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TECHNICAL NOTE

Multiband planar inverted-F dual-L antenna (PIFDLA) for WLAN applications

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Multiband antenna;
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Abstract A modified multiband single-feed planar inverted-F dual-L antenna (PIFDLA) is presented for WLAN applications. This proposed antenna with overall size of 24 mm × 30 mm × 7 mm mounted on a 30 mm × 30 mm × 1 mm finite ground plane, simultaneously operates in Bluetooth, IEEE 802.11a/b/g, and HIPERLAN2. This antenna is able to operate at the desired resonant frequencies for the lower band (2.4–2.63 GHz) and for the upper band (5.04–6.04 GHz).

1. Introduction

The rapid growth of local area network (WLAN) applications has created strong demands for small internal antennas. Due to the limited space availability in the wireless devices, the demand for low cost and small size antenna design is required. In current wireless environments, there are many wireless devices working in several frequency bands, and providing different services. There is an increasing need to provide many such wireless services with one device. An example of this is the integration of Bluetooth, mobile phone, and wireless local area network (WLAN) capabilities into some laptop computers. However, this normally requires many antennas to cover each service, and it is not possible to fit them all in a small device. To address this requirement, antennas that operate in multiple bands are required to support multiple standards. So, the idea is to enhance the functionality and performance of wireless communication devices and to cover the existing wireless communication frequency bands. One family of such antennas, the planar inverted-F antennas (PIFAs), is particularly interesting due to their compactness and suitable performance. PIFA antenna has been adopted in portable wireless units due to its low profile, light weight, and conformal structure (Balanis, 1982). Because of the limited space availability in wireless devices, the purpose is to keep the size of this type of antenna small and appropriate for portable wireless units without degradation of performance in terms of bandwidth and radiation patterns; so the radiation pattern should close to be omnidirectional and it should cover required operating frequency bands for the IEEE 802.11a/b/g standard. By adapting the research outcomes of authors (Olmos et al., 2004), this paper presents a modified dual-frequency (2.5/5.67 GHz) compact planar inverted-F dual-L-shaped antenna with overall size of 30 mm × 24 mm × 7 mm, mounted on a 30 mm × 30 mm × 1 mm finite ground plane. The target frequencies were chosen

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to cover IEEE 802.11a/b/g, HIPERLAN2 and systems such as Bluetooth and ZigBee.

2. Antenna configuration

The aim of this paper is to design an efficient, small and low profile PIFA antenna with multi-band operations for the WLAN and Bluetooth applications. Thus, to start with, a lot of studies have been done in this field (Zhou et al., 2008). Based on PIFA of Zhou et al. (2008), which describes a PIFA overall size of 30 mm × 15 mm × 8 mm, mounted on a 30 mm × 30 mm finite ground plane, and the thickness of the copper conductors is 0.5 mm. The modifying PIFA of Zhou et al. (2008) is adopted having a rectangular plate feed element because of its attractive enhanced bandwidth characteristic (Olmos et al., 2004). This PIFA is modified to operate as dual-band antenna so an inverted-L antenna is added to operate at the desired upper operating frequency for WLAN applications while the inverted-F antenna operates at the desired lower band for Bluetooth. The PIFA of Zhou et al. (2008) operates on two bands; the lower band (2.4–2.6 GHz) at a minimum return loss of −10 dB or less, encompassing the desired IEEE 802.11b/g, Bluetooth and ZigBee frequency band (2400–2485 MHz), and the upper band (5–5.65 GHz) fully covers the IEEE 802.11a (5.15–5.35 GHz) band. In this paper we modified the PIFA of Zhou et al. (2008) to achieve a slightly wider 10-dB return loss bandwidth in the upper and lower bands, in addition to overall size reduction with omnidirectional radiation pattern. The modifications on PIFA of Zhou et al. (2008) include increasing the thickness of copper conductors to 1 mm instead of 0.5 mm to strength the antenna because it is placed on air, creating slot in the planar element of the inverted-F antenna between short-circuit plate and feed plate. These slots in the PIFA top plate nominally provide series reactance when the slot opening is close to the feed, and this behavior allows bandwidth improvement to be realized (Kevin and Leo, 2006), furthermore, adding another inverted-L antenna as a parasitic element, which is found to enhance the bandwidth through controlling the resistance and reactance between the two resonance to achieve an overall broad-bandwidth (Kathleen and Yahya, 1997). The resulting modified PIFA structure is shown in Fig. 1. We start with F-patch of 18.6 mm × 14.5 mm and with 6 mm above the ground plane which is 30 mm × 30 mm × 1 mm.

The L-patch is of 10.5 mm × 10 mm, it was 4.5 mm above the ground plane. After performing different simulations, we noticed that the distance between the F-patch and L-patches affects the 10-dB return loss bandwidth in addition to the effect of the slot between short-circuit plate and feed plate in bandwidth enhancement; the bandwidth increases as the separation between F-patch and L-patches increases, but with frequency shift for both bands, so to compensate for this frequency shift, the distance between the ground plane and the L-patch should be adjusted to cover the desired bands.

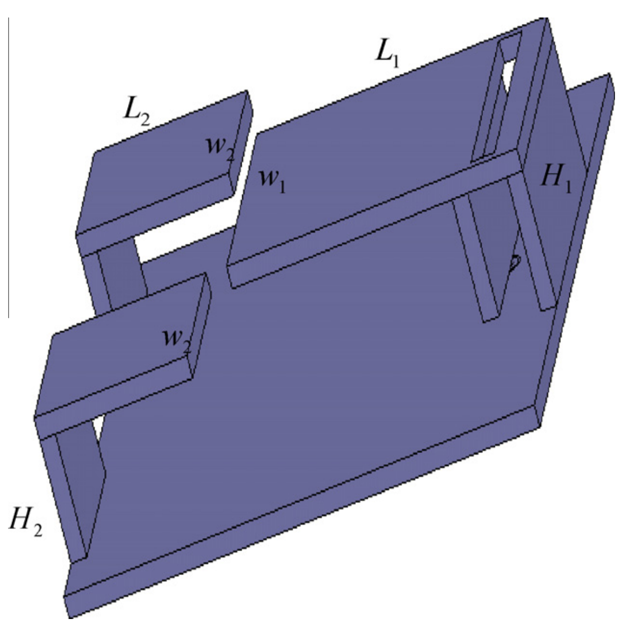

Figure 1 The geometry of PIFDLA.

