TUNING TECHNIQUES FOR THE PLANAR INVERTED-F ANTENNA

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Abstract: - The rapid growth of mobile communications since the introduction of GSM has challenged the industry for designing terminals of reduced size, cost and power consumption. The efficiency and size trade-offs of the antenna on such terminals become an important issue. On the other hand, multi-band operation covering the existing GSM900/DCS1800 and the future UMTS bands is another significant subject of investigation in the mobile phone industry. In this paper, different methods for tuning the planar inverted-F antenna (PIFA) are discussed, in particular with regard to the positioning of the short pins and the introduction of tuning capacitors. A reduced size dual band fine tuned PIFA for the GSM900/DCS1800 bands is introduced and its performance demonstrated. Finally, a technique employing reversed biased varactors for electronically tuning the PIFA is presented.

1. INTRODUCTION

Competition in the mobile phone industry has dictated the trends for miniature and power efficient terminals. The size of future hand-held phones is expected to be further reduced, while, with the introduction of the third generation of digital cellular systems, more functions will have to be provided. However, there are two limitations to achieve these goals: firstly, the battery size and capacity and, secondly, the external antenna dimensions and efficiency.

Built-in, low profile patch antennas offer a range of new possibilities towards compact and efficient terminal design. The PIFA, which has been the subject of recent research [1]-[5], is an alternative solution, characterised by both higher efficiency (compared to a typical microstrip patch antenna) and lower profile (compared to wire antennas). The absolute directive gain of the PIFA can be as high as 6dBi if good matching can be achieved. However, the narrow reflection coefficient bandwidth which characterises the simple PIFA is one of the limitations for its commercial application in mobile hand-sets. Typical required bandwidths for a VSWR<2 at the antenna input are 7.4% and 9.5% for the GSM900 and DCS1800 bands, respectively, and such bandwidths are nominally desirable under both free space and actual operating conditions. Further, for the future UMTS system, antennas should be capable of achieving bandwidths in excess of 15% (300MHz).

In this paper, different techniques for controlling the resonance frequency (f_r) of the PIFA are studied. By controlling f_r, in order, for instance, to match the allocated channel frequency, the operational bandwidth of the antenna can be enhanced, while by achieving lower VSWR for all frequency channels, the overall antenna efficiency can be increased.

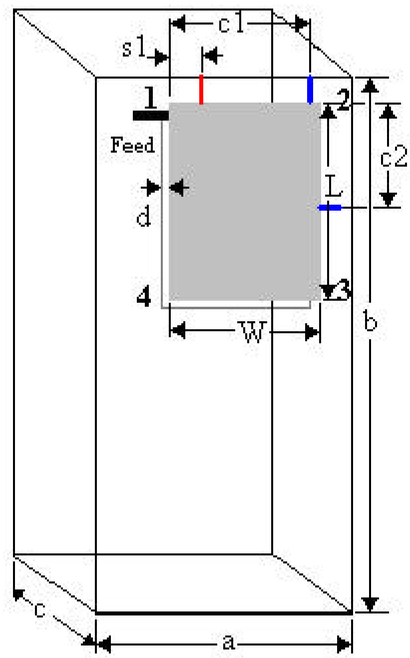

Figure 1: The dual-band fine tuned PIFA:
s1: short pin
c1: calibration variable capacitor
c2: tuning variable capacitor

2. SHORT PIN EFFECT ON RESONANCE FREQUENCY

The PIFA and radio case configuration is shown in Fig. 1. The position of the feed point and the dimensions of the conductive case and the dimensions and height of the patch are kept constant (L = 40mm, W = 35mm, d = 5mm). A fixed short pin at a distance s1=5mm from the top left corner is introduced to add the necessary inductance to the antenna so that the VSWR at any f_r is kept less than 2. A second short pin (traveling pin) is then introduced to achieve fine tuning of the PIFA. The VSWR and input impedance of the antenna is then measured in steps of 5mm. For instance, 1→4 in Fig. 2 indicates that the short pin is moving from reference corner 1 towards reference corner 4, as shown in Fig. 1. The resonance frequency for the four different cases studied, corresponding to the short pin traveling along the four edges, are plotted in Fig. 2. As the distance from the feed increases, f_r increases too, but up to a point. When the short pin is approaching the opposite corner, f_r starts increasing again. It can be said at this point that the corners of the patch have a noticeable effect on f_r and that f_r does not only dependent on the distance of the short pin from the feed point. This is because of the high electric field intensity around the corners [5].

