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Frequency Tuned Planar Inverted F Antenna with L Shaped Slit Design for Wide Frequency Range

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Abstract— A frequency tuned antenna has been designed to meet the coverage requirements of the DCS, PCS, UMTS and WLAN bands. The antenna consists of a main patch, and a planar inverted L (PIL) slot. The radiator patch is fed, and shorted, using simple feed lines with broadband characteristics. The handset represents the finite ground plane, and a varactor diode is mounted across the middle of the slot for tuning purposes. Initial tuning was obtained by placing lumped capacitors, instead of the varactor, over the radiator. Good agreement is obtained between the predicted and measured input return loss, gain and radiation pattern over the tuned frequency range.

1. INTRODUCTION

PIFA designs tend to be low profile, light weight and efficient space filling structures, and as such, are particularly attractive for handset and terminal applications. Conventional PIFA designs have constrained bandwidth; however, it is possible to realize novel structures which are electronically tunable over most of the wireless communication bands. Tunable multi-functional handset modules employ the same basic design aims to provide favorable trade-offs in terms of volume, weight and performance. Many interesting PIFA, and more general tuned printed antennas, have been proposed [1]. Various switching technologies, such as RF switches, MEMs switches, PIN diodes and varactor diodes have been used in reconfigurable antenna designs [2–4]. The varactor diodes in particular seem to offer a rich possibility for future designs over a wide frequency range, due to their excellent DC voltage controlled reactance property.

The increasing trend for slimmer, highly integrated mobile handsets and terminals, operating over several distinct and over-lapping frequency bands, has created a need for reconfigurable (tuned) antenna designs [5]. However, this trend towards slimmer, more space efficient integrated designs, poses a significant problem for the antenna designer. The trade-off between small antenna size, adequate bandwidth, and high efficiency, creates a difficult competing multi-objective optimization, which is also subject to fundamental physical constraints. To some extent this coverage problem can be solved by using multiple antennas, but the design of such an antenna module would add mutual coupling effects to an already substantial list of physical constraints.

Planar inverted F antennas (PIFA) may be modified to operate over multiple frequency bands by using, e.g., parasitic elements, and/or by the formation of several surface current paths through the introduction of slots in the radiator element. Recently, PIFA structures providing comprehensive coverage of the frequency ranges of six operating standards have been presented [6]. A common approach to tuning the operating frequency of a PIFA is to reconfigure a short circuit connection with an external tuning circuit. This has been used in single and dual band designs [7, 8]. Other reported tuning methods include the use of adjustable reactive components between the PIFA patch and a ground plane [9, 10], and switched tuning stubs, which have been applied in both single and dual band designs [3, 11].

2. ANTENNA DESIGN CONCEPT

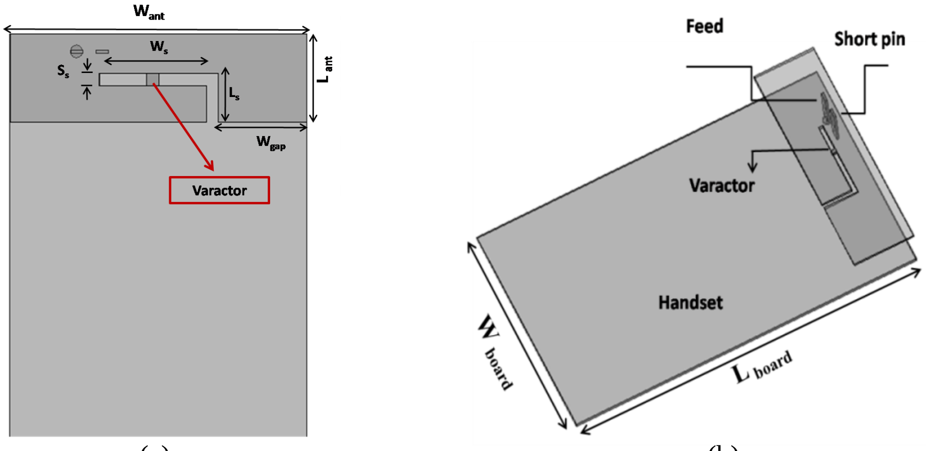
The design optimization for this study requires an antenna structure compatible with contemporary handset chassis dimensions. The structural and lumped element parameters were simulated using the general electromagnetic analysis packages HFSS [12]. The optimization was tracked in terms of the antenna return loss, radiation patterns and power gain. Initial frequency tuning is tested and evaluated by placing lumped capacitors in the range of 0.5 to 3.3 pF along the slot of the radiator.

