Design of Planar Double Inverted-F Antenna for Ultra-Wideband Applications

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Abstract

A novel miniaturized planar double inverted-F antenna is presented. The antenna design is based on the electromagnetic coupling of two air dielectric PIFA antennas, combined with a broadband rectangular plate feed structure to achieve ultra-wideband characteristics. The computed and experimental impedance bandwidths show good agreement over an UWB frequency band from 3.1 GHz to 10.6 GHz for $|S_{11}| < -10$dB. The antenna is electrically small, with size 0.31 x 0.16 x 0.09 wavelengths at 3.1 GHz and 1.06 x 0.55 x 0.31 wavelengths at 10.6 GHz. The simulated and measured gain and radiation patterns show acceptable agreement and confirm that the antenna has appropriate characteristics for short range wireless applications.

1. INTRODUCTION

Since the US Federal Communications Commission (FCC) released the 3.1 GHz to 10.6GHz ultra wide frequency band as licence-free spectrum in 2002 [1], there has been increasing telecommunications industry interest in the potential of this wide frequency band to cater for the ever-growing needs for high speed wireless communications. The distinctive feature of UWB technology is its use of extremely narrow RF pulses for communication between transmitters and receivers with high data rates (480Mbps and beyond) and low power consumption (less than 2mW/Mbps). This enables, for example, real-time seamless room-to-room video communications inside buildings, very high capacity personal area networks and also radar-like short-range remote sensing functions. Therefore, a UWB antenna with large bandwidth, compact size, consistent radiation pattern and gain of the order of unity is required to satisfy the market demand.

The PIFA antenna is a well-known candidate that has been widely used in mobile terminal devices due to its ability to generate multiple resonant frequencies [2-5] and potentially provide wideband characteristics [6-9]. In this paper, a novel miniaturised UWB double PIFA is proposed as a way of enhancing bandwidth. By optimising the shape of two PIFAs, the coupling distance and feed position, the two resonant frequencies which are generated by the two PIFAs can be combined and made to fully cover the required UWB operating frequency band. The overall size of the antenna was compressed to 30x 15mm x 8 mm to enable easy fitment into wireless terminals.

2. ANTENNA DESIGN

Fig. 1 illustrates the geometry of the proposed double PIFA antenna. The driven PIFA is optimised to a geometry size of 18.5 mm x 10 mm x 4.7 mm, while the other parasitic PIFA is about 7.5 mm x 14.5 mm x 7.5mm. Both of them are mounted on a 30 mm x 15 mm finite ground plane. For optimal coupling, the separation distance between the two PIFAs is found around 4 mm.

In comparison to the conventional narrow bandwidth wire-feed PIFA [7], a rectangular plate feed is employed in the driven PIFA in order to improve the impedance bandwidth. To approximately predict the resonant frequency for both driven and parasitic PIFAs, the following formula can be used [2]:

$$f \cong \frac{c}{4 \times (W + L)} \quad (1)$$

where c is the speed of light and W and L are the width and length of the radiating element respectively. As can be verified by simulation, the driven PIFA is resonant at $f_L \approx 3.2$ GHz whereas the parasitic PIFA is resonant at $f_H \approx 4.85$ GHz.

It should be noted that the lower resonant frequency is mainly dominated by the driven patch while the higher resonant frequency is excited by the combination of the area of the two PIFAs. Therefore, the coupling gap between the two patches is critical and has to be chosen carefully, otherwise only narrow impedance bandwidth or bad impedance matching will be observed over the required frequency band. In addition, the size of the ground plane also plays a significant role in this antenna in aiding achievement of good UWB impedance matching.