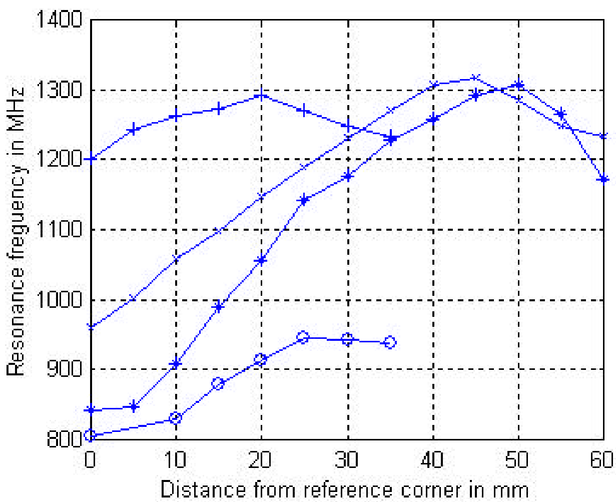

Figure 2: Resonance frequency of PIFA for various short pin positions.
o Reference corner 1→2, x Reference corner 2→3,
+ reference corner 3→4, * reference corner 1→4.

The effective bandwidth of the PIFA using this technique has been found to be as high as 502MHz (804 → 1306 MHz) and is by far wider than those associated with the whip and small helix antennas. The effective bandwidth is defined as the frequency range that can be covered by this antenna type, using one of the tuning techniques described in this paper. It should be further noted that the VSWR within this bandwidth is always less that 2. For this particular configuration, the use of the left or right side for tuning the PIFA is more suitable than the top and bottom because it gives a wider effective bandwidth.

3. CAPACITANCE SHORTED PIFA

The traveling short pin described above can be replaced by a capacitor. By varying the value of the capacitance, the reactance of the antenna changes and, as a result, f_r changes, as depicted in Fig. 3. The antenna dimensions are the same as those used in Section 2. The effect of the capacitance values have been measured at four reference points 1,2,3, and 4, as shown in Fig. 1. The capacitors used in these measurements are miniature, multi-layer, ceramic capacitors with a tolerance of ±5%.

In Fig. 3, the results of a number of measurements are shown for capacitance values ranging from 3pF to 100pF. For low capacitance values f_r has a high value. As the capacitance decreases f_r decreases, but the rate of change of f_r with capacitance is reduced. For capacitance values higher than 30pF, f_r is almost constant. By using this method, the effective bandwidth, when the capacitor has a fixed position, is 175 MHz. From these measurements it is also evident that f_r also depends on the position of the capacitors. The further the capacitor from the feed, the higher the frequency band covered.

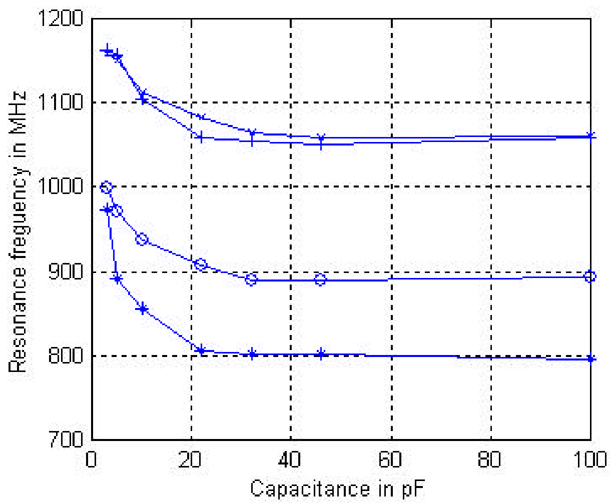

Figure 3: Resonance frequency vs pin capacitance placed at four reference points:
* Reference point 1, o Reference point 2,
x Reference point 3, + Reference point 4.

