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Triple-band antenna with defected ground structure (DGS) for WLAN/WiMAX applications

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Abstract. This paper presents a triple-band rectangular patch antenna that can be operated in three different resonance frequencies of 2.40 GHz, 3.50 GHz, and 5.80 GHz for WLAN and WiMAX applications. The FR-4 substrate with dielectric constant of 4.3 is used, with the dimensions of the substrate 34×30×1.6mm^3. The performance of the rectangular patch antenna has been simulated and measured and the proposed patch antenna operates at three different resonance frequencies of WLAN and WiMAX which are 2.35-2.54 GHz, 3.45-3.57 GHz and 5.74-5.83 GHz. These results correspond to a simulated bandwidth of 197 MHz, 118 MHz and 90 MHz. The radiation pattern of nearly omni-directional is obtained. Overall, the results obtained show the designed antenna have a good performances of the three operating bands

1. Introduction

Recently, wireless connectivity has been extensively used especially in mobile devices. The higher demand for wireless connectivity for example the Wireless Local Area Network and Worldwide Interoperability for Microwave Access known as WLAN and WiMAX among users are tremendously high and continuously growth every day. A method of wireless allocation for two or more devices within an area and also provide an access point to the internet is known as WLAN. As for WiMAX, it supports mobile users, vagrant users and fixed wireless applications. Generally, WLAN and WiMAX follows IEEE 802.11 and IEEE 802.16 standard specifications respectively. The range of resonant frequencies for WLAN are from 2400 MHz - 2484 MHz, 5150 - 5350 MHz and 5725 - 5825 MHz bands and WiMAX are from 2400 - 2690 MHz, 3400 - 3690 MHz and 5250 - 5850 MHz for broadband wireless access network [1].

In designing an antenna, it is essential to cover multiple bands. The performance of the antenna which include the return loss, radiation pattern, antenna gain and also efficiency of the antenna are considered to meet the requirement of the multiple bands communication system.

Abundant of multiband antenna have been designed in order to obtain the desired antenna features for wireless system. A coplanar waveguide (CPW) fed compact dual-band proposed by Y. Zhuo et al patch antenna utilizes a U-shaped slot and two mitered corners printed on polydimethylsiloxane (PDMS) substrate with dielectric constant of 2.65 to accomplish two operating bands which meet IEEE 802.11a/b/g standard for WLAN applications [2] and H. Zhai et al presented a novel compact triple-band antenna comprises of three simple circular-arc-shaped strips for WLAN and WiMAX applications [3]. Next, [4-7] proposed a novel coplanar waveguide CPW-fed antenna printed on FR-4 substrate. F. Li et al reported the design of triple-band monopole antenna by inserting S-shaped meander strip into a C-shaped strip [4], L. Zhu et al presented miniaturized slot antenna for triple-band operation [5], Y. Xu et al proposed an S-shaped strip antenna with a rectangular ring slot together with a crooked U-shaped strip and at the bottom there are three straight strips antenna having overall dimensions of 35×25×1mm^3 [6], and Q. Zhao et al proposed a wide-slot triple-band antenna includes a a square slot in the middle of the ground, a rectangular shaped feeding strip with two sets of planar