3. Results and discussion

The antenna design was performed using the HFSS software, and the following dimensions were found to yield the best

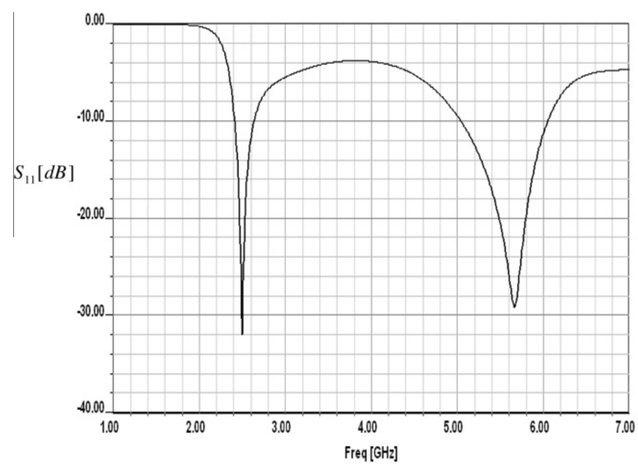

Figure 2 The return loss versus frequency for PIFDLA of F-patch 6 mm above the ground plane.

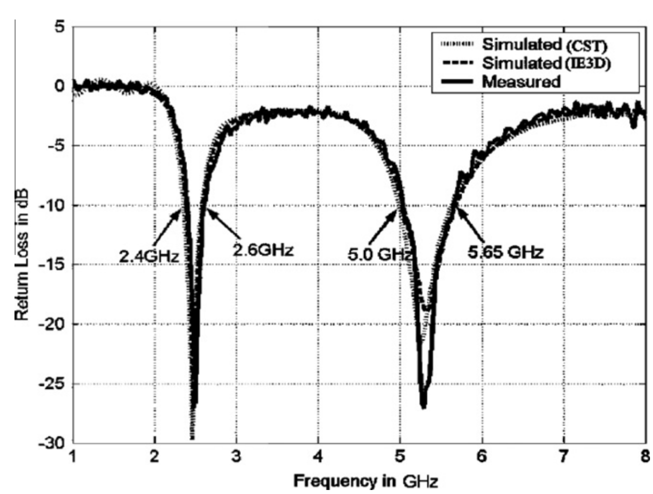

Figure 3 Measured and simulated return loss for PIFA of Zhou et al. (2008).

results: F-patch of 12 mm × 18.4 mm and 6 mm above the ground plane which is 30 mm × 30 mm, L-patch of 8.5 mm × 9.75 mm and 5.2 mm above the ground plane, in addition to the slot of 11 mm × 1.5 mm × 1 mm on the F-patch between short-circuit plate and feed plate which provides series reactance when the slot opening is close to the feed, and this behavior allows bandwidth improvement to be realized. These optimal dimensions are obtained based on the following calculations; we start with the resonant frequency of the lower band f_r which is 2.5 GHz, the lower band created from inverted-F antenna, so the wavelength λ is, $\frac{\lambda}{f_r} = 120\,\text{mm}$, where c is the speed of light. Because the width of the short-circuit plate W is equal to the width of F-planar element w_1, the effective current length is $H_1 + L_1$, where L_1 is the length of F-planar element, and H_1 is the height of the short-circuit plate. Then the resonant condition is $L_1 + H_1 = \frac{\lambda}{4} = 30\,\text{mm}\lambda = 53\,\text{mm}$. By fixing the height of the inverted-F to 6 mm above the ground plane and calculating the planar element length from above equation to be 24 mm, but due to the coupling between inverted-F and inverted-L and due to the open circuited edges, the best length for the planar element of inverted-F was 18.4 mm. For the upper band which created from inverted-L antenna, we start with the resonant frequency of 5.67 GHz, and then the wavelength is 53 mm.

Because the width of the short-circuit plate for inverted-L antenna W is equal to the width of L-planar element, the effective current length is $H_2 + L_2$, where L_2 is the length of L-planar element, and H_2 is the height of the short-circuit plate. Then the resonant condition is $L_2 + H_2 = \frac{\lambda}{4} = 13.25\,\text{mm}$.

By fixing the height of the inverted-L to 5.2 mm and calculating the L-planar element length from above equation to be 8.05 mm, but due to the coupling between inverted-F and inverted-L and due to the open circuited edges, the best length for the planar element of inverted-L was 9.75 mm.

The resulting multiband single-feed PIFA achieved an enhancement of 15% on the lower band (2.4–2.63 GHz) and an enhancement of 53.8% on the upper band (5.04–6.04 GHz) in addition to 12.5% size reduction compared with PIFA of Zhou et al. (2008). Figs. 2–4 show the return loss and radiation pattern, respectively, for the modified WLAN

