Broadband Tiny Triple Inverted-F Antenna for 5 GHz WLAN and Bluetooth Applications

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***Abstract*—The popularity of compact sized antennas are increasing recently due to their significant properties such as, tiny size, high gain, impedance merely 50 &! and very low phase difference. To achieve this goal, in this paper a Triple Inverted-F Antenna (TIFA) is designed for the 5 GHz WLAN and Bluetooth applications and it operates between the wide frequency ranges 4.75-8.2 GHz. This antenna also provides lower gain variation with peak return loss of -35.14, -25.795 and -22.37 dB at 5.2, 5.5 and 5.8 GHz respectively. In addition, the size of the antenna is only 12×20 mm^2.**

***Index Terms*— Inverted-F Antenna (IFA), Triple IFA (TIFA), WLAN, Bluetooth, Low profile antenna.**

I. Introduction

Inverted F Antenna (IFA) for Wireless Local Area Network (WLAN) and Bluetooth systems, capable of operating in as many as possible frequency band of the IEEE 802.11 at 2.4 GHz (2400–2484 MHz), 5.2 GHz (5150–5350 MHz) and 5.8 GHz (5725–5825 MHz).The Unlicensed National Information Infrastructure (U-NII) band (frequency range 5150–5350 MHz ,5.470-5725 MHz and 5725–5825 MHz) offers more non overlapping channels than the Industrial Scientific and Medical (ISM) band (frequency range 2400–2484 MHz). Instead of using multiple single-band antennas for multiband operations, a multiband antenna can simultaneously cover several operating band for different wireless services. The great demand in antenna design includes low profile, light weight, easy fabrication and multiband operations. So, to meet the requirement the use of compact multiband antenna is very attractive and important for practical commercial applications. In the mean time, TIFA antenna becomes a suitable candidate due to its merits of low profile and features of multiband operations.

The related antenna designed for WLAN and Bluetooth application have been presented by using C-shape Monopole Antenna (MA) for 2.6/3.5/5.5 GHz [1], CPW-fed compact monopole antenna for dual-band WLAN applications (2.4 and 5 GHz) [2], flat plate IFA Operation for 2.4 and 5 GHz Wi-Fi band [4], a tri-band planar inverted-F antenna for 2.4/5.2 GHz WLAN [5], a printed antenna with a quasi-self-complementary for 5.2/5.8 GHz WLAN operations [6], a novel broadband dual-frequency spider-shaped dipole antenna for 2.4/5.2 GHz WLAN operations [7], a novel dual-broadband T-shaped monopole antenna with dual shorted L-shaped strip-sleeves for 2.4/5.8 GHz WLAN applications [8], a very small size planar two-strip monopole printed on a thin (0.4 mm) FR4 substrate for 2.4/5.2/5.8 GHz triple band WLAN operations [9], a broadband low-profile printed T-shaped monopole antenna for 5 GHz WLAN operations [10], a printed double-T monopole antenna for 2.4/5.2 GHz Dual-band WLAN operations [11] and a planar CPW-fed slot antenna on thin substrate for WLAN operations [12]. Although some of them cover the whole 5 GHz band for WLAN application yet they hold a complex structure and still a large size. Therefore, in this paper, we proposed a triple inverted-F antenna for broadband WLAN and Bluetooth applications. From the simulation results, it provides a wider impedance bandwidth of 3.5 GHz (4750-8250 MHz) which fully covers the 5.2/5.5/5.8 GHz bands. Moreover it also gives an omni-directional radiation patterns with maximum measured peak antenna gains of 6.2/5.37/4.47 dBi across the operating bands, respectively. Details of the proposed antenna design are described in this study, and the related results for the obtained performance operated across the 5.2/5.5/5.8 GHz bands are presented and discussed.

II. Antenna Design

The design variables for this antenna are the height, width, and length of the top plate, the width and the location of the feed wire.In designing the broadband low profile antenna for 5 GHz WLAN and Bluetooth applications, we examine the possibility of increasing antenna bandwidth, gain and maintaining the input impedance near about 50 &! throughout the application bands with simplifying its structure.

