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A Study of Multiband PIFA Antenna for Mobile Devices

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Abstract— **A compact multiband tunable PIFA system using a varactor as an active tuning component with other paracitic elements is presented to cover 88–2175 MHz. The antenna was designed for different mobile telephone bands by controlling the value of the capacitance across the gap in the slotted PIFA and and two broadcast bands, FM radio (76–108 MHz) & mobile television DVB-H (470–702 MHz), were added by designing an appropriate matching circuit into the system. The antenna measured size lesser than λ/15*λ/43*λ/91 at 470 MHz and was easily integrated into a small mobile phone handset. Simulations are verified by using CST Microwave Studio.**

Index Terms — Antennas, mobile telephone antennas, planar in- verted-F antenna (PIFA), small antennas, tunable antennas.

I. INTRODUCTION

COGNITIVE radio requirements demand reconfigura-bility from mobile devices ranging from base stations to telephone handsets. Antennas can be tuned in many ways, for example by using pin diodes, varactor diodes, and MEMs
switches [1], [2] and by varying substrate properties with ferrites [3] and ferroelectrics[4]. Microwave antennas tuned using nematic liquid crystal (LC)substrates have been reported in [5]–[7] where the permittivity can be changed by applying a DC bias voltage and consequently the dielectric constant altered by up to 30% [8], [9]. The current distribution on an antenna can be varied to modify its geometry for different frequency bands by applying RF MEMS switches, PIN diodes, variable capacitors (varactors) or other variable elements [1], [2], and [10]. For the mobile telephone bands from 1710 to 2175 MHz a tunable matching circuit is another alternative as described in [11]–[13] describes a planar inverted-F antenna (PIFA) tuned by a varactor over the frequency range from 1.1 to 2.2 GHz. A PIFA tuned by varactor or pin diodes is described in [14] operating from 580 MHz upwards. It is also desirable to add broadcast channel reception to handsets and FM radio (88–108 MHz) and DVB-H (dig-ital video broadcasting—handheld, 470–702 MHz) antennas present some of the most challenging requirements due to the low frequency of the broadcasts. DVB-H features a large fractional bandwidth (40%) and low operating frequency(470–702 MHz). This is reflected in the implementation guidelines, currently indicating a realized gain of 10 dBi(at 470 MHz) to 7 dBi (at 702 MHz) as acceptable[15], where the realized gain G is gain reduced by the matching losses. Compared to the DVB-H band, FM radio with 20.8% fractional bandwidth at around 100 MHz is even more difficultto realize due to its very low operating frequency, though no requirements on gain (or radiation efficiency) are specified.Therefore, making a passive antenna to cover a wide frequencyband from 88 MHz to 2175 MHz, while preserving acceptable antenna characteristics, is a huge challenge for low-frequency mobile terminal antenna designs where the physical size of the terminal is so small particularly near 100 MHz.

Most modern mobile phones today in the mid-to-high price range are equipped with an FM radio receiver module. In many the earpiece cordhas traditionally beenused as the antenna, with the phone chassis, and also possibly the user, as counterpoise, thereby requiring long and unwieldy hands-free cords to be con-nected during radolistening.Recentlyaninbuilt coil antenna with matching circuits has been described in[16] with antenna gains varying from 19dBi to 32 dBi. In [17] a separate FM fractal antenna for a handset is described but no gains are quoted except that its perf ormance in terms of received signal power is 20 dB below a quarter wave monopole on the same handset.DVB-H antennas have attracted more interest. A concept of using a modified earpiece cord as the external antenna for a DVB-H antenna, similar to the earpiece cord solution for FM radio in mobile phones, has been reported by Lindberg et al. [18], in which a stable wideband input impedance is achieved, by winding the cord into a high-impedance RF choke at one-quarter wavelength distance from the connection on the chassis. Zla
Toljub et al. [19] and Berg [20] promoted tunable IFA and PIFAs, respectively, both mounted on the long side of the PCB using varactor tuning circuits to cover the DVB-H band. Huang et al.[21] presented a design procedure for internal
planar DVB-H antennas for mobile applications

