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Design of a Planar Inverted F-L Antenna (PIFLA) for Lower-band UWB Applications

H.I.Hraga[#1], C.H.See[#2], R.A.Abd-Alhameed[#3], S.M.R.Jones[#4], M.B.Child[#5], I.T.E.Elfergani[#6]and P.S.Excell[*7]

[#] *Mobile & Satellite Communications Research Centre, School of Engineering, University of Bradford, Bradford, West Yorkshire, United Kingdom, BD7 1DP.*

[1]h.i.hraga@bradford.ac.uk,[2]c.h.see2@bradford.ac.uk,[3]r.a.abd@bradford.ac.uk,
[4]s.m.r.jones@bradford.ac.uk, [5]m.b.child@bradford.ac.uk, [6]i.t.e.elfergani@bradford.ac.uk.
[*] *Centre for Applied Internet Research, Glyndwr University, Wrexham, LL11 2AW, Wales, UK*
[7]p.excell@glyndwr.ac.uk

Abstract — **This paper examines the case for an ultra-wideband planar inverted-F-L-antenna design intended for use in the lower sub-band. The antenna construction is based on the conventional inverted F, and inverted L as its feed element, and parasitic element, respectively. The optimized antenna size is 30×15×4mm^3. The prototype antenna has a good return loss of -10 dB, and a 66.6% impedance bandwidth (2.8 GHz – 5.6 GHz), the gain varies between 3.1 dBi and 4.5 dBi.**

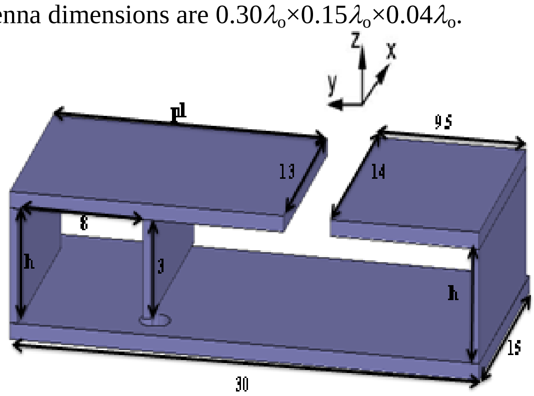
keywords — **Planar inverted-F-L antenna, broadband, ultra-wideband, impedance bandwidth.**

I. Introduction

A reliable low cost antenna module is a necessity for a multi-band mobile user terminal. Mechanically the module must be low profile, robust and cost effective through high volume production. From an electrical standpoint it must meet the requirement specification derived from the relevant communications standards, and have low coupling when placed or held in proximity to the human body. One such option is the planar inverted F antenna (PIFA) [1, 2]. However, the conventional PIFA has bandwidth constraints; typically 4-12% impedance bandwidth is achievable in an unmodified design. Modified PIFA designs include T-slot geometries [3], the introduction of parasitic elements, such as the inverted L [4, 5], modified ground planes [6, 7] and modifications to the feeding and shorting plates [8, 9]. The design adopted here is a miniaturized 'FL' antenna, or PIFLA [10]. A novel feeding structure is introduced to achieve a good impedance bandwidth for the design frequency range, which is the lower sub-band (3100MHz-4800MHz) of the UWB spectrum [11]. The design optimization is carried out using a frequency domain finite element analysis (Ansoft HFSS), the final model is also cross validated through the time domain using a conformal FDTD method (SEMCAD). A working prototype is constructed and tested on this basis.

II. Antenna Design

The PIFLA schematic is shown in Fig. 1. It is constructed from a standard PIFA with a broadband feeding plate, and a parasitic planar inverted L-shaped element. For ease of integration with a practical enclosure, the assembly is mounted over a finite ground plane. The minimum dimensions for the PIFA are 17.5×13×3.5 mm^3, where the 17.5mm is the length of F shape and 3.5mm is the antenna height. The minimum dimensions of PIFLA are: 9.5×14×3.5 mm^3 for the parasitic element PIFLA and the ground plane dimensions for the final assembly are 30×15 mm^2. Optimal coupling is achieved with an element separation distance of 3mm. The lowest resonant mode of this structure is approximately 3000 MHz, so if the corresponding wavelength of this mode is λ_o, then the scaled optimal antenna dimensions are $0.30\lambda_o \times 0.15\lambda_o \times 0.04\lambda_o$.



Unit:mm

Fig.1: Geometry of the proposed antenna.

The underlying design principle is straightforwardly based on the manipulation of multiple resonances, from the inverted F and L elements, both of which support strong current distributions. The driven PIFA element acts as the primary element, governing the lowest resonant frequency, whilst the higher resonant frequency is controlled by the parasitic element. Both the size of the ground plane, and the feed mechanism play a significant role in the determining the desired wideband characteristic for the impedance bandwidth.

