiMAX and WLAN applications.

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