The handset antennas described in [1]–[21] either cover mul-tiple mobile telephone bands at high frequencies or separate an-tennas for FM and DVB-H signal reception. For example [17] used a fractal antenna measuring mm for FM recep-tion, [16] used a coil for FM reception mm—neither could be used for higher frequency bands. Similarly [18]–[22]reported DVB-H antennas again these could not

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operate at the mobile phone bands and [11]–[14] reported antennas only op-erating at the mobile telephone bands. In this paper, a single PIFA on a small handset chassis is described which function radiation orientations. As an FM antenna and is tunable using a varactor diode from 470 to 2200 MHz covering the digital handheld TV bands and the mobile telephone bands. The whole chassis is part of the ra-diating structure as well as the PIFA as would be expected for a small antenna system. This is the first time a single antenna
system has been described covering the frequency bands from76 to 2200 MHz. Separate feeds are required for the telephone and broadcasting reception bands although these are often built into the front endfi lteringonthehandset. The advantages of this tuning antenna system are a relatively simple antenna structure, requiring fewer filters, and better performance,demonstratedbythepresentationofthemeasured and
simulatedresults.Thereturnlossesandantennagainsweremea-sured in an anechoic chamber at the mobile telephone bands and the DVB-H band, with the FM band being evaluated using an outdoor range at Antenova Ltd. The antennas were modeled and simulated using CST Mi-crowave Studio

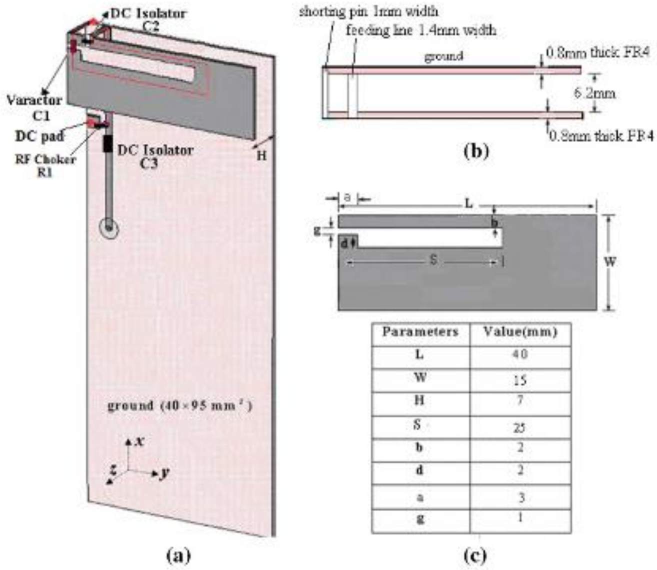
II. ANTENNA GEOMETRY

The configuration of the proposed PIFA type antenna is il-lustrated in Fig. 1. The radiating element is a shorted rectan-
gular patch with a slot to form a loop-shaped strip and occupies an area of 40 mm 15 mm. The width at the open end of the slot is shrunk to 1 mm in order to load surface mount compo- nent varactor C1 across the gap for the frequency-tuning func-tion. A Toshiba ISV245 varactor diode was used in this work and had a capacitance tuning range from 0.65–6.5 pF. The slot length S was set to 25 mm. The patch is printed on an FR4 sub-strate (thickness 0.8 mm and relative permittivity 4.4) with an air layer of 6.2 mm height above a printed circuit board (pcb)0.8 mm thick which has a ground plane on the back representing the mobile telephone chassis. The results presented here are for a small handset measuring 90 mm -45 mm although larger handset sizes were also studied and in all cases resulted in im- proved performance particularly at the low frequencies. At the top edge of the PIFA in the corner is a shorting pin. There is a break in the upper loop between the shorting pin and the feed point to accommodate a dc isolating capacitor C2 (0.1)so that the varactor can be biased. The feed is connected to a trans-
mission line with a 50coaxial connector. In order to apply the
DC bias current to the varactor diode C1, one RF choke resistor of 1 was inserted between the DC pad and the transmis- sion line and one DC isolator C3 with the value of 2.2 nF was placed on the transmission line. Multiband tuning of the PIFA is achieved by a combination of tuning the varactor diode anddifferent feed matching networks/filters for the various bands.A prototype antenna was constructed and tested.

