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Ameliorating the Performance of a Planar Inverted F Antenna by Minimization of Losses

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Abstract—This paper aims at designing a wideband planar inverted F antenna (PIFA). The design of a PIFA begins with an elementary step such as the etching of antenna element pattern in a metal trace. After the etching adherence is developed by incorporating bonding between it and a printed circuit board which is primarily an insulating dielectric substrate. A ground plane is developed by a prolonging metallic layer which is adhered to the opposite side of the substrate. The simulation is done using ANSYS HFSS full wave 3D simulation software. The proposed PIFA is very compact and also provides a gain of 2.86 dB. As a consequence of the exemplary feature like an omnidirectional radiation pattern, there is an exceptional improvement in coverage. Moreover, the frequency bands covered by the PIFA are for applications including USPCS, UMTS, ISM/ Bluetooth and WLAN at (1.85 to 1.99) GHz, (1.90 to 2.20) GHz, (2.4 to 2.485) GHz and (5.1 to 5.90) GHz, respectively.

1. INTRODUCTION

Among the different antenna designs in electronics and telecommunication there are microstrip antennas, also referred to as printed antennas with availability of many classifications. The most feasible, efficient and renowned design of these antennas is the imperceptibly small patch antenna of micro-dimensions also signified as the microstrip patch antenna. In order to design such an antenna, a flat rectangular metallic sheet of metal which is highly sleek is mounted upon a bigger metallic sheet serving as the ground plane with some intermediary space kept between them [1, 2]. This assembly of radiating elements is enclosed by a plastic covering for protection as the enclosure saves the antenna structure from deterioration and damage [4]. Patch antenna is the simplest design and can be easily modelled and customized. The passage of current through discontinues and rectangular slots created at each of the edges of the microstrip transmission line result in the radiation through excitation by Rabemanantsoa and Sharaiha [14]. The radiation thus originated at the edges enables the antenna to seem slightly bigger electrically than its actual physical structure and dimensions. Thus for the antenna to operate as a resonating element, a length of microstrip transmission line, which is slightly less than one half of the wavelength at selected frequency, is chosen [5].

A patch antenna whose dimensions comprise only one half wavelength length is mounted at a nominal distance above a ground plane which is large in size [6]. The patch antennas use an intermediate element such as a spacer made of a dielectric material between them. The edges of the ground plane exhibit the excitation of current, and the ground plane is kept closer to the radiating element which also radiates. The phenomenon of coupling subsequently gives rise to the process of resonance for the design [12]. Thus the two radiating metallic elements play an exemplary role in the development of the antenna radiation pattern, and the current thus developed follows the direction of the feed wire while propagating. In addition to this the magnetic vector potential electric field also follows the current. An astounding but simple design of such an antenna radiates a wave which is linearly polarized, and

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the radiation is considered to be from the numerous radiating slots on all the sides such as the top, bottom and as a consequence of the current flowing through the patch as well as the ground plane. For various applications, such as the wireless local area network (WLAN), wireless microwave access forum, ultra wideband and universal mobile communication systems, a wideband slotted antenna has been designed incorporating multifunctional reconfigurable frequency characteristics, and it has been proposed for cognitive radio applications [3]. Monopole antenna [7], microstrip patch antenna [8] and multiband antenna [9] are also proposed. Currently, the wireless area networks, WLAN in the 2.4-GHz, 2.4–2.485 GHz and 5-GHz, 5.l5–5.875 GHz bands are the extremely renowned and venerable networks for accessing the internet among subscribers.

Wireless communications using microstrip antennas have a tremendous exponential growth in industrial, scientific, and medical fields. For an incredible ultra wideband (UWB) manifestation, the transmitter and receiver antennas must possess desirable characteristics such as flat and high directive gain accompanied by a very narrow beam and low side and back lobes over the operational frequency bands. Also with the availability of such characteristics we have the ease to obtain the largest possible dynamic range. Furthermore, the advantages of such a design include the greatly enlightened and focused illumination area, low transmitter/receiver coupling losses, minimization of irresistible and irksome ringing and the development of uniformly shaped impulse radiation [15, 16].

2. ANTENNA DESIGN AND CONFIGURATION

The manifestation of the proposed antenna in terms of its geometry, structure and configuration is displayed in Fig. 1. The dimensions of the radiating element are 15 mm and 25.5 mm. Also the ground plane dimensions are equal to $X = 58$ mm, $Y = 40$ mm and $Z = 0$. Initially the design properties are selected by adjusting the local variables including the substrate thickness, height, material, transparency and position. As specified in Fig. 1, the proposed antenna design comprises a substrate over a radiating element with a dielectric spacer kept between them. The excitation of current through the discontinuities and irregularities in the radiating element stimulates the excitation of current through the ground plane too with coupling phenomenon. This design is coupled to the external world via the wave port. Further, the wave port is in link to the radiating element through the assembly made up a coax, coax pin and feed pin. This assembly of coax and a few other elements is cylindrical in shape, and Teflon is the material selected for them due to the desirable lower dielectric losses and higher bulk conductivity.

