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Title: A Frequency Tunable PIFA Design for Handset Applications.

Publication year: 2010

Conference title: 6th International ICST Conference on Mobile Multimedia Communications, (MobiMedia 2010), Lisbon, Portugal, 6-8 September, 2010.

Publisher: ICST

Link to conference site: http://www.mobimedia.org/2010/index.html

Citation: Elfergani, I., Abd-Alhameed, R., Bin-Melha, M. S., See, C., Zhou, D., Child, M. and Excell, P. (2010). A Frequency Tunable PIFA Design for Handset Applications. In: 6th International ICST Conference on Mobile Multimedia Communications, (MobiMedia 2010), Lisbon, Portugal, 6-8 September, 2010. ICST. ISBN: 978-963-9799-98-1. Paper No. 5, pp. 1-8.

A Frequency Tunable PIFA Design for Handset Applications

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Abstract. A frequency tunable planar inverted F antenna (PIFA) is presented for use in the following bands: DCS, PCS, and UMTS. Initially, the tuning was achieved by placing a lumped capacitor, with values in the range of 1.5 to 4 pF, along the slot of the radiator. The final tuning circuit uses a varactor diode, and discrete lumped elements are fully integrated with the antenna. The antenna prototype is tunable over from 1850 MHz to 2200 MHz, with an associated volume of 21×13.5×5 mm^3, making it suitable for potential integration in a commercial handset or mobile user terminal.

Keywords: PIFA, slot antenna, varactor diode.

1 Introduction

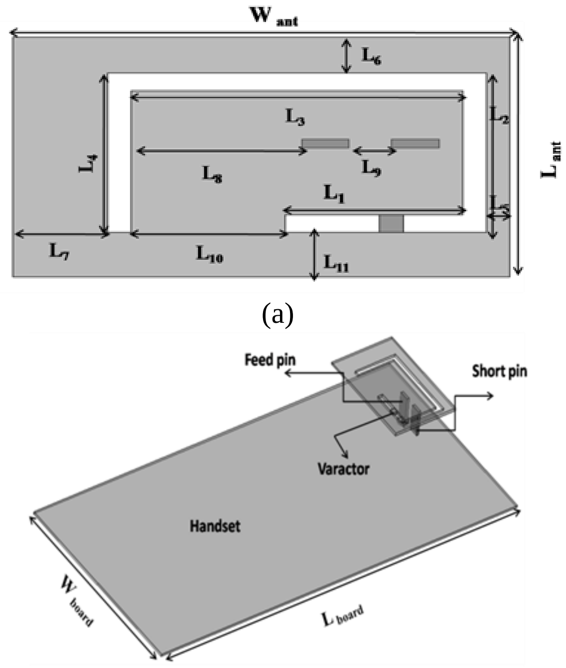
Low profile and space efficient antenna designs with suitable bandwidth for use in multi-standard mobile handsets and user terminals continue to pose a major design challenge. Microstrip patch radiators are a common starting point for such applications, but are constrained in both bandwidth and gain. Various techniques have been proposed to improve on both of these criteria, and one of the most common configurations is the planar inverted F antenna (PIFA) [1]. PIFA structures possess omni-directional radiation patterns, and have improved average power where the cross polarisation is relatively large [2]. They are of course, physically small and compact. The most basic PIFA realisation consists of a rectangular planar patch, shorting pins and a ground plane. Dual band operation may be achieved in several ways, but the introduction of a slot is among the most common [3]. However, the use of a slot may not be optimal in design terms as they can only generate narrowband resonances at two or three frequencies on interest, depending on the number and configuration of the perturbations, and resonators. Proper modal identification may also be an issue. A possible workaround, which preserves the same overall electromagnetic geometry, is the introduction of PIN or varactor diodes, the resulting tuning may have a large dynamic range [4]. Switches may be less desirable as their reactive load may affect the bandwidth of the PIFA; both performance improvement and degradation are both possible [5].

Recent attempts at producing viable multi-standard designs for small antennas have used a variety of techniques including RF switching, MEMS (relay) switching and the use advanced materials [6] [7]. Varactor diodes are an important departure here, as they combine the advantages of a large capacitance ratio, a suitable small size, and DC voltage control over the tuning of the resonant frequency. PIFA structures are eminently suited to this approach, in spite of the relatively narrow operating bandwidth [8]. Since a varactor tuned antenna uses a DC bias, two DC blocking capacitors are typically required. In the PIFA case, the antenna shorting pin is already connected to ground, and one of the DC capacitors can be removed. The final structure is still consistent with the volume constraint of a typical handset chassis.

This paper presents a new tuned PIFA-slot type antenna which covers the operating ranges of DCS, PCS and UMTS. The antenna is designed iteratively using a frequency domain finite element analysis (Ansoft HFSS), and work bench results. The final design optimisation was cross validated using CST Microwave Studio, and a representative prototype was constructed on this basis.

