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IMPEDANCE MATCHED COMPACT ZIGZAG MULTIBAND INVERTED-F ANTENNA FOR WI-FI, MOBILE WIMAX, BLUETOOTH AND WLAN OPERATIONS IN PORTABLE DEVICES

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ABSTRACT

Multiband loaded inverted-F antennas suitable to be applied in a portable device as an internal antenna having high gain property for mobile WiMAX , Wi-Fi, Bluetooth and WLAN operations are presented. Numerical simulation is carried out using method of moments in Numerical Electromagnetic Code (NEC-2). The proposed dual inverted-F antenna is suitable for 3.5/5 GHz and compact triple band inverted-F antenna is for 2.4/3.5/5.2 GHz operations. Total areas occupied by the antennas are 24mm×37mm and 29mm×37mm in case of dual IFA and triple IFA respectively. The antennas contain an incredibly high peak gain of 7.72 dBi at 5 GHz band and the gain variations at all frequency bands are less than 1 dBi . In addition, the antennas have satisfactory radiation characteristics at all the frequency bands. Due to compact area occupied, the proposed antennas are promising to be embedded within the different portable devices.

KEYWORDS

Inverted-F Antenna, WiMAX, Wi-Fi, WLAN, Bluetooth

1. INTRODUCTION

Wireless communications have been developed widely and rapidly in the modern world especially during the last decade. In the near future, the development of the personal communication devices will aim to provide image, DMB (Digital Multimedia Broadcasting) video telephony, speech and data communications at any time-anywhere around the world using the WLANs (Wireless Loca Area Networks). Rapid advances of various WLAN protocols have sparked the requirement for miniaturized multiband antennas with suitable frequency bands appropriate for the Wi-Fi (IEEE 802.11 standard) and mobile WiMAX (IEEE 802.16e-2005 standard) applications are highly desirable. Bluetooth and WLAN operate in 2.4 GHz industrial, scientific and medical (ISM) band (frequency range 2.4–2.5 GHz) and unlicensed national information infrastructure (U-NII) band used in WLAN, Bluetooth and Wi-Fi operation. This U-NII band can be divided into three sub-bands as U-NII low (frequency ranges 5.15–5.35 GHz), U-NII mid (frequency range 5.47–5.725 GHz) and U-NII high (frequency range 5.725–5.875 GHz), which offers more non-overlapping channels than the channel offered in the ISM

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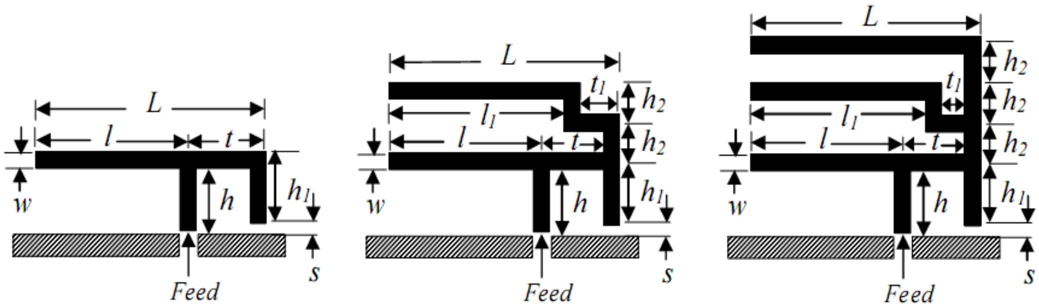
frequency band. On the other hand, IEEE 802.16e-2005 standard named mobile WiMAX provides maximum of 10 Mbps wireless transmission of data using variety of transmission modes from point to multipoint links to portable and fully mobile internet access devices. WiMAX is a possible replacement for cellular technologies such as global system for mobile (GSM) communication, code division multiple access (CDMA) or can be used as an overlay to increase capacity. It has also been considered as a wireless backhaul technology for 2G, 3G and 4G networks in both developed and poor nations. Mobile WiMAX operating bands are 2.3 GHz (frequency range 2.3–2.4 GHz), 2.5 GHz (frequency range 2.5–2.7 GHz) and 3.5 GHz (frequency range 3.4–3.6 GHz). To provide seamless internet access for the mobile devices a dual band antenna for Wi-Fi, mobile WiMAX and WLAN operation is necessary.