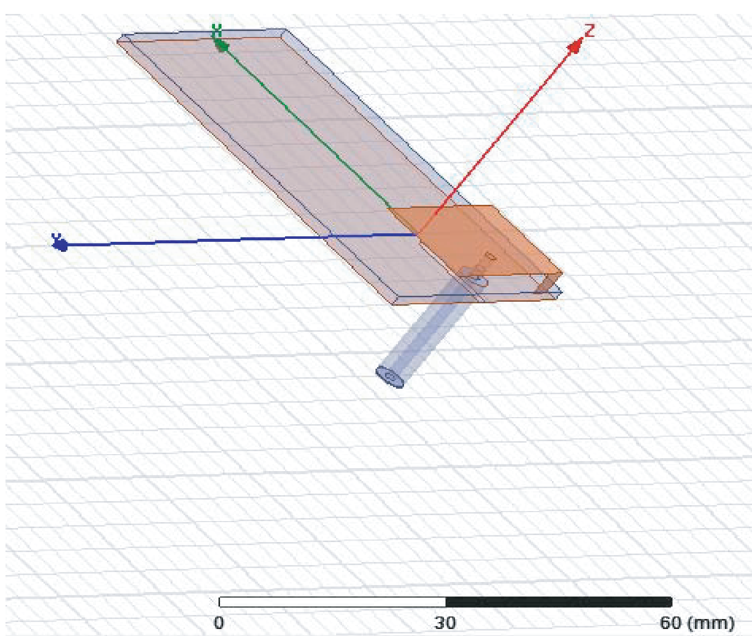

Figure 1. Front view of a planar inverted F antenna.

Even the material FR-Epoxy is chosen for substrates in many such designs because of its interesting metallic characteristics. FR-4 has general applications as an electrical insulator possessing considerable mechanical strength. Both dry and humid environments do not leave an adverse impact as the material retains its high mechanical values and electrical insulating characteristics. The attributes, such as dielectric strength of 20 MV/m, thermal conductivity of 0.81 W/m · K in addition to good fabrication characteristics, serve immense utilization for this grade thus exhibiting a wide variety of applications for electrical and mechanical purposes. The tilted design gives a schematic view of each and every element separately for the designed antenna. After tilting the designed structure for a better representation, a few elements as the coax and coax pin in the antenna get oriented along the negative Z axis as shown in Fig. 1. The height and radius of the coax are kept as 20 mm and 2.21 mm, respectively, and the height and radius for the coax pin are 20 mm and 0.81 mm, respectively in magnitude. Even the feed pin is cylindrical with a radius of 4 mm and height of 0.81 mm. A circular wave port on the substrate with a radius of 2.21 mm is developed before enclosing the design with a vacuum air box designed to be used with a compressed air source. Also the substrate thickness is equal to 1.6 mm. The air box is a model in open space facilitating the absorption and reflection from the structure. The radiation of a (planar inverted F antenna) PIFA is concentrated at broadside, which requires only a rectangular box in which the structure is enclosed. Finally, the design is covered with a vacuum air box before the beginning of simulation, analysis and operations.

There is a strong influence of the spacing amidst the radiating patch and the ground plane on the impedance bandwidth of a microstrip antenna. As we keep on moving the radiating element in the proximity to the ground plane, lesser energy radiates, and there is accumulation of more energy in the patch capacitance and inductance: that is, the efficiency and thus the quality factor Q of the antenna improves a lot at a separation of 20 mm equal to the length of the shorting pin. Fig. 1 presents the front view of the simulated antenna in the tilted configuration. It exhibits the basic structure of the antenna in which a view of every element of the design is given.

In Fig. 2, the tilted view of the antenna shows the dielectric spacing between the metallic substrate and the radiating element above it, and all the other elements used in the design can also be clearly seen. In addition to this short circuiting plate or pin, a feeding mechanism is used for the planar radiating element. The uppermost or top section is folded down in this design and becomes parallel to the ground plane. Thus, a shape resembling the alphabet F is developed and explains the reason behind the name PIFA. The excitation of currents in the ground plane is produced as a result of the phenomenon of coupling amidst the radiating planar element and the ground plane. Patch arrays have a number of benefits and applications such as airplanes and military applications because of their ability to develop extremely high gain in a low-profile antenna. The array of patch antennas developed by this technique is the easiest way for the design of an array which is peculiarly a phased structure of antennas and that, too, with advanced dynamic beam forming capability. The phenomenon of coupling plays an important role as the excitation of currents, and it results in the excitation of currents in the ground plane as well through this phenomenon. The radiation from two sets of radiating elements, including the patch and the ground plane, together results in the development of antenna patterns [20].