III. ANTENNA PERFORMANCE

A. Mobile Telephone Bands

The first results are presented for the mobile telephone bands from 820 to 960 MHz and 1710 to 2175 MHz. The Toshiba ISV245 varactor diode had a tuning range from 0.65 to 6.5 pF



Parameters	Value(mm)
L	40
W	15
H	7
S	25
b	2
d	2
a	3
g	1

requiring a dc voltage from 22 V to 4V andabiasnet- work current of a few mA. Although this is a high voltage for
a mobile device charge pumps or lower voltage varactor diodes will become available in the near future. The varactor is usually modeled using a RLC circuit, but in this case the parasitic in- ductance is normally very small and may be ignored [22]. The series resistance for the diode varied from 0.25to 1.2.The varactor was modeled in CST as a capacitor with discrete values and the corresponding series resistances taken from the device data sheet. The simulated current densi ties over the antenna and pcb ground are shown in Fig. 2 at the lower and upper bands. The resonance at 1950 MHz corresponds to the PIFA having a perimeter length of. Fig. 2 shows that the currents are primarily on the PIFA but that the pcb ground (chassis) also carries a significant current and is important for the general performance even at these higher frequencies.
The antenna was then measured and compared with the sim-
ulations. Fig. 3 shows the reflection coefficients for the capac-itance C1 varying from 0.7 to 3.1 pF for simulation and a cor-responding set of measurements. Bandwidths are determined at the 6dB reflection coefficient points in all cases. At GSM900 frequencies the bandwidth was 35 MHz and at GSM1800 verysimilar to that in [14]. This is sufficient to cover the up and downlink bandwidths.
There is a reasonable correspondence between the measure-
ments and simulations and the tuning range of the antenna

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covers the lower and upper mobile telephone bands from 820 MHz up to 2175 MHz. The measured tuning performancewas actually wider than that simulated. This may be due tothe fact that in the measurements the voltage bias taken from the diode data sheet may not correspond exactly to the stated capacitance or that the RC diode model was not sufficiently ac-curate. A recent publication [23] indicates that the model usedhere may be further improved. The simulated and measured

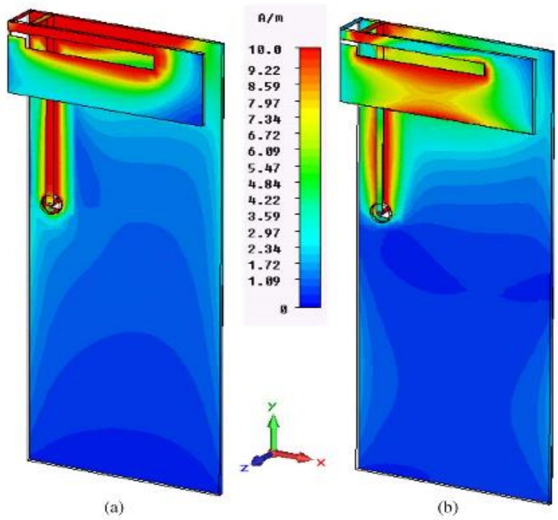

Fig. 2. Simulated current densities at (a) 900 MHz and (b) 1950 MHz.

radiation patterns for the antenna are shown in Fig. 4 where there is good agreement at both bands. The antenna gains were measured across the frequency bands and were 0.2 dBi to 0.5 dBi at the lower band and 1 dBi to 1.6 dBi at the upper band with corresponding minimum total efficiencies of between 60% at 900 MHz and 85% at 1900 MHz measured. The corresponding simulated efficiencies ranged from 72% at 900 MHz to 80% at 1900 MHz. The antenna efficiency was measured using the input impedance Wheeler Cap method [24]. The cap was a 300 mm cube metallic box and

the antenna was biased at the mobile telephone bands using a

simple bias T as there was no matching circuit required. At the DVB-H band the dc bias wires were tightly wound around the coaxial cable feed