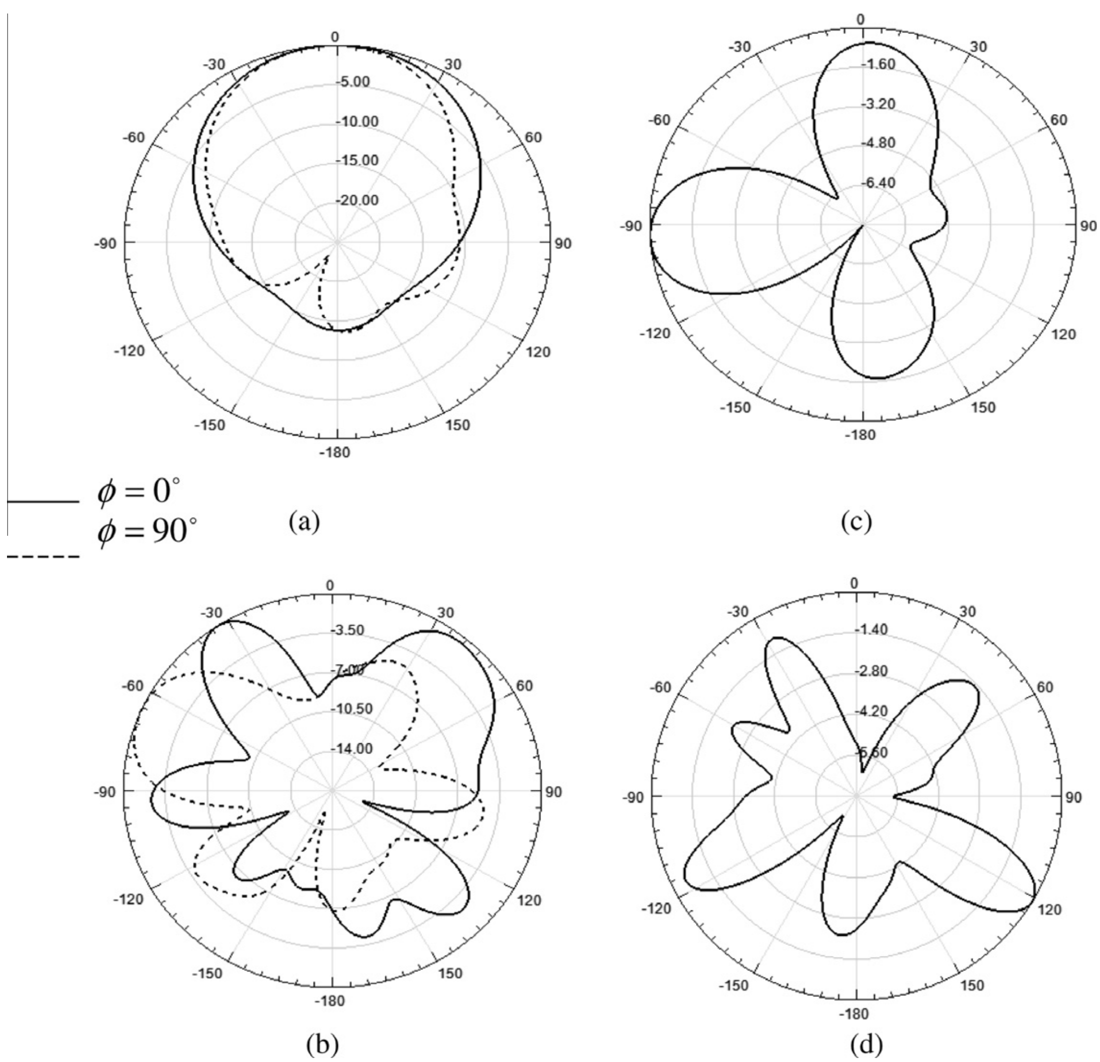

Figure 4 The radiation pattern for the PIFDLA of F-patch 6 mm above the ground plane (a) with respect to θ for $\phi = 0^\circ$ and $\phi = 90^\circ$ at 2.5 GHz, (b) with respect to θ for $\phi = 0^\circ$ and $\phi = 90^\circ$ at 5.67 GHz, (c) with respect to ϕ for $\theta = 90^\circ$ at 2.5 GHz and (d) with respect to ϕ for $\theta = 90$ at 5.67 GHz.

antenna and Figs. 3–5 show the return loss and radiation pattern, respectively, for the PIFA of Zhou et al. (2008).

To see the effect of the short-circuit plate width W, simulation for different values of short-circuit plate widths (8 mm, 10 , and 12 mm) was performed. Results of this simulation are shown in Fig. 6, the short-circuit width of $W < w_1$ (8 mm and 10 mm) give not good return loss (−10 dB, −15 dB, respectively), so the best result for the lower band was at $W = w_1 = 12$ mm, because the bandwidth and resonant frequency for PIFA decreases as the short-circuit plate width decreases (Hirisawa and Haneishi, 1992).

To see the effect of finite ground plane size on the performance of PIFDLA, simulations for different sizes of ground plane with length 30–60 mm of step size 10 mm were performed, these lengths are comparable to 0.25 λ, 0.3λ, 0.42 λ, and 0.5 λ.

Fig. 7 shows the return loss for square finite ground plane; the lower band is about 350 MHz for ground plane size of

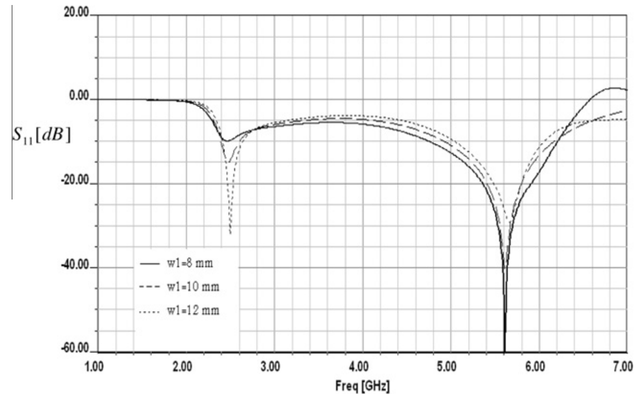

Figure 6 The effect of short-circuit plate width on the scattering parameter S_{11} versus frequency.

