
Development of Dual-Band Antenna for Wireless Applications

¹Pankaj Patil, ²Yogita Nafde

^{1,2}Department of Electronics & Telecommunication Engineering, Priyadarshini College of Engineering, Nagpur
Email: pankaj119patil@gmail.com, yogita.nafde@gmail.com

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Abstract

The multiband antenna technology has significant impact on today's advance wireless communication networks. The paper presents the design aspects along with analysis of a planar compact dual-band antenna for fulfilling the requirements of wireless applications. The optimized dimension of the designed antenna model is (28 x 36 x 1.6) mm³. The insertion of asymmetric L-shaped strips with variation in dimension such as the length, thickness and a space within the strips have considerable effect on the frequency of resonance of the antenna. The optimization of asymmetric strips and slots is done by performing number of iterations. The prototype is fabricated using FR-4 substrate. The measured result shows that the antenna is operating in 3.4-3.60 GHz and 5.2-5.85 GHz. The resultant frequency ranges are suitable for WiMAX (3.5 GHz) and Wi-Fi/WLAN/HiperLAN (5.5 GHz) bands respectively.

Keywords

Dual-Band Antenna, Printed Monopole, Asymmetrical Structure, WiMAX, WLAN

Introduction

The present day wireless advanced communication system shows increasing inclination towards antennas with multiband operations. Although the design of single antenna with multiband characteristics is complex to implement, its demand is still increasing rapidly. The printed monopole structure of antenna is a optimum choice due to its characteristics like compact size, simple structure and low profile. There is also possibility of integrating the monopole structure with Worldwide Interoperability for Microwave Access (Wi-MAX) and Wireless Local Area Network (WLAN) into single system. This is beneficial for mobile devices such as hand-held computers and intelligent phones. This facilitates the user mobility with wireless advance communication system. The major requirement for the same is multiband and wide band operation with simple and compact structure which is easier for fabrication.

The main challenge in designing compact antennas for wireless devices is not only to fulfill the wide and multi band requirements but also capability to provide good amount of efficiency, acceptable gain and omnidirectional radiation patterns. Printed antennas are frequently preferred for wireless communication devices due to their low cost, compact size, light weight, multiband and wide band operation. Numerous printed antennas were presented by several researchers for multiband applications [1]-[10]. A symmetrical inverted-F winding antenna structures were used to generate dual-band characteristics by some researchers [1,2]. A two layer patch with single-feed antenna was designed using E-shaped and U-shaped patches [3]. A mushroom-like rectangular substrate using zeroth order (ZOR) resonant mode was used to generate the resonance for dual-band operation [4]. A slotted antenna with metal covering for ultra-book applications was discussed by some researchers [5]. A pair of planar and vertically shorted patches with three asymmetrical U-shaped slots was used for high-gain base station dual-band antenna [6]. A hexagonal and circular geometrical shaped patch monopole printed antenna was investigated in some papers [7]. A modified rectangular E-shaped patch with partial ground plane connected through patch via hole was capable for generating dual-band [8]. A diamond-shaped single-layer substrate composition dual-band antenna was also discussed by some researchers [9]. A CPW-fed patch structure slotted antenna with pair of arc-shaped metal strips was used for wireless applications [10].

The main limitation of the antenna discussed earlier is large antenna size and use of fractals, stacked structures. In this paper, an attempt is made to achieve the multiband operation with asymmetric structures with high degree of miniaturization. In this work, a printed microstrip-fed monopole antenna is presented with dual-band operation for wireless applications. The paper is summarised as given below.

The materials with methodologies are given in section 2. The section 2.1 presents the antenna design. The development process of the antenna and antenna dimensions are given in section 2.2. The simulated and measured results are highlighted in section 3.

