High Gain Multiband Loaded Inverted-F Antennas for Mobile WiMAX, Wi-Fi, Bluetooth and WLAN Operation

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Abstract

Multiband loaded inverted-F antennas (LIFA's) suitable to be applied in a portable device as an internal antenna having high gain property for mobile WiMAX, Wi-Fi, Bluetooth and WLAN operation are presented. The proposed antennas are directly feed by 50 Ω coaxial connector. The antenna arms effectively control the excited resonant modes for the required operation. Total areas occupied by the antennas are 24 × 37 and 29 × 37 mm^2 in case of slightly loaded IFA (SLIFA) and moderately loaded IFA (MLIFA) respectively. The antennas contain an incredibly high peak gains of 8.31, 8.88 and 6.32 dBi and 8.48, 8.67 and 6.89 dBi for 2.3 GHz mobile WiMAX, 2.4 GHz WLAN/Bluetooth and 5.8 GHz Wi-Fi operation for SLIFA and MLIFA respectively, with less than 0.84 and 1.8 dBi gain variation at lower and upper operating band within the 10 dB return loss bandwidth. In addition, the antennas have achievable bandwidth, return loss and radiation characteristics.

Keywords: Inverted-F antenna, Loaded inverted-F antenna, Worldwide interoperability for microwave access (WiMAX), Wireless-Fidelity (Wi-Fi), Bluetooth, Wireless local area network (WLAN).

1. INTRODUCTION

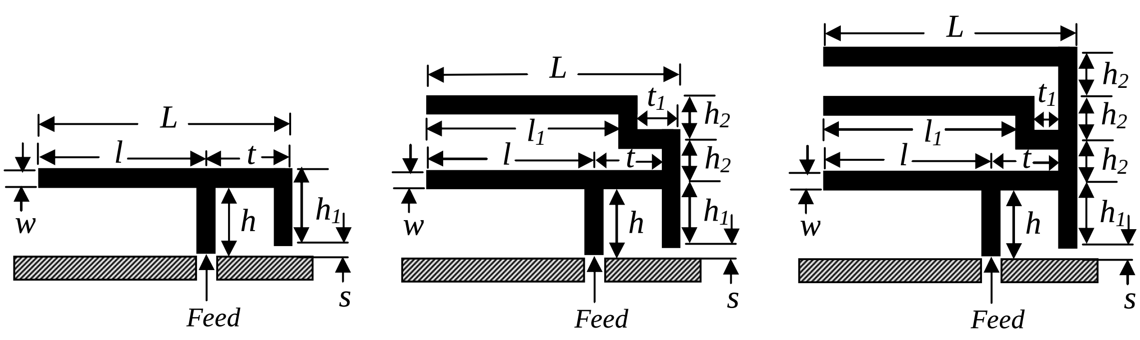
Bluetooth and WLAN operate in 2.4 GHz industrial, scientific and medical (ISM) band (frequency range 2.4–2.5 GHz) and unlicensed national information infrastructure (U-NII) band used in WLAN, Bluetooth and Wi-Fi operation. This U-NII band can be divided into three sub-bands as

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 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.

The key design configurations in order to meet multiband operation include a monopole antenna feed with SMA connector [1], integrated monopole slot antenna [2], coplanar waveguide (CPW) feed meandered monopole antenna [3], a CPW-fed compact monopole antenna with two resonant paths [4], a CPW-fed tapered bent folded monopole antenna [5], a microstrip-fed double-T monopole antenna [6], a meander-line monopole antenna with a backed microstrip line [7], a C-shaped monopole antenna with a shorted parasitic element [8], and a branched monopole antenna with a truncated ground plane [9], printed monopole antenna for WiMAX/WLAN operation [10]. Microstrip line feed printed antenna [11], printed monopole array [12], T-shaped monopole with shorted L-shaped strip-sleeves [13], microstrip coupled printed planar inverted-F antenna (PIFA) [14], surface mount monopole [15], flat-plate inverted-F antenna (IFA) [16], CPW-fed triangular shaped monopole [17], metal plate [18], internal composite monopole [19], multi slot [20], compact loop [21], compact PIFA [22], flat plate with shorted parasitic element [23], internal PIFA [24], miniaturized PIFA [25], and two strip monopole [26] antenna can support Bluetooth (BT)/WiMAX/Wi-Fi/WLAN operation. Previously, single band antenna for WLAN or Wi-Fi operation, printed quasi-self complementary [27], CPW-fed folded slot monopole [28], CPW-fed shorted F-shaped monopole [29], planar inverted-L antenna [30] and T-shaped monopole [31] have been analyzed and proposed. 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 multiband 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) [32], 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 Ω system impedance.



(a) (b) (c)

FIGURE 1: Geometry of (a) IFA, (b) SLIFA and (c) MLIFA.

In case of IFA as shown in Figure 1(a), the resonant frequency related to *w* given as [33]

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

Where c is the 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 is 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 $r = \frac{w}{l+t}$. With the help of resonant frequency theory of IFA, and impedance matching concept, we consider the dimension of the IFA as $l = 31\,mm$, $t = 6\,mm$, $h_1 = 13.6\,mm$, $h = 14\,mm$, $s = 0.4\,mm$, $w = 2\,mm$.