Using Method of Moments (MoM's) in Numerical Electromagnetic Code (NEC) [13], we conducted parameter studies to ascertain the effect of different loading on the antenna performance to find out the optimal design where optimum segmentation of each geometrical parameter are used. The antenna is assumed to feed by 50 &! coaxial connector. In our analysis we assume the copper conductor and the antenna was intended to be matched to 50 &! system impedance. Fig. 1 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 Printed Circuit Board (PCB) with permittivity of ε_r=2.2, substrate thickness of 1.58 mm and the dimensions of the ground plane considered as 60 × 60 mm^2. Fig. 2 represents the modified IFA where a additional L branch is added and termed as Inverted F-L Antenna (IFLA). An additional inverted F branch is added in Fig. 3 with the IFLA termed as Inverted F-L-F Antenna (IFLFA). In Fig. 4 three

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inverted F antenna implemented jointly and termed as Triple Inverted F Antenna (TIFA).

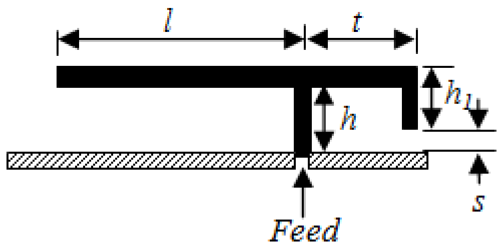

Figure 1. Basic inverted-F Antenna (IFA)

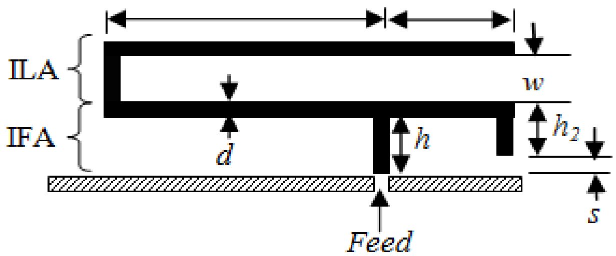

Figure 2. Inverted-F-L Antenna (IFLA)

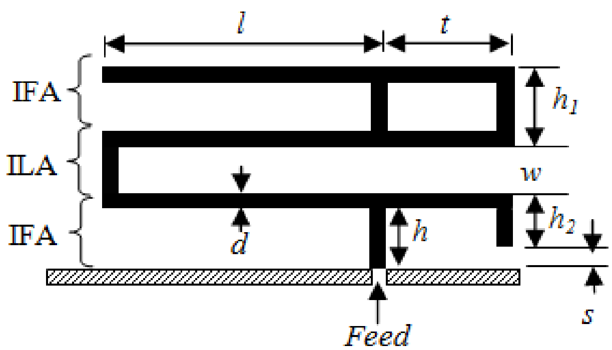

Figure 3. Inverted-F-L-F Antenna (IFLFA)

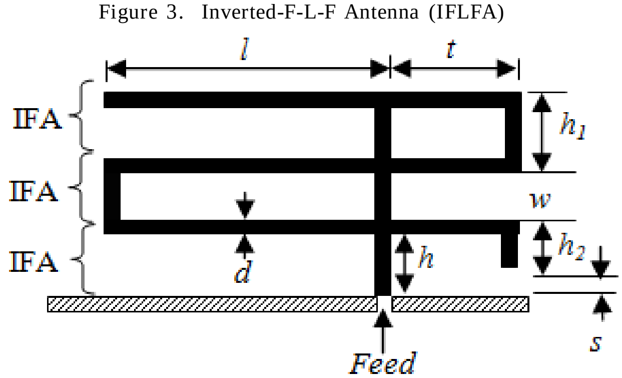

Figure 4. Triple Inverted-F Antenna (TIFA)

With the help of resonant frequency theory of IFA and impedance matching concept, we consider the dimension of the IFA as *l=14 mm, t=5 mm,* h_1*=3 mm, h=4 mm, s=1 mm* and *d=4 mm*. Fig. 5 shows the effects of length *l* on the return loss as a function of frequency on the IFA of Fig. 1. From the simulated results when *l=14 mm, t=5 mm, h=4 mm,* h_1*=3 mm, d=4 mm* and *s=1 mm* the variation of return loss with frequency is like covering the whole 5 GHz operating band (frequency ranges 5150 – 5850 MHz) band but the return loss is not so desirable. When a load equal to the IFA is applied on the horizontal strip of IFA then the performance of the return loss improves slightly. But when we added three IFA jointly then the performance of return loss improves appreciably and the antenna structure of Fig. 4 titled as Triple IFA (TIFA).