Materials and Methods

The objective of this research is to develop a dual or multiband compact antenna for wireless applications. The target frequency range for the design is 3-3.5 GHz. FR-4 material is chosen for the substrate which is flame retardant. This is fiber glass reinforced epoxy laminate having self-extinguishing property. This is cost effective and easily available material. The material used for the patch is copper. The analysis of the design is executed by transmission line model. The design parameters and equations used for analysis are given below:

For effective radiation, the patch width (W) is given by

$$W = \frac{c}{2 f_o \sqrt{\frac{\epsilon_r + 1}{2}}} \dots\dots(1)$$

Where, ϵ_r = dielectric constant,

f_o = resonant frequency and c = velocity of light

The effective dielectric constant (ϵ_{reff}) expression is given by

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \dots\dots(2)$$

Where h = height of substrate

The length extension (ΔL) expression is given by

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.259) \left(\frac{W}{h} + 0.8 \right)} \dots\dots(3)$$

For a given resonant frequency f_o , the effective length (L_{eff}) of patch is given by

$$L_{eff} = \frac{c}{2 f_o \sqrt{\epsilon_{reff}}} \dots\dots(4)$$

Hence actual length (L) of patch is given by

$$L = L_{eff} - 2\Delta L \dots\dots(5)$$

The antenna design is discussed in next section.

Antenna Design

Using the transmission line analogy and design equations discussed in earlier section the final length and width of the patch are optimized as W = 28 mm and L = 36 mm. The partial type ground plane is used for getting the monopole printed structure. In this design, an attempt is made to obtain the multiband operation by the use of asymmetric structure without the use of fractal or stacked geometry and any kind of switches. The antenna development process is described in next section.

Antenna Development Process

The microstrip line feeding is used with antenna structure. The patch is a radiating element. The patch dimensions such as patch length and width affect the return loss, resonant frequencies and consequently the impedance bandwidth.

Antenna development process in Fig.1 shows various iteration performed to design a dual-band operational antenna. The patch structure is initially taken as rectangular and resonance characteristics are noted. After this process step wise changes in the structure of patch is carried out by observing the reflection coefficient characteristic. The due attention is paid for maintaining proper impedance matching. In the first iteration a simple rectangular patch of 28 mm of width and 30 mm of length is fed with a microstrip line of 3 mm width and 14 mm length. In the next iteration, a U-shaped inverted slot is inserted. The width of U-slot is 14 mm, length 17.5 mm and a thickness is of 0.5 mm. The inverted U-slot within the patch gives undesired resonance. With proper slot optimization in the III, IV and V iterations the resonance within desired band of frequency is obtained. In the VI iteration, desired frequency dual bands are obtained. The detail results are presented in section 3.

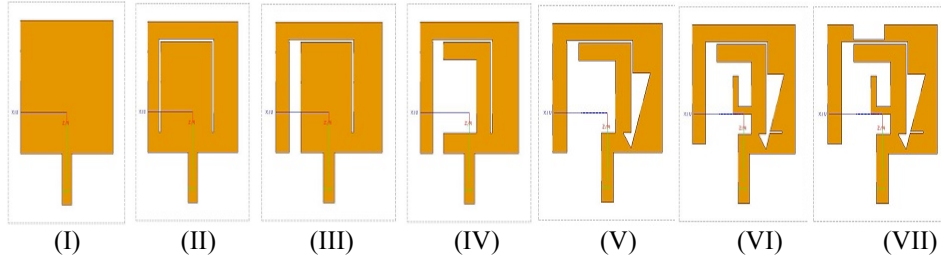


Fig. 1: Various Iterations Performed to Achieve Proposed Antenna

The limited ground plane is developed for the antenna ground which helps in bandwidth improvement. The illustrative diagram of the designed antenna is shown in Fig.2. The antenna dimensions are mentioned in the Table I. The optimized dimensions of the proposed antenna are depicted in the Table II. Fig.3 shows the fabricated prototype of the designed antenna.