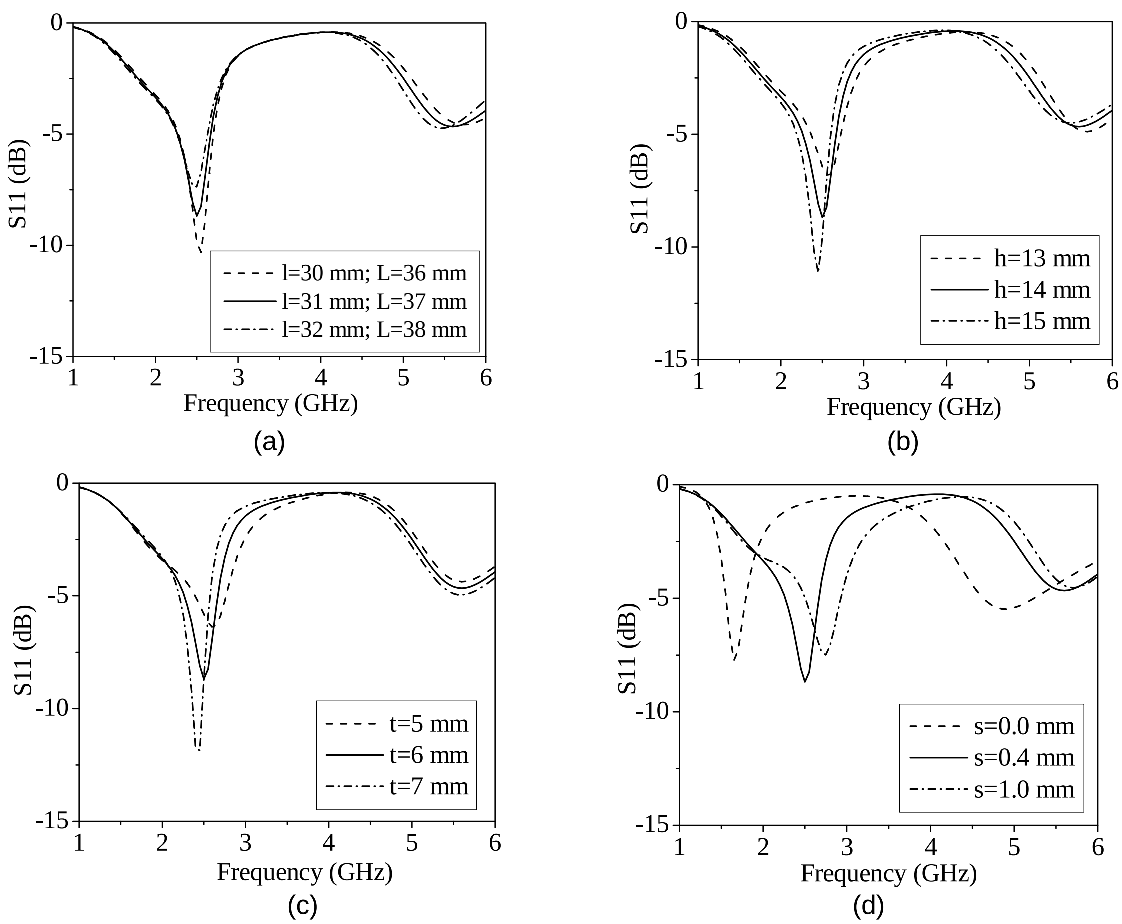


FIGURE 2: Effects of (a) length *l*, (b) height *h*, (c) tap distance *t* and (d) spacing *s* on the return loss as a function of frequency on the antenna structure of Figure 1(a).

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 Ω coaxial connector, 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.

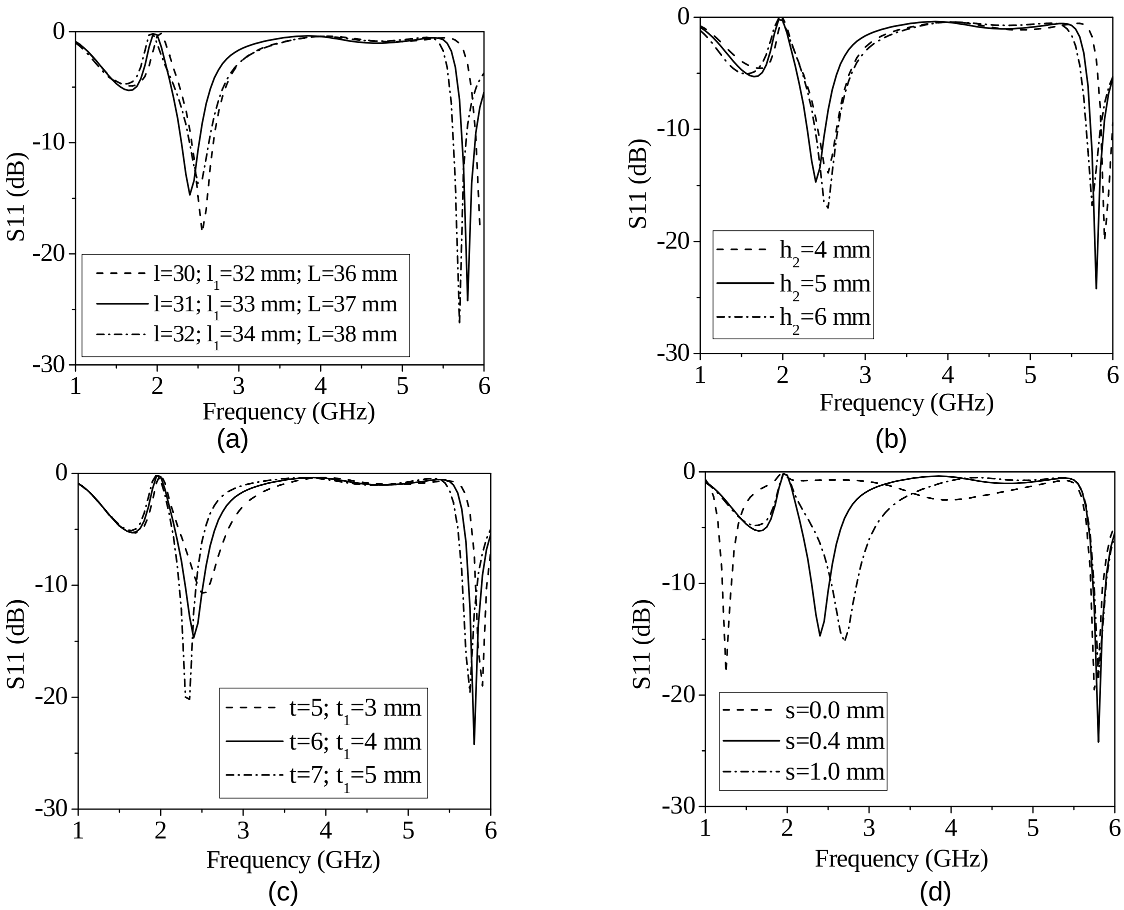


FIGURE 3: Effects of (a) length *l*, (b) height h_2, (c) tap distance *t* and (d) spacing *s* on the return loss as a function of frequency on the antenna structure of Figure 1(b).