All the antennas, i.e., monopole antenna, slot antenna, flat-plate antenna and L-slit antenna provides Wi-Fi operation at 2.4 and 5 GHz frequency bands which is not suitable for the operation of mobile WiMAX frequency band. Uni-planar dual band monopole antenna provides two operating frequency bands for Wi-Fi operation with near about 3 and 5.5 dBi gain at frequency 2.4 and 5.8 GHz respectively [1]. If the monopole antenna is designed in hook shaped the gain is not over 2.8 and 4.29 dBi at frequency 2.4 and 5 GHz respectively [2]. Moreover, dual band slot by using two linear slot are arranged to be close, equilateral triangular slot antenna, compact double L-slit or compact dual band slot antenna has the moderate gain in both frequencies but the antenna geometry are not simple[3]-[6]. The gain of the flat-plate antenna with shorted parasitic element also limited to 3 dBi at 2.4 GHz and 5.5 dBi at 5.2/5.8 GHz operating frequency [7].Compact loop type Antenna [8] and compact monopole antenna [9] have been proposed recently but they are unable to provide the 3.5 GHz mobile WiMAX operation. However, modified two-strip monopole antenna [10] can provide 3.5 GHz operation but the antenna geometry is not simple.

It is realized that some low-profile microstrip and printed slot antennas are required for Wi-Fi and mobile WiMAX operations which can overcome the constraints of size, weight, cost, performance, installation complexity and aerodynamic profile. To ensure all the mentioned requirements, inverted-F antenna is one of the good candidates. Inverted-L antenna suffers from lower input impedance than PIFA and slot antennas. In this paper, we present high gain slightly loaded and moderately loaded IFA to support dual and triple band operation.

2. ANTENNA DESIGN

In designing multiband antenna for Wi-Fi, mobile WiMAX and WLAN operation, we examine the possibility of increasing antenna gain with simplified structure. Using method of moments (MoM's) in Numerical Electromagnetic Code (NEC) [11], we conducted parameter studies to ascertain the effect of different loading on the antenna performance to find out the optimal design. For our study we assume the copper conductor and the antenna was intended to be matched to 50 ohm system impedance. The geometrical configuration of the inverted-F antennas are depicted in Fig. 1.



(a) (b) (c)

Figure 1. Geometry of (a) IFA (b) dual IFA (c) Triple IFA

In case of IFA as shown in Figure 1(a), the resonant frequency related to *w* given as [12]

$$f_1 = \frac{c}{4(l+t+h_1)} \tag{1}$$

Where c is he speed of light. The effective length of the current is $l+t+h_1+w$. Under this case the resonant condition can be expressed as

$$l+t+h_1+w = \frac{\lambda_0}{4} \tag{2}$$

The other resonant frequency that is a part of linear combination with the case $0< w<(l+ t)$ and expressed as

$$f_2 = \frac{c}{4(l+t+h_1-w)} \tag{3}$$

The resonant frequency (f_r) is a linear combination of resonant frequency associated with the limiting case. For the antenna geometry of figure 1 (a) f_r can be written from equation (1) and (2) as [34]

$$f_r = r.f_1+(1-r)f_2 \tag{4}$$

Where $r= w / (l+ t)$

For the analysis of the accuracy optimum segmentation of each geometrical parameter are used in NEC. Figure 1 (a) represents the basic geometry of the IFA. Here one leg of IFA directly connected to the feeding and another leg spaced s from the ground plane. For the simulation we consider portable circuit board (PCB) with permittivity of ε_r= 2.2 and substrate thickness of 1.58 mm. The antenna is assumed to feed by 50 ohm coaxial conductor, with its central conductor connected to the feeding point and its outer conductor soldered to the ground plane just across the feeding point. In the analysis the dimensions of the ground plane considered as 60 mm × 60 mm.

