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SMALL BROADBAND ANTENNA DESIGNS FOR 3G HANDSET APPLICATIONS

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Abstract. Two improved, small, compact, and broadband handset antenna designs for 3G band based on gap-coupled patch and FS-PIFA techniques are presented. The antennas, the Inverted Gap-Coupled Coplanar patch antenna (IGCC) and Finite ground plane Full-Shorted Planar Inverted-F Antenna (FFS-PIFA) are simulated using *Zealand IE3D 8.2 em* simulator. Simulation results give fractional bandwidths of 28.2% and 40.1% at 10 dB Return Loss for IGCC and FFS-PIFA respectively. The IGCC was fabricated due to its simple fabrication. Measured results for IGCC gave a fractional bandwidth of 31% at 10 dB Return Loss at f_c = 1.95 GHz and with 4 dBi gain. The patch dimensions for both antennas are 33 × 32 mm with a ground plane size of 40 × 60 mm. These antennas are promising for 3G applications.

Keywords: Handset antenna, microstrip patch antenna, inverted-F, gap-coupled, IMT-2000

Abstrak. Dua reka bentuk antena set tangan yang diperbaiki, kecil, padat dan berjalur lebar bagi jalur 3 G berdasarkan kaedah tompok gandingan-sela dan FS-PIFA dibentangkan. Antena gandingan-sela sesatah tompok tersongsang (IGCC) dan satah bumi terhingga satah tersongsang-F terpintas-penuh (FFS-PIFA) disimulasi dengan menggunakan simulator *Zealand IE3D 8.2 em*. Hasil simulasi memberikan pecahan lebar jalur sebanyak 28.2% dan 40.1% pada kehilangan balikan 10 dB bagi reka bentuk IGCC dan FFS-PIFA masing-masing. Reka bentuk IGCC difabrikasi kerana ia mudah difabrikasi. Hasil pengukuran bagi IGCC memberikan pecahan lebar jalur sebanyak 31% pada 10 dB pada f_c = 1.95 GHz dengan gandaan 4 dBi. Dimensi tompok bagi kedua-dua antena ialah 33 × 32 mm dengan satah bumi bersaiz 40 × 60 mm. Antena ini sesuai bagi aplikasi 3G.

Kata kunci: Antena set tangan, antena tompok microstrip, satah tersongsang F, gandingan sela, IMT-2000

1.0 INTRODUCTION

The first generation and some of the earlier second-generation handset antennas are of linear types, like whip, sleeve and helical. The advancement in RF circuit and miniaturization technologies together with improved battery size in the early nineties compels handset antennas towards smaller designs. With the onset of third generation systems, the emphasis is hence directed towards a much smaller, compact, and efficient

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Table 1 Comparison of handset antenna design focus

Generation	Antenna characteristics
First	Linear and external antennas (monopole derivatives) Spatial diversity Protruded and bulky
Second	Planar and internal antennas (microstrip derivatives) Dual-frequency (commonly 900 MHz and 1800 MHz) Built-in diversity Low-profile Small and light-weight
Third	Broadband internal antennas (microstrip derivatives) Triple-frequency (commonly 0.9 GHz, 1.8 GHz and 2 GHz) Compact design Efficient radiation (SAR)

SAR: Specific Absorption Ratio

handset antenna design. Furthermore, the improvement in microstrip antenna technology in terms of its bandwidth and performance permits the use of low profile antenna for handset antenna applications. Table 1 summarizes some of the antenna features for the respective generations.

This paper reviews various third generation handset antenna designs and describes the improved compact broadband microstrip-based antenna designs for third generation handsets. Two broadband handset antenna designs are presented: i.) Inverted Gap-Coupled Coplanar patch antenna (IGCC) and ii.) Finite ground plane Full-Shorted Planar Inverted-F Antenna (FFS-PIFA). The IGCC is selected for fabrication due to its simple structure and fabrication. Simulation and measurement results are also presented.

2.0 REVIEW OF 3G HANDSET ANTENNA DESIGNS

Heberling [1] has given a thorough review on second-generation handset antenna technologies. This section investigates various 3G handset antenna designs that had been reported in open literature. These antennas are presented according to their types: a) External antennas; dielectric resonator antenna, sleeve monopole, and loop antenna, and b) Internal antennas; FS-PIFA and gap-coupled. The discussion covers the properties and results of respective designs especially in terms of their compactness and impedance bandwidth.

2.1 External Antenna Designs

2.1.1 Dielectric Resonator Antenna

Jung-Ick and Seong-Ook [2] had realized a dielectric resonator antenna (DRA) that supports dual-band operation (PCS and IMT-2000). They realized a relatively low DRA by encapsulating a conducting strip in a thin high dielectric material to achieve a fractional bandwidth of 25% at 10 dB return loss (RL10) and a maximum achievable gain of 0.4 dBi. The antenna as shown in Figure 1 has a dimension of $34 \times 10.5 \times 11.9$ mm and is mounted on a 30×30 cm finite ground plane.

