Computational and experimental analysis of high gain antenna for WLAN/WiMAX applications

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Abstract In this paper a new microstrip-fed planar triple-band antenna has been proposed which is applicable for wireless communication standards WLAN/WiMAX applications. The proposed antenna is composed of radiating patch loaded with open square-loop and arc slots and rectangular full length ground plane with defect on it. The geometry of the designed antenna has been parametrically analyzed and optimal dimensions are obtained through numerical computations by using a commercial electromagnetic field simulator. On the basis of conceptual design, a physical module of the antenna has been realized on ceramic filled polytetrafluoroethylene based dielectric substrate of $\varepsilon_r = 10.2$ and loss tangent, $tan\delta = 0.0023$. The measurement results from the antenna prototype show -10dB impedance bandwidths of 630 MHz (2.16–2.79 GHz), 600 MHz (3.27–3.87 GHz) and 690 MHz (5.28–5.97 GHz) which can simultaneously cover the bandwidth requirements for all WLAN/WiMAX standards. The designed antenna exhibits nearly symmetric and omnidirectional radiations patterns over the three operating bands. The antenna prototype has shown maximum radiation gains at the frequency bands of 2.49, 3.54 and 5.6 GHz are about 5.71, 6.16, and 6.48 dBi. The experimental results are in good agreement with the results obtained from numerical computation and the designed antenna can be a good candidate for multiband operations in 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX standard wireless applications.

Keywords Microstrip feed · Triple-band antenna · Patch antenna · WLAN/WiMAX · Defected ground

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1 Introduction

The recent development in wireless communication systems particularly in the field of portable devices that deal with voice, video and data communications has directed the demand towards multiband antennas. The contemporary cutting-edge technology always requests the wireless communication services with efficient and enhanced information accessibility from a single device. These requirements inspire the researcher to search for a single antenna module that can function more than one frequency band. As a multiband transmitting unit, it will reduce the total cost and size of the system by replacing single frequency antennas. Beside the multiband operation, some other features are also significantly important; such as compactness, low-profile, simple radiating element, good radiation performance, single feeding structure, easy fabrication and integration, cost effectiveness etc. [1]. The microstrip patch antennas satisfy these requirements and have gained lots of interest among the researchers for providing planar printed structure with simple design procedures [2]. However, the microstrip antennas have some limitations in terms of narrow band, inadequate gain, reduced radiation efficiency and increased cross-polarization arising from surface wave disturbance with edge diffraction. Moreover, the multiband wireless systems require considerable wide band, stable gain and apposite radiation patterns which make the design of microstrip antenna most challenging [3]. Therefore, researchers from the academia and industry have paid their effort in developing efficient antenna to meet the increasing demand of wireless communication systems.

In recent times, a rapid advancement in wireless communications can be observed to fulfill the requirements of wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) where multi-band and broadband antenna is required for simultaneous operations. The standard frequency spectrum for WLAN are 2.4/5.2/5.8 GHz and for WiMAX are 2.5/3.5/5.5 GHz. Literature review of recent research work has revealed a number of designs suitable for WLAN/WiMAX operations in multiple bands [5–13]. Exploration through the published work assert some developed procedures to design microstrip antenna for achieving multiple frequency with acceptable bandwidth. Antenna researchers have come with several ideas like asymmetric coplanar strip (ACS) fed monopole antenna with split ring resonator (SRR) [4] and open ended slots [5] for WLAN/WiMAX applications. Despite their compactness, the antennas have comparatively narrow bands and reduced gain profiles which may limit their applicability in many wireless communication systems. Different ring type antennas are also analyzed for WLAN/WiMAX applications; trapezoidal ring antenna with fractal characteristic [6] and rectangular ring on the ground with L-T shaped strips as radiator [7] are good examples. These antennas also offer low gains, unstable electromagnetic radiations and/or inferior bandwidths. Combination of slot and strip techniques based on different English alphabets are also applied for realizing multiple frequency to cover WLAN/WiMAX bands out of microstrip patch antenna. The radiating element with symmetrical L- and U-shaped slots [8], C- and S-shaped meandered strips [9] are proposed for catering the services for WLAN/WiMAX bands. Some other methods like slotted patch antenna [2], defected ground plane [10], multi-resonator loaded patch [11], inclusion of parasitic elements [12] and complementary split ring resonator structure [13] were successfully employed to achieve WLAN/WiMAX bands. However, most of the reported antennas still have deficit in providing sufficient bandwidth, invariable gain, appropriate radiation patterns, easy geometrical structure and/or the ability to cover all the WLAN/WiMAX bands.