Figure 2 (a) and (b) shows the effects of *L* and *h* on the performance of IFA (antenna structure of Figure 1(a)) and Figure 2(c) and (d) represents the effects of *t* and *s* on the return loss (S11) of the antenna. Variation of return loss with frequency is like dual band shape but both band stay above the required 10 dB level. From the simulated results, antenna has stable dual shaped bandwidth at *L*=*l*+*t*=37 mm and *h*=14 mm. As the performance of IFA is not satisfactory for the multiband operation then we apply a small suitable structured load on the horizontal branch of the IFA named slightly loaded IFA as shown in Figure 1 (b). On the other hand, increase in *t* causes increase in S11 and narrowing the bandwidth whereas the increase in s causes shift of resonance to the higher frequency. We observe that when we apply that load then the antenna performance improves significantly. We further analysis on the slightly loaded IFA for achieving the structure of best performance. Figure 3 (a) and (b) shows the effects of *L* and h_2 on the performance of slightly loaded IFA (antenna structure of Figure 1(b)) while Figure 3(c) and (d) represents the effects of *t* and *s* on S11. From figure 3 (a) and (b) we observe that a higher value of *L* or h_2 shifts the antenna resonance to the lower frequencies and a lower value of *L* or h_2 shifts the antenna resonance to the higher frequencies at upper frequency band and for both lower and higher value of L and h_2 antenna resonance shifts to the higher frequencies at lower band. Also, change in t for the antenna of structure Figure 1 (b) affect the S11 at lower and upper band. Increase in t results change in resonance from lower to upper frequency while change in s change the resonance as well as maximum values of S11 and mainly it affects the lower resonance band and has smaller effect on upper return loss bandwidth. From the simulation, the optimum dimensions of L and h_2 of slightly loaded IFA are $L=l+t=l_1+t_1=37$ mm and $h_2=5$ mm. From Figure 3 (a) and (b) we also observe that though the return loss of lower band is just below the 10 dB level. But more negative value of antenna return loss means more effectively power transmitted by the antenna in electromagnetic form into free space.

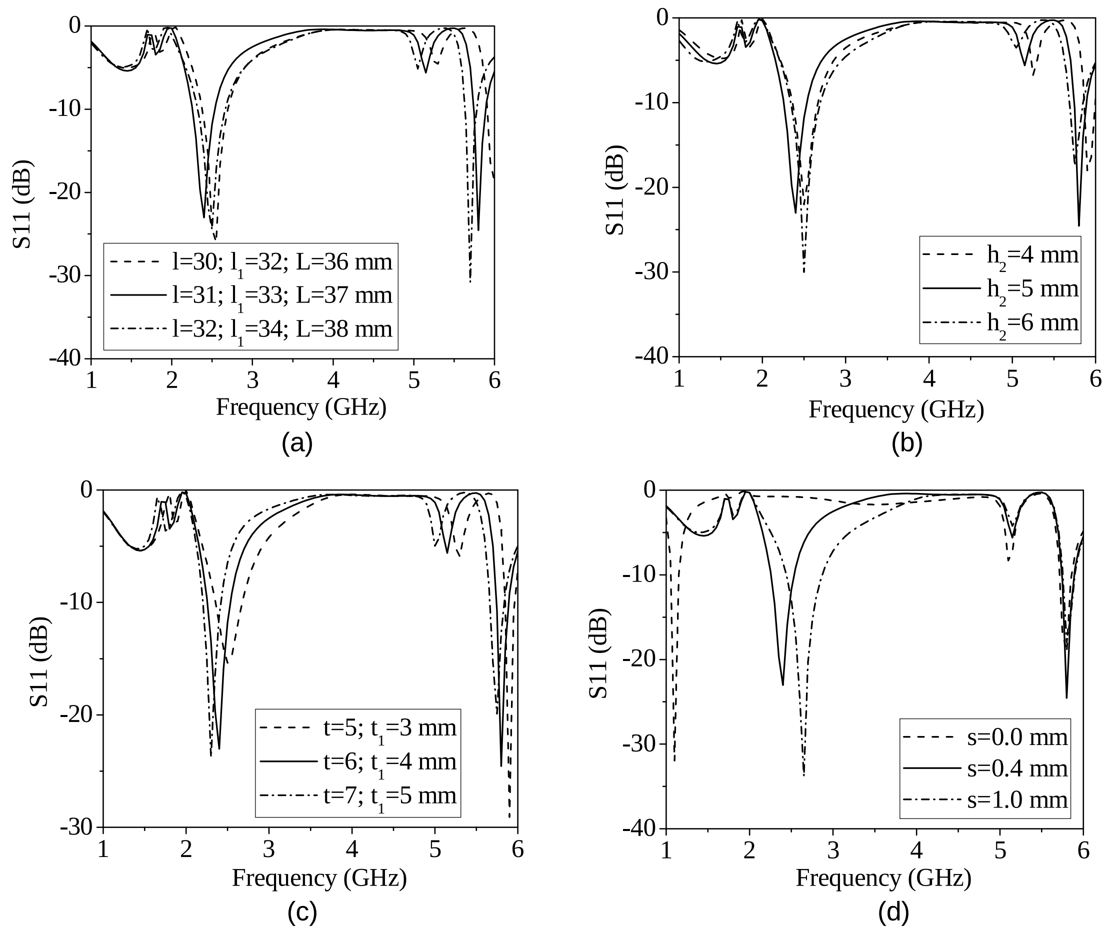


FIGURE 4: Effects of (a) length *l,* (b) height h_2, (c) tap distance *t* and (d) spacing *s* on the return loss as a function of frequency on the antenna structure of Figure 1(c).