This process is equivalent to replace the varactor operation. The design was further constrained by the impedance matching requirements covering a frequency range comprising the DCS, PCS, UMTS and W-LAN bands.

The prototype radiator patch is suspended over a 50 mm × 80 mm (W_{board}, L_{broad}) ground plane with a 2 mm × 7 mm shorting pin, and the antenna is fed by means of a vertical plate, of maximum height 6.5 mm and width 2 mm as shown in Fig. 1. It is also connected to the feeding probe through the slot in the ground plane for which the effective substrate is considered air. The rectangular patch dimensions, (L_{ant}, W_{ant}), are 14 mm × 50 mm. The L-slot has a uniform width (S_s) of 1 mm, and the lateral dimensions, (L_S, W_S, and W_{gap}), are 8 mm, 17.5 mm, and 15 mm.

3. IMPACT OF THE LOADING ON THE ANTENNA

The impact of the loading capacitance on overall antenna performance, including the return loss, gain and radiation pattern needs to be investigated both in simulation, and through performance assessments on the physical prototype. For comparison purposes in simulation, we require a fully characterized reference antenna which omits the varactor; this structure resonates at 2.47 GHz (see Fig. 2). A loading capacitor with values selected from {0.5–3.3} pF is placed over the slot radiator in a fixed location, making the antenna resonate over wide range $1.75 \leq f_0 \leq 2.4$ GHz. In the first instance the tuning is investigated via a lumped (ceramic) capacitor, instead of a varactor, therefore the DC bias and circuit parasitic effects are excluded. The effects of lumped capacitors have been tested on the working prototype, in order to find out how the loaded capacitors could affect the antenna performance; and the optimal location on the slot 'arm'. The working prototype in Fig. 3 was tested without the bias circuit. The loading capacitor was varied over [0.5, 3.3] pF,



(a) (b)

Figure 1: Basic antenna structure. (a) Top view, (b) 3D.

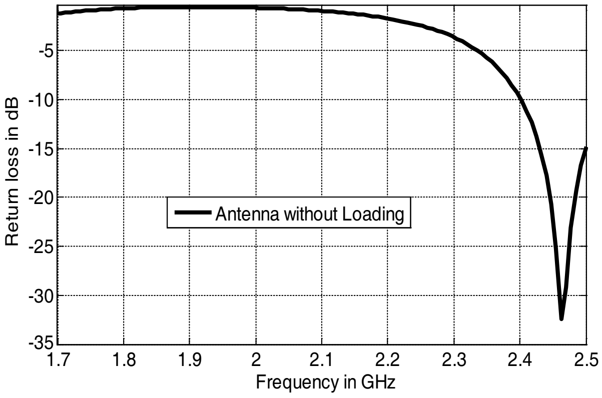


Figure 2: Return loss of antenna prototype, without loading capacitor present.

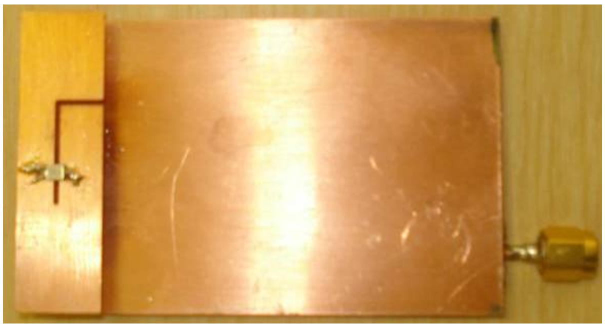


Figure 3: The prototype (loaded) antenna structure.

which was found to be sufficient to control the antenna response.

4. SIMULATED AND MEASURED RESULT DISCUSSIONS

This tuned antenna design relies on the introduction of the L-shaped slot on the radiator arm, and a varactor diode is attached to a location over the slot to achieve the required tuning. As the capacitance is varied, tuning is exhibited over a wide frequency band. The first resonance occurs at 2400 MHz, and then shifts, to the lower frequency band of 1750 MHz. However, the resonant frequencies are not only be controlled by changing the value of applied capacitance of the varactor, but also by its location along the slot.

