A New Low-Profile Inverted A-Shaped Patch Antenna for Multi-band Operations

Md. Rezwanul Ahsan · Mohammad Tariqul Islam · Mohammad Habib Ullah

Abstract This paper presents the design and analysis of a compact modified inverted-A shape multi-band patch antenna for WiMAX and C-band telecommunication satellite applications. The proposed antenna has simple geometrical structure which consist of 20 mm x 20 mm radiating patch with slot loading and fed by 4 mm long microstrip line. The proposed antenna is designed and analyzed by using commercially available full-wave 3D high frequency electromagnetic simulator namely Ansys HFSS. The optimized design of the proposed multi-band patch antenna is fabricated on 1.6 mm thick fiberglass polymer resin dielectric material substrate with reduced ground plane by using in-house PCB fabrication machineries and antenna performances are measured in a standard far field anechoic chamber. From the experimental results it is observed that, the antenna prototype has achieved operating bandwidth (return loss <- 10dB) 360 MHz (2.53 – 2.89 GHz) and 440 MHz (3.47 – 3.91 GHz) for WiMAX and, 1550 MHz (6.28 – 7.83 GHz) for C-band. The measured maximum radiation gains for the antenna are about 3.62 dBi, 3.67 dBi and 5.7 dBi at lower, middle and upper operating bands respectively. The designed antenna shows good radiation characteristics and appreciable gain over the operating bands which make it a reliable candidate for WiMAX bands and C-band applications.

Keywords Microstrip patch antenna · Multiband application · Fiberglass polymer resin · Anechoic measurement chamber · WiMAX and C band satellite

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Md. R. Ahsan (✉) · M. T. Islam
Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
e-mail: rezwanul.ahsan@yahoo.com

M. H. Ullah
Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

1 Introduction

The modern technological advancement and emerging trends in the area of wireless communications raise considerable research interest in antenna designs to integrate easily with system by ensuring low physical profile with multi functionality in a single device. Moreover, the recent improvement and versatile use of personal communications and portable devices necessitate the mandatory use of low-cost, lightweight, compact, multi-frequency antenna. Printed microstrip patch antennas are competitive solution for its inherent advantages of low-cost, low-profile, lightweight, less troublesome fabrication and ease of integration to the system [1,2]. In general, the antenna performance and its dimension are essentially interlinked together; an antenna performance is said to be good when its resonance and size is analogous to the wavelength. To deal with the current and future mobile communications, wireless services and satellite applications, a multiband/multifunctional microstrip patch antenna associated with high-performance and good radiation characteristics are certainly required [3,4]. An extensive research efforts have been contributed by the researchers in the augmentation of patch antenna performances by integrating various technologies to make it small and operate in several discrete frequencies while ensuring overall steady performance. Despite design complexities associated with multiband antenna, many researchers have discussed the design configuration of patch antenna which can operate more than one frequency band. A number of studies accompanying the applications and techniques have reported in designing multiband antennas; making tapered structure with coplanar waveguide (CPW) fed [5], configuring slots over the radiating patch [6,7], introducing capacitive coupled patch [8], employing multi-layered structure [9], integrating electromagnetic band gap (EBG) structure [10] and proposing metamaterials [11]. In recent times, the Worldwide interoperability for Microwave Access (WiMAX) operate at 2.5/3.5/5.5 GHz bands is becoming very popular due to its strategic features [5]. Whereas, microwave C-bands operating at 4–8 GHz has advantages over the Ku-band and the developing regions in Africa, Asia see a promising expansion of C band satellite applications in near future [12].

Through reviewing a number of articles it has been found that numerous studies have performed in the design of multiband patch antenna. A double G-shaped planar multiband antenna of $40 \times 30\,\text{mm}^2$ has been designed for WLAN, WiMAX, HIPERLAN2 [13]. A $50 \times 50\,\text{mm}^2$ slot ring antenna integrated with capacitive patch has been proposed which is able to function at frequencies related to WLAN and WiMAX applications [8]. Coplanar Waveguide (CPW)-fed slotted patch antennas of $23 \times 30\,\text{mm}^2$ to operate in 2.4–2.63, 3.23–3.8 and 5.15–5.98 GHz bands [14], and $25 \times 25\,\text{mm}^2$ to cover 2.14–2.85, 3.29–4.08, and 5.02–6.09 GHz bands [5] have been developed. Two-U slot shaped patch antenna of $40 \times 50\,\text{mm}^2$ with three resonant frequencies 2.7, 3.3 and 5.3 GHz has been implemented to cover tri-band wireless system [15]. In all afore mentioned proposals and designs, the main target of the researchers is to achieve multiband antenna by compromising either fabrication cost or effective electrical area of the patch or steady radiation performance or gain or efficiency. In spite of everything, opportunities are ahead to research for designing low profile patch antenna with high gain, good radiation characteristics and high efficiency.