So we further trying to improve the return loss level for the lower frequency band. We observe that when we apply a small load on the horizontal branch of slightly loaded IFA named as moderately loaded IFA shown in Figure 1 (c), the return loss level of lower band improves significantly remaining the return loss level of upper band almost unchanged. Then we tried to find the suitable structure for moderately loaded IFA which provide the best performance for multiband operation. Figure 4 (a) and (b) shows the effects of L and h_2 and Figure 4 (c) and (d) represents the effects of tap distance, t and spacing, s on the performance of moderately loaded IFA (antenna structure of Figure 1(c)). In case of moderately loaded IFA tap distance has not significant effect and does not responsible for causes change in S11 significantly. But change of spacing has significant influence on S11 at lower return loss bandwidth. Zero spacing generate resonance at 1.1 GHz, 0.4 mm spacing shifts the resonance from 1.1 GHz to 2.4 GHz; on the other hand 1 mm spacing shift this resonance to higher frequency and is the order of 2.6 GHz.

While the change in spacing causes no change in return loss bandwidth in the upper band. Thus for slightly loaded and moderately loaded IFA, spacing has no significant effect on the upper operating band but has a great influence on the lower band. Under no load condition spacing has significant effect on the performance of IFA in both lower and upper band. From figure 4 (a) and (b) we observe that a higher value of L or h_2 shifts the antenna resonance to the lower frequencies and a lower value of L or h_2 shifts the antenna resonance to the higher frequencies at upper frequency band, and for both lower and higher value of L and h_2 antenna resonance shifts to the higher frequencies at lower band. From the simulation, the optimum dimensions of L and h_2 of slightly loaded IFA are $L=l+t=l_1+t_1$=37 mm and h_2=5 mm. Table 1 represents the optimized numerical value of geometric parameters of the antennas of Figure 1.

TABLE 1: Dimensions of the antennas.

Antenna Name	Antenna Parameters	Values (mm)	Dimension (mm^2)
IFA	l	31	14 × 37
	t	6	
	h	14	
	h_1	13.6	
	w	2	
	s	0.4	
SLIFA (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	
MLIFA (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. NUMERICAL SIMULATION RESULTS

The simulated return losses of IFA (geometry of Figure 1 (a)), proposed slightly loaded (geometry of Figure 1 (b)) and moderately loaded (geometry of Figure 1 (c)) IFA are shown in Figure 5. From the simulation results, the slightly loaded IFA has return loss bandwidth of 235 MHz (frequency ranges 2285 – 2520 MHz) at lower operating band and 150 MHz (frequency ranges 5730 – 5880 MHz) at upper operating band. The lower operating band covers the 100 % of 2.3 GHz mobile WiMAX (2.3 – 2.4 GHz) operating band and 2.4 GHz IEEE 802.11b/g WLAN/Bluetooth (2.4 – 2.5 GHz) operating band. On the other hand, at the upper return loss bandwidth of the antenna of geometry of Figure 1(b) cover the 97 % of 5.8 GHz Wi-Fi (frequency ranges 5725 – 5875 GHz) operating band. Due to the increase in load to the IFA, the modified moderately loaded IFA has improved return loss than antenna of structure 2 (geometry of Figure 1(b)). Moderately loaded IFA has lower band return loss bandwidth of 270 MHz (2260 – 2530 MHz) which fully occupy the 2.3 GHz Mobile WiMAX and 2.4 GHz Bluetooth/WLAN operating band. Moreover, the upper band bandwidth of 150 MHz (5735 – 5885 MHz) covers 93 % of 5.8 GHz Wi-Fi operation. The variations of voltage standing wave ratio (VSWR) as a function of frequency are shown in Figure 6 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.