Figure 4 illustrates the simulated and the measured return loss, the simulated was generated by using HFSS software package while the measured was obtained using a HP 8510C VNA. Five frequencies were selected: 1750 MHz, 1850 MHz, 2040 MHz, 2200 MHz, and 2400 MHz, respectively. The results show a satisfactory agreement between the results achieved by both simulation and measurement. It can be seen that the antenna is capable of covering the frequency ranges of digital cellular system (DCS: 1710–1880 MHz), personal communication service (PCS: 1850–1990 MHz), universal mobile telecommunications system (UMTS: 1900–2200 MHz), wireless LAN (WLAN: 2400 MHz).

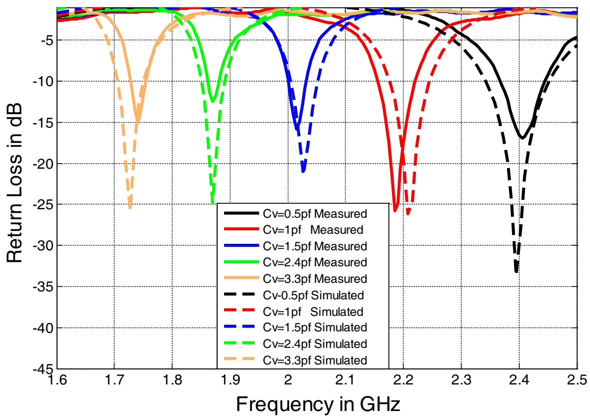


Figure 4: Measured and simulated return loss.

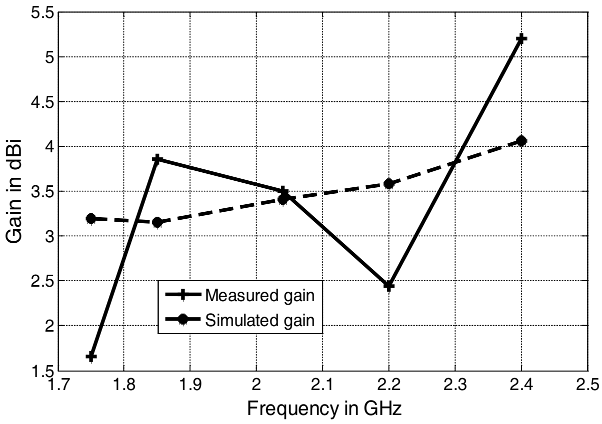
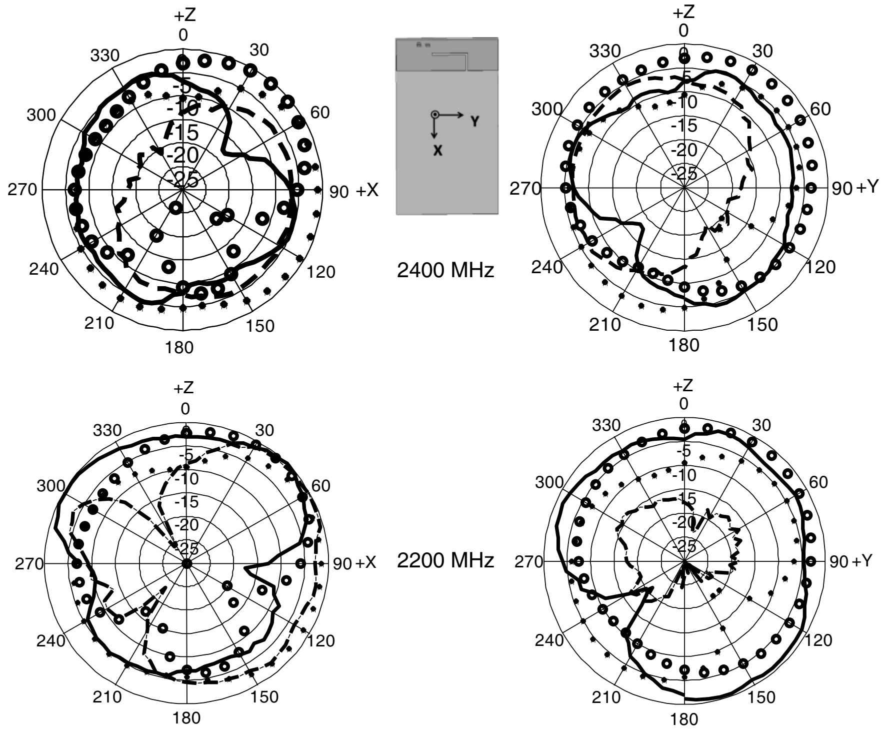
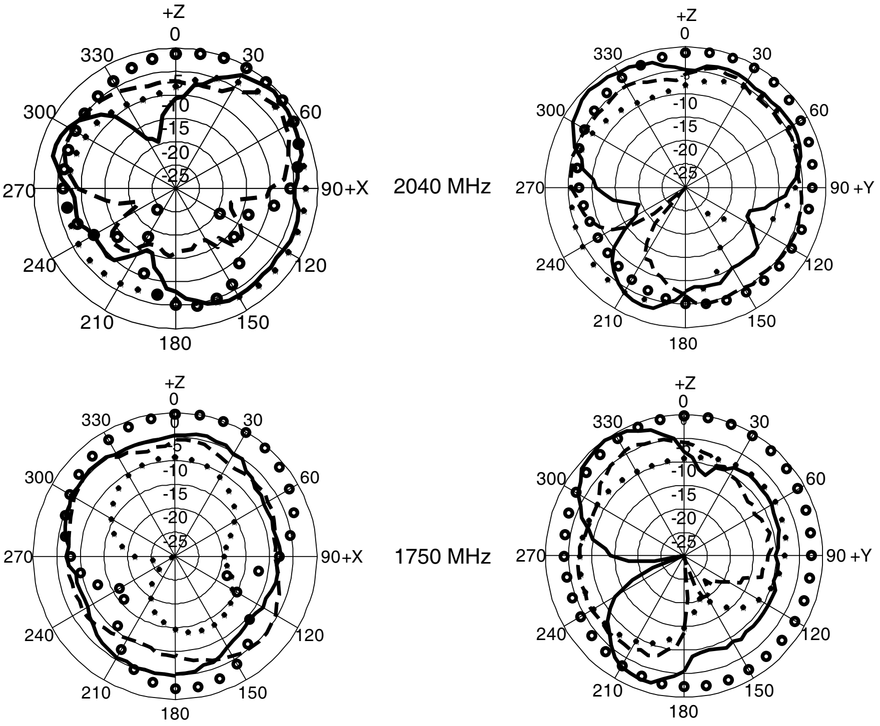


