DESIGN OF PLANAR INVERTED-F ANTENNA

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ABSTRACT

These days communication devices smaller than palm size have appeared in the market. Antenna size is a major factor that limits device miniaturization. Planar inverted F antenna has been designed here which is very popular for handheld wireless devices which are working well for wi-fi and LTE application. it can be easily placed in small space present inside the mobile device. This work concentrates on design and development of compact antenna used for mobile devices. For low profile micro strip patch is popular but it is not good candidate for the portable devices as their designs are based on half wavelength of operation, and not meet the strict small space requirement of these devices. Whereas PIFA design invokes the quarter wavelength operation. Additionally the PIFA offers very high radiation efficiency and sufficient bandwidth in a compact antenna.

Keywords: Antenna Designing, Low Profile Antenna, LTE, PIFA, WI-FI Antenna

I INTRODUCTION

Mobile communications, wireless interconnects, wireless local area networks (WLANs), and cellular phone technologies compose one of the most rapidly growing industrial markets today. The advancement in the field of wireless communication leads to a great demand of developing compact antenna to support multiple applications that can be easily integrated within the small space available inside the device. This being the case, portable antenna technology has grown along with mobile and cellular technologies. It is important to have the proper antenna for a device. The proper antenna will improve transmission and reception, reduce power consumption, last longer and improve marketability of the communication device.

Antennas used for early portable wireless handheld devices were the so-called whip antennas. The quarter-wavelength whip antenna was very popular, mostly because it is simple and convenient [1]. It has an omni-directional pattern in the plane of the earth when held upright and a gain satisfying the device's specifications. New antenna designs have appeared on radios with lower profile than the whip antenna and without significantly reducing performance. These include the quarter-wavelength helical antenna and the "stubby" helical antenna, which is the shortest antenna available.

In recent years, the demand for compact handheld communication devices has grown significantly. Devices smaller than palm size have appeared in the market. Antenna size is a major factor that limits device miniaturization. In the past few years, new designs based on the Planar Inverted-F Antenna (PIFA) and Microstrip Antennas (MSA) have been popular for handheld wireless devices because these antennas have a low profile geometry instead of protruding as most antennas do on handheld radios. Conventional PIFAs and MSAs are compact, with a length that is approximately a quarter to a half of the wavelength. These antennas can be further optimized by adding new parameters in the design, such as strategically shaping the conductive plate, or judiciously locating loads.

The major limitation of many low-profile antennas is narrow bandwidth. Bandwidth in these antennas is almost always limited by impedance matching. The common criterion is a 2:1 VSWR into a 50-Ω load. Typical conventional PIFA's have a 5% bandwidth, but advanced designs offer wider bandwidth. A variety of techniques for broadening bandwidth have been reported, including the addition of a parasitic structure whose resonant frequency is near that of the driving antenna structure. One example described in the literature is a stacked microstrip patch antenna [1].

In addition to solving the problem of broadening the antenna bandwidth to the required specifications of the system, one has to worry about developing new structures for devices that covers more than one frequency band of operation. Dual-band wireless phones have become popular recently because they permit people to use the same phone in two networks that have different frequencies. Tri-band phones have also gained popularity. Still, there exist more than three frequency bands used for wireless applications. Systems that require multi-band operation require antennas that resonate at the specified frequencies. This only adds complexity to the antenna design problem.

II VARIOUS ANTENNA STRUCTURES

This work concentrates on the design and development of compact antenna used for mobile devices. Microstrip patches are popular antennas because of their low profile. Various types of low-profile elements have recently been developed and they are fairly efficient radiators that can be easily manufactured at low cost. However, the conventional microstrip patch is not a good candidate for the portable devices as their designs are based on half-wavelength of operation [2], [3] and not meet the strict small space requirement of these devices. Therefore, more unusual approaches must be examined for reduced size operation.

2.1 The Inverted-L Antenna

The ILA is an end-fed short monopole with a horizontal wire element placed on top that acts as a capacitive load. The design of the ILA has a simple layout making it cost efficient [4]-[6]. Figure 1 shows the physical layout of the inverted-L antenna. Many of the electrical characteristics of the inverted-L are similar to those of the well understood short monopole.

The input impedence of ILA has relatively low resistance and high reactance that make the inverted-L difficult to impedance match to typical feedlines.