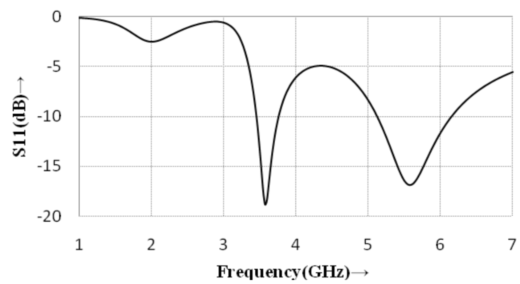
It is observed that when a load is applied to the single band IFA, the antenna can operate in two bands namely 3.5 GHz and 5 GHz frequency bands. It is shown in Fig. 1(b). We further studied on this antenna to increase the bands.We applied another zigzag load on the dual band IFA and at this time the antenna can effectively cover 2.4/3.5/5.2 WiFi/mobile WiMAX frequency bands with satisfactory return loss and radiation characteristics. The geometrical configuration of the proposed zigzag triple band inverted-F antenna is depicted in Fig. 1(c) and the design parameters are listed in Table 1.

Table 1. Dimensions of the antennas

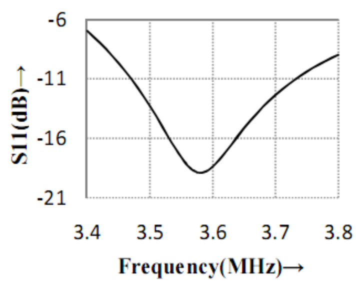
Antenna name	Partameters	Values (mm)	Dimension(mm^2)
IFA	l	31	14 ×37
	t	6	
	h	14	
	h_1	13.6	
	w	2	
	s	0.4	
Dual IFA (Proposed)	l	31	24×37
	l_1	33	
	t	6	
	t_1	4	
	h	14	
	h_1	13.6	
	h_2	5	
	w	2	
	s	0.4	
Triple IFA (proposed)	l	31	29×37
	l_1	33	
	L	37	
	t	6	
	t_1	4	
	h_1	13.6	
	h_2	5	
	w	2	
	s	0.4	

3. SIMULATION AND RESULTS

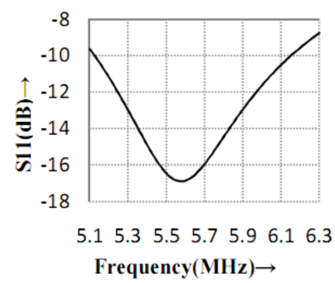
The simulated return losses of the proposed slightly loaded dual IFA(geometry of Figure 1 (b)) and moderately loaded triple IFA (geometry of Figure 1 (c)) are shown in Figure 2& 3. From the simulation results, the slightly loaded IFA has return loss bandwidth of 250 MHz (frequency ranges 3400 – 3650 MHz) at lower operating band and 1050 MHz (frequency ranges 5150 – 6200 MHz) at upper operating band. The lower operating band covers the 100 % of 3.5 GHz (IEEE 802.16e-2005 standard) mobile WiMAX (3.4 – 3.6 GHz) operating band. On the other hand, the upper operating band covers the 100 % of 5 GHz (IEEE 802.11a standard) WiFi (5.15– 5.875 GHz) operating band. Due to the increase in load to the IFA, the modified moderately loaded IFA has an additional band (2.4 GHz) with improved return loss and gain characteristics. Moderately loaded IFA has lower band return loss bandwidth of 150 MHz (2450 – 2600 MHz) which fully occupy the 2.4 GHz WiFi and Bluetooth/WLAN operating band. The middle band shows a bandwidth of 100 MHz (3475 – 3575 MHz) covering the 3.5 GHz for mobile WiMAX operating band (IEEE 802.16e-2005 standard). The upper band shows a wider bandwidth of 925 MHz (4750 – 5675 MHz) covering the 5 GHz band for the Wi-Fi operation (IEEE 802.11a standard). The variations of voltage standing wave ratio (VSWR) as a function of frequency are shown in Figure 4 for both all operating bands. From the obtained results, as the load applied to the IFA, the VSWR improves significantly and appear close to standard value 1 in both antenna return loss bandwidth.