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inverted-L strips (PIL) interfacing with the slotted ground of 40×40mm^2 overall dimensions [7]. T. Wang et al proposed a defected ground structure works on a triple-band microstrip-fed planar rectangular patch with two inverted L-shaped strips where the defected ground structure is stacked it with a U-shaped strip and an E-shaped strip [8], L. Dang et al presented a compact triple-band microstrip slot antenna with trapezoid and rectangular shaped slots etched on ground plane of the antenna with the overall dimensions of 35×30×1.6mm^3[9], J. Cao et al shows a planar triple-band antenna with a U-shaped strip line and L-shaped of a planar slot on triple-band antenna printed on a PDMS substrate [10]. Other than that, H. Wang et al implementing two open ended straight slots on a microstrip-fed printed antenna made out of a rectangular shaped radiator and partial rectangular ground plane [11], L. Li et al proposed a multiband rectangular ring slot antenna with a fork-shaped strip on the radiating element and a rectangular-deserted ground plane on 34×18×1.6mm^3 FR-4 substrate [1], Y. Han et al introduced a triple-band antenna with two fold coupled C-shaped strips on 27×41.5mm^2 PDMS substrate [12], S. Verma et al proposed a triple-band planar antenna comprises of an inverted L shaped emanating component and a branched structure of parasitic component in the ground plane having overall dimensions of 30×40mm^2 [13], K. G. Thomas et al presented a triple-band antenna comprises of a microstrip-fed rectangular radiating element and a trapezoidal-shaped etched on the ground plane [14], and C. Byrareddy et al proposed a compact triple-band rectangular microstrip antenna comprises of a rectangular-shaped patch, two identical slots symmetrically placed on the radiating patch, and twin inset fed with a large ground plane printed on FR-4 substrate having overall dimensions of 40×48×1.6mm^3 [15]. Last of all, A. Manouare et al proposed a novel triple band patch antenna made out of three emanating components with partial ground plane etched on Rogers 4350 20×43mm^2 [16]. Basically, the proposed antenna from [1-16] having the return loss ,S11 smaller than -10 dB and accomplishes good performances for both WLAN and WiMAX applications. All of the designs have been presented in numerous shapes and techniques to obtain the desirable features and defeat the restrictive weaknesses of microstrip antenna in covering multiband operations.

However, there are several limitations such as complex structures, large size and certain operating application need to be solved in order to obtain the desirable specification of the antenna. Thus, this paper proposed a triple-band rectangular patch antenna with a simple structure consist of inset fed on radiating patch and introduced a DGS which consists of square-ring slot with multiple vertical slots asymmetrically that can operate in frequency bands of 2400 MHz, 3500 MHz, and 5800 MHz for various application especially WLAN and WiMAX.

2. Methodology

a. Implementation stages of Triple-band Antenna

The implementation of this project consists of two main stages which are the software simulation and hardware fabrication. After the antenna design has been finalized, which is the rectangular patch antenna, the parameters of the antenna are determined. The rectangular patch antenna is designed and simulated using the CST Software. The design is modified until it achieves the desired results.

b. Design process for Triple-band Antenna

The process continues where the microstrip patch antenna has been selected in designing the triple band antenna for WLAN and WiMAX applications. Despite of various forms of patch antenna, the rectangular patch antenna is used and consists of three layers of structures which are radiating element, substrate and ground plane. The FR-4 has been choose as dielectric substrate dielectric constant of $\varepsilon_r = 4.3$. The length and width of the substrate is 34 mm and 30 mm respectively. The FR-4 substrate having a thickness of 1.6 mm. The parameters of the rectangular patch antenna is calculated using the equations as (1)-(4) [17-20

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

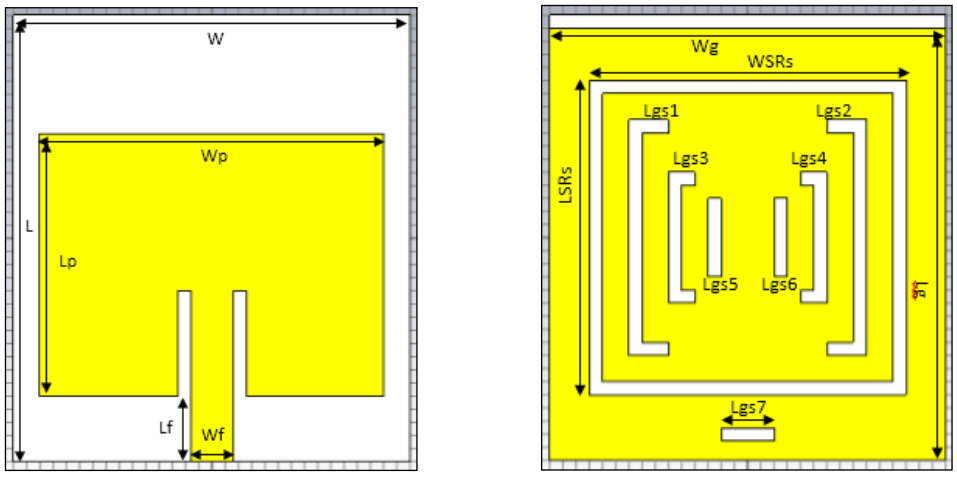
$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