2.2 The Inverted-F Antenna

The inverted-F is a variation on the inverted-L that modifies the input impedance to be nearly resistive and thus provides reduced mismatch loss. The inverted-F antenna is known as a "shunt-driven inverted-L antenna-transmission line with an open end". Figure 2 shows the layout of the inverted-F antenna.

The inverted-F adds a second inverted-L section to the end of an inverted-L antenna. This additional inverted-L segment adds a convenient tuning option to the original inverted-L antenna and greatly increases the antenna usability. The location of the feedpoint, S, along the length of the upper element provides the impedance tuning mechanism.

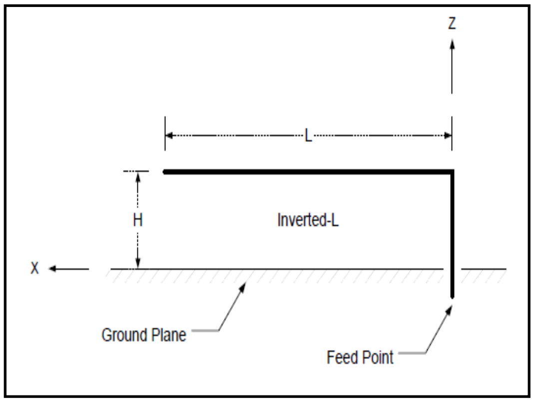


Figure 1: Inverted-L Antenna Geometry

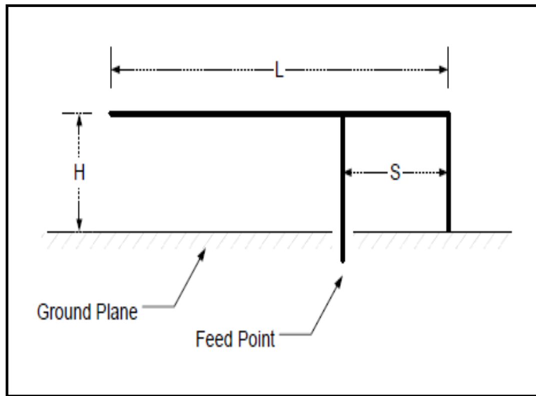


Figure 2: Inverted-F Antenna Geometry.

2.3 The Dual Inverted-F Antenna

One critical problem that both the inverted-F and L antennas share with the short monopole is very low impedance bandwidth. Several modifications to the inverted-F have been examined that increase the bandwidth of the antenna. One such variation is shown in Figure 3, the dual inverted-F antenna (DIFA). The dual inverted-F uses a parasitic inverted-L antenna placed next to the inverted- F. The parasitic element has a length that is equal or nearly equal to L on the inverted-F.

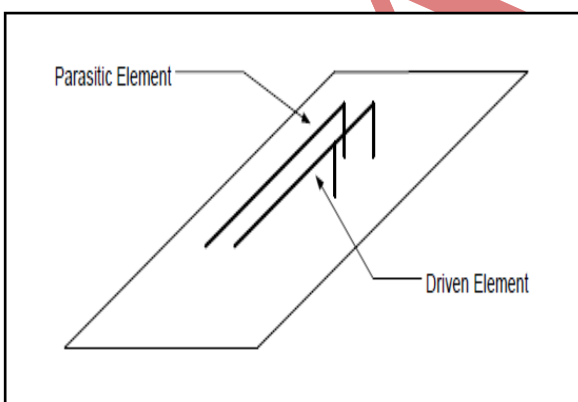


Figure 3: Dual inverted-F antenna geometry.

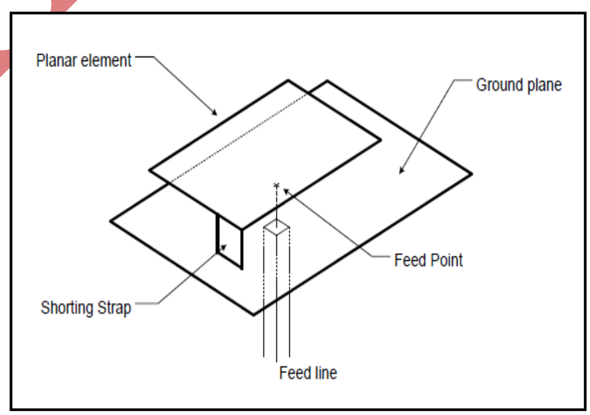


Figure 4: Basic layout of the planar inverted-F antenna.