(a)

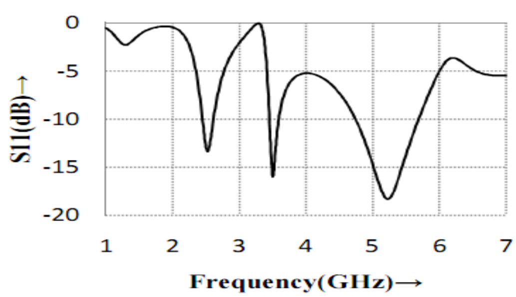


(b)

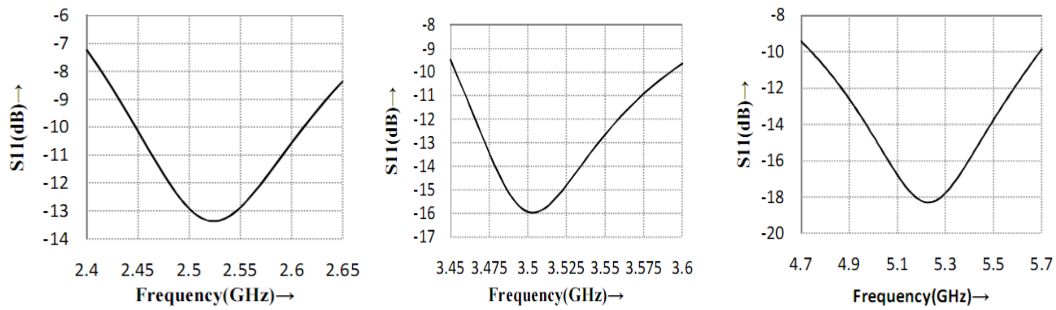


(c)

Figure 2: Antennas return loss of dual IFA (a) as a function of frequency (b) lower return loss bandwidth and (c) upper return loss bandwidth

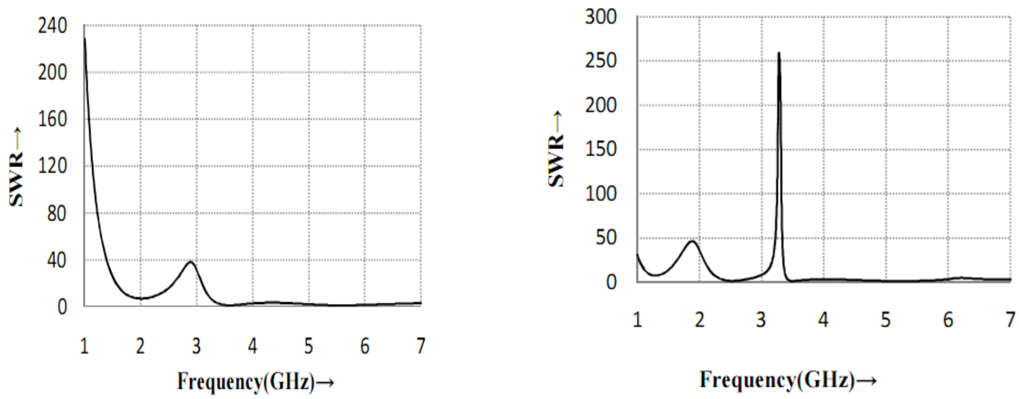


(a)



(b) (c) (d)

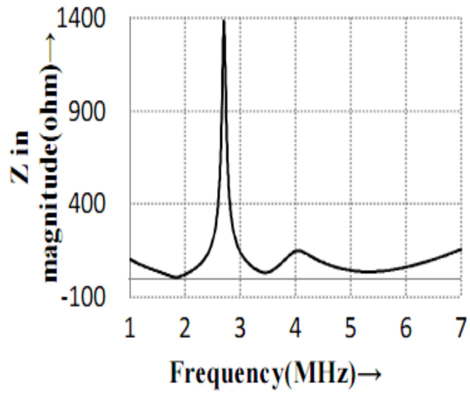
Figure 3: Antennas return loss of triple IFA (a) as a function of frequency (b) lower return loss bandwidth (c) middle return loss bandwidth (d) upper return loss bandwidth



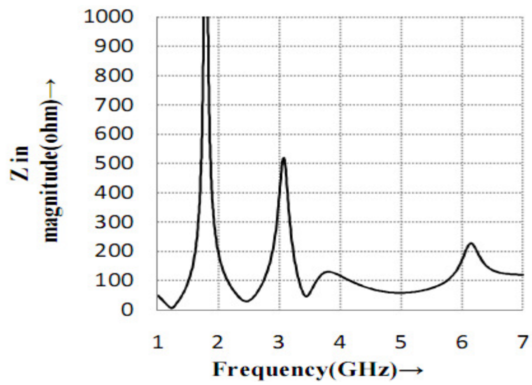
(a) (b)

Figure 4: Variation of VSWR of the antennas as a function of frequency for
(a) dual IFA (b) triple IFA

Figure 5 represents the antennas input impedance variation and Figure 6 represents the antennas phase shift causes due the impedance mismatch as a function of frequency. From the obtained results, moderately loaded IFA has much better antenna input impedance than rest two structures .Also, from the simulation study, the phase shift decrease with the application of load to the IFA.