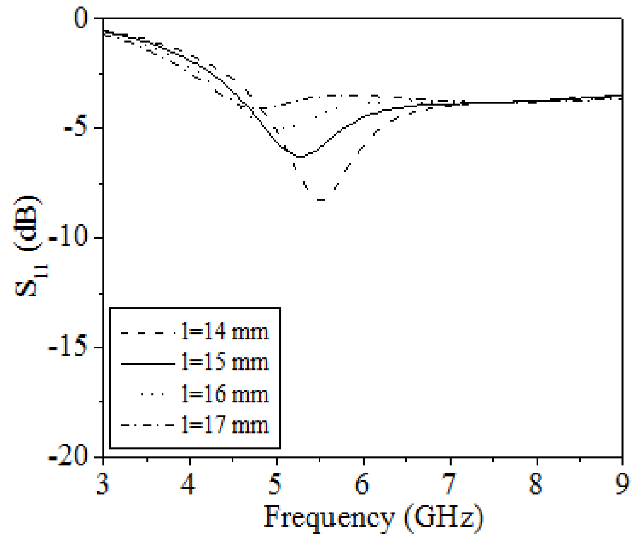

Figure 5. Effects of length *l* on the return loss as a function of frequency on the antenna structure of Figure 1

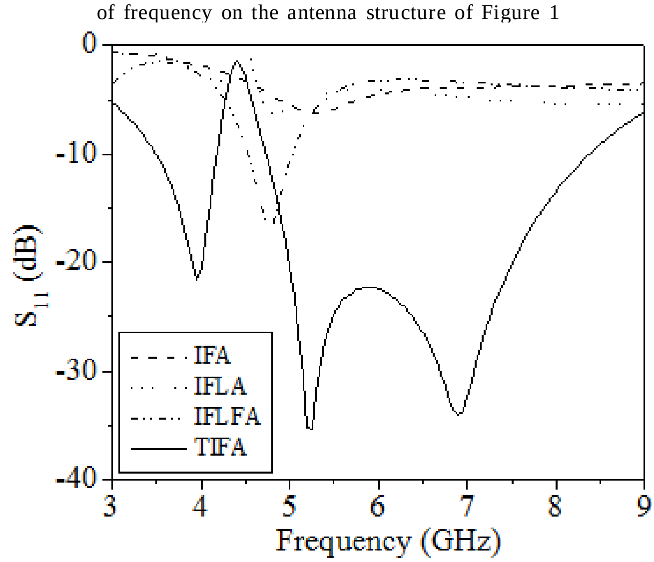

Figure 6. Return loss as a function of frequency for different types of antennas

Fig. 7 shows the effects of *l* on the return loss of TIFA, when d*=4 mm, t=5 mm, h=4 mm,* h_1*=4 mm,* h_2*=3 mm, s=1 mm* and *w=4 mm*. considering return loss the best performance of the TIFA is obtained when *l=15 mm*. Now maintaining the length *l=15 mm* we continue our advance analysis on the tap distance *t* as shown in Fig. 8 and we observed that when *t=5 mm* the TIFA provides more negative return loss at the application bands than other values. Fig. 9 shows the effects of width *d* on return loss when the tap distance *t=5 mm* and length *l=15 mm*. From overall analysis we see that Ttriple IFA (TIFA) provides best performance for the desired applications. The optimized dimensions of the proposed TIFA are listed in Table I.