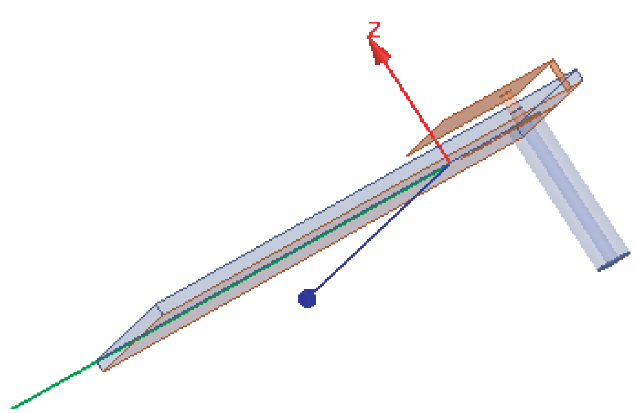

Figure 2. Tilted view or the side view of a planar inverted F antenna.

PIFA is extremely popular these days and is highly used in the mobile phone markets in different cellular phones with built-in antennas. The space needed on the phone is reduced a lot as the antenna exhibits resonance at a quarter-wavelength, and it also has very good specific absorption rate (SAR) properties. This antenna design has a unique name because of its resemblance to the inverted alphabet F. Besides, as the shorting plane of the half-patch is decremented in length, the frequency of resonance also decreases subsequently. Generally, PIFAs have multiple branches, and due to these multiple branches, the resonance at the multiple cellular bands is possible.

In addition to these on some phones, the radiation bandwidth characteristics are improved by applying the grounded parasitic elements, and this process is done differently from patch antennas which are conventionally made up of half wavelength dimensions. The PIFAs are referred to as quarter wavelength resonators because of their quarter wavelength design. Fig. 3, which is a side view of the design, depicts the various elements legibly such as the microstrip transmission line shorting plane, planar radiating element and ground plane. Moreover, a very compact and internally embedded microstrip PIFA has been designed due to all of the above-mentioned desirable structural characteristics. In Fig. 3, the quarter wavelength resonance is represented by the term lambda/four where lambda is the wavelength. PIFA is gaining more and more popularity because of its low profile and exquisite features such as omnidirectional radiation pattern.

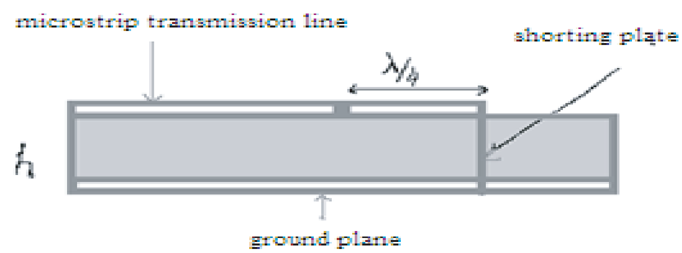

Figure 3. Quarter wavelength resonating element.

3. ADVANTAGES AND DISADVANTAGES OF PIFA

The microstrip antenna such as PIFA which has been designed is comparatively inexpensive in manufacturing and design, and the reason for this is their easy two-dimensional physical construction, design and geometry. Most of the applications of microstrip antennas are at ultra-high frequency (UHF) and other higher frequencies as the size and structure of this antenna are varied in relation to the wavelength at the frequency of resonance. A maximum directive gain around 6 dB to 9 dB is available from a single patch antenna. It is relatively easy to print an array of patches on a single (large) substrate, and lithographic techniques are used for the purpose.

Further, the impedance matching and phase adjustment are also possible in printed microstrip feed structures using similar operations that result in the design of radiating patches. Microstrip antennas such as rectangular patch and PIFA have the capability to create high gain arrays, and it is the vital fact that patch arrays are renowned among the airplanes and even in military applications. These steps and techniques comprise the easiest way to design a phased array of antenna with an excellent dynamic beam formation. Polarization diversity is one of the exquisite features available from the microstrip antennas [10]. Various polarization states are modeled with patch antennas such as the vertical, horizontal and even other orientations such as right-hand circular or left-hand circular polarization or other different polarization states using multiple feed points, and even an asymmetric patch structure is designed using a single feed point [17]. Apart from the advantages, Like MIMO, PIFA has a few disadvantages, such as weights and directivity; input impedance and bandwidth are highly sensitive from the tradeoff point of view. In addition to this, there is antennas venerability to physical damage and an uncontrolled radiation towards the operator [11].