In this article, a triple-band antenna of slotted radiating patch and defected ground plane has been proposed for WLAN and WiMAX applications. The proposed antenna offers three distinct frequency bands which are broad enough to accommodate the frequency allocations for WLAN and WiMAX standards. The antenna has got a simple structure which consists of a combination of two open square-loop and two arc slots embedded on the radiator, and full ground plane with small defect made at the center. With the generous adjustment of the slot dimension and position through optimization techniques, the antenna has achieved intended frequency bands with satisfactory gain and bandwidth. A physical prototype of the antenna has been fabricated and tested to verify its functionalities. Besides providing almost stable and omnidirectional radiation patterns, the other performance characteristics of the realized antenna closely correspond with the numerically computed results.

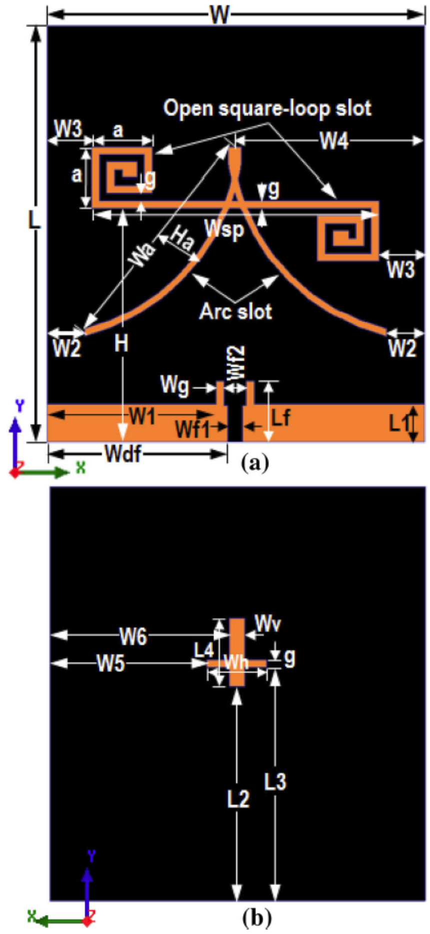

Fig. 1 The geometrical configuration and detailed dimensions of the proposed antenna. **a** *Top view*and **b** *bottom view*

2 Antenna design and fabrication

The geometrical structure of the proposed multiband patch antenna excited through microstrip feeding is shown in Fig. 1. For the designing and fabrication process, the high

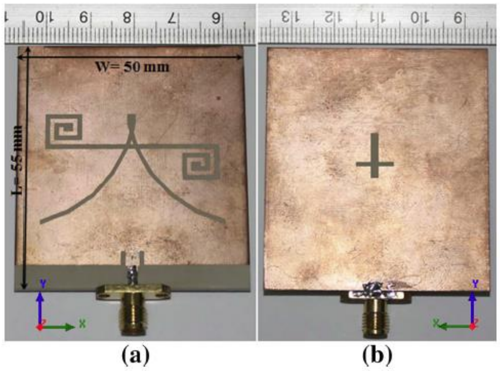

Fig. 2 Fabricated model of the proposed antenna **a** *Top view* and **b** *Bottom view*

Table 1 Optimal parameter values of the proposed antenna

Param.	Value (mm)	Param.	Value (mm)
W	50	*L*	55
*W*1	22.5	*L*1	5
Wf1	2	*Lf*	8
Wf2	3	*H*	31
Wg	1	*g*	1
Wdf	24	*a*	8
*W*2	5	*Ha*	25.7
*W*3	6	*Wa*	4.67
*W*4	25	*L*2	28.5
Wsp	38	*L*3	31
*W*5	24	*L*4	9
*W*6	21	*Wv*	2
Wh	8	–	–

frequency laminates ceramic filled Polytetrafluoroethylene (PTFE) dielectric substrate has been chosen. The substrate material has following specifications: thickness 1.905 mm, relative permittivity $\varepsilon_r = 10.2$, $tan\delta = 0.0023$, thickness of copper 35 µm, surface roughness 0.0022 and conductivity of copper 5.882×10^7 Siemens.