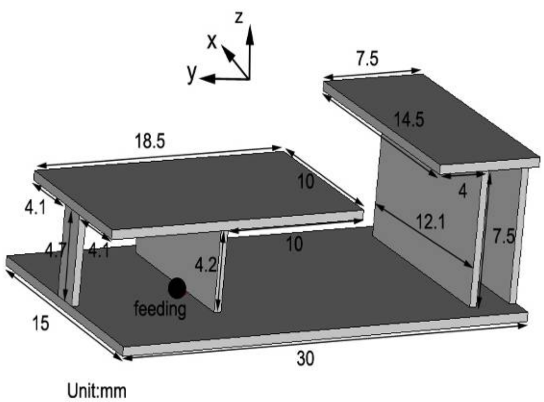

Figure 1 Geometry of the proposed antenna

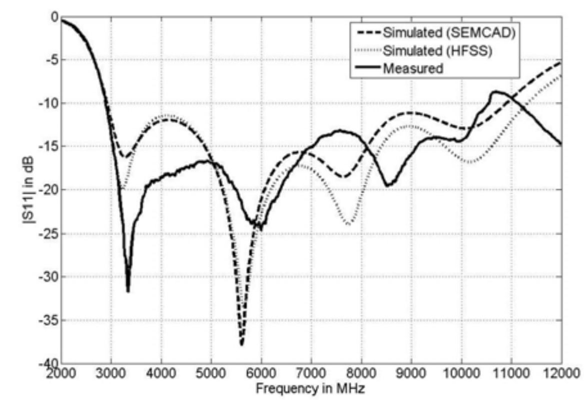

Figure 2 Measured and simulated reflection coefficients $|S_{11}|$

3. RESULTS AND DISCUSSION

The modelling of the individual antenna's structures and the optimisation of the final assembly was carried out, and cross validated, using SEMCAD and Ansoft HFSS. Simulated and measured reflection coefficients $|S_{11}|$ are compared in Fig. 2. The individual structures were analysed to determine their impedance bandwidths, as a necessary step in understanding the individual contribution of the driven and parasitic antennas. For the driven PIFA, the impedance bandwidth covers the range 3.6GHz to 12GHz, at the reflection coefficient of $|S_{11}| < -6$dB. The corresponding range for the parasitic PIFA is 4.8GHz to 9.2GHz, for the same reflection coefficient. Constructive addition of these impedance bandwidths enables a good impedance match over 3.0GHz to 10.6GHz for $|S_{11}| < -10$dB.

In order to understand the effect of the ground plane on the antenna, intensive simulations were conducted to check the variations of the reflection coefficient $|S_{11}|$ against the size of the ground plane, as presented in Fig. 3. Defining λ_o as the largest value (i.e. 100mm, at 3000MHz), Fig. 3 shows the effect of five different ground planes: 30 mm × 15 mm ($\cong 0.3\lambda_o \times 0.15\lambda_o$), 40mm x 40mm ($\cong 0.4\lambda_o \times 0.4\lambda_o$), 60 mm x 60mm ($\cong 0.6\lambda_o \times 0.6\lambda_o$), 80mm × 80mm ($\cong 0.8\lambda_o \times 0.8\lambda_o$) and 100mm x 100mm ($\cong \lambda_o \times \lambda_o$). It is noticeable that when the ground plane side length is greater than or equal to $0.4\lambda_o$, a slightly impedance mismatch occurred within the lower frequency components from 3000 to 3500 MHz at $|S_{11}| \approx -6$ dB, in which, this can be recommended as an acceptable reflection coefficient level for commercial exploitation. When the ground plane size is reduced to $0.3\lambda_o \times 0.15\lambda_o$, the impedance bandwidth at lower frequency components is slightly improved; this might be due to the combination of the geometries of the antenna and the ground plane with the presence of dual modes operation.

The computed and experimental gains of the proposed antenna are also described in Fig. 4. As can be seen, the variation of the gains is about ±1.5dBi in which the maximum and minimum gains are 3.75 and 5.5 dBi respectively. The simulated and computed results are in satisfactory agreement in the general trend of gain variation. Fig. 5 depicts the simulated and computed radiation patterns of the proposed antenna at 3, 5, 7 and 9 GHz. The antenna is seen to be generally omnidirectional and consistent at lower frequencies, except for yz-plane in Fig.5 (a) and 5 (b). In these cases the nulls predicted in simulation are not fully realised; this is believed to be due to subtle differences in the effects of the simulated verse physical feeding arrangements. As the frequency increases; a more directional behaviour is manifested, caused by the feeding of the driven PIFA. Nonetheless, the performance will be adequate for commercial wireless applications.

4. CONCLUSION

A compact and low profile UWB antenna is proposed using two air-dielectric PIFAs on a finite ground plane. The integration of two resonant modes of the two PIFAs, the antenna has demonstrated sufficient impedance bandwidth, suitable radiation characteristics, and adequate gains for UWB applications.

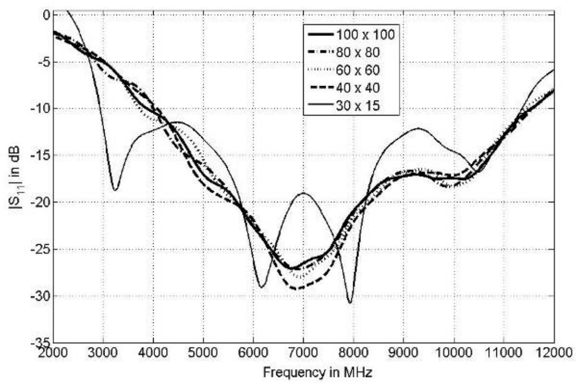

Figure 3 Simulated reflection coefficients $|S_{11}|$ corresponding to the variation of ground plane size