2.4 The Planar Inverted-F Antenna

To increase the bandwidth, the Planar inverted-F antenna (PIFA) is developed. The PIFA can be considered a direct extension of the inverted-F antenna that has the horizontal wire radiating element replaced by a plate to increase its usable bandwidth. Figure 4 shows the general structure of the planar inverted-F antenna. PIFA designs invoke the quarter-wavelength operation. Additionally, the PIFA offers very high radiation efficiency and sufficient bandwidth in a compact antenna. Technique like use of reduced ground plane can to be employed to further increase the bandwidth [7], [8]. Multi-frequency capability with the antenna structure can be achieved by exciting various resonant modes using branched structure, created by cutting slots in the radiating element [9]-[12].

III DESIGN EQUATIONS

Fig. 5 shows the schematics of the planar inverted-F antenna. The patch length and width are L_1 and L_2 respectively. The shorting pin (or shorting post) is of width W, and begins at one edge of the PIFA. The feed is at a distance D from the shorting pin. The PIFA is at a height H from the ground plane. Air ($\epsilon_r = 1$) is used as a substrate in between the patch and the ground plane. The resonant frequency of the PIFA is proportional to the effective length of the current distribution. The following cases can be considered for getting the expression of frequency at which PIFA radiates.

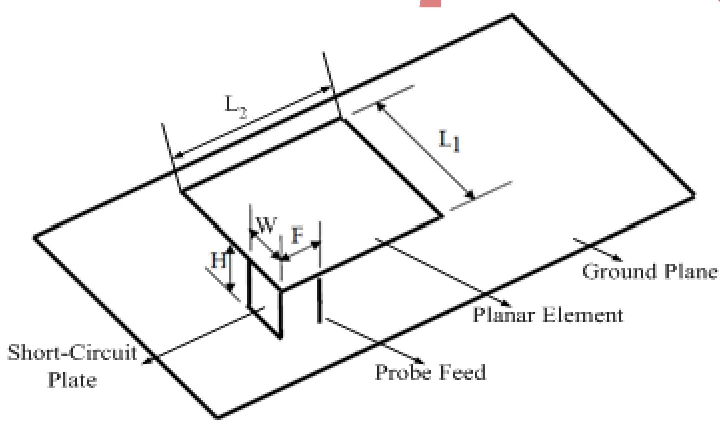


Figure 5: Schematic of planar inverted-F antenna.

Case 1: W = L_1 i.e., when the width (W) of the short-circuit plate is equal to the length of the planar element, say L_1. This corresponds to the case of the short-circuit MSA, which is a quarter-wavelength antenna. The effective length of the MSA is L_2 + H where, H is the height of the short-circuit plate. The resonance condition then is expressed by Eq. 1.

$$L_2 + H = \frac{\lambda}{4} \qquad (1)$$

where λ is the desired wavelength.

As $\lambda = {}^{c}/_{f}$, where f is the desired operating frequency of PIFA and c is the speed of light. Thus,

$$f = \frac{c}{4(L_2 + H)} \qquad (2)$$

Case 2: W = 0 i.e. short-circuit plate is represented by a thin short-circuit pin. The effective length of the current is then $L_1 + L_2 + H$. For this case, the resonance condition is expressed by

$$L_1 + L_2 + H = \frac{\lambda}{4} \quad (3)$$

Therefore,

$$f = \frac{c}{4(L_1 + L_2 + H)} \quad (4)$$

Case 3: $0 < W < L_1$, the resonant frequency f is a linear combination of the resonant frequencies associated with the limiting cases and is given by

$$f = \frac{c}{4(L_1 + L_2 + H - W)} \quad (5)$$

IV LITERATURE REVIEW

The popularity of mobile communication systems has increased remarkably during the last decade and the market demand still continues to increase that leads to the development of number of antenna structures for obtaining multiband and wideband functionality. K. L. Virga *et al.* [13] addressed the development and characterization of several low-profile and integrated antennas with enhanced bandwidth for wireless communications systems. In this paper the new radiators are developed by adding parasitic elements or tuning devices to the planar inverted-F antenna (PIFA). P. Nepa *et al.* developed a novel compact planar inverted-F antenna operating in the IEEE 802.11a, IEEE 802.11b/g, and HIPERLAN2 frequency bands, to be mounted on laptop computers. In this structure the multiband behavior is obtained by combining a trapezoidal feed plate with two different resonance paths in the radiating structure [14]. A dual-band digital video broadcasting-handheld antenna is presented in which the proposed antenna is composed of a meandered line inverted-L shape and loop antenna for the broadband performance [15]. The measured operational bandwidth of the antenna (VSWR < 3.5) is 400 MHz (470–870 MHz) at UHF band and 300 MHz (1380–1680 MHz) at L-band. C. H. See *et al.* [16] proposed a planar inverted-F-L antenna (PIFLA) with a broadband rectangular feeding structure for lower-band ultra-wideband (UWB) applications, which is constructed from a driven F-shaped element and a parasitic L-shaped element. Both the patches are inverted and aligned face-to-face over a finite ground plane. A novel compact multiband planar inverted-F antenna for bluetooth, satellite digital multimedia broadcasting, wireless broadband, worldwide interoperability for microwave access, and wireless local area network applications is presented by Y.S. Shin [17].