Where, the patch effective length, L_{eff} represents by $\frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$.

c. Simulation and fabrication process

The next process is simulation using the CST Studio Suite software and fabrication process. Basically, there are five steps in designing the antenna in CST Software. The steps can be summarized as creating a new project, modelling an antenna, inserting a waveguide port, setting the field monitor, and running the simulation. After the design process has been verified the fabrication process is done.
Fig.1(a) shows the design of the rectangular patch antenna from the top view. The radiating element of the antenna has been modified to obtain the desired S11 results of antenna performance by introducing inset feed. The bottom view of the rectangular patch antenna as shown in Fig.1(b) where this bottom part has been modified by creating a square ring slot together with few other slots to form a DGS where 1mm width of the slots. All parameters involved in the design are listed in Table 1. The triple-band patch antenna prototype has been shown in Fig. 2.

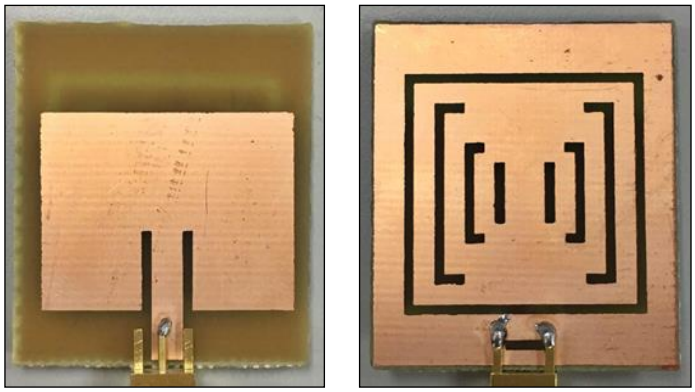


(a) Top (b) Bottom

Figure 1: The top and bottom view of the rectangular patch antenna

Table 1: Parameters of the rectangular patch antenna design

Parameters	Dimension, mm	Parameters	Dimension, mm
W	30	Wg	30
L	34	Lg	33
Wp	26	WSRs	24
Lp	20	LSRs	24
Lps1	8	Lgs1,2	18
Lps2	8	Lgs3,4	10
Wf	3.2	Lgs5,6	6
Lf	5	Lgs7	4



(a) Top (b) Bottom

Figure 2: The triple-band patch antenna prototype

3. Result and Discussion

The proposed triple band antenna with rectangular shaped patch antenna with additional ground square-ring slot and asymmetrical vertical slots has been designed and fabricated. The performance of the simulation rectangular patch antenna has been compared with measurement. The parameters of the triple band antenna are listed as in Table 1 has been optimized to get the desired S11 results as in Fig 3. The return loss S11 obtained is less than -10dB. The rectangular patch antenna resonated at three different resonance frequencies of WLAN and WiMAX which are 2345-2543 MHz, 3447-3566 MHz, and 5740-5830 MHz with the impedance bandwidth of 197 MHz, 118 MHz, and 90 MHz respectively. Fig.4 shows the S11 or return loss for simulation with different length by 2 mm. The simulated rectangular patch antenna is compared with three different length 32, 34 and 36 mm. The proposed antenna length of 34 mm shows a better performance with the S11 less than -10 dB and achieved the required impedance bandwidth.