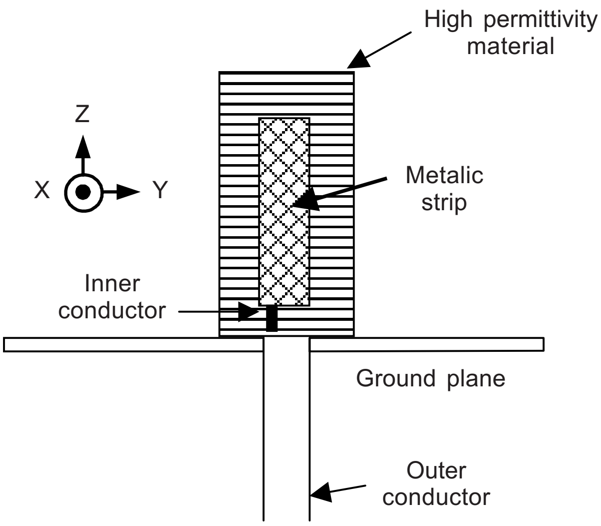

Figure 1 Dielectric resonator antenna [2]

2.1.2 Sleeve Monopole Antenna

Jung-Ick *et al.* [3] had also investigated the application of sleeve monopole handset antenna for dual-band operation (PCS and IMT-2000). Their design is as shown in Figure 2. The antenna consists of an outer tubular and inner monopole, which has two rods of different diameter. They obtained a fractional bandwidth of 24.2% at 20 dB return loss (RL20) with measured gain of 2.9 dBi. The antenna is mounted on a 30×30 cm finite ground plane.

2.1.3 Loop Antenna

Li *et al.* [4] had simulated and measured a broadband rectangular loop antenna for dual-band operation (DCS-1800 and IMT-2000). The antenna structure is based around

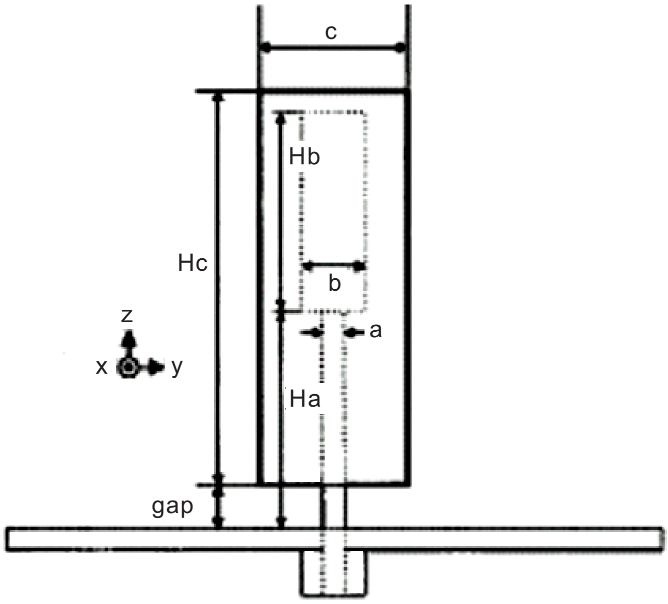

Figure 2 Sleeve monopole antenna [3]

a 30 × 14 mm rectangular wire loop but with a 1 mm gap near a corner as shown in Figure 3. By introducing a small gap of 1 mm in the wire loop, they achieved an impedance bandwidth of 24% at RL10. The wire loop antenna is mounted on a metal box with dimension of 90 × 50 × 20 mm. The antenna provides radiation pattern with a reduced gain in the direction of user's head.

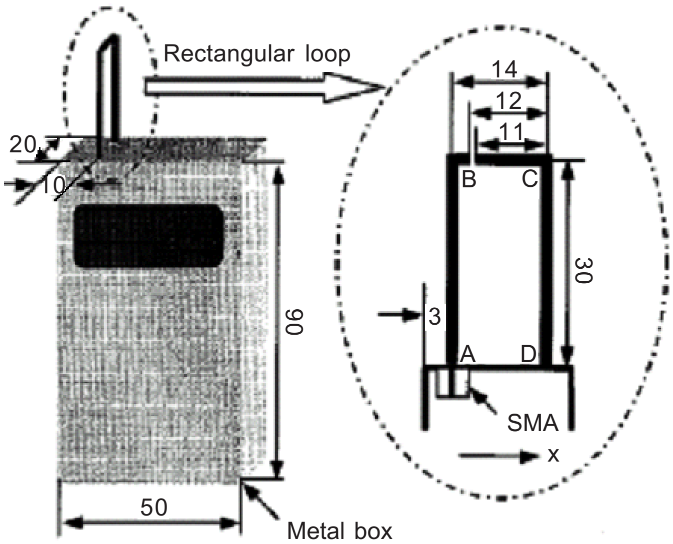

Figure 3 Loop antenna. The units are given in mm [4]