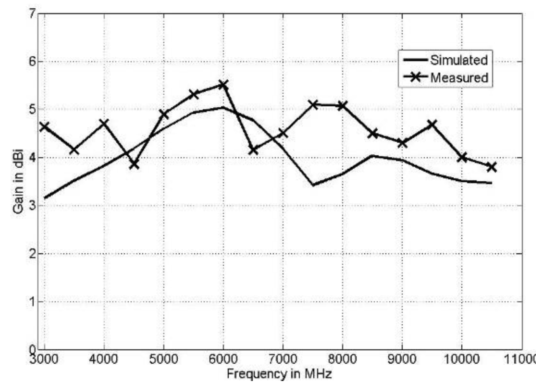

Figure 4 Measured and simulated antenna gains

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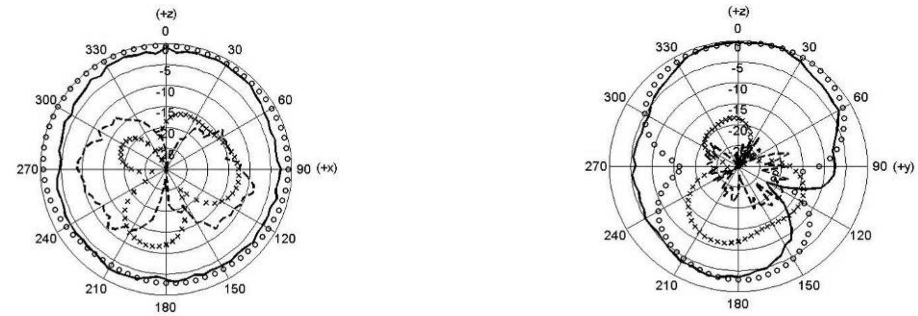
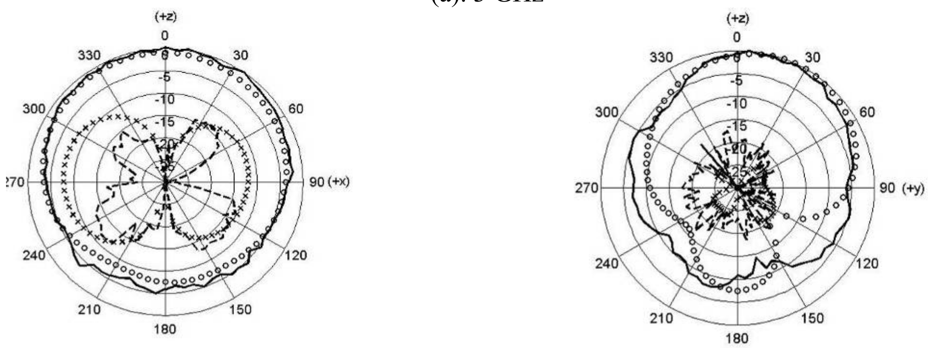
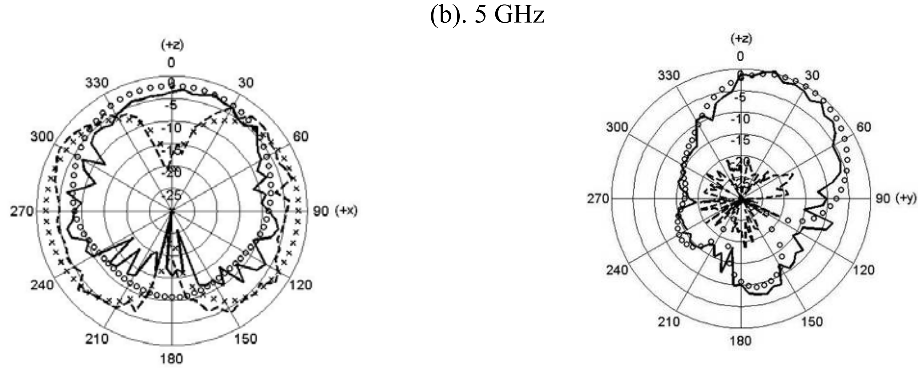


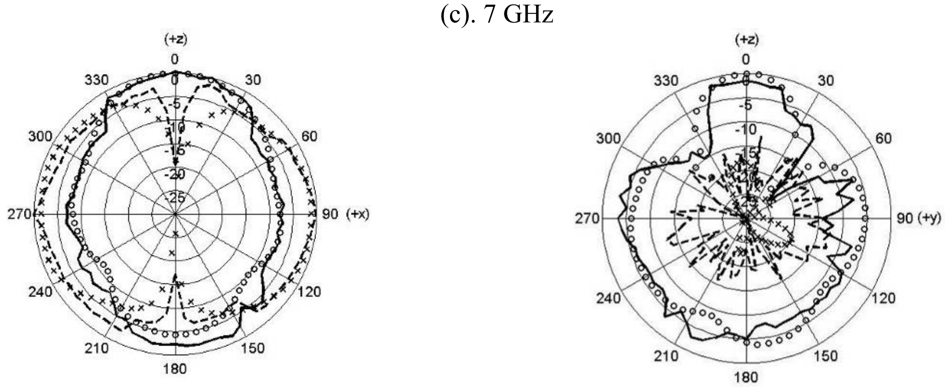
(a). 3 GHz



(b). 5 GHz



(c). 7 GHz



(d). 9 GHz

Figure 5 Simulated and measured normalised radiation patterns of the proposed antenna for two planes (left: x-z plane, right: y-z plane) at (a) 3GHz (b) 5 GHz (d) 7 GHz and (e) 9 GHz
'xxxx' simulated cross-polarization
'oooo' simulated co-polarization
'------' measured cross-polarization
'——' measured co-polarization