4. DUAL-BAND FINE TUNED PIFA

Based on the information from the measurements described above regarding the position and capacitance value of the pins, a dual-band (GSM900/DCS1800) PIFA has been designed. The dimensions of the antenna can be significantly reduced to L=40mm and W=35mm, since the frequency band can be controlled by the position of the pins and their capacitance value. The position of the fixed short pin for this antenna is again 5mm from reference corner 1 and the height of the antenna from the case is d=5mm. Two variable capacitors (1.8–12.5pF) have been used. The first one (c1=25mm from corner 1) is referred to as the calibration capacitor, because its value is set once during calibration. For the particular antenna dimensions considered here, its value was measured to be 7.3pF. The second capacitor is referred to as the tuning capacitor, because it is used to tune the antenna at any frequency channel within the two bands.

In Fig. 4, the VSWR and the normalised bore-sight gain of the dual band fine tuned PIFA are shown for three tuning capacitor values. Both GSM900 (890-960MHz) and DCS1800 (1710-1880MHz) bands can be accommodated from this antenna model just by changing the tuning capacitor value from 1.8pF to 3.0pF.

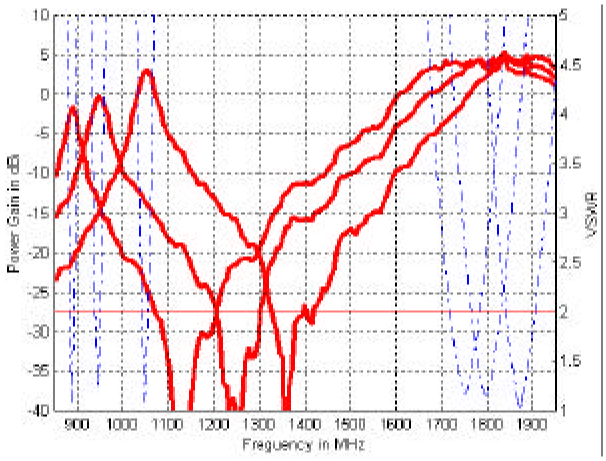

Figure 4: Bore-sight gain (dBi) and VSWR vs. frequency for the dual-band fine tuned PIFA for three tuning capacitor values.

5. VOLTAGE CONTROLLED FINE TUNED PIFA

Based on the experience gained from the experiments outlined above, a voltage controlled fine tuned PIFA for the GSM900 band has been designed. The antenna geometry is illustrated in Fig 5. A top patch has been introduced to provide the electric isolation between the varactor and voltage-source system and the antenna, since the PIFA is connected to the ground via the short pin. Note that the patch can be replaced by a low value capacitor. The inductor is used to de-couple the RF signal from the voltage supply. The BB619 varactor has been selected from a range of similar components tested. The capacitance value of this varactor starts from approximately 37pF when the reverse voltage is 0 Volts and goes down to 3pF when the reverse voltage becomes 30 Volts.

The VSWR measurements from this test antenna are presented in Fig. 6. It is evident that the effective bandwidth is much wider than that required by the GSM900 system. The maximum reverse voltage to satisfy the GSM900 band requirements is 15Volts for VSWR < 2. From Fig. 6 it can be also observed that for low reverse voltage values the variation of the resonance frequency is relatively small. Further, it should be noted that the required range of the applied reverse bias can be reduced by cascading two or more varactors in series.