However, it should be noted that the lower frequency component is dominated by the large effect of the capacitive coupling between the feeding element and the finite ground. Thus, a broadband rectangular plate, with a 0.5 mm gap, is used to excite the PIFA. This technique provides an improved impedance matching over the conventional probe feed. The optimum gap width was achieved after several model attempts. To further adapt this antenna for commercial wireless transceiver applications, ground plane size effect of the proposed antenna is crucial. The influence of the ground plane size using the proposed feeding plate mechanism is fully addressed in the following section.

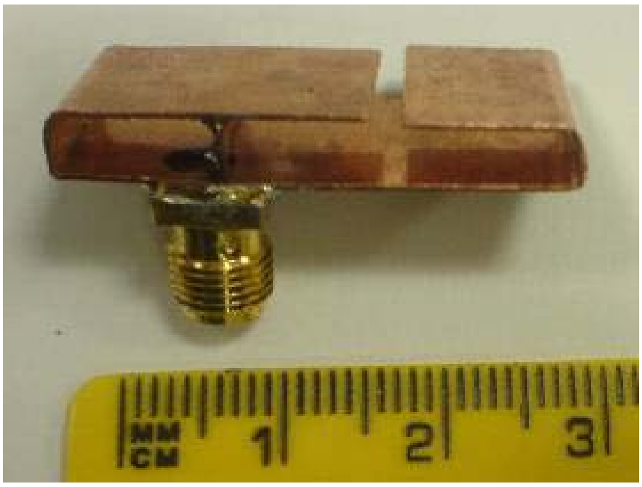
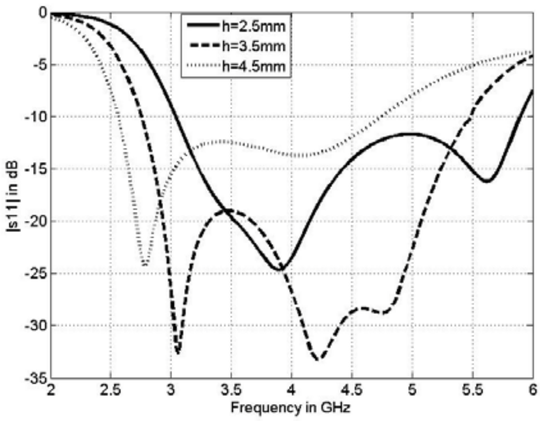


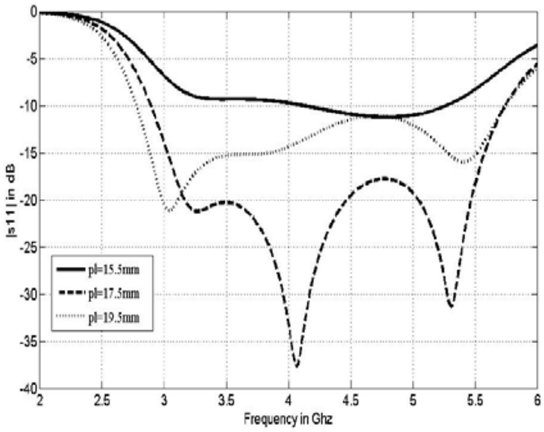
Figure 2: Practical Prototype of proposed antenna

III. Parametric Design Studies

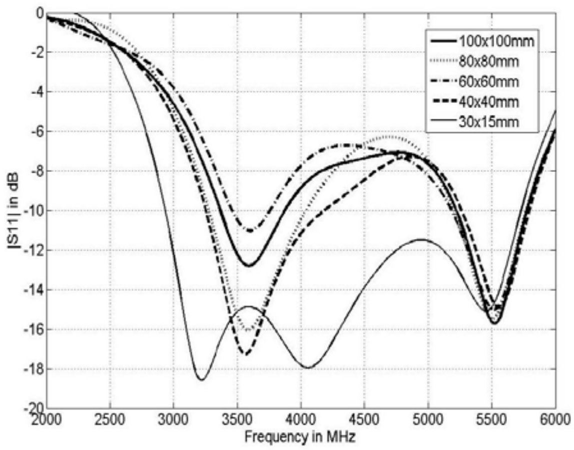
The parametric study is useful because it provides a comprehensive picture of the antenna characteristic. The first cut design (in the frequency domain) was made by varying each parameter by 1mm and 2mm increments, whilst holding the remaining parameters at their initial values. Fig. 3(a) exhibits the simulated return loss for different height of the antenna as can be seen that the -10dB return loss bandwidth of the antenna is achieved at 3.5mm. It can be seen very clearly in Fig. 3(b) that the lengths of PIFA has come at the optimised value of 17.5mm is the best size of the PIFA length. Fig.3 (c) shows the variations of the reflection coefficient $|S_{11}|$ with five selected ground plane sizes; once the ground plane size was reduced to 15x30mm^2 the optimized result was obtained Fig.3 (c).