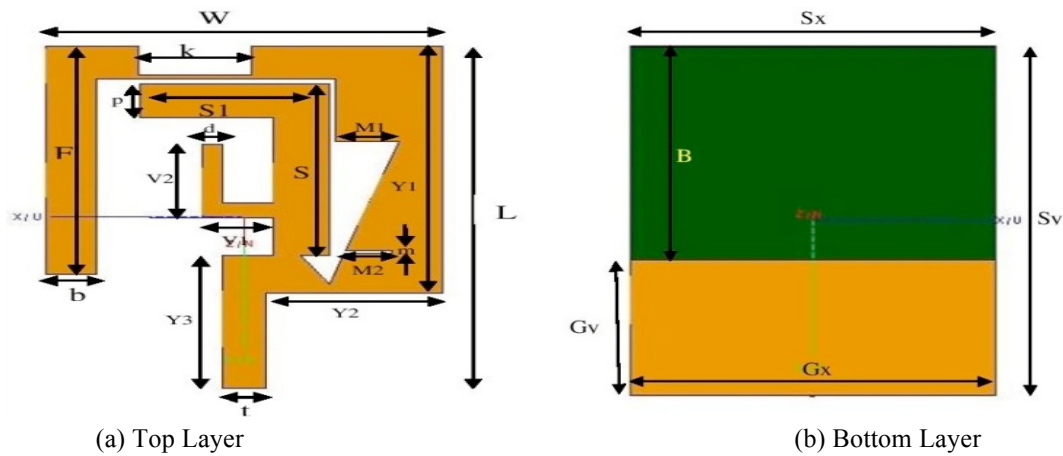


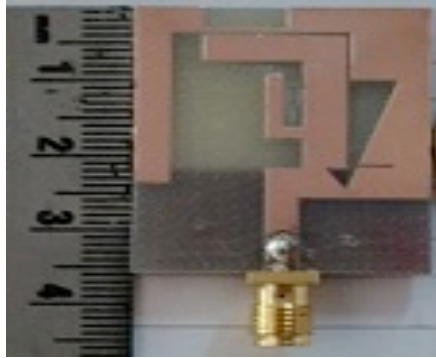
Fig. 2: Geometry of the Antenna Design

Parameters	Material Used	Dimensions
Patch	Copper	(28mm × 36mm), 1.6mm thickness
Substrate	FR-4 Epoxy ($\epsilon_r=4.4$)	(28mm × 36mm)
Ground plane	Partial ground plane	(28mm × 14mm)
Feed-line	-	(3mm × 14mm)

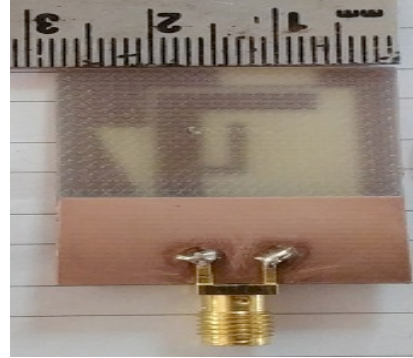
Table I: Antenna Dimension

Top Layer			Bottom Layer
W=28mm	V1=3.5mm	F=24mm	Sx=28mm
L=36mm	V2=8.7mm	b=3.5mm	Sy=36mm
Y1=26mm	d=1.5mm	k=8mm	Gx=28mm
Y2=12.5mm	S=18mm	M1=4.5mm	Gy=14mm
Y3=14mm	S1=13.4mm	M2=3.43mm	B=22mm
t=3mm	p=3.5mm	m=0.3mm	

Table II: Optimized Antenna Dimensions



(a) Top View



(b) Bottom View

Fig. 3: Antenna Prototype

Results and Discussion

The dual band antenna with asymmetric structure has been designed and simulated using Altair’s FEKO software. FEKO is comprehensive computational electromagnetic (CEM) software based on Finite Element Method (FEM) and Method-of-Moments (MoM). The patch optimum length gives the improved return loss and the better impedance bandwidth.