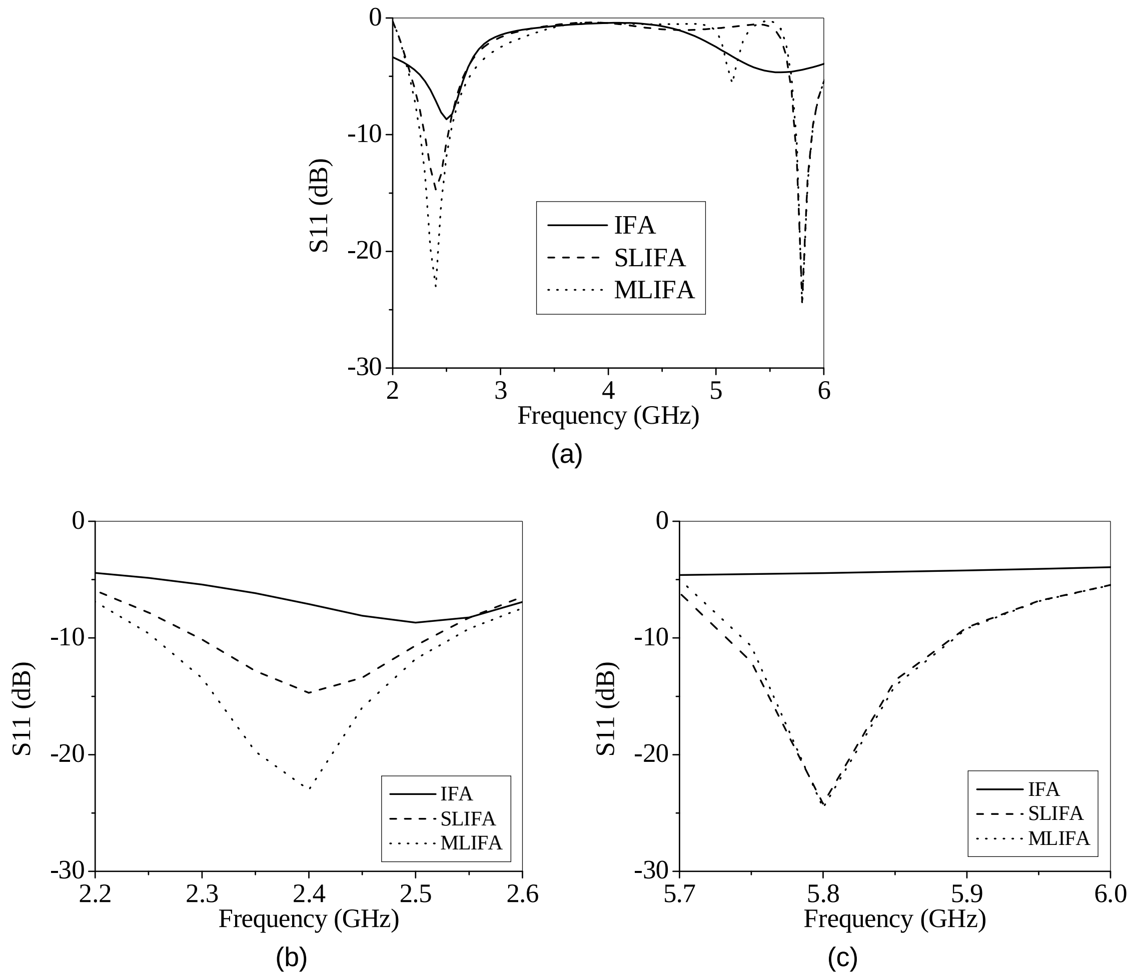


FIGURE 5: Antennas return loss (a) as a function of frequency (b) lower return loss bandwidth and (c) upper return loss bandwidth.

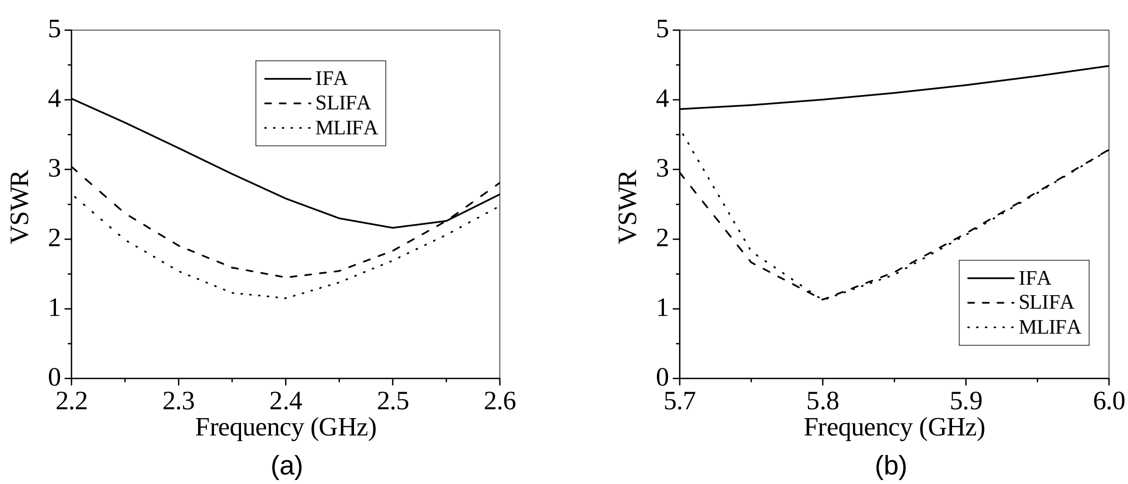
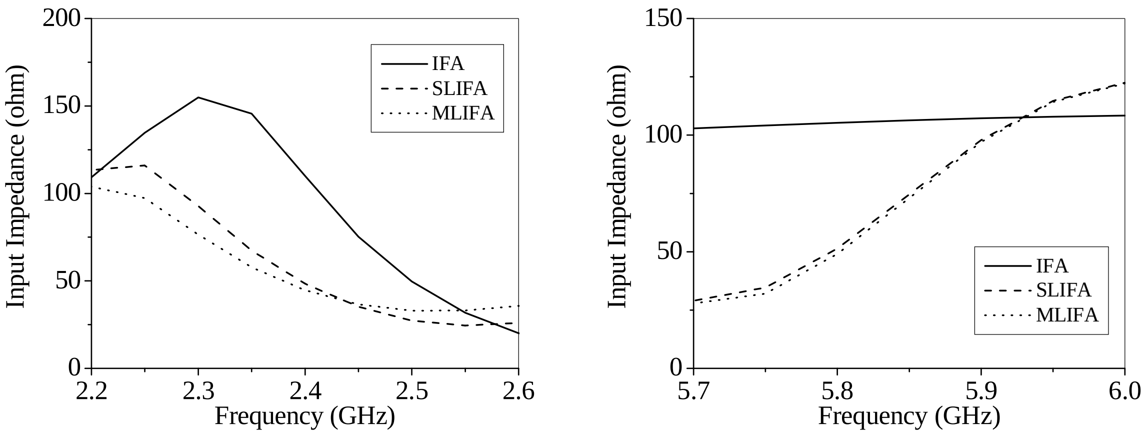


FIGURE 6: Variation of VSWR of the antennas of geometry of Figure 1, as a function of frequency at (a) lower return loss bandwidth and (b) upper return loss bandwidth.