A more compact design of a meander line antenna was designed to operate at 2.4-GHz for WLAN application [18]. The researchers described two different designs of meander line antenna with and without conductor line. The designed antennas were fabricated on a double-sided FR-4 printed circuit board using standard PCB technique and tested with a Network Analyzer. A bandwidth of 152 MHz and return loss of -37.7dB were obtained at the operating center frequency of 2.4 GHz. The effect on the antenna radiation and reflection properties with varying the MLA length, width, number of turns and conductor dimensions are also discussed in this paper.

In [19], a meander line antenna with smaller dimensions (40 x 40 cm) is presented. The designed antenna exhibited a bandwidth of 274 MHz and return loss of -25 dB at a center frequency of 1.575 GHz. In [20], where the authors design the antenna for LTE mobile in 800 MHz but the antenna has a very small gain -16 dB.

V PROPOSED ANTENNA STRUCTURE

Over a ground plane of dimension 100 X 50 X 0.8 mm^3 an antenna element is made of dimension 18 X 13 mm^2. Both the antenna element and the ground plane are grown over the FR4 substrate. The antenna element is at a height of 4 mm above the ground plane. The element is connected to the ground via a shorting strip of 2 mm width. The antenna element is fed by a coaxial probe at the suitable location to get better impedance matching. Three slots of suitable dimensions are cut in the antenna element to get the required bandwidth. The dimensions of all three slots are given as follows

Slot 1: (8.25 X 1 mm^2)

Slot 2: (9.5 X 1.25 mm^2)

Slot 3: (5.25 X 2.5 mm^2)

The side view, top and bottom view of the proposed structure are shown in Fig. 6 and 7 respectively.

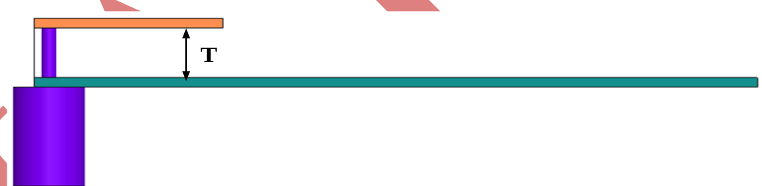


Figure 6: Side View

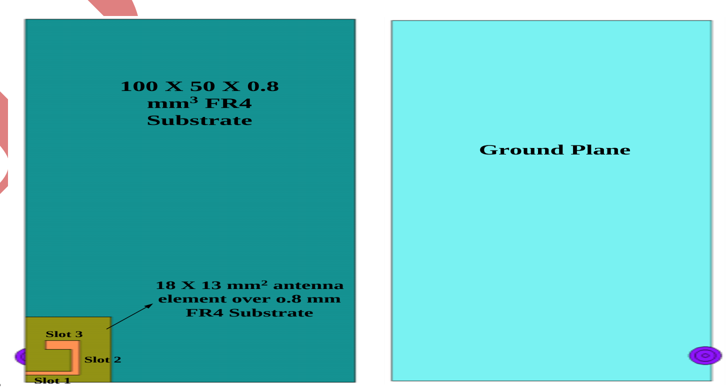


Figure 7: Top and Bottom View.

The suspended view of the antenna element over the ground plane at a height of 4 mm is shown in Fig. 8.

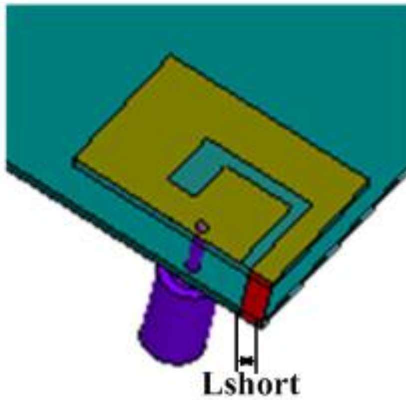


Figure 8: Suspended View.