2 The Basic Antenna Geometry

The antenna is placed on the ground plane of dimensions by means of a shorting pin of height of 5 mm and width 2 mm, as shown in Fig. 1. The antenna is fed by means of a vertical plate, of maximum height 4.5 mm and width 2 mm. It is connected to the feeding probe through the slot in the ground plane and the effective substrate is air. The slot has a uniform width of 1mm. The detailed dimensions of the radiator patch are illustrated in Table I. The structure and lumped element parameters were simulated using HFSS. The tuning range was investigated initially through manipulating lumped capacitance parameters in the range [1.5, 4.0] pF.



(a)

(b)

Fig. 1. Basic antenna structure; (a) plan view (b) 3D.

Table I. Detailed Dimensions of Radiator Patch

Parameter	**Value/mm**	**Parameter**	**Value**
L1	7.5	L7	4
L2	9	L8	7.2
L3	14	L9	1.8
L4	9	L10	6.5
L5	1	L11	2.5
L6	2	W_{ant}, L_{ant}	21, 13.5

3 The Impact of the Loading Capacitor

The impact of the loading capacitance on overall antenna performance, including the return loss 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 characterised reference antenna which omits the varactor, this structure resonates at 2.36 GHz (see Fig. 2). A loading capacitor with values selected from {1.5, 2, 3, 4} pF is placed over the slot radiator in a fixed location, making the antenna resonate over the range $1.88 \leq f_0 \leq 2.2$ 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, without the DC circuit, 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 [1.5, 4.0] pF, which was found to be sufficient to control the antenna response.

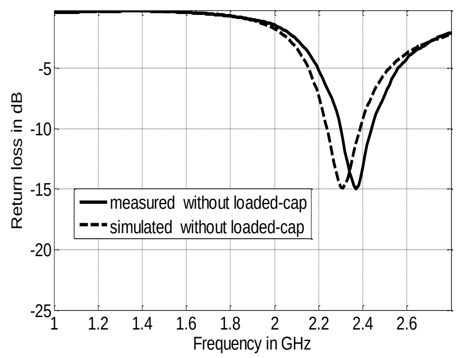


Fig. 2. Return loss of antenna prototype, without loading capacitor present.

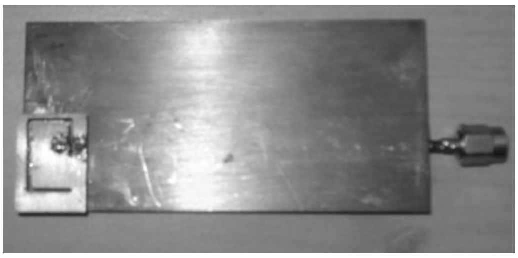
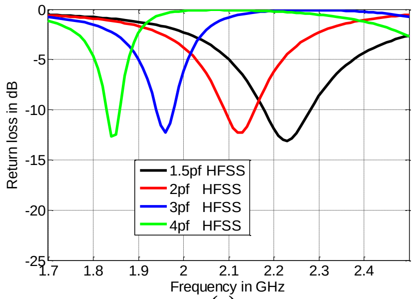


Fig. 3. The prototype (loaded) antenna structure.

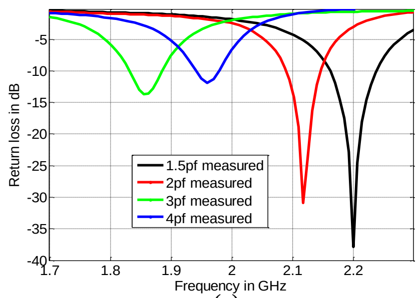
4 Results and Discussion

The tuned working prototype relies on the introduction of the slot on the radiator arm, and the placement of a varactor diode over the slot, to achieve the required tuning range. As the capacitance is varied tuning may be demonstrated over the range

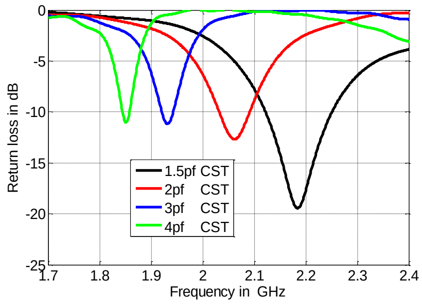
1.88≤f_0≤2.2 GHz. Measurements from a VNA are presented in Fig. 4(c) illustrating this performance for the antenna reflection coefficient. Both the predicted and measured return loss results of this antenna are presented for different values of capacitors (varactor). Fig (4) shows fairly good agreement between simulated and measured results. By increasing the capacitor value from 1.5 to 4 pF the resonant frequency is increased from 1.85 to 2.2 GHz. The simulated gain of the proposed tuned PIFA over the various target frequencies is shown in fig. 5. The simulated radiation patterns are shown in Fig. 6, along with the maximum gain forecast. Two pattern cuts were selected (H-plane, E-plane) for the three operating frequencies, covering the designated composite bandwidth. Corresponding measurements were made for the working prototype, with radiation patterns presented in the xz-plane and yz-plane at 2.1 GHz, 1.95 GHz, and 1.85 GHz.