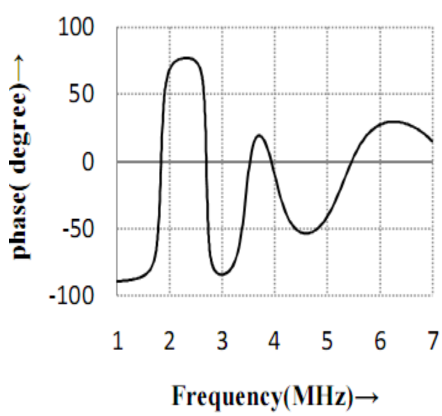
(a)



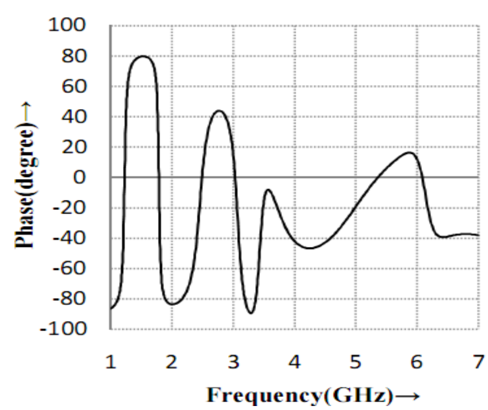
(b)

Figure 5: Input impedance variation with respect to the frequency for
(a) dual IFA and (b)triple IFA

Fig 7 shows the total antenna gain for dual IFA at 3.5 and 5 GHz bands respectively. It is found that in the 3.5 GHz band , the peak gain is about 7.49 dBi and less than 0.3 dBi of gain variation is observed. In the 5 GHz band, the peak gain reaches about 7.72 dBi and gain variation is less than about 2 dBi . Fig 8 shows the total antenna gain for triple IFA at 2.4, 3.5 and 5.2 GHz respectively. In the 2.4 GHz band, the peak gain is about 3.82 dBi and about 0.1 dBi of gain variation is observed. In the 3.5 GHz band, the peak gain reaches about 6.15 dBi and gain variation is about 1.3 dBi. In case of 5.2 GHz band, peak gain is 4.3 dBi with only 0.9 dBi gain variations. Therefore both the antennas have stable gain at all the operating bands and satisfied the required gain variation for the mobile WiMAX and Wi-Fi operation.