VI RESULTS

The simulation of the proposed design is done with HFSS. The proposed structure is covering Wi-Fi (2.4-2.484 GHz) and LTE2500 (2.5-2.57 GHz for uplink, 2.62-2.69 GHz for downlink) bands. This structure is having single band that is covering two applications. The proposed structure is having a band of 2.31-2.83 GHz at -10 dB return loss. Figure 9 shows the return loss characteristics of the proposed antenna. The VSWR of the antenna is given in Fig. 10.

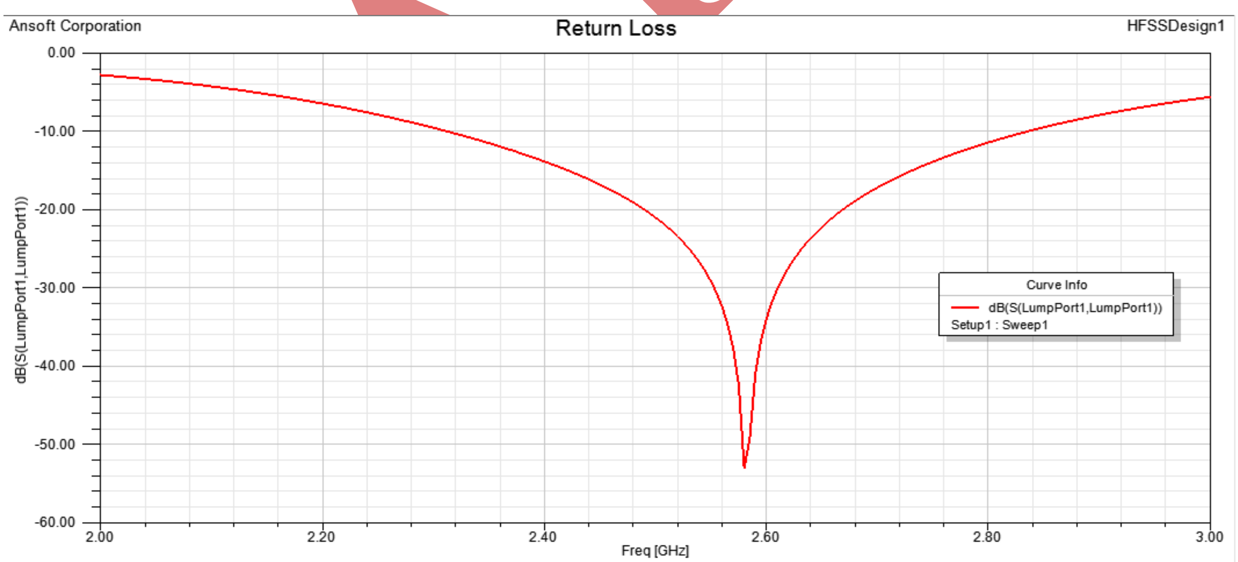


Figure 9: Return Loss Characteristics of Proposed Antenna.