B. Broadcast Antenna Performance

Thefrequencybandtobecoveredbytheantennaforthemo- bileTV bandsisfrom 470 to 702MHzwith achannelbandwidth

of 8 MHz. The FM band resides from 88 to 108 MHz globally.The same varactor C1 tunes the antenna over the TV band but does not tune the FM band as discussed later. Fig. 5 shows theantenna handset geometry and the matching circuit on the feed transmission line required to tune the antenna to the FM radio band. The matching circuit contains a series capacitor of 47 pF and a shunt inductor of 22 nH. Fig. 6 presents measured reflection coefficients with the DC voltage ranging from 0 V to12 V, in equal voltage steps.

It can be observed that two resonances are excited to satisfy

the demand of the FM and DVB-H bands below 800 MHz. The first resonance stays stable at around 100 MHz for the FM band,whilethesecond resonanceprovidestheDVB-H band.On tuning the value of C1, the second resonance sweeps though thefull range of DVB-H band (470–702 MHz). It clearly indicates that the 6dB reflection coefficient target for an instantaneous bandwidth of 20 MHz or more was successfully achieved over the DVB-H band, with the deepest reflection coefficient value of 32 dB at around 584 MHz. The minimum bandwidth was 21 MHz. Fig. 7 shows the simulated current density on the handset at 100 MHz and 550 MHz. At 100 MHz the radiation mainly occurs from the currents concentrated on the PIFA, the feedline which strongly excites the upper corner of the pcb ground and some current on the pcb at the opposite lower corner. This does not change across the bandwidth nor as the capacitor C1is tuned. At 550 MHz the currents are excited around the PIFA and there are significant currents on the pcb as expected. The

matching circuit is shown as the blue block on the feed line

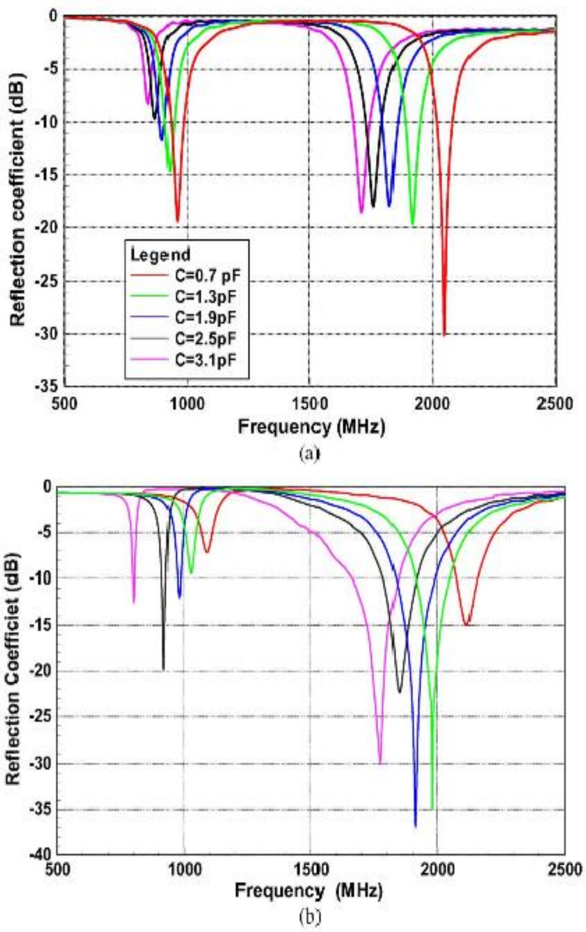

Fig. 3. Reflection coefficients for capacitance C1 = 0.7 pF to 3.1 pF. (a Simulated; (b) measured.