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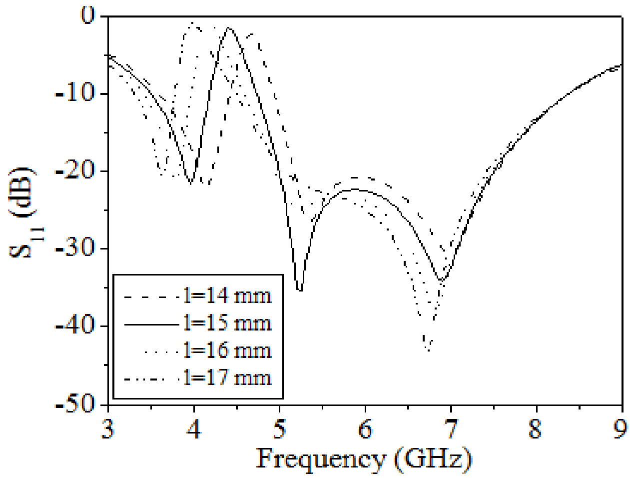

Figure 7. Effects of length *l* on the return loss as a function of frequency on the antenna structure of Fig. 4

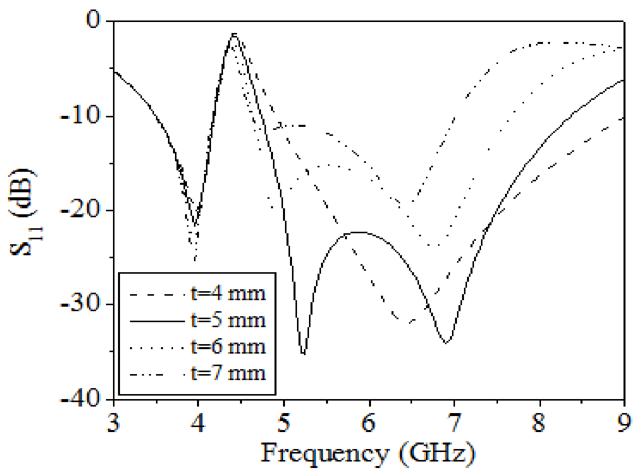

Figure 8. Return loss as a function of frequency with the different tap distance *t* of the TIFA of Figure 2 when *l=15 mm*

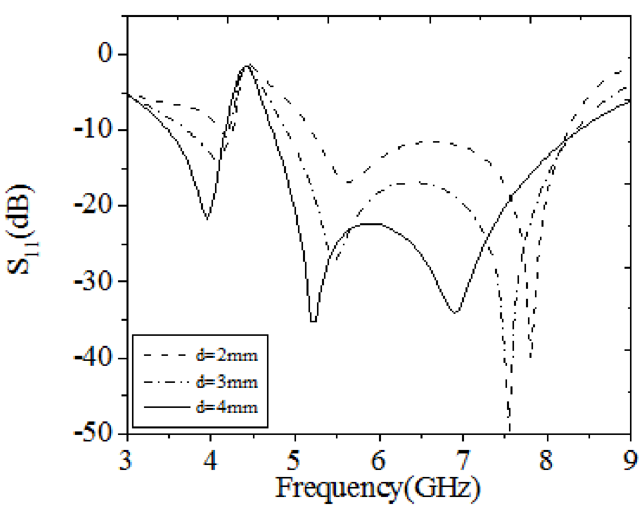

Figure 9. Return loss as a function of frequency with different value of width *w* of the TIFA of Figure 2 when *t=5 mm* and *l=15 m m*

Table I. Optimized Dimensions of the Proposed Antenna

Antenna Name	Antenna Parameters	Values (mm)	Dimension (mm^2)
IFA	*l*	15	4×20
	t	5	
	h	4	
	d	4	
	s	1	
TIFA	*l*	15	12×20
	t	5	
	h	4	
	h_1	4	
	h_2	3	
	w	4	
	d	4	
	s	1	

III. Numerical Simulation Results

The proposed antenna is constructed and numerically analyzed using MoM's. The proposed TIFA has the return loss appreciable than the commonly required 10 dB level. Fig. 10 and Fig. 11 show the variation of Voltage Standing Wave Ratio (VSWR) and return loss respectively. The TIFA provides a wide impedance bandwidth of 3.5 GHz (4750-8250 MHz) which fully covers the 5.2/5.5/5.8 GHz bands and the peak value of return loss are -35.14, -24.795 and -22.371 dB respectively. The value of VSWR of TIFA varies from 1.0356 to 1.1647 within the operating band and obtained result indicates that the variation of VSWR is very low and it is near to 1 as shown in Fig. 10.