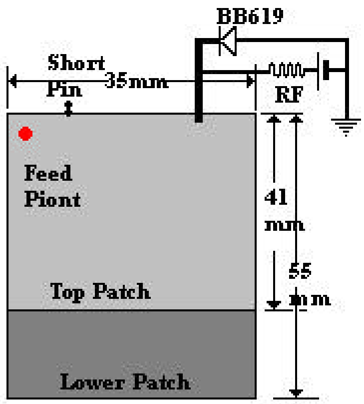

Figure 5: The varactor controlled PIFA design.

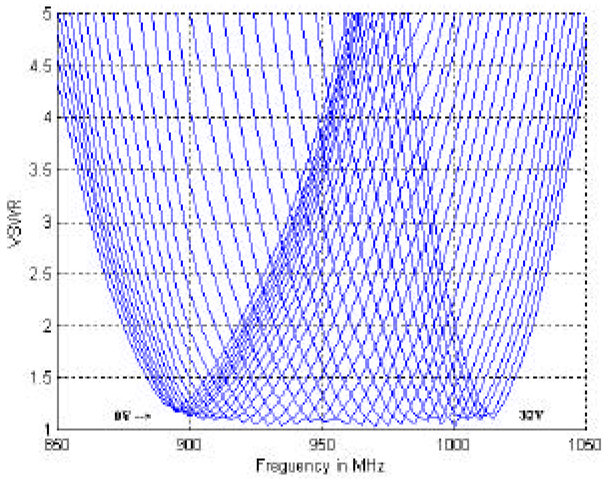

Figure 6: VSWR vs. frequency for the PIFA shown in Fig. 5 for a reverse voltage range of 0 to 32 Volts.

6. DISCUSSION

From the PIFA studies highlighted above, it is concluded that the narrow bandwidth problem can be effectively addressed by varying the position or by changing the capacitance value of the short pins. In an electronically fine-tuned PIFA the short pins can be replaced by transistors or PIN diodes, and the variable capacitors by varactor diodes. However, a number of problems are associated with these solutions.

Firstly, replacement of the short pins with transistors or the capacitors with varactors requires consideration and modeling of their characteristics at RF frequencies. In addition, for high power operation, their non-linear behaviour must be accounted for. Secondly, the capacitance range of the varactors is limited by the maximum voltage supply range available in a mobile phone.

A closed loop circuit can be introduced that controls the tuning of the antenna either dynamically or based on a look-up table derived from an initial calibration. A generic diagram of such a control loop is shown in Fig.

7. If real-time control is implemented, the algorithm should be able to rapidly adjust the resonance frequency of the antenna under different operating scenarios, e.g. when the antenna is de-tuned due to its proximity to the user's head or hands. It has been observed, for instance, that the PIFA resonance frequency can shift by approximately 15MHz due to parasitic coupling with and absorption by the head and hands of the user in a realistic operating situation. Hence, a dynamically tuned narrow-band PIFA should provide further enhancement of the transmission efficiency and receiver sensitivity in practical applications. Nevertheless, the speed of the algorithm and the lock time and stability of the loop are issues of further concern, along with wideband phase noise and spurious emissions issues.

Despite the problems highlighted above for migrating from the manual to the electronically tuned PIFA, the low profile, the broad effective bandwidth, the low VSWR and the high efficiency that can be achieved by using these techniques, are important points that encourage further research.

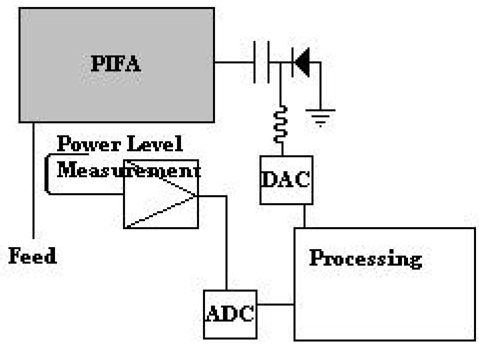

Figure 7: Block diagram of an electronically fine-tuned PIFA.

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