The fabricated triple band rectangular patch antenna is measured using the Vector Network Analyzer (VNA). The impedance bandwidth values are compared with the simulation result. Fig.5 shows the impedance bandwidth for both measured and simulated result of the proposed rectangular patch antenna. The results obtained from the measurement are tabulated in Table 2.

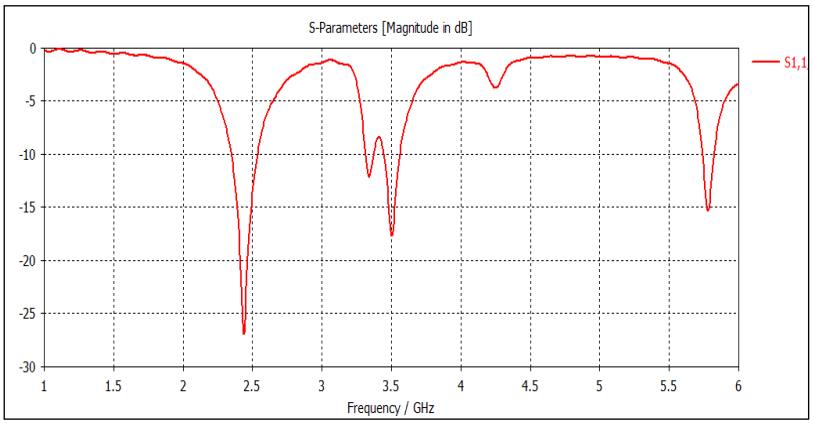


Figure 3: The S11 of the proposed triple band rectangular patch antenna with DGS

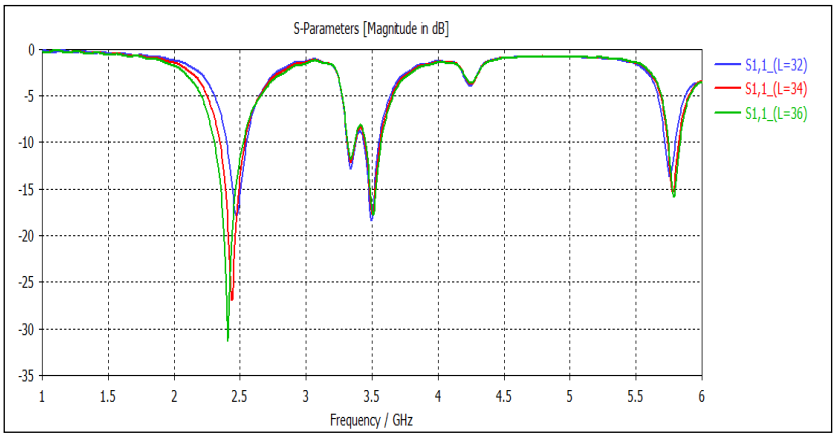


Figure 4: The return loss of rectangular patch antenna with different length

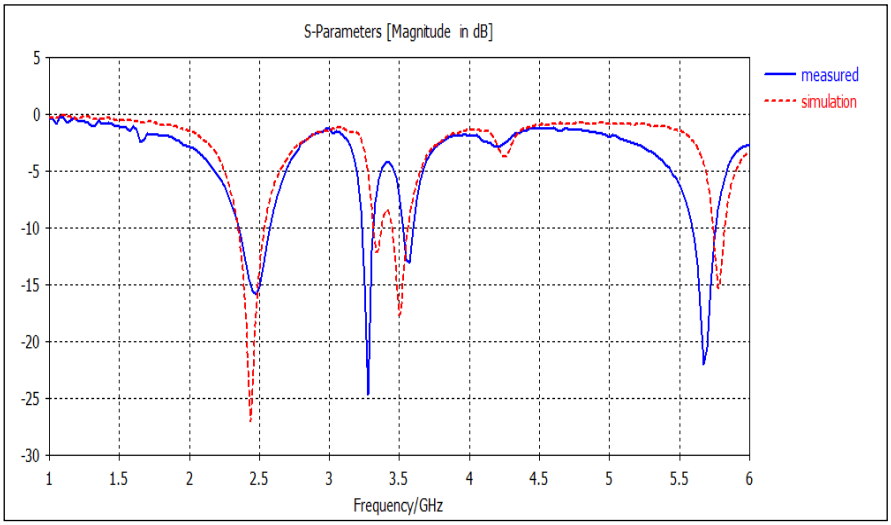


Figure 5: Return loss comparison for the simulation and measurement result

The simulation of proposed triple band antenna, Electric-field (E-Field) radiation pattern been done. The radiation patterns of the triple band rectangular patch antenna are shown in Fig.6 (a)-(c) at desired operating frequency of 2400 MHz, 3500 MHz, and 5800 MHz. It can be seen that the radiation pattern for all frequency bands are almost omnidirectional. The gain obtained from the simulation for these three frequency bands are 2.017dBi, 2.994dBi, and -3.362dBi respectively.

Table 2: simulated and measured results of impedance bandwidth

Simulation				
	Resonant frequency, f (GHz)	Lower frequency, f (GHz)	Upper frequency, f (GHz)	Bandwidth, BW (MHz)
f_1	2.437	2.345	2.543	197
f_2	3.505	3.447	3.566	118
f_3	5.780	5.740	5.830	90
Measurement				