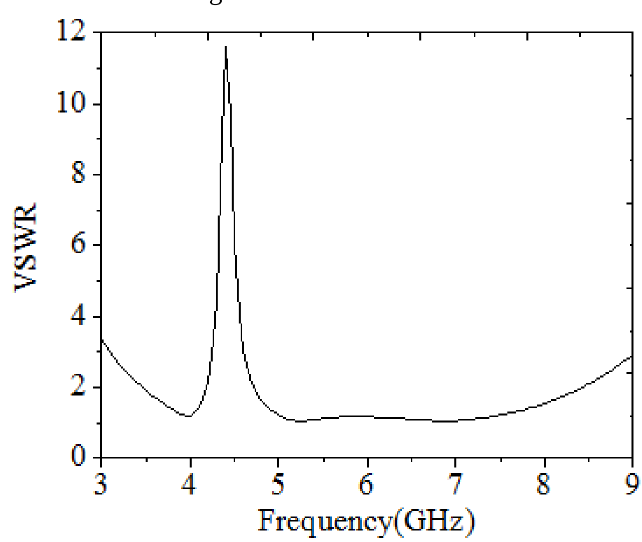

Figure 10. VSWR variation of TIFA with frequency

Fig. 12 shows the gain of TIFA. The peak gains of TIFA is 6.27, 5.37 and 4.47 dBi with a very small gain variation within the 10 dB return loss bandwidth at 5.2, 5.5 and 5.8 GHz band respectively, which indicates that the antenna has stable gain within the every separate operating bandwidth. Fig. 13 represents the antenna input impedance variation and Fig. 14 represents the antenna phase shift causes due the impedance mismatch as a function of frequency. From the obtained results, the input impedance of TIFA is 50.44, 45.03

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and 45.46 Ω at 5.2, 5.5 and 5.8 GHz so the input impedance of the proposed antenna is near about 50 &!. Also, from the simulation study, the antenna offers a phase shift of -1.93^0, 2.77^0 and 6.80^0 respectively. So phase shift of TIFA closer to 0^0 all over the antenna bandwidth. A comparison in gains between the proposed and reference antennas are listed in Table II. In overall considerations, TIFA is much better than all other antennas.