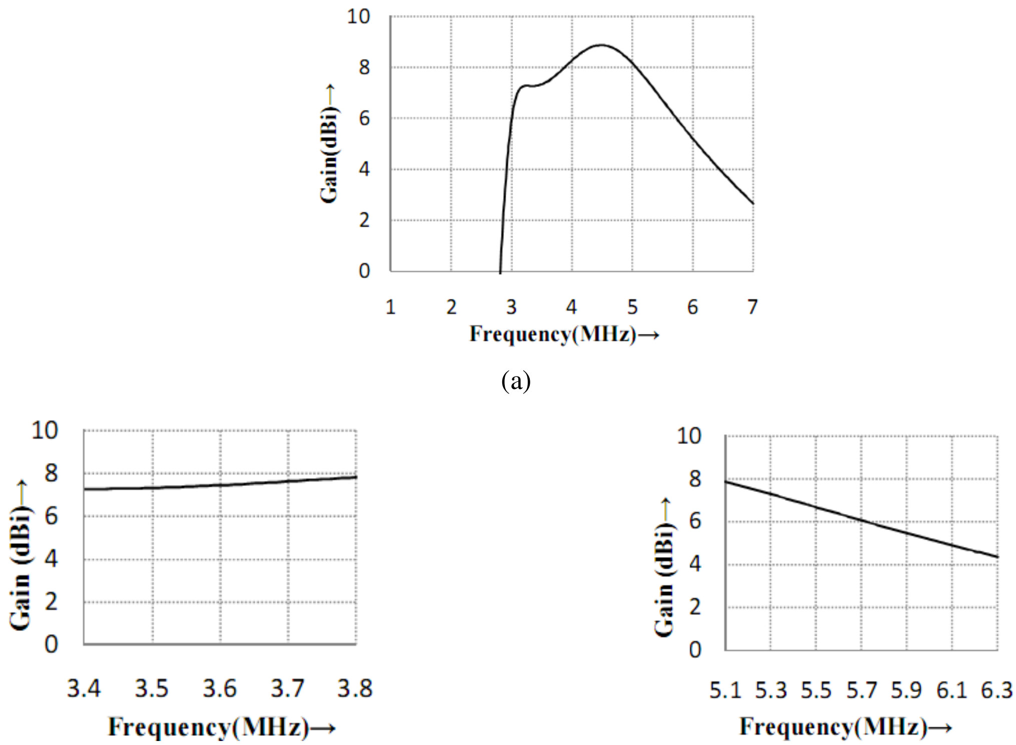


(a)



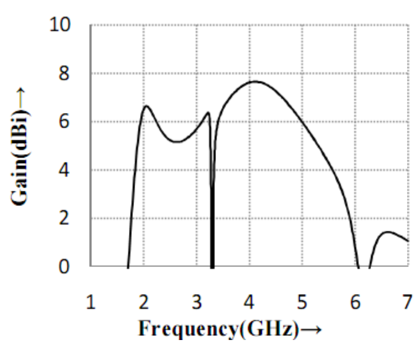
(b)

Figure 6: Phase shift of the antennas as a function of frequency for
(a) dual IFA and (b) triple IFA

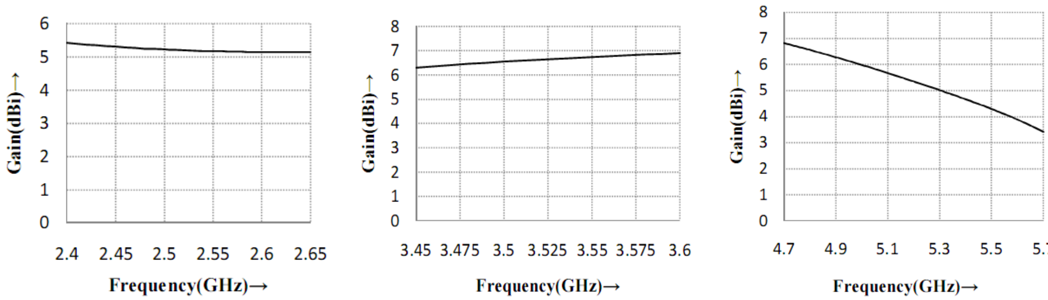


(a) (b) (c)

Figure 7: Variation of antenna gain as a function of frequency for dual IFA
(a) Total gain (b) 3.5 GHz band (c) 5 GHz band



(a)



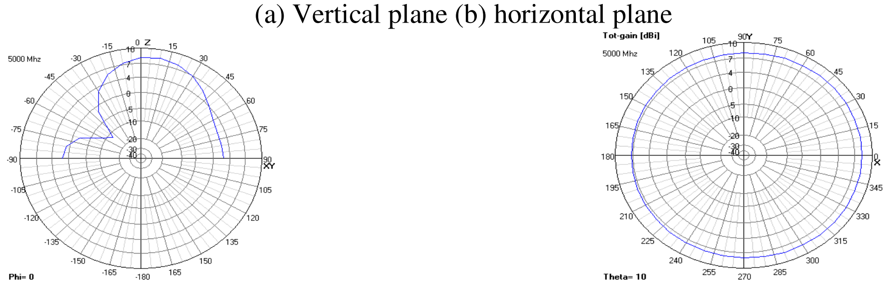
(b) (c) (d)

Figure 8: Variation of antenna gain as a function of frequency for triple band IFA
(a) Total gain (b) 2.4 GHz band (b) 3.5 GHz band (c) 5.2 GHz band