4. PIFA ANTENNA DESIGN CONSIDERATION

A gain at least 3 dB to 4 dB is expected from the wideband antennas, and these are basically designed for smart grid applications. The design and simulation process is performed using high frequency structure simulation tool developed by ANSYS, and this is an industry standard simulation technique for the simulation of full wave electromagnetic field structure which is three-dimensional in design and view. High frequency structure simulator (HFSS) greatly reduces engineering time and investments for high frequency and high speed EM-based designs. HFSS is originally dedicated for simulations of RF, microwave and millimeter waves and provides many capabilities to support higher level design and design of manufacturing (DFM). One of the most renowned designs given by the tool is the microstrip antenna known as PIFA. It has got its development from the simplest designs using a patch in which the length is approximately around one half wavelength of the radio waves. The multiple branches resonating at different cellular bands subsequently produce the desired high gain in the vertical and horizontal states of polarization. Generally, the conventional lithographic techniques are used, which develop an array of patch on the metallic substrate. The materials such as Epoxy and Teflon are always selected as they have the exquisite properties such as low dielectric losses, high mass density and bulk conductivity.

Optimization of space amidst the feed elements and shorting pins enables the impedance matching. Hence, the simplest PIFA radiates a linearly polarized wave in which the resonance frequency is determined by the length of the antenna, and the bandwidth is maneuvered by the height. In addition to controlling the impedance matching, the feed position from the shorting plate affects the resonance on PIFA. The structure is made up of radiating planar element, and the ground plane behaves as an asymmetric dipole where the difference in current distribution in the two dipole arms is responsible for a little bit of distortion in the radiation pattern finally produced.

The planar inverted F antenna discussed here is a variation of the monopole antenna in which the top section is folded thereby making it parallel to the ground plane [11]. This enables the reduction of the height of the antenna subsequently maintaining a resonant trace length. Further an F shape is developed for the antenna and so the PIFA name is assigned. The phenomenon of coupling between the radiating elements plays its role as the excitation of currents in the printed inverted F antenna subsequently resulting in excitation of currents in the ground plane. The antenna pattern is thus a combination of the radiation from two sets of radiators. The fabrication of a microstrip antenna radiating circularly polarized waves is also possible by the excitation of a single square patch using two feeds. A phase difference of 90 degrees relative to each other is kept between the two feeds. Thus, transverse modes are developed this way with equal amplitudes and the required 90 degrees of phase difference. Among these different modes, each mode has a separate radiation, and the patterns combine to produce the desired circular polarization. For achieving the feed condition, a 90-degree hybrid coupler is generally used. By using this mechanism of polarization, there is the maximization of vertical current flow, and its prowess causes the horizontal current flow to become zero, and thus electric field radiated also turns to be vertical. After a quarter cycle elapses, there is a reversal of situation thereby becoming opposite, and the field becomes horizontal. A circularly polarized wave is thus developed by the radiating field rotating relative to the time [21]. Another alternative option is the use of a single feed with the inclusion of some kinds of asymmetric slots or other such features on the patch consequently manipulating the current distribution and leading it to be completely displaced [18, 19]. Besides, we have a design in which a square patch is perturbed or unsettled slowly so as to produce a rectangular microstrip antenna driven along a diagonal, thus developing polarization which is circular. At the driving point of these antennas, the two prominent modes are +45 degrees and −45 degrees, and this is the prerequisite for producing an exact 90-degree phase shift which is necessary for circular polarization [22].

5. RESULTS AND DISCUSSION

Now here we present the numerical and experimental results of the reconfigurable PIFA design [13], and the proposed PIFA design are also discussed. In the reconfigurable PIFA, the power losses such as return loss are very high at different resonant frequencies even the gain is low. The varactor serves fine frequency tuning which functions between USPCS and WCDMA as there is the reduction of inductance of the shorting line by the capacitance of the varactor. Also it is operational between approximately 5 pF at 4 V and 52 pF at 0 V. The radiation patterns describe the angular or directional dependence of the strength of radio waves from the antenna or other sources. As the radiation pattern obtained at 1.95 GHz, 3.5 GHz and 5.5 GHz for the reconfigurable PIFA is not omnidirectional, another design is proposed which is the planar inverted F antenna, and the simulated results for it are also presented here. For further clarification, in this section the numerical and experimental results regarding the radiation characteristics of the designed PIFA are discussed. The simulated results are deduced by incorporating the ANSYS simulation tool. The measured and simulated characteristics of the antenna include the far-field rectangular plot, 3D polar plot and radiation characteristics.