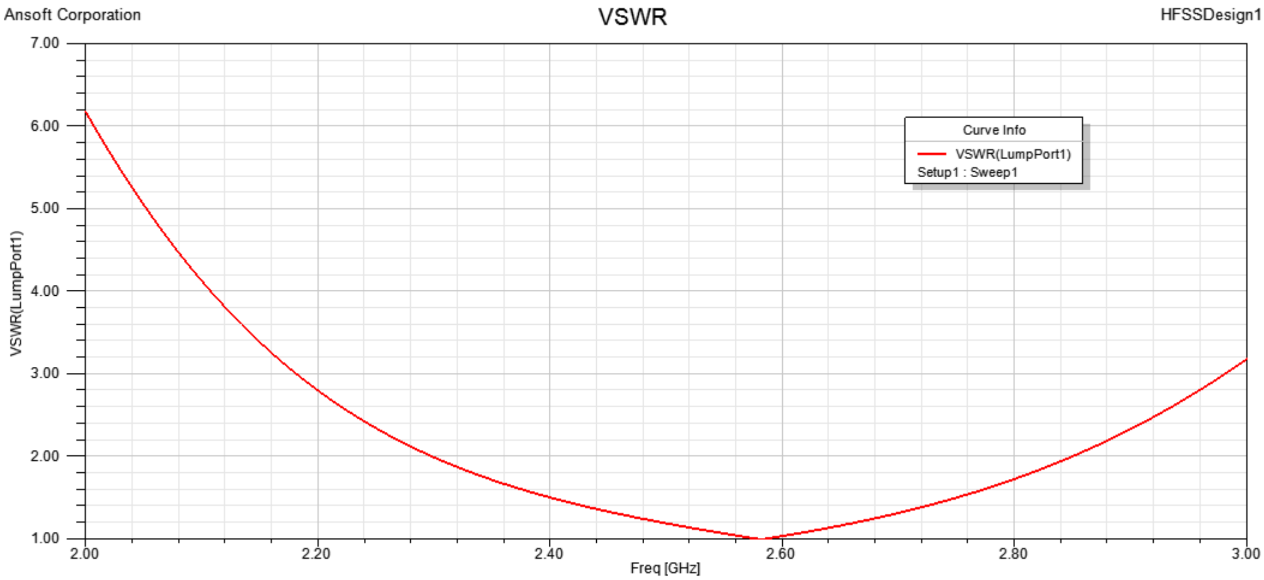
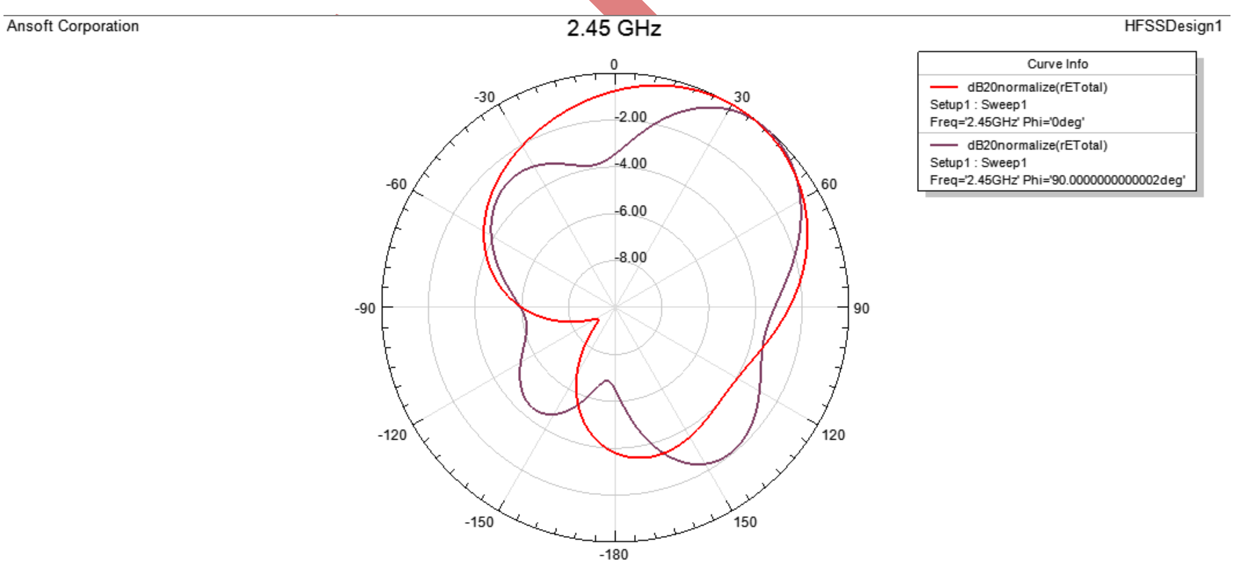
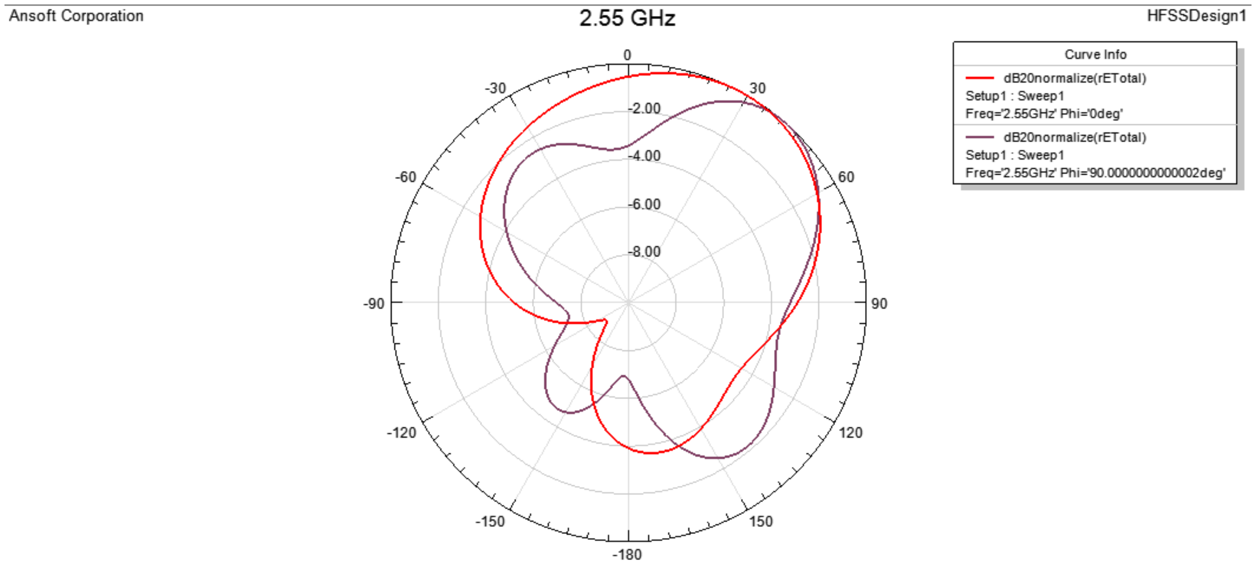