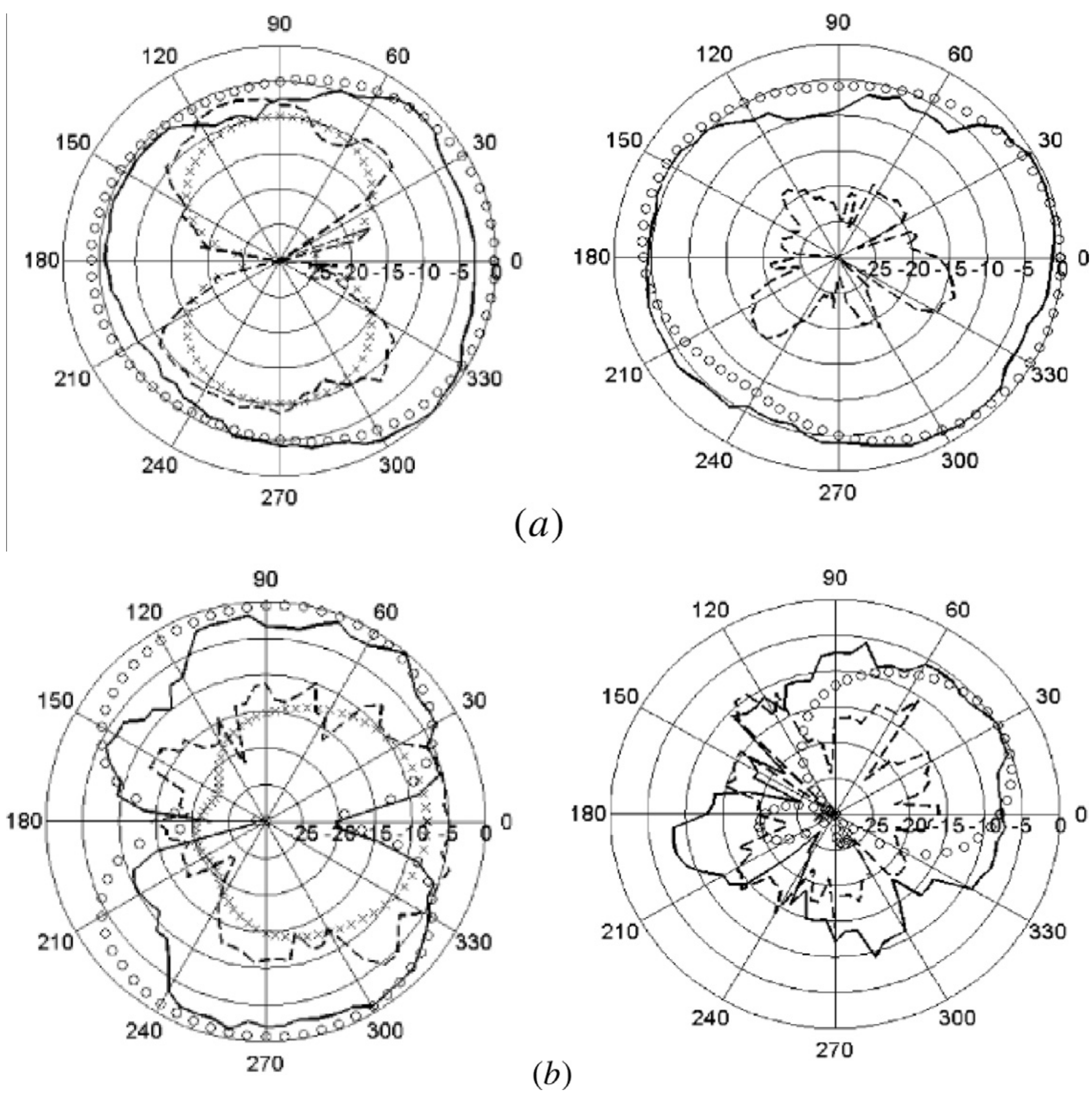

Figure 5 Simulated and measured radiation patterns for PIFA of Zhou et al. (2008) (left: x–z plane, right: y–z plane) at (a) 2.45 GHz and (b) 5.2 GHz. ''xxxx'' simulated cross-polarization, ''oooo'' simulated co-polarization,''———'' measured cross-polarization, ''—— ''measured co-polarization.

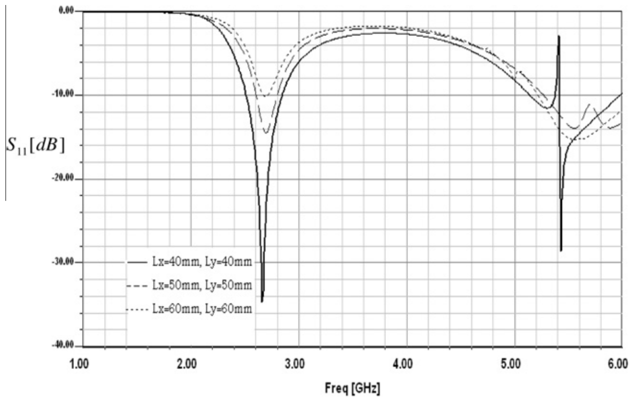

Figure 7 The effect of square finite ground plane size on the scattering parameter versus S_{11} frequency.

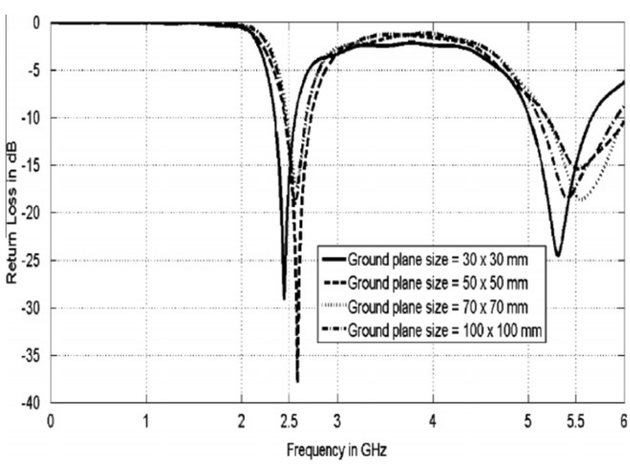

Figure 8 The effect of square finite ground plane size on the scattering parameter S_{11} versus frequency for PIFLA of Zhou et al. (2008).

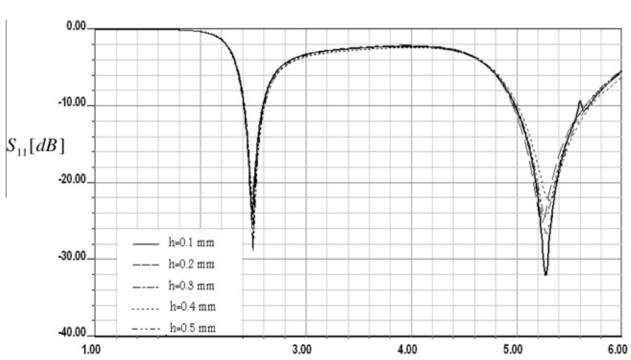

Figure 9 The effect of ground plane thickness on the scattering parameter S_{11} versus frequency.

40 mm × 40 mm, but for ground plane of sizes 50 mm × 50 mm, and 60 mm × 60 mm, the return loss is −10 dB, −14 dB, respectively.

If we compare our results for different ground plane sizes with that presented for PIFA of Zhou et al. (2008), we found that as shown in Fig. 8, the ground plane size of

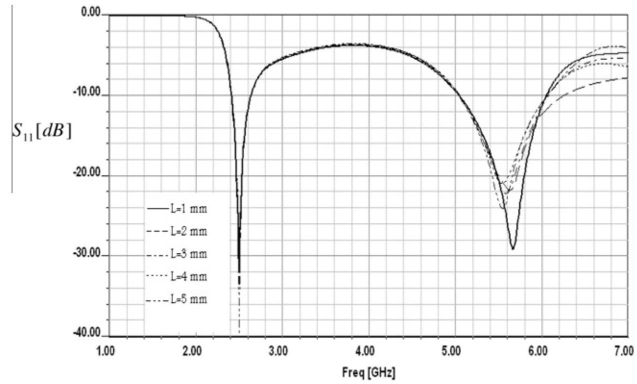

Figure 10 The effect of coaxial cable length on the scattering parameter S_{11} versus frequency.

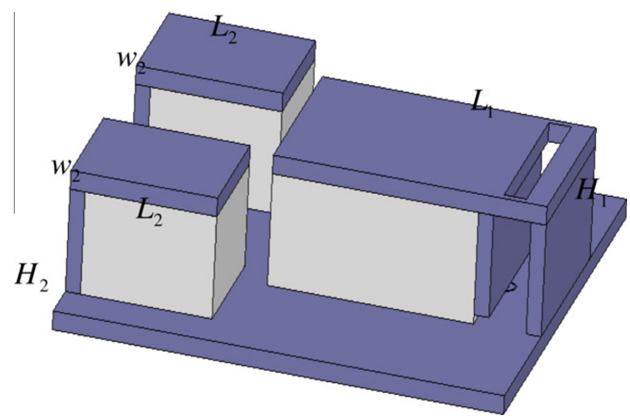

Figure 11 The geometry of PIFDLA supported by substrate.