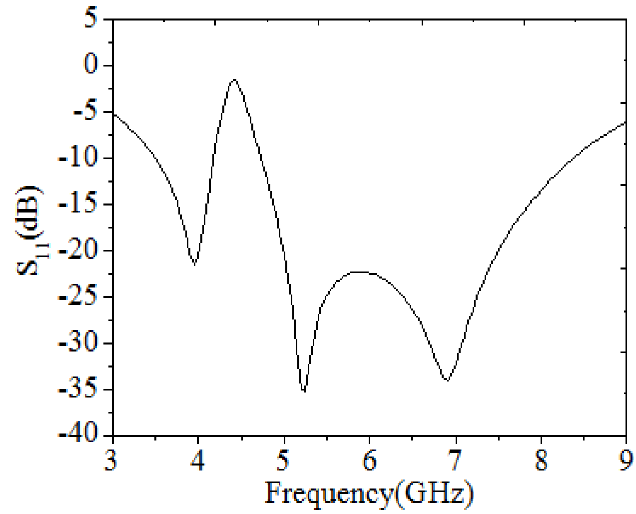

Figure 11. Return loss variation of TIFA with frequency

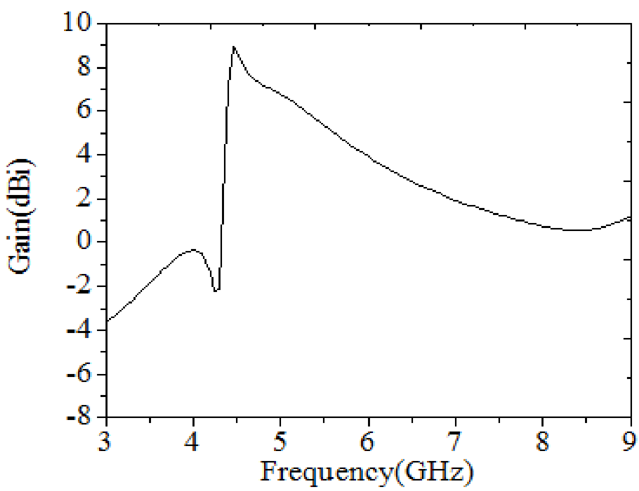

Figure 12. Total gain variation of TIFA with frequency

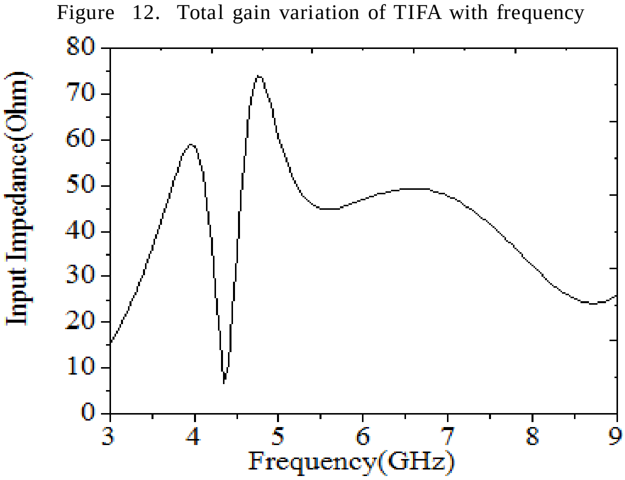

Figure 13. Impedance variation of TIFA with frequency

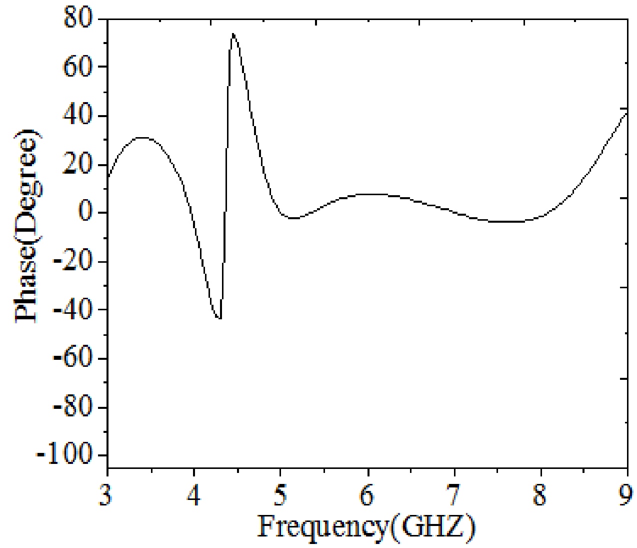

Figure 14. Phase variation of TIFA with frequency

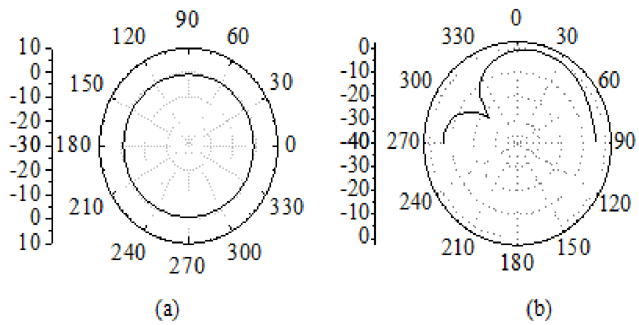

Figure 15. Radiation pattern (normalized) (a) Total gain in E-plane and (b) total gain in H-plane of TIFA at 5.2 GHz