It is observed during antenna development process that as the patch length increases the resonance frequency decreases significantly. This is due to the increase in the current on the patch. The effect of the asymmetries is observed over the antenna impedance. Fig.4(a) and Fig.4(b) shows the impedance at 3.5 GHz and at 5.5 GHz respectively have matched approximately to 50 Ω.

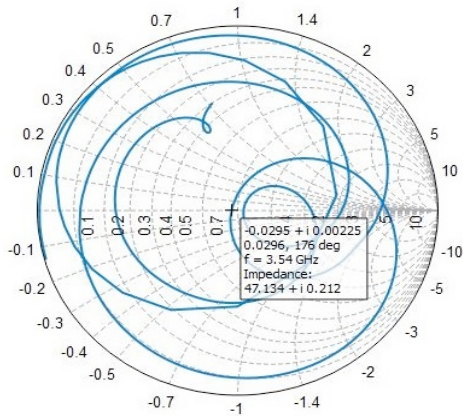


Fig. 4(a): Impedance at 3.5 GHz

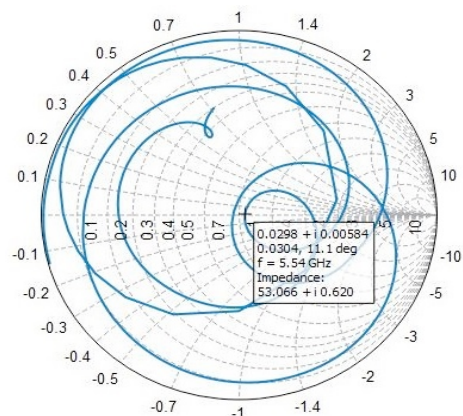


Fig. 4(b): Impedance at 5.5 GHz

Fig.5 shows the surface current distribution. As frequency increases, current is observed in a smaller region of the patch. The path of current follows the edge of the rectangular slot. It reveals that the lowest resonant frequency at 3.5 GHz is generated with the insertion of small rectangular L-shaped strip in the patch. As depicted in Fig.5(b), the path of current flows along the strip edge to the top side of the rectangular slot. Therefore, the inverted L-shaped strip in the slot generates another band i.e. 5.5 GHz. With the addition of a rectangular notch towards the top strip, the return loss of both the frequencies are improved as shown in Fig.7. The optimization of the width and length of the strip alters the distribution of current and in turn the resonance performance of the antenna.

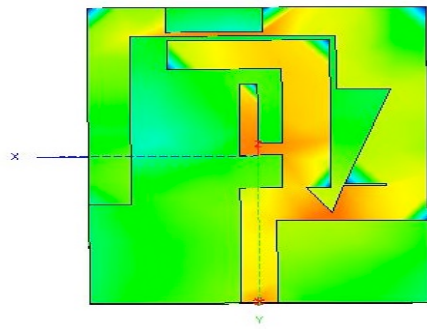


Fig. 5(a): at 3.5 GHz

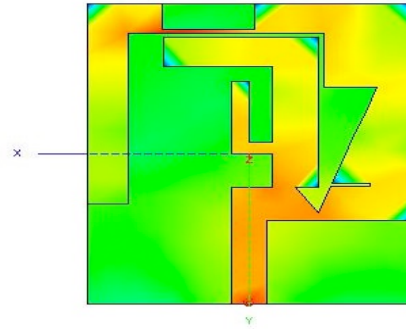


Fig. 5(b): at 5.5 GHz

Fig. 5: Surface Current Distribution

The radiation patterns of the antenna at 3.5 GHz and 5.5 GHz, are shown in the Fig.6(a) and Fig.6(b) respectively. The dipole-like radiation pattern in the xz plane and omni-directional radiation pattern in the yz plane are obtained at these frequencies. The simulated gain of antenna is 4 dB and 5dB at 3.5 GHz and at 5.5 GHz respectively.