Based on the background of the researches above, this paper proposes a simple and small form factor multifunctional patch antenna fabricated on low cost, durable fiberglass polymer resin material substrate. The inverted-A shaped multiband patch antenna of $20 \times 20\,\text{mm}^2$ has been designed, fabricated and its performance criteria has been critically analyzed by comparing other similar work.

2 Antenna Design

The geometrical structure and configuration with detailed design parameters of the proposed inverted-A shaped patch antenna is shown in Fig. 1. The antenna is designed and fabricated on a 1.6 mm thick fiber glass polymer resin (FR4) substrate with relative dielectric constant $\varepsilon_r = 4.6$ and loss tangent tan $\delta = 0.02$. The industry standard, 3D full wave electromagnetic field simulation tool HFSS package is used for the design and simulation of the proposed antenna and in house LPKF PCB prototyping machine is used for the prototype fabrication process. The two sided structure of the antenna which consists of standard 50 Ω SMA connector, a microstrip line for feed, inverted-A shaped radiating patch on top and a reduced rectangular ground plane. The proposed antenna structure is achieved by cutting slots and etching out different shapes from a conventional rectangular patch.

The analytical study shows that the width of the patch has insignificant effect on obtaining resonance and through mathematical modeling the patch width for desired frequency can be calculated by utilizing the already established mathematical equations [7]. The length L of the radiating patch has domination on the antenna performances other than the width W.

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

$$L = \frac{c}{2f_o\sqrt{\varepsilon_r}} - 2\Delta l \quad (2)$$

The usual symbol W is the width and L is the length of the radiating patch in Eqs. (1) and (2) respectively; whereas c is the speed of light, f_o is the center frequency, $\varepsilon_r$is the relative dielectric constant and Δl is the change in length. The effective dielectric constant, ε_{eff} can be formulated as

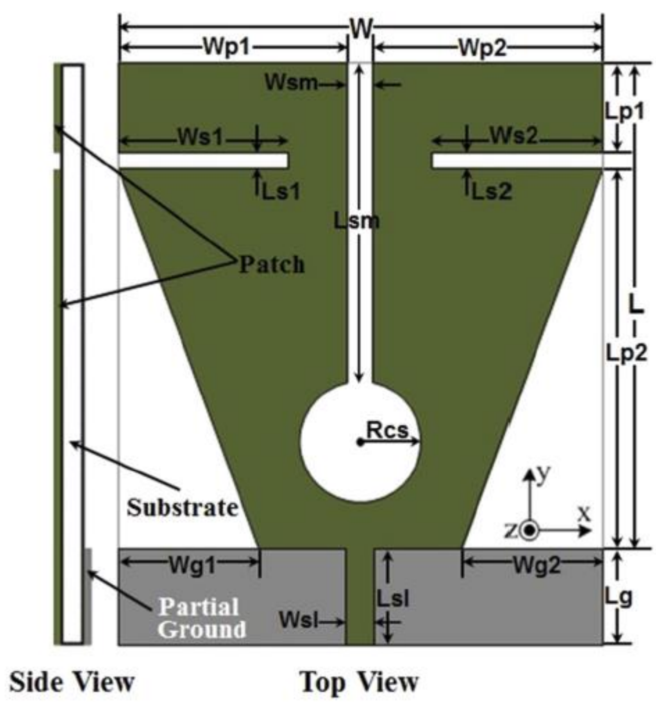

Fig. 1 Geometry of the proposed inverted-A multiband antenna

$$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\sqrt{\left(1 + \frac{10h}{W}\right)} \tag{3}$$

where h denotes the thickness of the substrate used.

Because of the effect of fringing field surrounding the radiating patch, the electrical dimension of the antenna seems to be bigger than the physical dimension. The change of length of Δl due to the effect of fringing field can be presented by the following equation (4).

$$\Delta l = 0.412h \frac{(\varepsilon_e + 0.3)\left[\frac{w}{h} + 0.264\right]}{(\varepsilon_e - 0.258)\left[\frac{w}{h} + 0.8\right]} \tag{4}$$

The available equations are applicable for conventional rectangular radiating patch, however the geometric shape and dimension of the proposed antenna has been achieved by modify, test and run method. The dimension of the microstrip line is optimized through design and simulation to obtain enhanced impedance matching over the operating frequency bands. The designing process of the antenna is started with the estimating the overall dimension of radiating patch which is chosen to be of inverted-A shape that is responsible for providing compact size of the antenna.