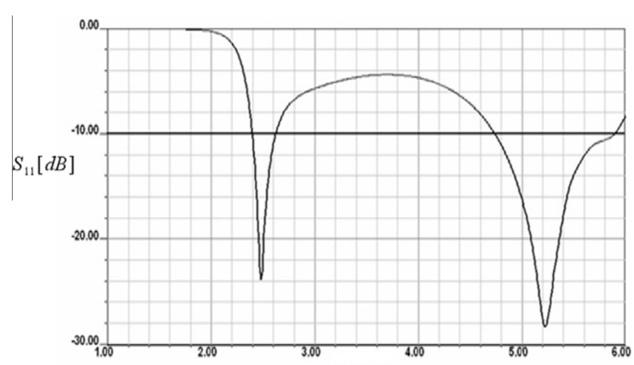

Figure 12 The return loss versus frequency for PIFDLA supported by substrate (ε_r = 1.2).

30 mm × 30 mm is the suitable size for both antennas. For an antenna to be mounted on finite ground plane, the outer edge of the ground plane diffracts incident radiation in all directions. At the outer edge of the ground plane, the current on the top and bottom faces of the ground plane are equal in magnitude and opposite in direction, so the total net current is zero at the edge (Hirisawa and Haneishi, 1992). The outer edge diffraction can alter the input impedance, so the more suitable ground plane size will be chosen from simulation for different

ground plane sizes. To see the effect of ground plane thickness, a simulation for different ground plane thicknesses from 0.1 to 0.5 mm with 0.1 mm step size was performed. Fig. 9 shows the return loss for different ground plane thicknesses; the lower band is still the same for all thicknesses, but for the upper band an enhancement of about 4.5% is obtained at thicknesses of 0.4 mm and 0.3 mm and an enhancement of 3% at thickness of 0.2 mm.

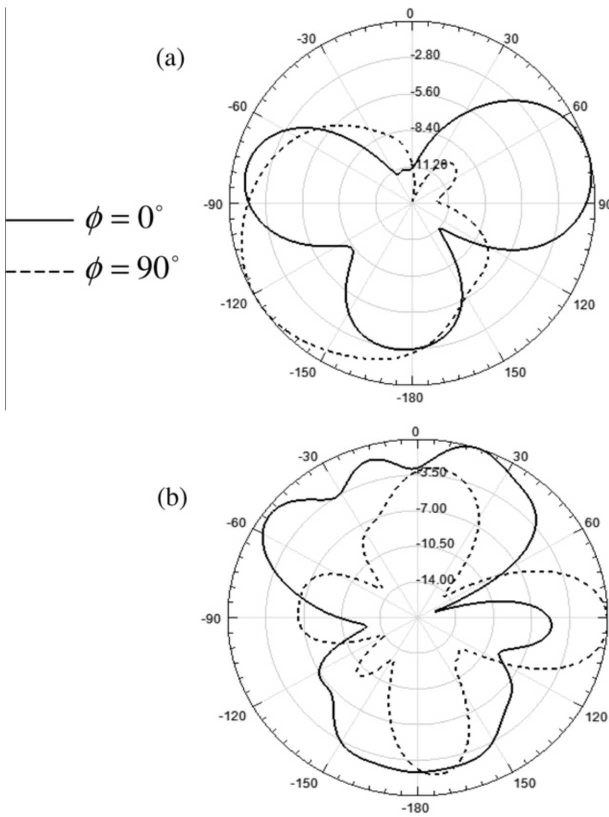

Figure 13 The radiation pattern for PIFDLA with $\varepsilon_r = 1.2$ substrate with respect to θ for $\phi = 0^\circ$ and $\phi = 90^\circ$ at (a) 2.48 GHz and (b) 5.22 GHz.

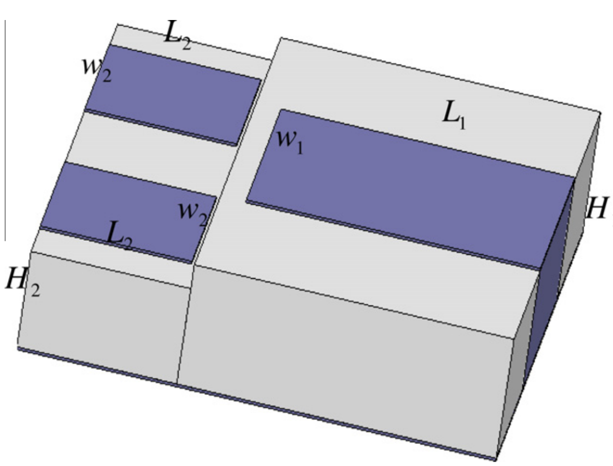

Figure 14 The geometry of supported PIFDLA with copper thickness 0.17 mm.

Also the effect of coaxial cable length which is feeding the antenna is considered, a simulation for different coaxial cable lengths from 1 to 5 mm with 1 mm step size was performed. Fig. 10 shows the return loss for different coaxial cable lengths, in which that the coaxial cable length does not affect the bandwidth for the upper and lower bands, but causes small shift in the resonant frequency for the upper band.

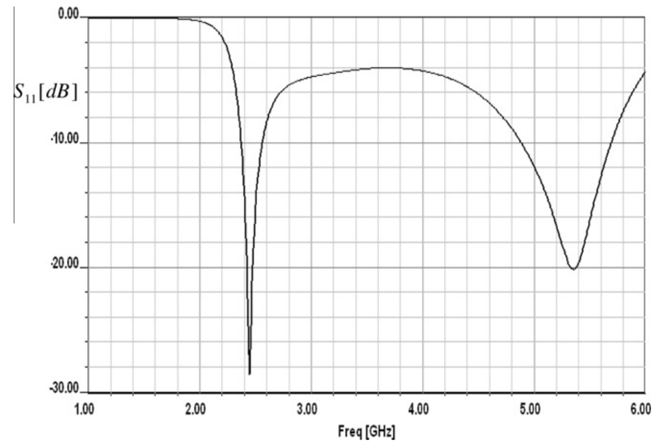

Figure 15 The return loss versus frequency for supported PIFDLA with 0.17 mm copper thickness.