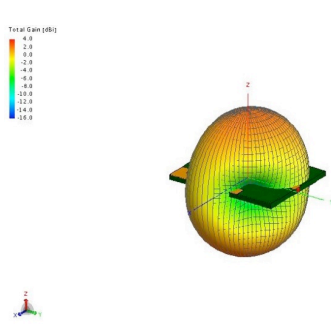


Fig. 6(a): Radiation Pattern at 3.5 GHz

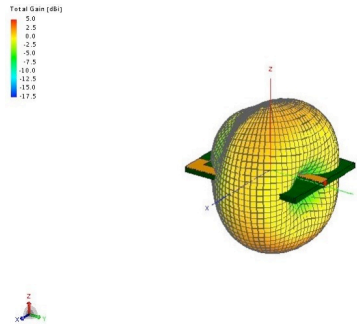


Fig. 6(b): Radiation Pattern at 5.5 GHz

The antenna prototype is fabricated as per the optimized dimensions depicted in the Table I & II. A photograph of the antenna prototype is given in Fig.3. The testing of the fabricated antenna prototype is done on Agilent PNA series Network Analyzer (N5230A). The designed antenna reflects the dual-band operation as shown in Fig.7 and Fig.8. According to simulated results, the designed antenna is effectively covering two separate impedance bandwidths of 7% at 3.5 GHz (3.4-3.67GHz) and 13% at the frequency of 5.5 GHz (5.14-5.86 GHz).

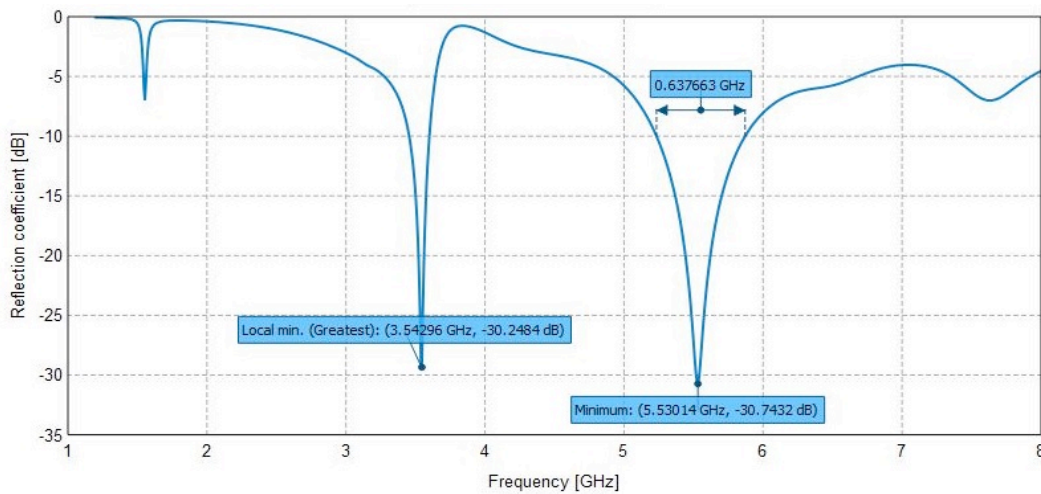


Fig. 7: Simulated S-Parameter

Fig.8 shows the result of measurement of designed antenna. The measured results are operating at bandwidths of 6% (3.4-3.60 GHz) and 12% (5.2-5.85 GHz) at 3.45 GHz and 5.4 GHz bands respectively.