(a)



(c)



(b)

Fig. 4. Input return loss at the input port; (a) HFSS output (b) CST output (c) measured

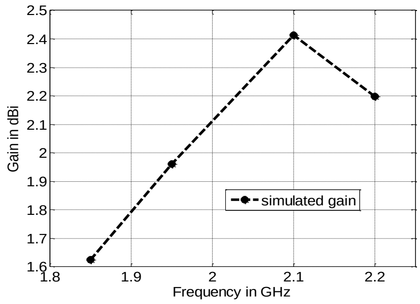


Fig. 5. predicted (HFSS) antenna gain

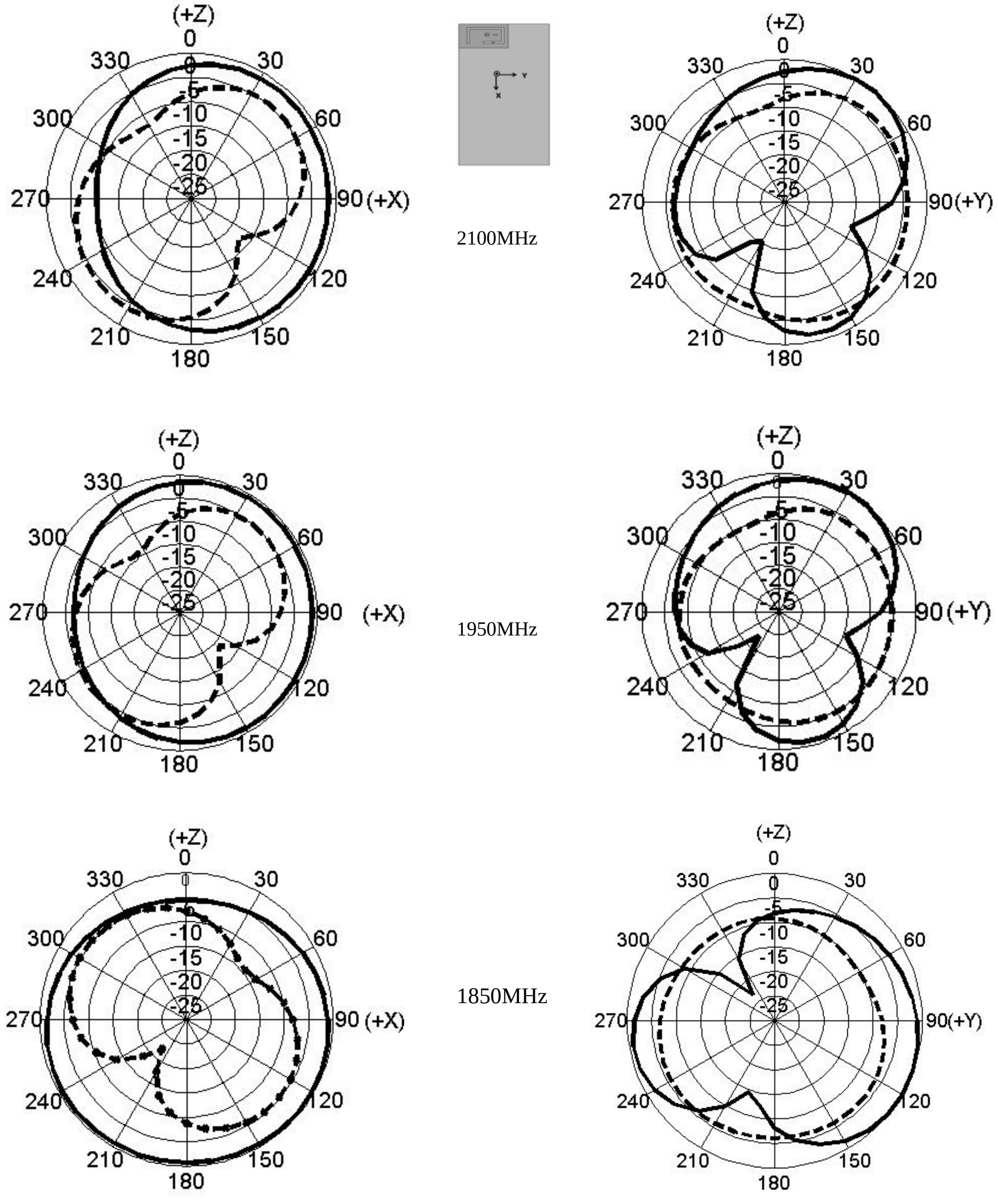


Fig. 6. Simulated radiation field patterns of the antenna for various operating frequencies; left: xz plane, right: yz plane'—— ': Simulated co-polar, '------': Simulated cross-polar.

6 Conclusions

A tuned PIFA prototype has been designed and constructed. This antenna consists of a radiating element, and a tuning circuit. The tuning circuit consists of simple fixed capacitor that is equivalent to varactor diode operation to control the frequency response of the antenna. The antenna has an effective operating band which covers the union of the DCS, PCS and UMTS frequency standards. The simulated and measured reflection coefficients, gains and radiation patterns are consistent, and indicate a potentially good performance, and the physical dimensions are consistent with the volume constraint for a mobile handset. The actual antenna volume is $21 \times 13.5 \times 5$ mm^3. This tuneable PIFA design may be used in other wireless applications.

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