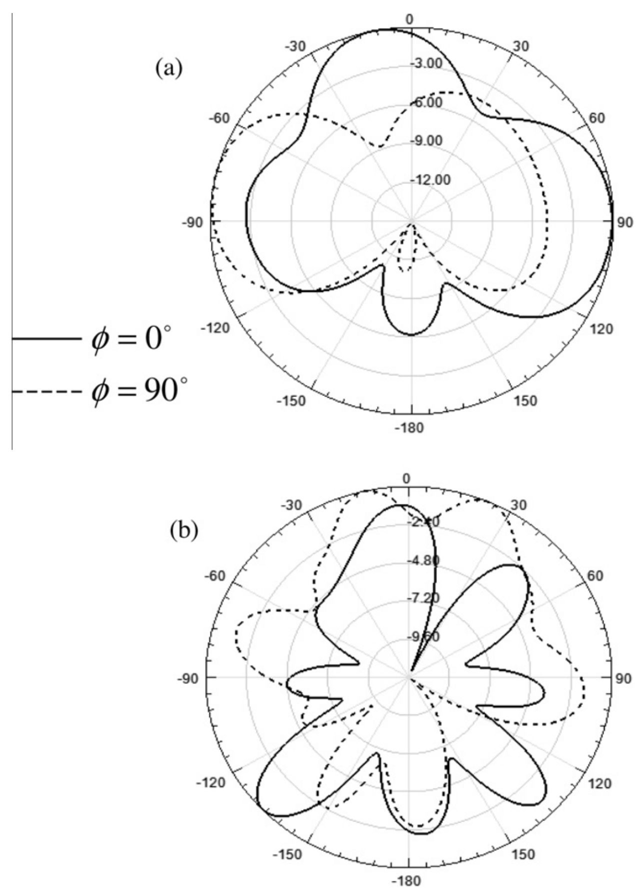

Figure 16 The radiation pattern for supported PIFDLA with 0.17 mm copper thickness with respect to θ for $\phi = 0^\circ$ and $\phi = 90^\circ$ at (a) 2.45 GHz and (b) 5.35 GHz.

For our modified WLAN antenna to be more supported a dielectric material of $\varepsilon_r = 1.2$ – or any dielectric material with relative permittivity around unity like foam as an example – was added as shown in Fig. 11, By adjusted all antenna parameters ($L_1 = 18.2$ mm, $w_1 = 12$ mm, $H_1 = 7$ mm, $L_2 = 9.75$ mm, $w_2 = 8$ mm, $H_2 = 6.5$ mm), Figs. 12 and 13 show

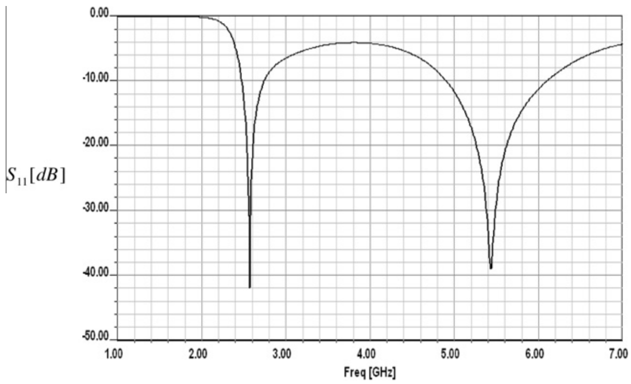

Figure 17 The return loss versus frequency for PIFDLA of F-patch 5 mm above the ground plane.

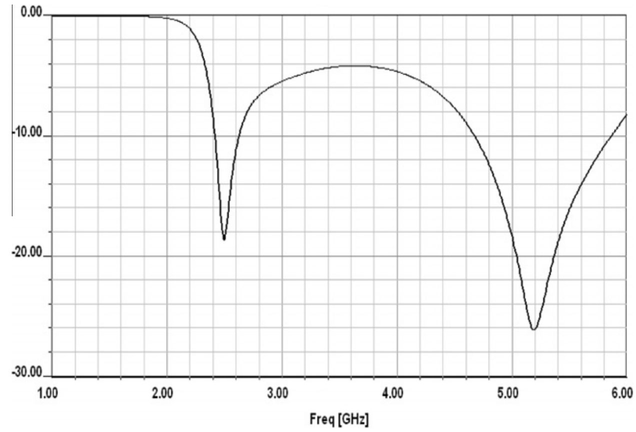

Figure 19 The return loss versus frequency for PIFDLA with F-patch 5 mm above the ground plane with substrate $\varepsilon_r = 1.2$.