The antenna gains over the DVB-H band were simulated and measured and are plotted in Fig. 8. The minimum gain speci-fied for the antenna is shown by the solid unmarked line. As can be seen, both simulation and measurement results have sat-isfied the specification requirement. At the lower frequency of 470MHz, the measured gain is 9.6dB, giving a 0.4-dB margin to the specification of 10 dB. The margin increases as the fre- quencyincreases.The measurement reaches a maximum margin of 6.6 dB at 700 MHz. It can be observed that measured realized gains are lower than the simulated gains, except at 470 MHz where the measurement is slightly higher. The reason for this may be fabrication and measurement inaccuracy or the inaccu-racy in modeling the DC isolator, RF choke and matching com-ponents in , which may add more losses into the system than expected. Both simulated and measured radiation patterns are presented in Fig. 9 for the DVB-H band at four frequen-cies, 500–700 MHz, and in three planes. Overall the patterns give good symmetrical coverage in the YZ plane, the plane most likely to be presented to the signal when holding the phone. The measurements and simulations are also in good agreement in all planes

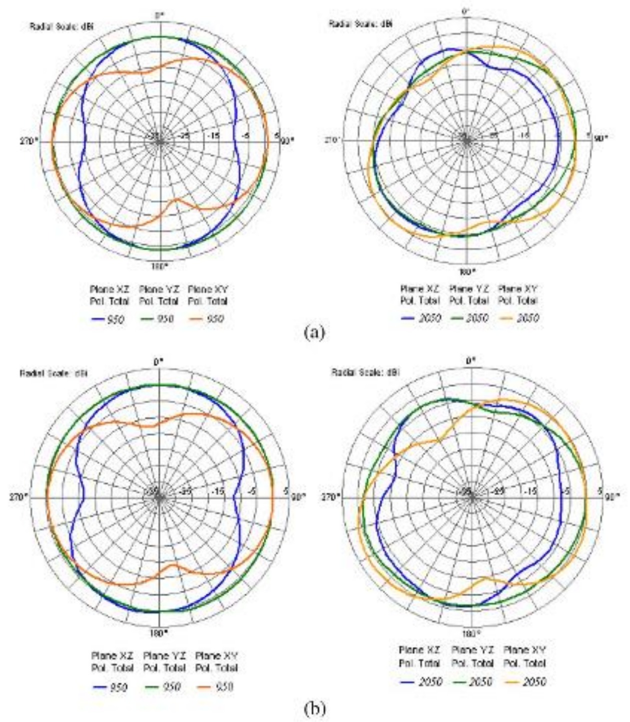

Fig. 4. Simulated and measured radiation patterns in three planes at the lower 950-MHz and upper 2050-MHz frequency bands. (a) Simulated; (b) measured.

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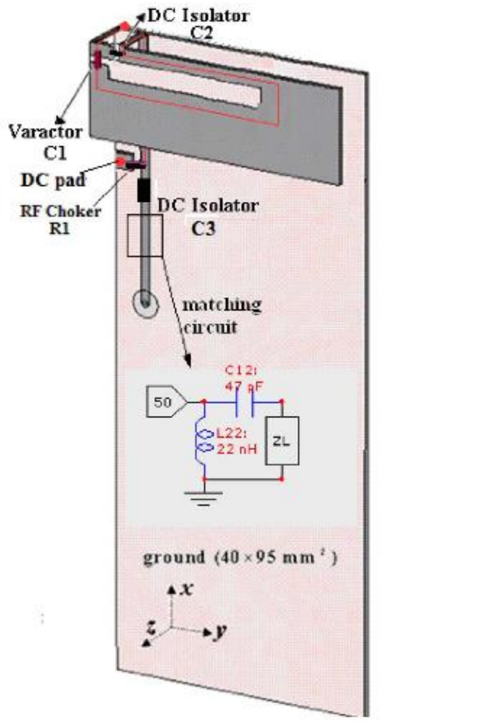

Fig. 5. Matching circuit for FM band inserted into the transmission line.