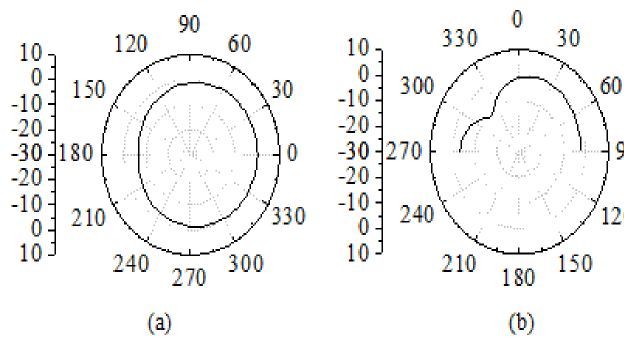

Figure 16. Radiation pattern (normalized) (a) Total gain in E-plane and (b) total gain in H-plane of TIFA at 5.5 GHz

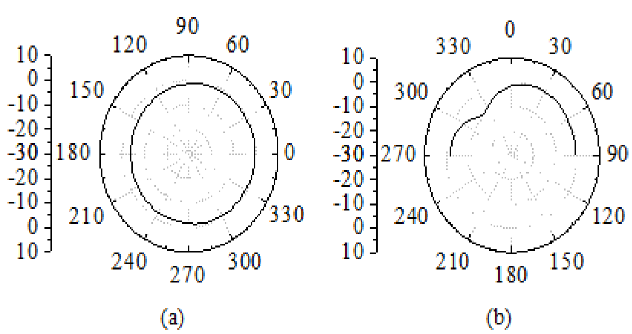

Figure 17. Radiation pattern (normalized) (a) Total gain in E-plane and (b) total gain in H-plane of TIFA at 5.8 GHz

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Fig. 15 to 17 show the normalized radiation patterns of TIFA at 5.2, 5.5 and 5.8 GHz bands respectively. Normalized radiation patterns for three resonant frequencies are shown as: total gain in H-plane and E- plane. The antenna's normalized total radiation in E and H-plane is almost omni-directional at the 5 GHz WLAN and Bluetooth applications**.** A C–shaped monopole, compact monopole, Planar inverted-F,printed quasi-self-complementary structure, spider-shaped dipole, T-shaped monopole, planar two-strip monopole, printed T-shaped monopole , printed double-T monopole and slot antenna [1-12] have been proposed for WLAN Bluetooth applications suffers from gain limitations. But from Table II the our proposed antenna has much improved gain and stable gain variation within the antenna bandwidth then the antennas proposed earlier.

TABLE II.
Gain Comparison Between the Proposed and Reference Antennas

Antenna	Peak Gain (dBi)		
	5.2 GHz WLAN	5.5 GHz WiMAX	5.8 GHz WLAN
TIFA (Proposed)	6.27	5.37	4.47
C-shaped monopole [1]	–	2.9	–
CPW fed compact monopole [2]	2.8	–	–
Compact monopole [3]	–	–	2.105
Planar inverted-F [5]	2.3	4.4	
Printed quasi-self-complementary structure [6]	3.3–4.0	–	3.2–3.8
Spider-Shaped Printed Dipole [7]	4.6		
T-shaped monopole [8]	–	1.0	
Planar two-strip monopole [9]	3.6–4.3		
Printed T-shaped monopole [10]	3.5	–	3.5
Double-T monopole [11]	0.8–1.5	–	–
Slot antenna [12]	-1.58 – 0.78		

Conclusions

A tiny size double IFA with broadband operation for WLAN systems has been proposed and investigated. The proposed antenna provides a small size with a large bandwidth of 3.5 GHz (4750-8250 MHz). In addition, it also ensures nearly Omni-directional radiation patterns with peak gain 6.27/5.37/4.47 dBi across the operating bandwidth respectively. The improved impedance, bandwidth, gain and size reduction is achieved by inserting an I-shaped slot between two IFA. Designed antenna found suitable in WLAN services and in Bluetooth devices. Hence, it is also compact enough to be placed in typical wireless services.

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