The radiation patterns of the proposed dual band IFA at the two resonant frequencies 3.5 & 5 GHz are illustrated in figure 9 and 10 in both vertical and horizontal plane respectively. For the proposed triple IFA the radiation patterns at 2.4, 3.5 & 5.2 GHz frequencies are shown in figure 11 ,12and 13. From the obtained radiation pattern, the slightly loaded IFA has good radiation characteristics in both planes at both operating frequencies and also the moderately loaded triple IFA has acceptable radiation characteristics at all the operating frequency bands in horizontal and vertical planes. At 5.2 GHz Wi-Fi operation, the antenna has somewhat less omnidirectional gain pattern but it is full omnidirectional at other frequency bands.

(a) (b)

Figure 9: Total gain patterns of the proposed dual IFA at 3.5 GHz in
(a) Vertical plane (b) horizontal plane



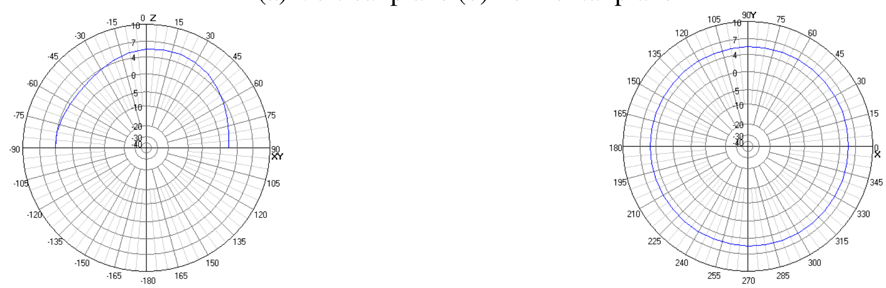
(a) (b)

Figure 10: Total gain patterns of the proposed dual IFA at 5 GHz in

(a) Vertical plane (b) horizontal plane

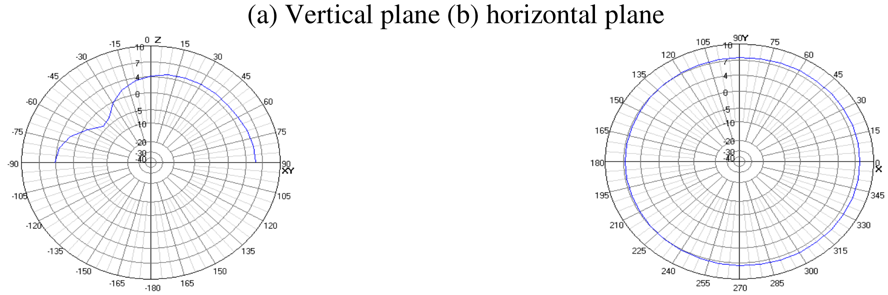
(a) (b)

Figure 11: Total gain patterns of the proposed triple IFA at 2.4 GHz in
(a) Vertical plane (b) horizontal plane



(a) (b)

Figure 12: Total gain patterns of the proposed triple IFA at 3.5 GHz in
(a) Vertical plane (b) horizontal plane



(a) (b)

Figure 13: Total gain patterns of the proposed triple IFA at 5 GHz in

(a) Vertical plane (b) horizontal plane

4. CONCLUSIONS & FUTURE WORK

Multiband slightly and moderately loaded inverted-F antennas have been proposed and analyzed by means of numerical simulations using MOM's in NEC. The antennas geometry analyzed by varying the four major geometry parameters (length, height, tap distance and spacing). For both antennas, spacing has significant influence on the lower operating band while it has negligible effect on the upper band. From the four parameters analysis antenna geometry chosen and proposed antennas performance parameters are analyzed for multiband operations. The proposed antennas have high gain for mobile WiMAX, WLAN, Bluetooth and Wi-Fi operation. It is also observed that improvements in antenna gain, input impedance, phase shift and return loss have been obtained when structured load is applied to the IFA. The antennas are of small size and good radiation characteristics. Due to the compact area occupied, the proposed antennas are promising to be embedded within the different mobile devices employing mobile WiMAX, Wi-Fi, Bluetooth and WLAN operation.

Our future target is miniaturization of the proposed antennas with increasing operating bandwidth and gain.

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