The evolution of the final radiating patch has been developed by etching some of the part in different shape from the conventional rectangular patch. Through numerous simulation analysis it has already been verified that the placement of narrow strips and/or cutting slits are accountable in creating meandered path for the surface currents which mainly responsible for producing the resonant frequencies. To examine the effects of introducing different slots embedded with the rectangular patch, investigations on the reflection coefficients and resonant frequencies have been performed which is illustrated in Fig. 2.

For the triangular cut at the lower part of the patch along with the placement of the slits at the top produces lower resonant frequency which is in this case near about 3 GHz. This can be due to the increased flow of surface currents around the triangular cut sides and the top slits as clearly observed in the figures for surface currents (refer to surface currents distribution in Fig. 7a). Introducing the circle in the patch creates the second resonant frequency (at

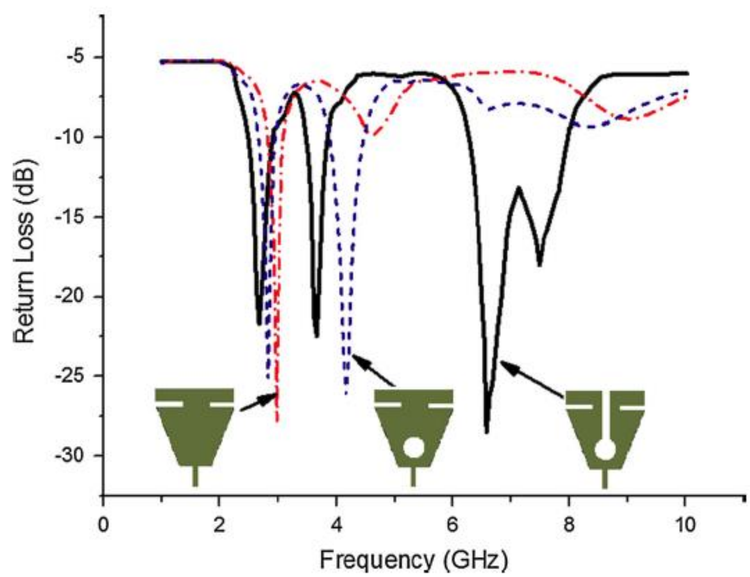

Fig. 2 Simulated return losses and associated resonant frequencies from different cases of radiating patch

around 4.32 GHz) along with the lower resonance frequency. In this case, the first resonant frequency is shifted a bit and also the return loss also reduced as expected. Observing the surface current distribution for the second resonant frequency is clearly validated this in which situation the currents become more concentrated near to the circular slot. Finally, the addition of middle slot with the triangular cut, top slits and circle cut is accountable for generating the third resonant frequency. This insertion of middle slot not only affect the two lower frequency band by shifting to desired resonant frequency and reducing the return loss, but also their combined effect yield the wider band for higher resonant frequency. By examining the surface current distribution presented in Fig. 7c can justify this where, it is seen that increased surface currents are converging near the middle slot. After successful completion of the simulation process for the proposed antenna, the optimal geometrical structure has been achieved depending on the expected frequency bands. The overall size of the patch is of $20 \times 20\,\text{mm}^2$ ($0.2\lambda \times 0.2\lambda$) and the complete dimensions for optimized design parameters are given in the Table 1. The prototype of the proposed antenna has been fabricated and is presented in Fig. 3.

3 Results and Discussion

After successful completion of the design aspects, a fabrication prototype has been constructed and measured. With the aid of Agilent's Vector Network Analyzier (Agilent E8362C), the antenna parameters have been measured in a standard far-field anechoic measurement chamber. The simulation and measured outputs for antenna parameters have been further analyzed and graphically presented by available software package and computer aided tools.

Table 1 Design parameter for the proposed inverted A-shaped antenna geometry

Parameter	W	Wp1	Wp2	Wg1	Wg2	Ws1	Ws2	Wsm	Wsl
Value (mm)	20	9.5	9.5	6	6	8	8	1	0.5
Parameter	L	Lp1	Lp2	Ls1	Ls2	Lg	Lsm	Lsl	Rcs
Value (mm)	20	3.5	16	0.5	0.5	4	13.5	4	2.5