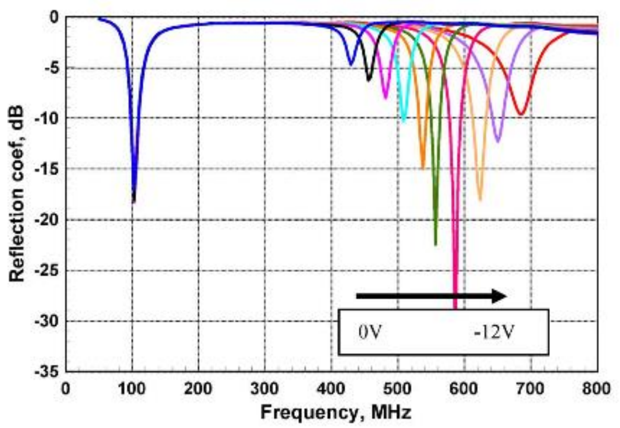

Fig. 6. Measured reflection coefficient for the broadcast bands-capacitance C1 tuned from 0 V to −12 V.

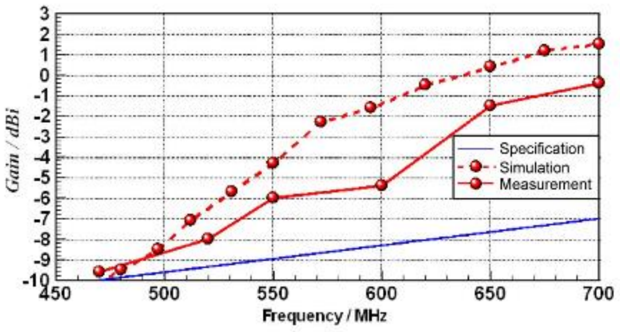

Fig. 8. Measured gains of antenna at DVB-H TV band.

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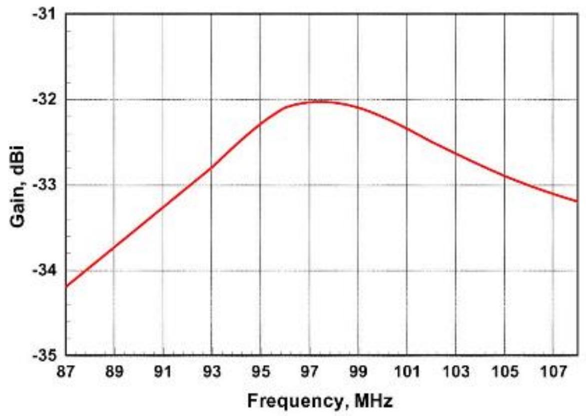

Fig. 10. Measured gain for FM band.

The antenna gain at 100 MHz was also tested in an out-door testing system using a gain-comparison method. It is well known that one of the major problems in measuring RF prop-erties of small FM antennas is the effect of the coaxial cables.Therefore, an optical-RF conversion system has been developed to transmit the RF to minimize the cable effect [25]. The mea-sured average antenna gain shown in Fig. 10 varied from 32dBi to 34 dBi across the band, while the simulated minimum gain from CST was 34 dBi. This compares with 32 dBi mea-sured in [16] for a separate anten
na. Simulations of the radiation patterns in three planes are plotted in Fig. 11 showing a peak gain of 24 dBibut considerable variations of 15 dB with angle.Further tuning of the antenna is also possible to the European digital radio bands from 174–240 MHz and GPS at 1575 MHz.This involves using a separate matching circuit and tuning the matching circuit with another varactor