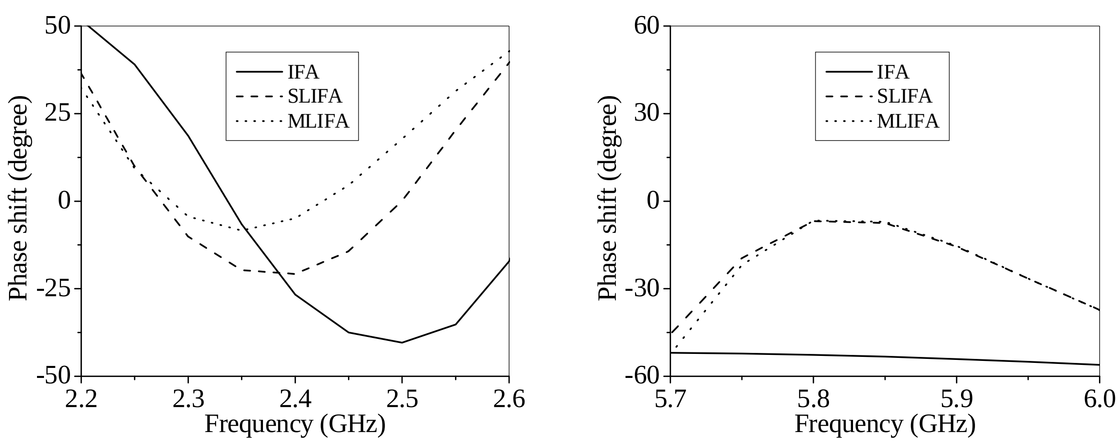
Figure 7 represents the antennas input impedance variation and Figure 8 represents the antennas phase shift causes due the impedance mismatch as a function of frequency. From the obtained results, structure 3 (moderately loaded IFA) has much better antenna input impedance than rest two structures (structure 1 and 2). Also, from the simulation study, the phase shift decrease with the application of load to the IFA.



(a) (b)

FIGURE 7: Input impedance variation of the antennas of Figure 1 with respect to the frequency at (a) lower return loss bandwidth and (b) upper return loss bandwidth.

The antennas gain variation as a function of frequency is shown in Figure 9. From the obtained results, antenna gain varies 6.91 to 8.95 dBi at within 2.25 GHz to 2.55 GHz for the IFA (geometry structure 1), 8.04 to 8.97 dBi for slightly loaded IFA (geometry structure 2) and 8.3 to 8.65 dBi for moderately loaded IFA (geometry structure 3). And within the upper return loss bandwidth (frequency 5.7 – 5.9 GHz) the gain varies from 2.79 to 2.56 dBi, from 6.98 to 4.69 dBi, and from 7.61 to 5.18 dBi for the IFA, slightly loaded IFA and moderately loaded IFA respectively.



(a) (b)

FIGURE 8: Phase shift of the antenna as a function of frequency at (a) lower return loss bandwidth and (b) upper return loss bandwidth.

Peak gain comparison with the proposed antenna and reference antenna for mobile WiMAX, Wi-Fi, WLAN and Bluetooth application are listed in Table 2. From the comparison table, proposed loaded IFA's has much higher gain than the antenna have been proposed for mobile WiMAX, Bluetooth, WLAN and Wi-Fi operation.

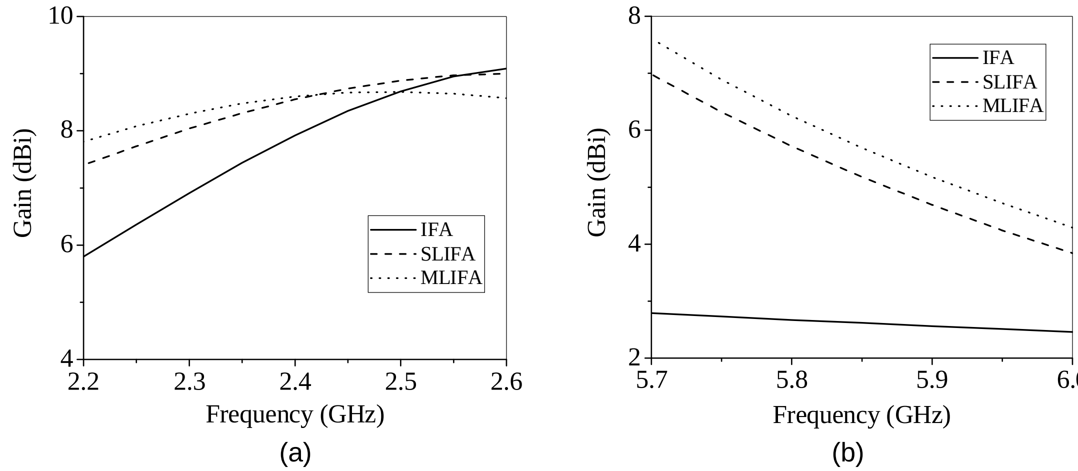


FIGURE 9: Variation of antenna gain as a function of frequency at (a) lower return loss bandwidth and (b) upper return loss bandwidth.

TABLE 2: Gain comparison between the proposed and reference antennas.

Antenna	Gain (dBi)		
	2.3 GHz mobile WiMAX	**2.4 GHz WLAN or Bluetooth**	**5.8 GHz Wi-Fi**
Slightly loaded IFA (structure 2)	8.31	8.88	6.32
Moderately loaded IFA (structure 3)	8.48	8.67	6.89
Compact monopole antenna [1]	-	1.35	2.10
Printed multiband antenna [11]	-	-3.1	3.21
Printed monopole array antenna [12]	-	3.4	6.4
T-shaped monopole with shorted L-shaped strip sleeves antenna [13]	-	3.4	1
Microstrip coupled printed PIFA [14]	-	4.2	6.4
Surface mount monopole antenna [15]	-	4.3	5.1
CPW-fed triangular shaped monopole antenna [17]	-	2.14	3.05
Metal plate antenna [18]	2.12	2.5	4.8
Composite monopole antenna [19]	-	2.3	4.8
Compact loop antenna [21]	-	2.63	5.48
Flat plate antenna with shorted parasitic element [23]	-	2.8	5.48