	Resonant frequency, f (GHz)	Lower frequency, f (GHz)	Upper frequency, f (GHz)	Bandwidth, BW (MHz)
f_1	2.458	2.375	2.550	175
f_2	3.558	3.550	3.600	50
f_3	5.676	5.600	5.750	150

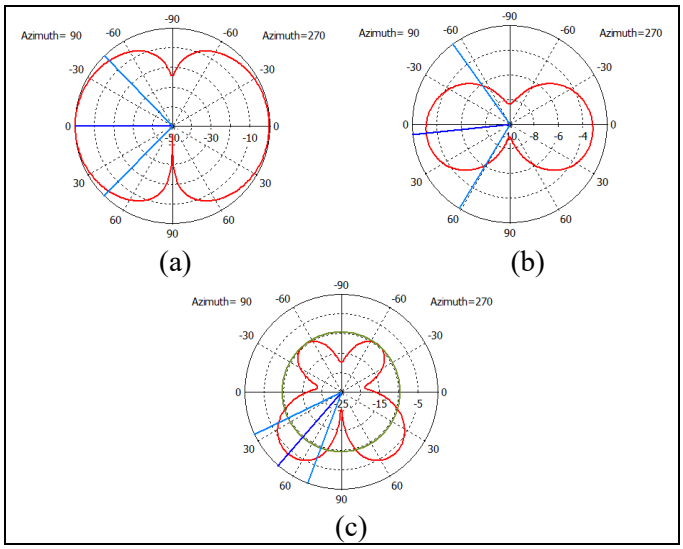


Figure 6: The E-Field radiation pattern simulation of the proposed triple-band rectangular patch antenna at (a) 2400 MHz (b) 3500 MHz (c) 5800 MHz.

4. Conclusion

A triple-band rectangular microstrip patch antenna with square-ring slot and asymmetrical vertical slots has been designed and fabricated. The simulation and measurement results of the rectangular patch antenna has been analysed. The reflection coefficient, S11 of the three frequency bands of 2.4 GHz, 3.5 GHz, and 5.8 GHz achieved less than -10dB. The simulated and measured results show that

the impedance bandwidth obtained are acceptable and covers both 2.4 GHz, 5.8 GHz and 3.5 GHz for WLAN and WiMAX bands applications respectively. The radiation pattern of the rectangular patch antenna shows a good results with the omnidirectional pattern. The gain obtained from the simulation for the three resonant frequencies are 2.017dBi, 2.994dBi, and -3.362dBi, respectively. The proposed rectangular patch antenna produced a good performances with overall dimensions more small compared with other existing antenna in. After all, it is recommended that this antenna undergoes some optimization or modification in the future since the results obtained is good but maybe due to error of some parts it produced such results.

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