The proposed antenna has got rectangle radiating patch with inscribed slots, 50 ohm input impedance compatible microstrip feed line and slotted ground plane. The signal is transmitted to the antenna through coaxial cable connected 50 ohm SMA connector which is properly soldered to the physical module of the proposed antenna (presented in Fig. 2). The overall dimension of the patch antenna is $W \times L\,\text{mm}^2$ and inset type microstrip line is used for feeding the radiator. The inset feed is located at centerline along the antenna width which is at a distance of *Wdf* from left edge. The length of the microstrip feed is Lf and the variation of width is chosen wisely inside inset area of the patch and in non-radiating area to comply with the 50 ohm input impedance requirement. The design criteria of the 50 ohm microstrip line is considered to simplify the impedance match at the input by assuming the existence of minimum reflection coefficient.

The commercially available full-wave electromagnetic (EM) field solver namely high frequency structural simulator (HFSS) is used for working with design and optimization processes [14]. Initially the dimension of the antenna and patch are estimated by using the standard formulation available in literatures [15,16]. The simulation software is supplied with the material properties (substrate thickness, dielectric constant, loss tangent, copper thickness etc.) to smoothly carry out the computation and optimization process. The readily available Optimetrics engine in HFSS is effectively utilized for the simulation of proposed antenna. The Optimetrics is built-in smart parametric and optimization engine that enables the users to execute parametric analysis, design studies and optimization through accurate EM simulations. Two open square-loop slots and two arc slots are placed on both sides of centerline along x-axis of the antenna. By proper optimization, this arrangement enables the patch to resonate in three different frequencies range applicable for WLAN and WiMAX bands. Additionally, defected ground is created by placing one narrow slots horizontally and one vertical slot equidistant from both edges. The defected ground plane is a well-establish technique to enhance impedance matching and thus provide reasonable impedance bandwidth for the expected resonant frequencies. Numerous computations are carried out for different design structures of the antenna and the optimized dimensions are obtained for attaining the desired frequency bands with good reflection coefficients values. The optimized parametric values for the proposed triple band antenna are tabulated in Table 1 and the fabricated prototype with theses optimized dimensions is shown in Fig. 2. To clearly understand the effects of key parameters on the antenna performance in terms of reflection coefficient and bandwidth, parametric investigations are performed which are discussed in following section.

3 Parametric analysis and optimization

The analytical studies in available literatures have already ensured that the length of the radiating element has governing effect for creating the resonance and the width is not always involved. After determining the approximate dimension of the substrate and thereby the radiating patch, many geometrical designs are studied by cutting slots and analyzing the antenna performances using EM simulation software. The slot cutting technique is well popular technique among the antenna researchers to shift the resonant frequencies towards low value and consequently helps to substantially

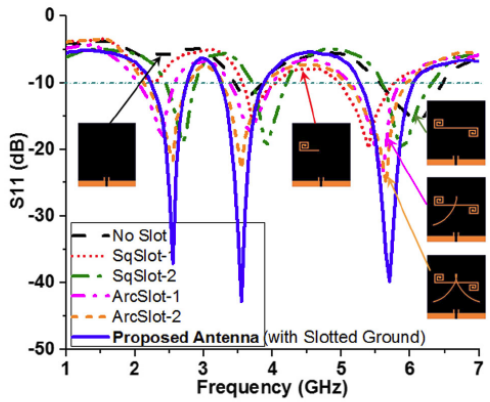

Fig. 3 Frequency response of the antenna for different geometrical structure and proposed antenna structure

decrease the overall dimension of the antenna. With the help of finite element method (FEM) based 3D EM field solver, several parametric studies are implemented by considering best impedance match where lowest value of reflection coefficient occurs. To realize the factual effects of some key parameters of the proposed antenna, only one item undergoes in optimization process through parametric studies in simulator whereas other items remain constant.