At the resonant frequencies of 2.1 GHz and 5 GHz, Fig. 4 gives the values of simulated return loss of the antenna, and they are lesser than the return loss given by the reconfigurable PIFA. Fig. 5, at an operating frequency of 2.5 GHz, presents the plot of graphical representation of gain as a function of the directional coordinates also depicted as the radiation pattern of the antenna. It is clearly visible in Fig. 5 that the proposed antenna manifests a design of radiation pattern much better than the reconfigurable PIFA [13]. Radiation pattern, also known as antenna pattern or far-field pattern, primarily exhibits angular dependence of the intensity of radiations from the antenna or some other sources. In addition to this, the far-field pattern of an antenna is determined experimentally and expressed at a frequency band of 1.85 to 1.99 GHz for USPCS and 1.9 to 2.2 GHz for UMTS, respectively. Alternatively, for obtaining a near-field pattern, a near-field scanner is used, and the radiation pattern is subsequently developed. The antenna produces resonance at 2 GHz, 2.4 GHz and 5 GHz and a gain around 2.86 dB, 3.43 dB and 4.14 dB, respectively. Unlike other antennas mentioned in literature till now, the proposed PIFA design presents a very good omnidirectional radiation pattern even at very high frequencies such as USPCS (1.85–1.99) GHz, UMTS (1.90–2.20) GHz and ISM/Bluetooth (2.4–2.485) GHz. The designed antenna is compact too, and even the return loss is lower making it more efficient. Characteristics of the radiation pattern are obtained in the high frequency band which is desirable and selected.

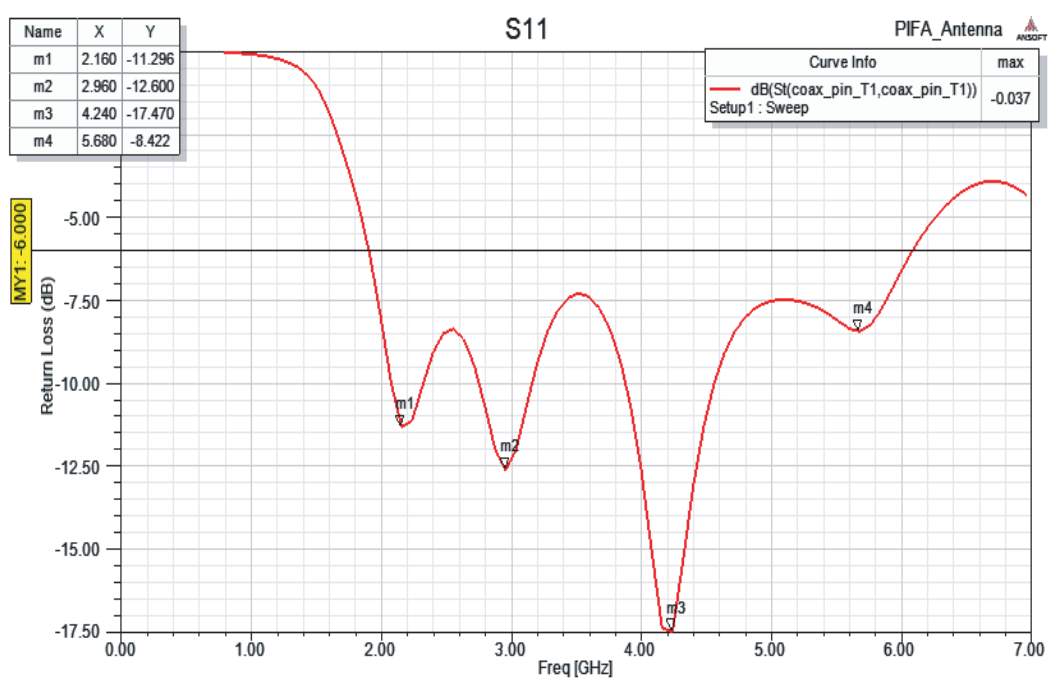

Figure 4. Return loss of proposed antenna.

Figure 6 gives the antenna's power gain which is the prime performance parameter combining the antenna's directivity and electrical efficiency. As a transmitting element, it demonstrates how proficiently and efficaciously the antenna converts input power into radio waves oriented in a specific direction. Also as a receiving antenna, the gain presents how effectively the antenna transforms the