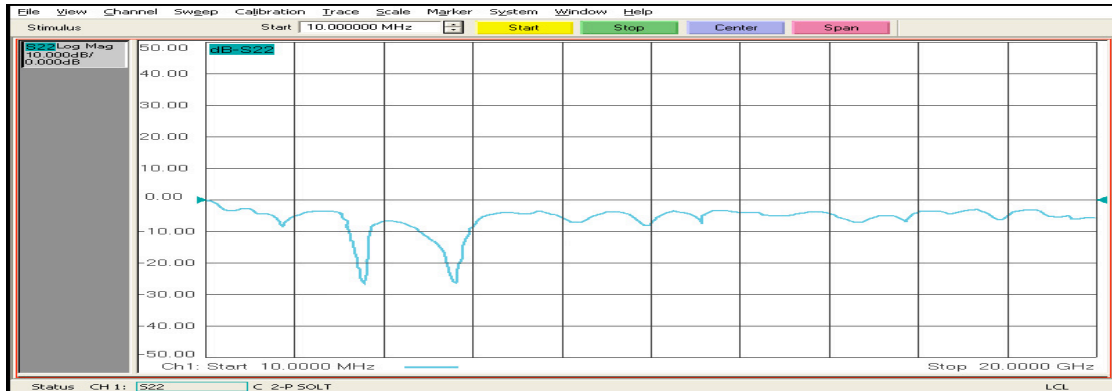


Fig. 8: Measured S-Parameter

The graph shown in Fig.9 presents the simulated and measured results of the designed antenna. Table III illustrates a comparison of simulated and measured results. Good match between simulated and measured results is observed. However, the little deviation in the measured results is attributed to the fabrication tolerances.

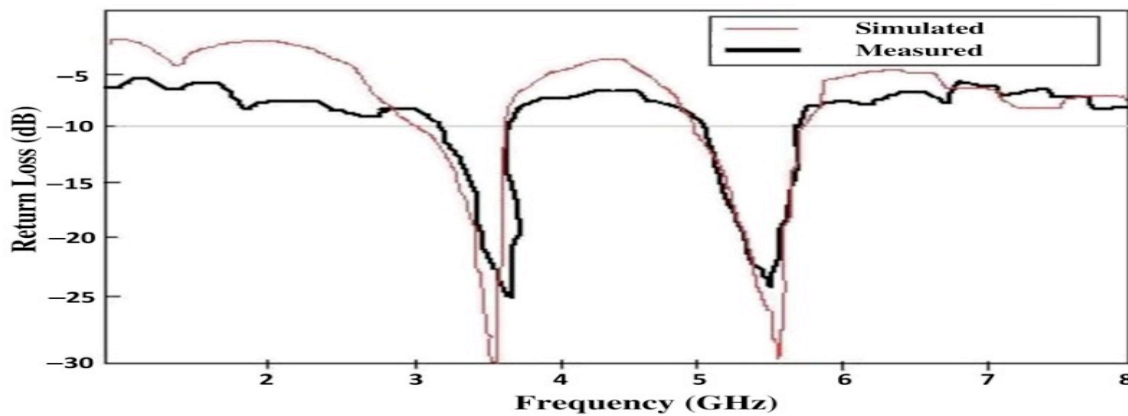


Fig. 9: Simulated and Measured Results of Proposed Antenna

Parameters	Simulated Results		Measured Results	
	I st Band	II nd Band	I st Band	II nd Band
Resonance frequency (GHz)	3.5	5.5	3.45	5.4
Return Loss (dB)	-30.24	-30.74	-25.16	-24.12
VSWR	1.063	1.06	1.18	1.13
Bandwidth (%)	7	13	6	12
Impedance (Ω)	47.13	53.06	46.95	48.76
Gain (dB)	4	5	-	-

Table III: Comparison of Simulated and Measured Results

Conclusion

A compact planar dual-band antenna for wireless applications is designed and fabricated. The optimum antenna design is showing better match between simulated and measured results. The dual band is obtained with the help of asymmetric structure without the use of fractal or stacked geometry and any kind of switches. The smaller size, omnidirectional radiation patterns with good gain and multiband operation capability of designed antenna makes it an ideal candidate to use it in WiMAX and WiFi/WLAN/HiperLAN application devices.

Acknowledgement

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