Figure 10: VSWR of Proposed Antenna

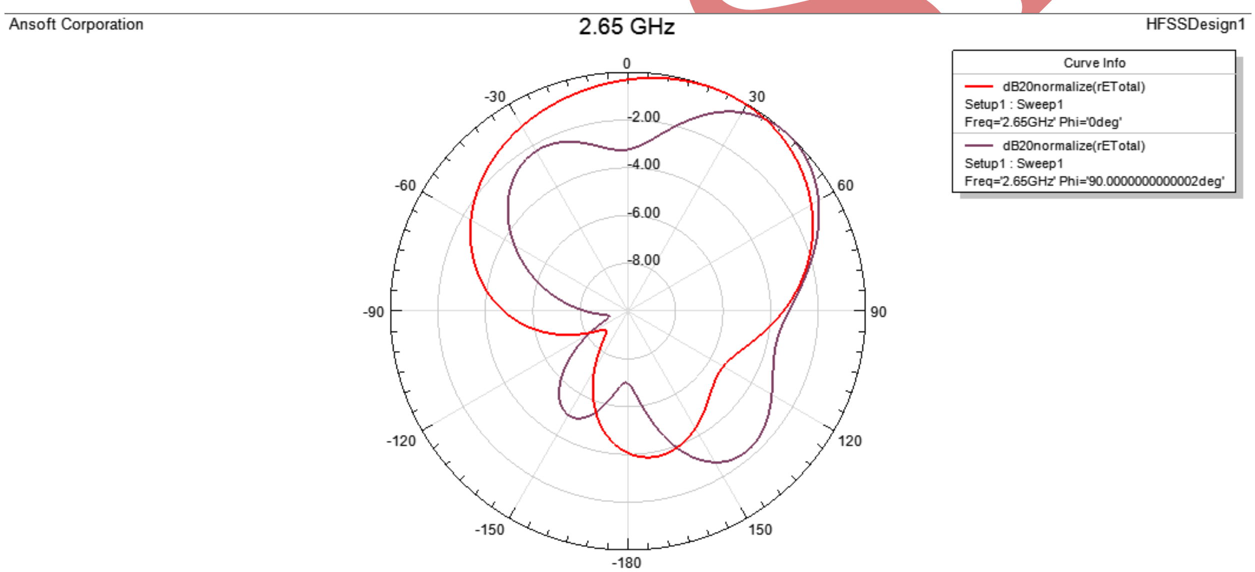
The radiation patterns of the proposed structure at 2.45 GHz, 2.55 GHz and 2.65 GHz in the XZ and YZ planes are shown in Fig. 11 (a,b,c).



(a) at 2.45 GHz



(b) at 2.55 GHz



(c) at 2.65 GHz

Figure 11: Radiation patterns of the proposed structure

VII CONCLUSION

To meet the need of mobile communications, wireless interconnects, wireless local area networks (WLANs), and cellular phone technologies, an antenna structure are proposed that is working well for the Wi-Fi and LTE2500 application. This antenna element can easily be placed in the small space present inside the mobile device. The proposed structure is having a VSWR of less than 2 in the required bands. The radiation patterns in the two principal planes are also good at all the frequencies and are suitable for proper reception of the signals.