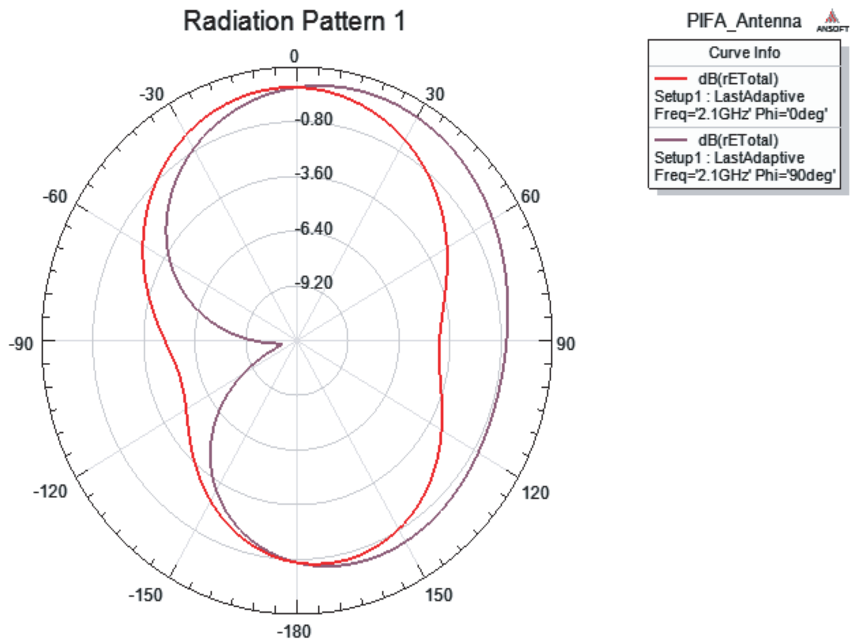

Figure 5. Radiation pattern of proposed antenna.

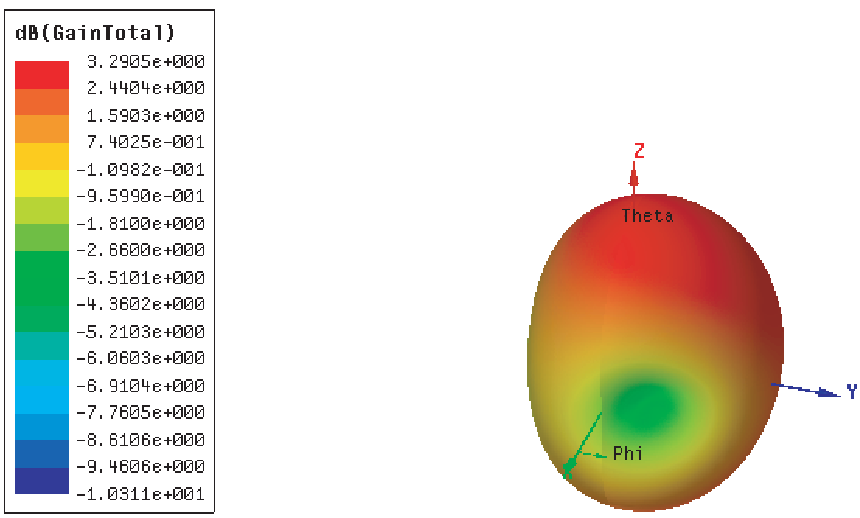

Figure 6. Gain of the proposed antenna.

radio waves arriving from a peculiar orientation into electrical power. In addition to this, with no specific direction, gain is understood referring to the utmost value of the gain. Standing wave ratio for the antenna is expressed as the ratio of the two amplitudes including the amplitude of a partial standing wave at an anti-node relative to maximum to the amplitude at an adjacent node relative to minimum in an antenna design or electrical transmission line. Another parameter for the evaluation of antenna performance among the observations is the voltage standing wave ratio for the proposed antenna design. It is a tool for the efficiency measurement of antenna designs as the transmission lines conducting radio frequency signals are used for applications like the conjunction of radio transmitters and receivers to their antennas, and subsequently the distribution of cable television signals.

Figure 7 at a frequency of 2.1 GHz gives an exemplary view of the three-dimensional polar plot of the antenna using the various polar coordinates such as the radial distance, polar and the azimuth angle.

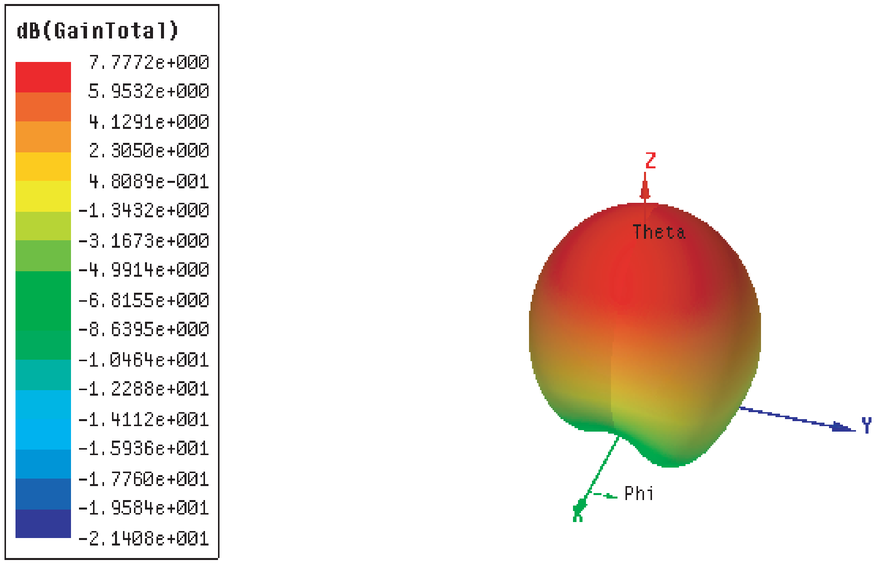

Figure 7. 3D polar plot of the proposed antenna.