The proposed design of the antenna has been finalized and its parameters are well optimized by going through gradual design approaches applied on the radiating patch and ground plane. Based on the different strategic influential parameters, the performance characteristics of the antenna have been observed and illustrated in Fig. 3. With the estimated dimension and predefined substrate element, the arrangement of finite copper conductor on both sides of the substrate generates resonances at around 3.6 and 6.3 GHz. Introducing a narrow horizontal slot of $Wsp/2$ along with left open square-loop slot interfere the typical current flow and intensity. This phenomenon helps to move the resonant frequency towards low frequency and also increase the bandwidth of operation as seen in the Fig. 3. Further extension of similar type of slotted shape in upside down and opposite side along x-axis assists to create one more mode of resonance near around 2.7 GHz whereas the upper resonant frequencies are shifted towards high frequency. This may be due to the quasi-symmetric/complementary placement of open square-loop slot (legend 'SqSlot' in Fig. 3) on both sides of the patch which in turn generate impedance mismatch that pushes the resonant frequency towards higher value. To mitigate the issue, a well-designed arc slots (legend 'ArcSlot' in Fig. 3) are placed on both sides along the central line in x-axis (see Fig. 1). The arc slot has been designed properly and optimization criteria has to be applied wisely to obtain the expected outcome in the frequency response curve. The radius of the arc (*Ra*) slot is very much important for this purpose, which can be determined by $Ra = Ha/2 + Wa^2/8Ha$, where *Ha* is the height and *Wa* is the width of the arc slot.

The inclusion of vertical and horizontal slots make the ground plane as defected one and help to reduces some coupling mismatch along central line. As indicated by several published articles [10, 17, 18], the main function of defected ground plane is to increase the impedance bandwidth by improving the impedance matching. As a result of the proposed design of defected ground plane, the antenna performances are enhanced slightly and the desired impedance bandwidths are achieved. The simulation results for the proposed antenna structure show that (Fig. 3), the achieved impedance bandwidths ($\leq$ -10dB reflection coefficients) are of 2.22–2.74, 3.24–3.8 and 5.25–6.05 GHz with reflection coefficients (S11) of -37.1, −42.71 and −39.4 dB at three resonant frequencies centered at 2.54, 3.55 and 5.7 GHz respectively. The parametric analyses are further expanded by examining the influential effects of each item on the antenna performances and thereby finding the optimized value by performing several numerical computations.

The open square-loop slot of side length 'a' and thickness 'g' is first designed. The open square-loop slots are positioned on the both sides of radiating patch along width of the antenna and the effect of their separation distance and height from the bottom edge are analyzed through various simulations. Fig. 4a–b shows the simulated reflection characteristics of the proposed antenna for variation in separation distance and the height associated with the open square-loop slot arrangement of the antenna. A separation distance of 0 mm i.e. vertical placement of the open square-loop slots yields narrow bandwidth and shifted resonances from the desired frequency of interest. This is due to the improper impedance match that can be improved by properly adjusting the space between the open square-loop slots. As the distance increased due to the addition of horizontal narrow slot of thickness 'g', the current paths get much disturbed and impedance matching improves. The Fig. 4a shows that, a separation distance of *Wsp* = 38.0 mm will attain best reflection coefficient values with expected resonant frequencies and bandwidths. The height of the total arrangement is also studied and variation of antenna performances can be observed in Fig. 4b. To obtain a good impedance bandwidth, the height from the bottom edge has to be optimized and it is found that H = 31.0 mm gives best results in terms of lowest value of reflection coefficients (S11), wider bandwidths and preferred mode of resonances.

The parametric study is also carried out for finding the optimum radius of the arc shape slots and their fine placement. By varying the radius of the arc slots and their symmetrical placement on both sides of vertical central line, the desired resonant mode of operation and bandwidth can

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