(a)



(b)



(c)

Figure 3: Simulated reflection coefficients $|S_{11}|$ with different dimensions of (a) antenna height h, (b) PIFA length pl and (c) ground plane

IV. Results and Discussion

Fig. 4 compares the predicted (frequency domain, HFSS) and measured reflection coefficient response, the impedance bandwidth of the prototype operates over the range 2800 MHz to 5600 MHz, with $|S_{11}| \leq -10$ corresponding to a 66.7% relative bandwidth with respect to a centre frequency of 4200 MHz. This operating range gives full coverage of the UWB uplink frequency spectrum (3100 MHz to 4800 MHz). There is small discrepancy between predicted and measured results, but this does not indicate the need for additional design optimization, this may be a construction error.

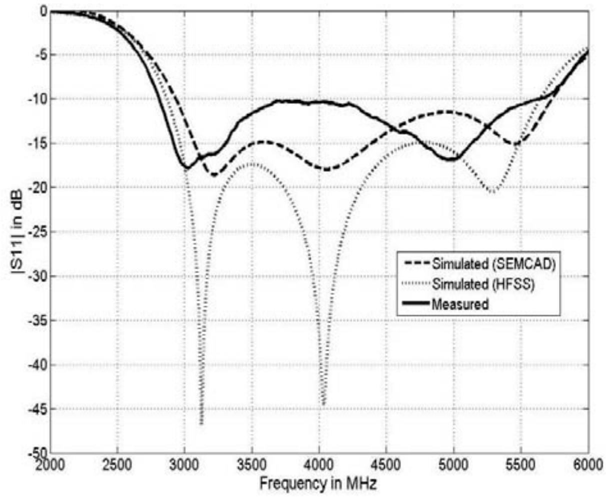
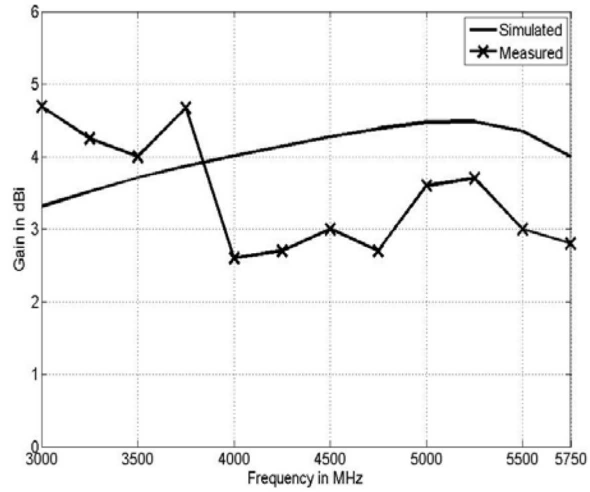


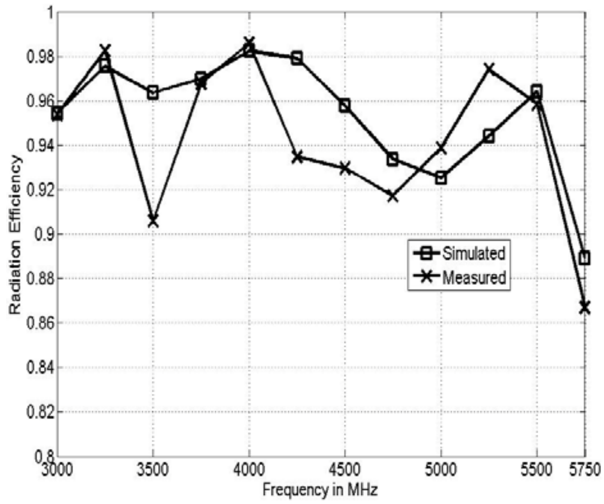
Figure 4: Measured and simulated reflection coefficients $|S_{11}|$

The effect of the ground plane is a significant aspect in this design. Fig. 3 (c) shows the variations of the reflection coefficient with five possible ground planes (scaled in units of λ_o): $\lambda_o \times \lambda_o$, $0.80\lambda_o \times 0.80\lambda_o$, $0.60\lambda_o \times 0.60\lambda_o$, $0.40\lambda_o \times 0.40\lambda_o$, and $0.30\lambda_o \times 0.15\lambda_o$. The performance is significantly degraded as the size of the ground plane is increased, as the resonant mode of the ground plane is essentially out of band, and therefore makes no constructive contribution to the impedance bandwidth.