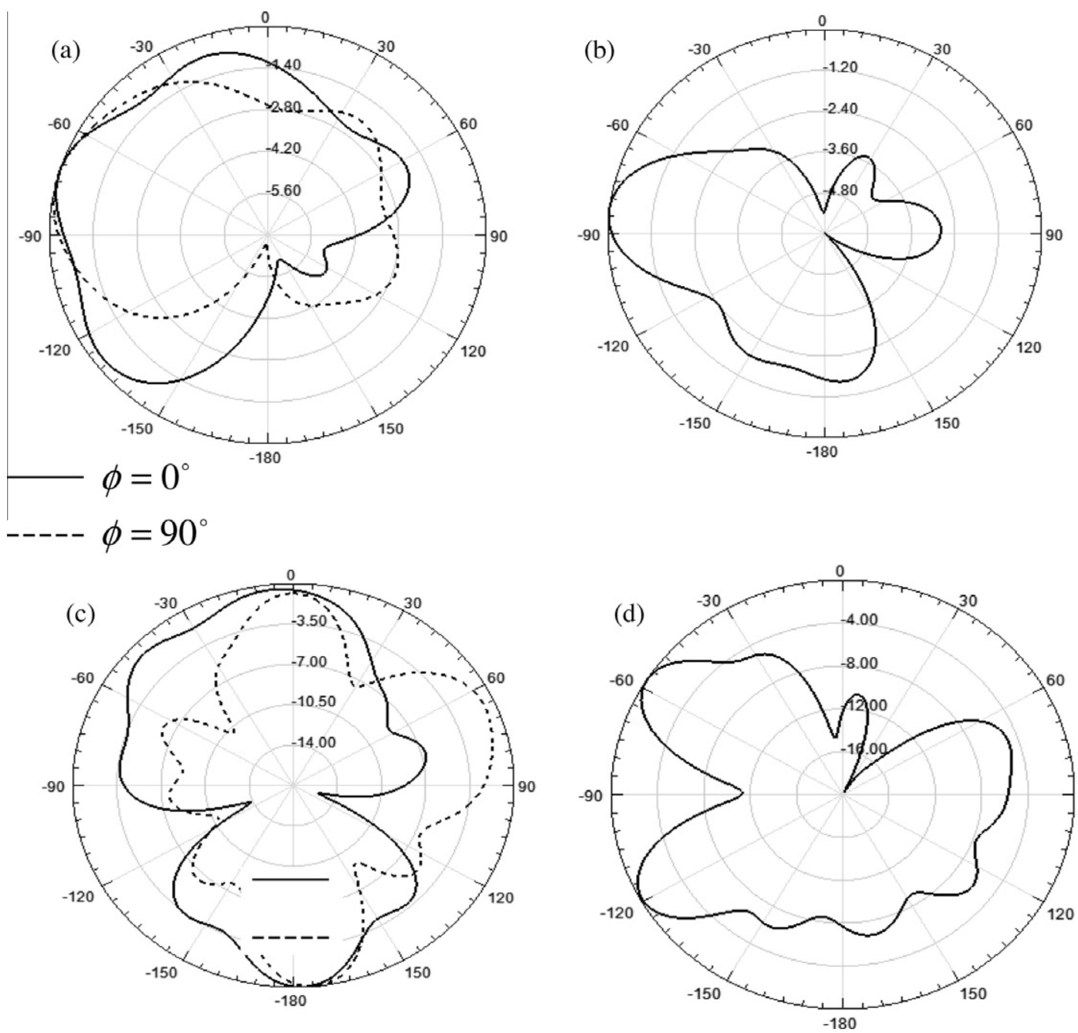

Figure 18 The radiation pattern for PIFDLA of F-patch 5 mm above the ground plane (a) with respect to θ for $\phi = 0^\circ$ and $\phi = 90^\circ$ at 2.57 GHz, (b) with respect to θ for $\phi = 0^\circ$ and $\phi = 90^\circ$ at 5.44 GHz, (c) with respect to ϕ for $\theta = 90^\circ$ at 2.57 GHz and (d) with respect to ϕ for $\theta = 90^\circ$ at 5.44 GHz.

the return loss and radiation pattern respectively for supported antenna. Fig. 12 shows an enhancement of 15% on the lower band (2.39–2.62 GHz) and 78.5% on the upper band (4.74–5.9 GHz), in addition to a size reduction of 12.5% compared with PIFLA of Zhou et al. (2008). But the radiation pattern for supportive antenna does not look to be omnidirectional and this because the ground surface waves can produce spurious radiations or couple energy at discontinuities, leading to distortions in the main pattern, or unwanted loss of power. The surface wave effects can be controlled by the use of photonic band gap structures or simply by choosing air as the dielectric. This solves the limitation of poor efficiency as well along with certain degree of bandwidth enhancement.

Good results obtained by supporting the antenna with dielectric material ($\varepsilon_r = 1.2$) lead us to start with the PIFDLA antenna with substrate that covers all the ground plane with $\varepsilon_r = 1.2$ and height of 7 mm for inverted-F which is 7 mm above the ground plane and 4.5 mm for inverted-L which is 4.5 mm above the ground plane, in addition to the copper thickness of 1 mm for copper conductors and removing the slot between the feeding plate and short-circuit plate. By adjusting all parameters ($L_1 = 18.4$ mm, $w_1 = 12$ mm, $H_1 = 8$ mm, $L_2 = 9.5$ mm, $w_2 = 8.5$ mm, $H_2 = 5.5$ mm), this proposed antenna operates from 2.37 to 2.55 GHz for the lower band and from 5.01 to 5.72 GHz for the upper band. But for the copper thickness of 0.17 mm for F-patch and L-patches and copper thickness of 1 mm for short-circuit plates with substrate of height 7.5 mm for the inverted-F antenna and 6 mm for the inverted-L antenna; the antenna operates from 2.36 to 2.56 GHz for the lower band and from 4.88 to 5.69 GHz for the upper