Figure 10 (a) and (b) represents the normalized radiation pattern of the antenna of Figure 1(b) (slightly loaded IFA) for 2.4 GHz resonant frequency of total gain in vertical plane (XZ, YZ plane) and horizontal plane (XY plane) respectively. Figure 10 (c) and (d) represents the normalized horizontal gain in horizontal plane and normalized vertical gain in horizontal plane respectively for slightly loaded IFA. Also, the normalized total gain pattern of the antenna at 5.8 GHz in vertical plane (XZ, YZ plane) and horizontal plane (XY plane) are shown in Figure 11 (a) and (b). Moreover, Figure 11 (c) and (d) represents the normalized horizontal gain in horizontal plane (XY plane) and normalized vertical gain in horizontal plane (XY plane) respectively at 5.8 GHz. From the obtained radiation pattern, the slightly loaded IFA has good radiation characteristics in both planes at both operating frequencies. Combining all radiation, it seems to be a half-orange shape with very high gain. Figure 12 (a) and (b) represents the normalized total gain pattern of moderately loaded IFA (antenna of Figure 1(c)) in XZ/YZ and XY plane at 2.4 GHz frequency and the normalized total gain pattern for 5.8 GHz are shown in Figure 13 (a) and (b) for XZ/YZ and XY planes. Figure 12 (c) and (d) presents the normalized horizontal and vertical gain in XY plane at 2.4 GHz while Figure 13 (c) and (d) shows the normalized horizontal and vertical gain in XY plane at 5.8 GHz for moderately loaded IFA. From the obtained radiation patter for this antenna, it has acceptable radiation characteristics in all planes (XY, YZ, ZX) at both operating frequencies (lower and upper band).

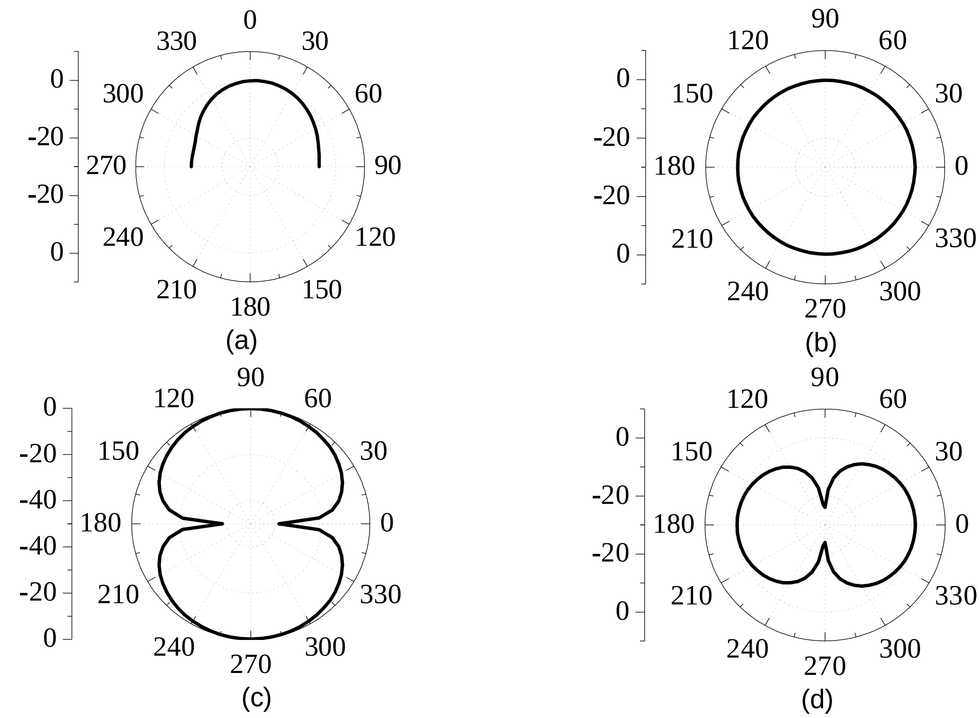


FIGURE 10: Radiation pattern (normalized) of slightly loaded IFA (antenna geometry of Figure 1(b)) at 2.4 GHz: (a) total gain in vertical plane (XZ, YZ), (b) total gain in horizontal plane (XY), (c) horizontal gain horizontal plane (XY) and (d) vertical gain horizontal plane (XY).

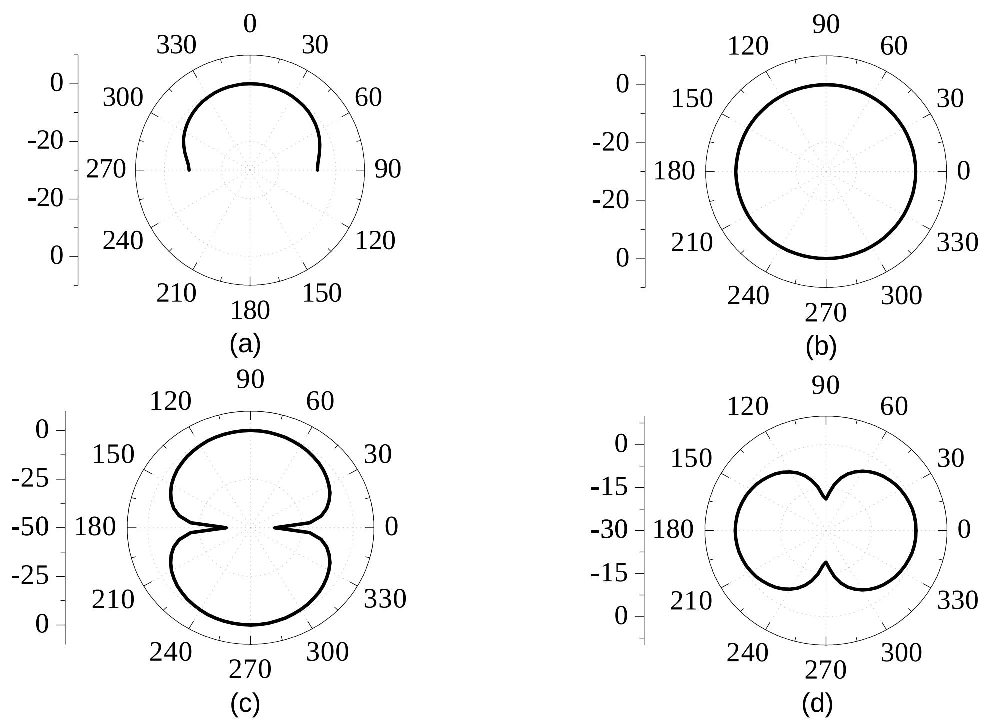


FIGURE 11: Radiation pattern (normalized) of slightly loaded IFA (antenna geometry of Figure 1(b)) at 5.8 GHz: (a) total gain in vertical plane (XZ, YZ), (b) total gain in horizontal plane (XY), (c) horizontal gain horizontal plane (XY) and (d) vertical gain horizontal plane (XY).