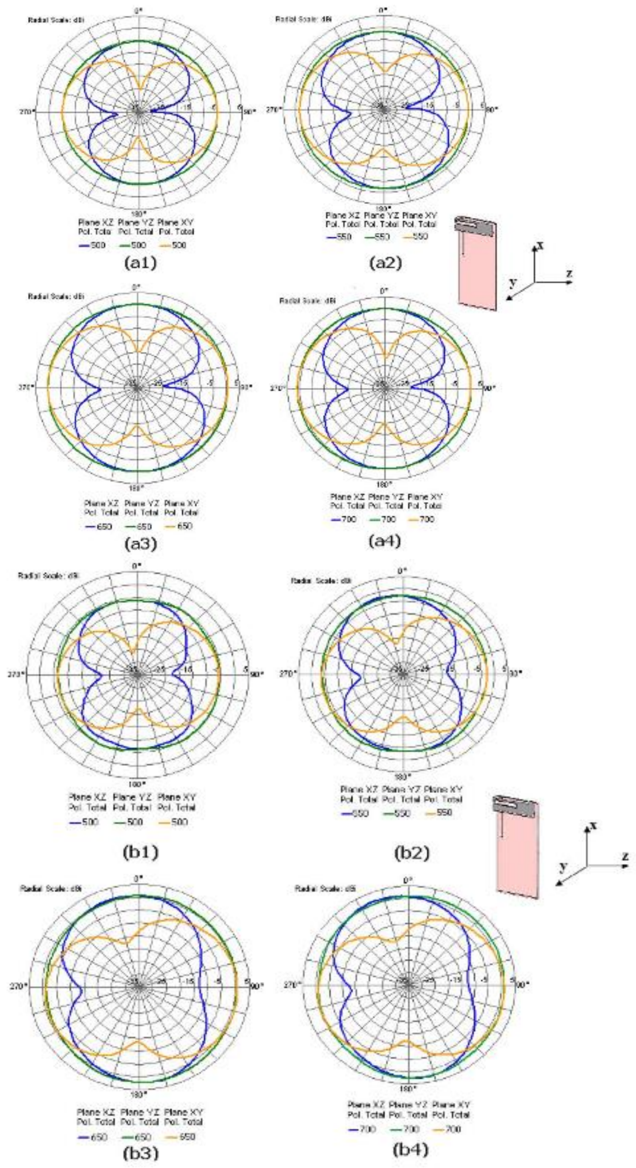

Fig. 9. Simulated and measured radiation patterns at DVB-H band (a1) simu-lated at 500 MHz; (a2) simulated at 550 MHz; (a3) simulated at 600 MHz; (a4) simulated at 700 MHz; (b1) measured at 500 MHz; (b2) measured at 550 MHz; (b3) measured at 600 MHz; (b4) measured at 700 MHz blue XZ plane, green YZ plane, orange XY plane.

IV. CONCLUSION

A single PIFA measuring 40 mm to 15 mm on a small handset 95 mm to 40 mm is presented which is tunable using a varactor diode from 470 MHz to 2200MHzcovering the digital handheld TV bands and the mobile telephone bands. In addition it alsofunctions as an FM antenna.Separate feeds are required for the telephone and broadcasting reception bands although these areoften built into the front endfiltering on the handset. The basic structure of the PIFA consists of a shorting pin, a feed line and a shorted rectangular patch with a slot to form a loop-shaped strip.It is able to operate at different frequencies, by controlling thevalue of the capacitance across the gap at the ends of the strip, which was implemented by a varactor diode. The five mobile telephone bands (GSM850, 900, 1800, 1900, UMTS) achieved 60% to 85% radiation efficiencies in each tuning state, with the DC tuning range of the varactor providing the capacitance ranging from 3.1 to 0.7 pF. By inserting a matching circuit into the transmission line a dual-band broadcast antenna was config-ured for the FM band and DVB-H band. The DVB-H band had a measured realized gain of 9.6 dBi, giving a 0.4 dB margin on the minimum specification of 10 dB. The margin increases as the frequency increases. The gain reached a peak of 0 dBi at 700 MHz. The performance of the antenna at the FM band was comparable with published results for separate antennas on handsets with a minimum gain of 34 dBi. Furthermore, the op-erating bands could be extended to cover the GPS (1.575 GHz). Overall the tunable PIFA performance met the requirements of all three applications, making this tunable an-tenna system a promising candidate for many mobile devices.In advance with this two additional frequencies are tuned using parasitic elements.

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