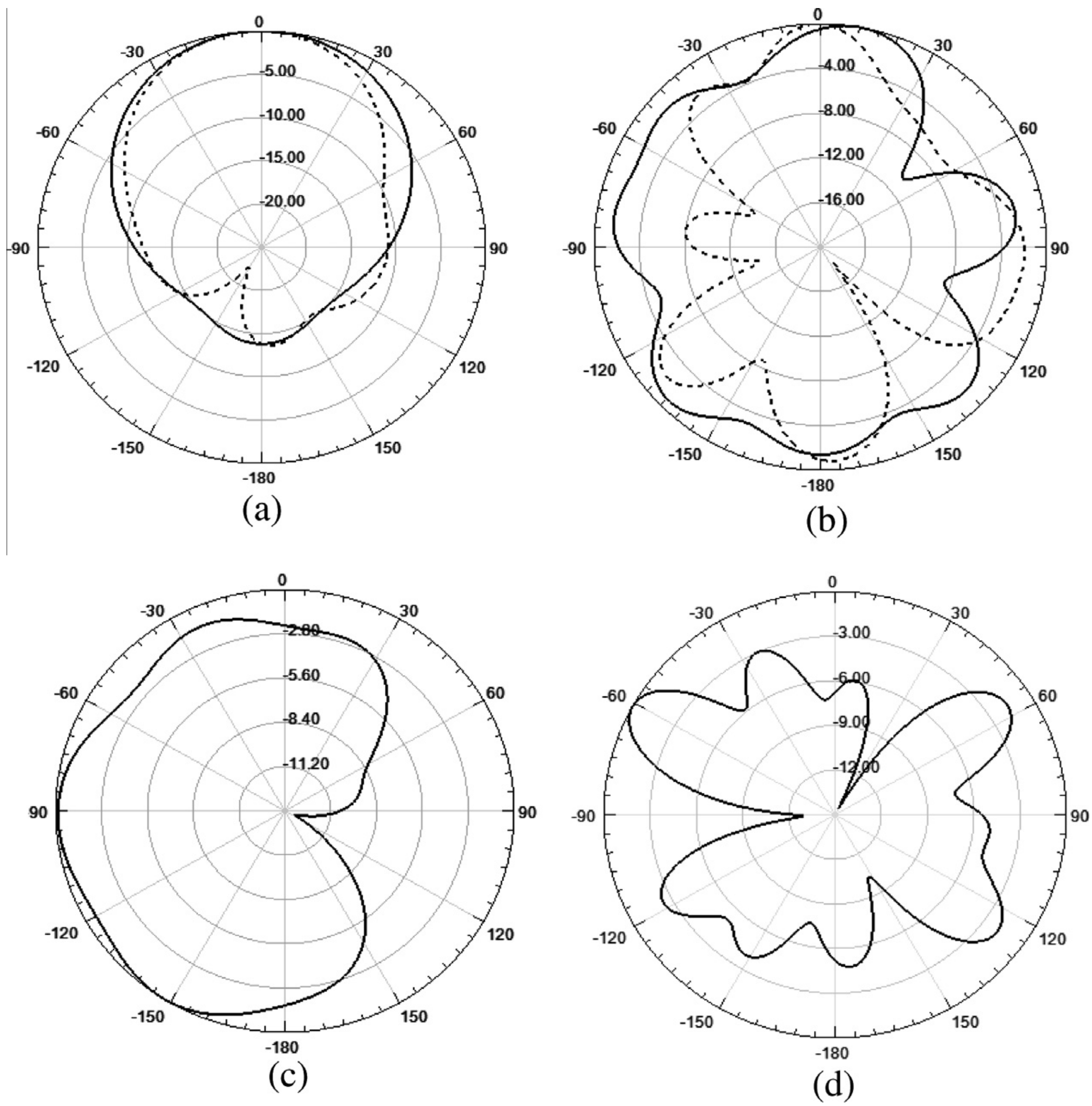

Figure 20 The radiation pattern for PIFDLA of F-patch 5 mm above the ground plane with substrate (a) with respect to θ for $\phi = 0°$ and $\phi = 90°$ at 2.5 GHz, (b) with respect to θ for $\phi = 0°$ and $\phi = 90°$ at 5.19 GHz, (c) with respect to ϕ for $\theta = 90°$ at 2.5 GHz and (d) with respect to ϕ for $\theta = 90°$at 5.19 GHz.

Table 1 Summary of final results.

	Bandwidth of the lower band (MHz)	Bandwidth of the upper band (MHz)	Bandwidth enhancement for the		Size reduction (%)
			Lower band (%)	Upper band (%)	
PIFLA (Zhou et al., 2008)	200	650	Our reference		Our reference
PIFDLA of F-patch 6 mm above the ground plane	230	1000	15	53.8	12.5
Supported PIFDLA of F-patch 6 mm above the ground plane	230	1160	15	78.5	12.5
Supported PIFDLA with 0.17 mm copper thickness	200	810	0	24.6	4
PIFDLA of F-patch 5 mm above the ground plane	270	1200	35	84.6	25
Supported PIFDLA of F-patch 5 mm above the ground plane	220	1180	10	81.5	24

band. Figs. 14–16 show the geometry return loss and radiation pattern, respectively, for supported antenna of copper thickness 0.17 mm.

Another simulation was performed for 5 mm between the F-patch and the ground plane instead of 6mm as in previous discussion with air substrate, for this modified antenna the lower band enhanced by 35% (2.47–2.74 GHz) and the upper band enhanced by 84.6% (4.9–6.1 GHz) in addition to size reduction of 25% compared with PIFA of Zhou et al. (2008). This proposed multiband single-feed PIFA simultaneously operates in the IEEE 802.11a/b/g, HIPERLAN2 and WiMax band (2.5–2.7 GHz) instead of Bluetooth (2.4–2.48 GHz). Figs. 17 and 18 show the return loss and radiation pattern, respectively, of this planar inverted-F dual-L antenna (PIFDLA).

By the same way we supported the PIFDLA – 5 mm F-patch above the ground plane – by dielectric material $\varepsilon_r = 1.2$, the return loss and radiation pattern for this antenna are shown in Figs. 19 and 20, respectively. Fig. 19 shows an enhancement of 10% on the lower band (2.41–2.63 GHz) and an enhancement of 81.5% on the upper band (4.7–5.88 GHz) in addition to a size reduction of 25% compared to PIFLA of Zhou et al. (2008). Note that the existent of substrate shifts the lower frequency band to operate on Bluetooth not WiMax band. All results are summarized in Table 1.

4. Conclusion

In this paper a modified multiband single-feed planar inverted-F dual-L antenna (PIFDLA) with overall size of 24 mm × 30 mm × 7 mm mounted on a 30 mm × 30 mm × 1 mm finite ground plane, is presented. The simulation for this multiband single-feed antenna with air substrate has been carried out using HFSS software to investigate the antenna's performance and characteristics. From the simulation results, it has been found that the antenna is able to operate at the desired resonant frequencies for the lower band (2.4–2.63 GHz) and for the upper band (5.04–6.04 GHz), in addition to size reduction of 12.5% or lower band (2.47–2.74 GHz) and for the upper band (4.9–6.1 GHz), in addition to size reduction of 25% – depending on its height – so this antenna at return loss of −10 dB fully covers Bluetooth band (2.4–2.4835 GHz) or WiMax band (2.5–2.7 GHz) – depending on its height – in addition to IEEE 802.11a (5.15–5.35 GHz, 5.725–5.825 GHz) band, and HIPERLAN2 (5.47–5.725 GHz) band. Also the radiation pattern for this antenna is omnidirectional.

References

Balanis, A., 1982. Antenna Theory Analysis and Design. John Wiley and Sons.

Hirisawa, K., Haneishi, M., 1992. Analysis, Design, and Measurement of Small and Low-profile Antennas. Artech House, Boston.

Kathleen, L.V., Yahya, R.S., 1997. Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging. IEEE Trans. Antennas Propag. 45, 1879–1888.

Olmos, M., Carrasco, H., Feick, R., Hirstov, D., 2004. PIFA input bandwidth enhancement by changing feed plate silhouette. Electron. Lett. 40, 921–922.

Further reading

Azad, M.Z., Ali, M., 2006. A new class of miniature embedded inverted-F antennas (IFAs) for 2.4 GHz WLAN applications. IEEE Trans. Antennas Propag. 54, 2585–2592.

Janapsatya, J., Esselle, P., Bird, T.S., 2008. A dual-band and wideband planar inverted-F antenna for WLAN applications. Microw. Opt. Technol. Lett. 50, 138–141.

Kevin, R.B., Leo, P.L., 2006. Radiating and balanced mode analysis of PIFA antennas. IEEE Trans. Antennas Propag. 54, 231–237.

Looi, C.K., Terence, S.P., Chen, Z.N. Study of Human Effects on the Planar Inverted-F Antenna. Department of Electrical and Computer Engineering, National University of Singapore.

Minh, C.H., 2000. A Numerical and Experimental Investigation of PIFAs for Wireless Communication Applications. Virginia Polytechnic Institute of State University.

Mueiz, E.A., 2006. Multi-Band Antenna for GSM 3G, Bluetooth and Wireless LAN Application. Department of Electrical Engineering, University of Technology, Malaysia.

Nepa, P., Manara, G., Serra, A.A., Nenna, G., 2005. Multiband PIFA for WLAN mobile terminals. IEEE Antennas Wireless Propag. Lett. 4, 349–350.

Zhou, D., See, C.H., Abd-Alhameed, R.A., Excell, P.S., 2008. Dual-frequency planar inverted F-L antenna (PIFLA) for WLAN and short range communication systems. IEEE Trans. Antennas Propag. 56, 3318–3320.

Wang, Y.S., Lee, M.C., Chung, S.J., 2007. Two PIFA-related miniaturized dual-band antennas. IEEE Trans. Antennas Propag. 55, 805–811.