REFERENCES

[1] L. Setian, *Practical Communication Antennas with Wireless Applications*, Prentice Hall PTR, New Jersey: 1998.

[2] Constantine A Balanis "Antenna theory analysis and design" John Wiley and Sons II nd edition

[3] Pozar D.M., "The Analysis and Design of Microstrip Antennas and Arrays", IEEE press, New York, 1995.

[4] Z.N.Chen and M.Y.W.Chia,,"Broadband planar inverted-L antennas", IEEE proceedings Microw. Antennas Propag., Vol. 148, no. 5, October 2001

[5] Jieh-sen kuo and Kin-lu wong, "Dual-frequency operation of a planar inverted-L antenna with tapered patch width", Microwave and optical technology letters, vol. 28, pp. 126-127 January , 2001.

[6] Z.N. Chen, "Note on impedance characteristics of L-shaped wire monopole antenna", Microwave and optical technology letters,Vol.26, Pp 22_23.July 2000.

[7] Ahmad R. Razali and Marek E. Bialkowski, "Dual-band slim inverted-f antenna with enhanced operational bandwidth," *Microwave And Optical Technology Letters*, vol. 54, No. 3, pp. 684-689, March 2012.

[8] A.R. Razali and M.E. Bialkowski, "Coplanar inverted-F antenna with open-end ground slots for multi-band operation," *IEEE Antennas Wireless Propagation Letters*, vol. 8 , pp. 1029–1032, 2009.

[9] Byndas, R. Hossa, M.E. Bialkowski, and P. Kabacik, "Investigations into operation of single and multi-layer configurations of planar inverted-F antenna," *IEEE Antennas Propagation Magazine*, vol 49, pp. 22–33, 2007

[10] G. Marrocco, "The art of UHF RFID antenna design: Impedance matching and size-reduction technique," *IEEE Antennas Propagation Magazine,* vol. 50, pp. 66–79, 2008.

[11] K. L Virga, Y. Rahmat-Samii, "Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging," *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, pp.1879-1888, October 1997.

[12] C. T. P Song, P. S. Hall, H. Ghafouri-Shiraz, and D. Wake, "Triple band planar inverted F antennas for handheld devices," *Electronics Letters*, vol. 36, pp. 112-114, January 2000.

[13] Kathleen L. Virga, and Yahya Rahmat-Samii, "Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging," *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, no. 10, pp. 1879- 1888, October 1997.

[14] P. Nepa, G. Manara, A. A. Serra, and G. Nenna, "Multiband PIFA for WLAN mobile terminals," *IEEE Antennas and Wireless Propagation Letters*, vol. 4, pp. 349-350, 2005.

[15] C. Yang, H. Kim and C. Jung, "Compact broad dual-band antenna using inverted-L and loop for DVB-H applications," *Electronics Letters*, vol. 46, no. 21, 14th October 2010.

[16] Chan Hwang See, Raed A. Abd-Alhameed, Dawei Zhou, and Peter S. Excell, "A planar inverted-F-L antenna (PIFLA) with a rectangular feeding plate for lower-band UWB applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 149- 151, 2010.

[17] Yong-Sun Shin, Ki-Bok Kong, and Seong-Ook Park, "A compact multiband PIFA with the modified ground plane and shorting plate for wireless communication applications," *Microwave and Optical Technology Letters*, vol. 50, no. 1, pp. 114-117, 2007.

[18] A.Salamat, M. F. Abdul Kadir, M. R. Che Rose, M. S. R. Mohd Shah, and D. Misman, "The Effect of Conductor Line to Meander Line Antenna Design," in *ASIA-Pacific Conference on Applied Electromagnetic Proceedings*, 2007.

[19] R. Bancroft, "Fundamental Dimension Limits of Antennas," Westminster, Colorado, White paper, Centurion Wireless Technologies.

[20] M. S. Sharawi, Y. S. Faouri, and S.S. Iqbal, ‘‘Design of an Electrically Small Meander Antenna for LTE Mobile Terminals in The 800 MHz Band”, IEE GCC Conference and Exhibition (GCC), February 19-22, Dubai, United Arab Emirates, 2011.