Figure 8. Antenna prototype testing on VNA.

Now as the length of the radiating element is a quarter wavelength, we get around nominal 3.29 dB of gain out of the directivity relative to the vertical axis of the antenna. Now if the radiating element is completely square, the pattern in the horizontal plane is directional, somewhat as if the radiating patch would resemble dipoles which were segregated from each other by a half-wave. Therefore, the gain is enhanced by 2–3 dB. Thus the inclusion of ground plane resembles most or all radiation left behind the antenna, thus diminishing the power averaged over all directions by a factor around 2 and subsequently incrementing the gain by a huge factor of 3 dB.

Figure 8 shows the fabricated antenna prototype attached to a vector network analyzer (VNA) for measurement purpose. VNA used is from Anritsu with the range 0.1 GHz to 20 GHz. The desired frequency sweep is selected for the measurement, and the VNA port is calibrated as per the sweep.

Table 1 manifests the properties of the proposed PIFA design and its comparison with reconfigurable PIFA [13]. In comparison to the reconfigurable PIFA, the proposed design shows an improvement in gain from 2.82 dB to 2.86 dB at the resonating frequency of 2.1 GHz, and another improvement of gain from 1.49 to 4.14 dB at the resonating frequency of 5 GHz. Furthermore, the proposed design provides higher efficiency at the resonating frequency with return losses of −11.5 dB and −7.5 dB.

Figure 9 manifests an incredible improvement in return loss and illustrates the loss of power in the signal returned by the different discontinuities in the design. Return loss evaluated from the incident

Table 1. Comparison of proposed antenna with reconfigurable PIFA [13].

Antenna design Parameters	**Reconfigurable PIFA ([13])**	**Simulated results of proposed design**	**Measured results of proposed design**
Volume (mm^3)	11350	1500	1500
Resonant freq. (GHz)	2.1 GHz, 5 GHz	2.1 GHz, 5 GHz	2.1 GHz, 5 GHz
Gain (dB)	2.82, 1.49	2.86, 4.14	———
Frequency bands	USPCS (1.85 to 1.99) GHz, UMTS (1.92 to 2.18) GHz, WLAN (5.1 to 5.35) GHz	USPCS (1.85 to 1.99) GHz, UMTS (1.90 to 2.20) GHz, ISM/Bluetooth (2.4 to 2.485) GHz, WLAN (5.1 to 5.90) GHz	USPCS (1.85 to 1.99) GHz, UMTS (1.90 to 2.20) GHz, ISM/Bluetooth (2.4 to 2.485) GHz, WLAN (5.1 to 5.90) GHz