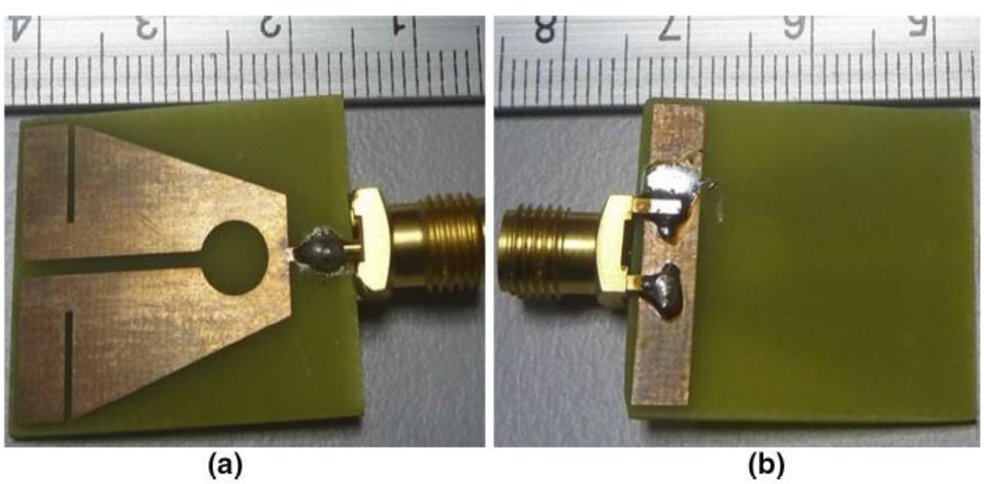

Fig. 3 Prototype of the developed inverted-A multi-band antenna **a** radiating patch and **b** ground plane

The measured and simulated reflection coefficients (return loss) versus frequency of the proposed antenna have been presented in Fig. 4. It is readily apparent from the figure that that an excellent agreement has been attained between simulated and measured results. Three distinct impedance bandwidths with 10 dB return loss are achieved: 360 MHz from 2.53 to 2.89 GHz, 440 MHz from 3.47 to 3.91 GHz, and 1,550 MHz from 6.28 to 7.83 GHz, which are able to cover the 2.5/3.5 GHz WiMAX band and C-band respectively. A little variation in between the simulated and measured result may be due to the fabrication tolerance caused by thickness uncertainty, SMA soldering effect and/or inconsistency in the dielectric constant of the material used.

Figure 5 exhibits the comparison between the measured and simulated far-field radiation patterns in E-plane and H-plane for the frequencies at 2.66, 3.65, and 6.58 GHz. A little inconsistency can be spotted in measured result, more specifically the backward radiation. This may be due to the cable loss which is interposed between the antenna and controller. Other than this, the presented results indicate fairly good and steady patterns in the plane over the operating frequency bands. The co-polarization patterns for E- and H-plane are almost symmetric and directional. Whereas the cross polarization radiation patterns at different operating frequency bands though seems almost similar, however its effect observed to be increased with the increased frequencies as predicted. It has been observed that the designed antenna performs well in producing nearly balanced radiation pattern radially for operating bands by maintaining low cross polarization as desired. These performance criteria would be certainly beneficial while designing antenna arrays, thus reasonably would produce more stable radiation pattern across the operating frequency bands.

Free-space ranges are used to measure the gain of the designed multiband antenna. With the guidance from IEEE standards [16] and following the well-known Friis transmission equation, the peak gain is measured by utilizing two identical horn antennas whose gain and radiation patterns are known. Figure 6 shows the measured and simulated gains (left Y-axis) against the corresponding operating frequency bands. For the lower operating bands, at 2.53–2.89 GHz the average gain is 2.43 dBi whereas for the band 3.47–3.91 GHz the gain is observed 2.67 dBi. The average gain for upper band at 6.28–7.83 GHz is achieved 4.57 dBi which in turn increases directivity of the designed antenna. The radiation efficiency of the proposed antenna is shown in Fig. 6 with right Y-axis as percentage. It has been observed that highest efficiency 87.7 % is achieved at upper C-band with average efficiency over the

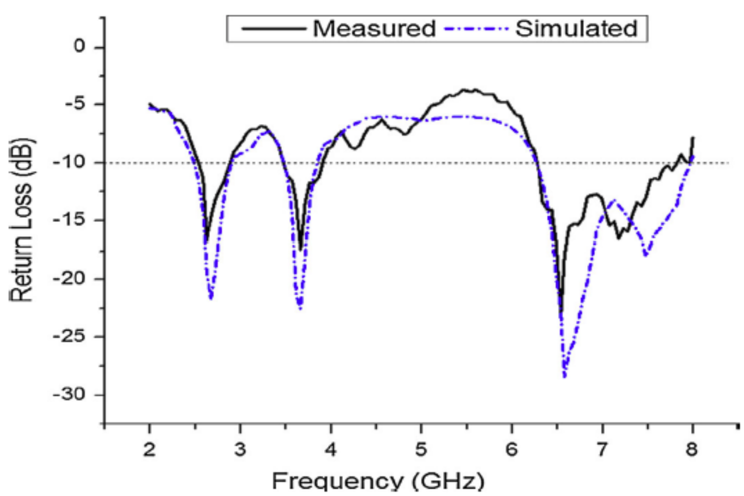

Fig. 4 Measured and simulated reflection coefficient of the proposed antenna

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