Figure 5: Simulated and measured antenna gains.





(a) (b)

Figure 6: Measured and simulated normalised radiation field patterns of the proposed antenna for various operating frequencies. (a) xz plane, (b) yz plane. 'ooo': Simulated co-polar, '***': Simulated cross-polar, '—': Measured co-polar, '----': Measured cross-polar.

Figure 5 shows the measured and simulated gains of the proposed antenna across the 2400 MHz, 2200 MHz, 2040 MHz, 1850 MHz and 1750 MHz bands. It can be seen that the maximum measured gains values for the mentioned five bands were 1.6 dB_i, 3.8 dB_i, 3.2 dB_i, 2.5 dB_i, and 5.2 dB_i, respectively. The maximum simulated gains over the five bands were 3.3 dB_i, 3.4 dB_i, 3.5 dB_i, 3.55 dB_i, and 4.1 dB_i, respectively.

The simulated and measured radiation patterns are quite similar, and are shown in Fig. 6. The slight variations in these field patterns may be attributed in inaccuracies introduced during fabrication, and construction, the patterns are essentially omni-directional. The far field measurements were performed in an anechoic chamber, the simulated patterns were generated using HFSS. Two pattern cuts were selected for three operating frequencies covering the whole designated bandwidth; radiation patterns in the xz-plane and yz-plane at 2400 MHz, 2200 MHz 2040 MHz, and 1750 MHz were measured.

5. CONCLUSIONS

In this paper, a PIFA-tuned antenna is proposed and validated through practical measurement. By carefully selecting different sets of optimal structural and tuning parameters, basically, this antenna has wide frequency range operation that covers DCS, PCS, UMTS, and WLAN that makes it suitable for multifunctional mobile handsets or terminals. By attaching a varactor diode on the L-slot, the proposed antenna achieved more wideband frequency coverage. In addition, the antenna size was small enough to be fit within the mobile handsets. The proposed frequency-tuning concept can be extended to more complex PIFA structures as well as other antenna types. Instead of the varactor diode, RF diode switch, or RF MEMS components may be used to further improve the electrical performance and functionality of the antenna.

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