Fig. 5(a) gives the predicted and measured gain of the antenna in the broadside direction, over the interval 3000 MHz to 5750 MHz. It was interesting to find an average measurement gain of 3.6dB$_i$ with ±1.1dB$_i$ fluctuation. Fig. 5(b) exhibits the simulated radiation efficiencies of the antenna. The average measurement efficiency was observed to be 92.5% with ±5.5% efficiency fluctuation. This compares well with the simulations.



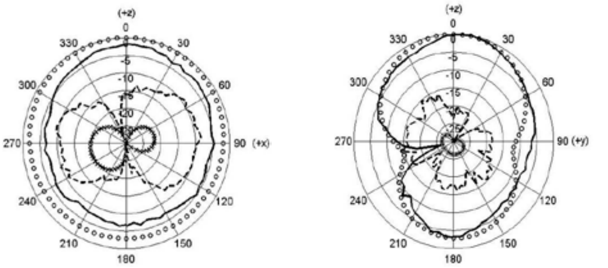
(a)



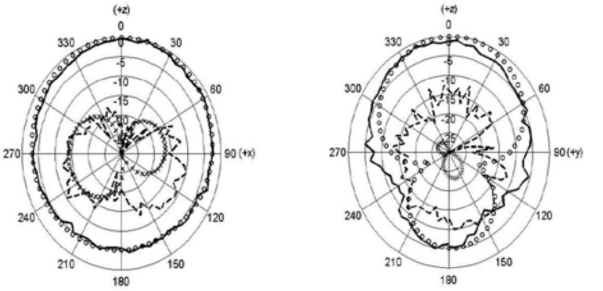
(b)

Figure 5: Measured gains and radiation efficiencies for proposed antenna; (a) antenna gain, (b) radiation efficiency.

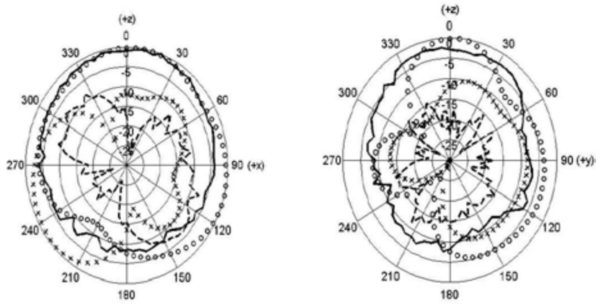
The far field radiation patterns are presented in Fig.6. Two pattern cuts (the *xz* and *yz* planes) were taken at three selected operating frequencies which cover the aggregate bandwidth. The radiation patterns were found to stable and consistent at all the designated frequencies, as shown in Fig. 6. Significantly, it also indicates that the maximum co-polarized component appears at the direction of bore sight (+z) for both the E and H planes.



(a)



(b)



(c)

Figure 6: Simulated and measured normalized radiation patterns of the proposed antenna for two planes (left: x-z plane, right: y-z plane) at (a) 3000 MHz (b) 4000 MHz and (c) 5000 MHz ‘xxxx’ simulated cross-polarization ‘oooo’ simulated co-polarization ‘------’ measured cross-polarization ‘——’ measured co-polarization

The group delay spread in the required bandwidth is approximately 0.5 ns. The group delay measurement is given in Fig. 7.

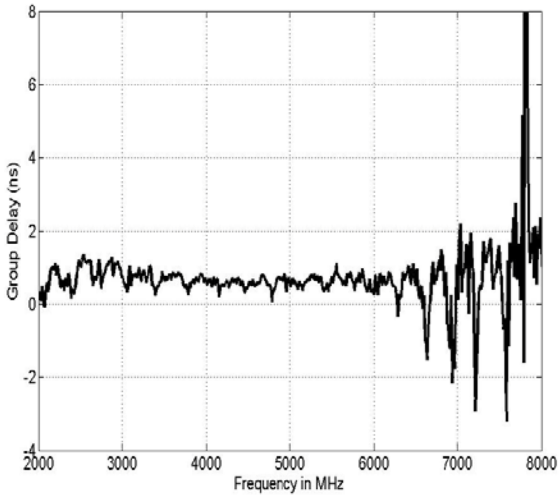


Fig.7: Measured group delay of the proposed antenna

V. Conclusion

A wideband planar inverted F-L antenna (PIFLA) has been designed and studied. The optimized design is a compromise between antenna size and impedance bandwidth in the lower operating UWB frequency spectrum. The prototype package dimensions are $30\times15\times4$ mm^3. This antenna displays stable radiation patterns, gain performance, and radiation efficiency for the entire bandwidth of operation, thus making it suitable for UWB applications.

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