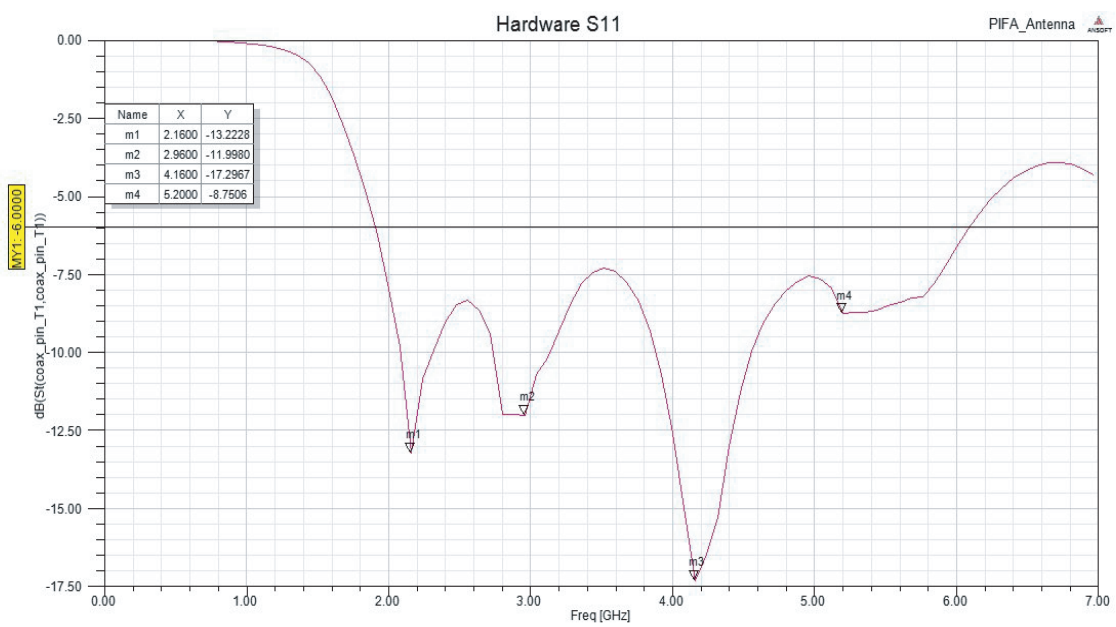

Figure 9. Measured result of return loss for proposed antenna.

power and reflected power is a measure of how well the lines are matched. It should be noted that in the reconfigurable PIFA [13], return loss is measured at different modes by using the PIN diode and also by varying the tunable varactor. The proposed design gives much lower losses than all of them. Furthermore, the return loss is preferable as it has better resolution for smaller values of reflected wave. The proposed PIFA design shows an overall exemplary performance by improvement in gain from 1.49 to 4.14 dB at the resonant frequency of 5 GHz. Besides this, the return loss is highly reduced from 5 dB to 7.5 dB. Furthermore, the return loss decreases to even −11.5 dB at the resonating frequency of 2.1 GHz. The PIFA design also exhibits effectiveness by covering wider frequency bands for different applications such as 5.1 to 5.9 GHz for WLAN and 1.90 to 2.20 GHz for UMTS. It also provides services and applications for ISM/Bluetooth purposes.

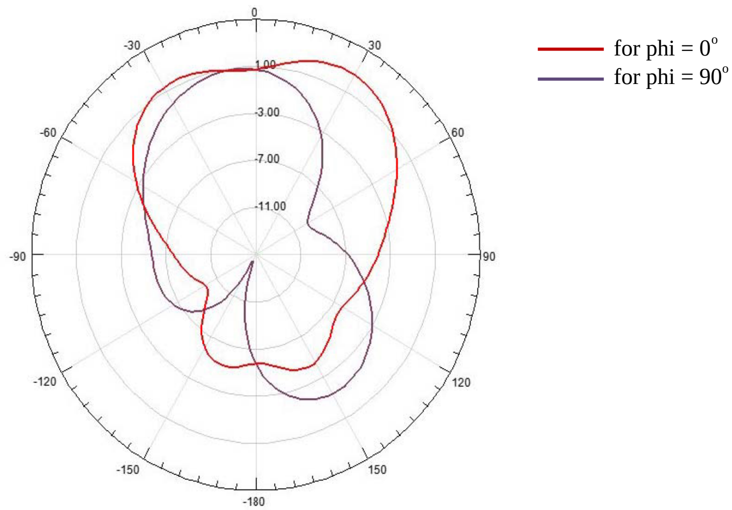

Figure 10. Measured result of radiation pattern for proposed antenna.

Figure 10 refers to the radiation pattern and shows the directional dependence of the intensity of radiations from the antenna. It is the graphical representation of the gain as a function of the directional coordinates. The radial distances from the origin in peculiar directions represent the intensity of radiations emitted in that direction with the intensity of radiation being more in certain directions irrespective of the nearly omnidirectional pattern. Furthermore, the radiation pattern manifested for the proposed antenna design is much better than the reconfigurable PIFA.

6. CONCLUSION

The objective is to design a multiband antenna for the use in hand-held devices, which provides support to several cellular and non-cellular technologies. Many interesting characteristics of PIFA have been uncovered, and good results are achieved. The work deals with aspects of multiband planar inverted F antenna studies, design and simulation. The results affirm that the antenna structure is suitable for the use in hand-held device. The proposed PIFA design even provides better performance, coverage and frequency bands for USPCS, UMTS, ISM/Bluetooth and WLAN applications. This is a primary design with the simple configuration, but still it provides incredible amelioration over the reconfigurable PIFA with reduction in losses and improvement in other parameters. It is a simple design and easiest antenna to be fabricated as per the configuration in comparison to the conventional microstrip antenna, and other antennas such as dipole antenna and rectangular patch antenna. The return loss for the proposed PIFA is lesser than the rectangular patch antenna and the reconfigurable PIFA using a switchable PIN diode. Further, the three-dimensional radiation pattern for the proposed PIFA gives a much better omnidirectional view than the reconfigurable PIFA and even the rectangular patch antenna. High gain is also available from PIFA at different resonant frequencies compared to other antennas such as the reconfigurable PIFA. Thus the proposed PIFA design gives a much better overall performance in terms of various simulated characteristics and obtained results.

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