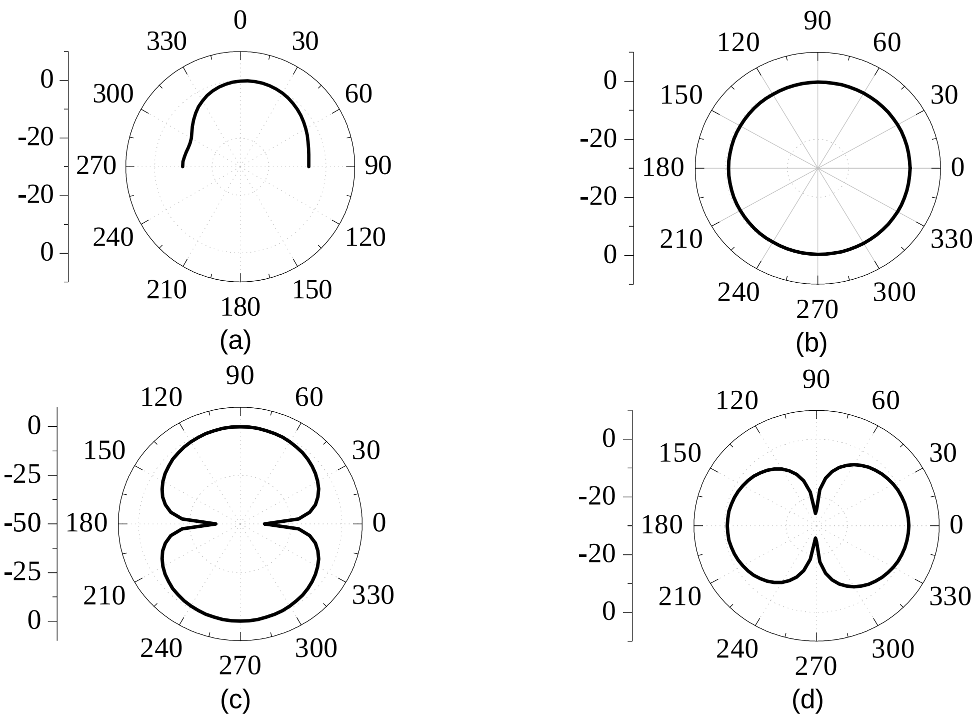


FIGURE 12: Radiation pattern (normalized) of moderately loaded IFA (antenna geometry of Figure 1(c)) at 2.4 GHz: (a) total gain in vertical plane (YZ, XZ), (b) total gain in horizontal plane (XY), (c) horizontal gain horizontal plane (XY) and (d) vertical gain horizontal plane (XY).

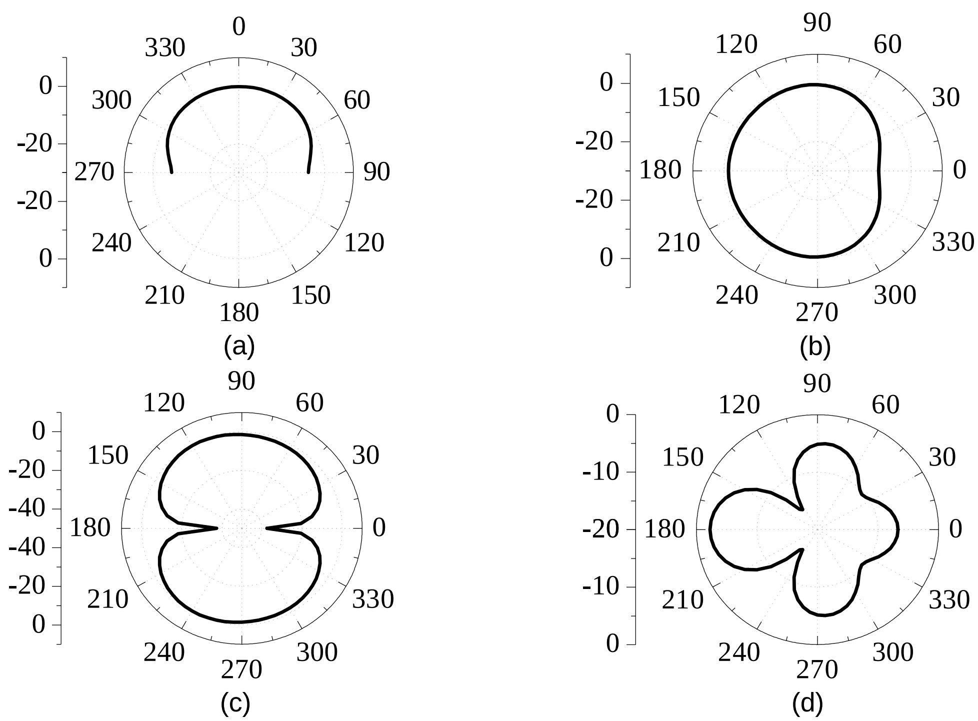


FIGURE 13: Radiation pattern (normalized) of moderately loaded IFA (antenna geometry of Figure 1(c)) at 5.8 GHz: (a) total gain in vertical plane (YZ, XZ), (b) total gain in horizontal plane (XY), (c) horizontal gain horizontal plane (XY) and (d) vertical gain horizontal plane (XY).

4. CONCLUSION & 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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