2.2 Internal Antenna Designs

2.2.1 Full-Short Circuit Planar Inverted-F Antenna

Xiaoxiao He and Xiaowei Zhu [5] had realized a broadband Full-Short circuit Planar Inverted-F Antenna (FS-PIFA) for 3G handset as shown in Figure 4. The design had achieved a fractional bandwidth of 12.2% (250 MHz: from 1.92 GHz - 2.17 GHz) with VSWR < 2.0 and a gain of 4 dBi. The horizontal part of the antenna is 40 × 36 mm (W × L) with 6 mm spacing between the horizontal part and the ground plane. The infinite ground plane dimension is 160 × 140 mm.

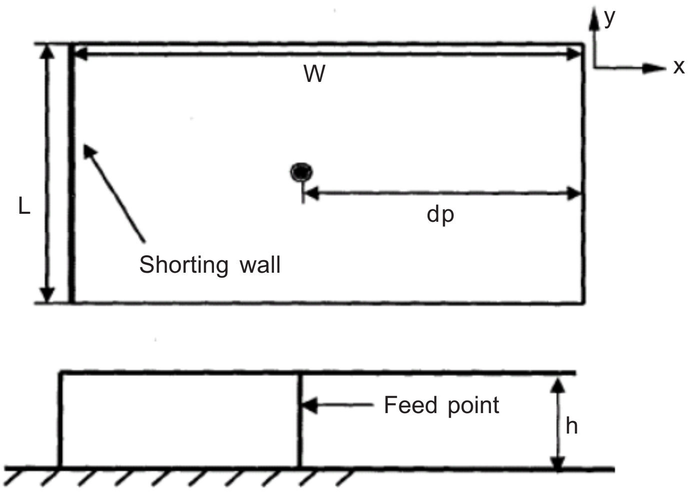

Figure 4 Full-Short circuit Planar Inverted-F Antenna [5]

2.2.2 Gap-Coupled Antenna

Wang *et al*. [6] developed a novel broadband microstrip patch antenna for IMT-2000 handset as shown in Figure 5. They have shown that compactness and wide bandwidth can be obtained by coupling two shorted semi-disc patches together along their radiating edges. The two similar elements are electro-magnetically coupled together to give a dual-frequency operation by closing two adjacent resonant frequencies while the shorting pin acting as an inductive element significantly reduces the size of the antenna. This design achieved RL10 bandwidths of 25.3% for air and 24.5% for foam. The maximum thickness is about 1/15 of a wavelength, while the maximum planar dimension is a quarter-wavelength. The ground plane dimension is comparable to those of modern handsets, 40 × 90 mm.

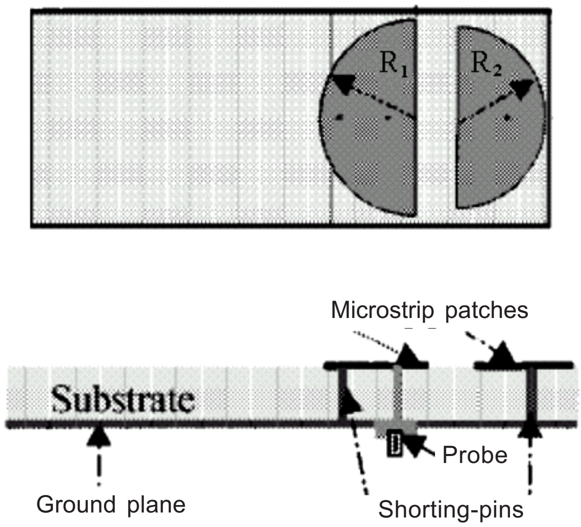

Figure 5 Two semi-patches with shorting pins [6]

Table 2 summarises the measurement results of handset antennas for 3G applications reviewed in this section.

Table 2 Comparison of existing antenna designs for IMT-2000

Antenna design	**Dimensions/mm (length × width × thickness)**	**RL10 Frequency range (Impedance bandwidth)**	**Gain /dBi**
DRA [2]	(a) 34 × 10.5 × 11.9 (b) 300 × 300	1.73 – 2.22 GHz (24.8%)	0.4
Sleeve [3]	(a) 20.6 (b) 300 × 300	1.72 – 2.19 GHz* (24.0%)*	2.9
Loop [4]	(a) 30 × 14 (b) 90 × 50 × 20	– (24.0%)	–
FS-PIFA [5]	(a) 36 × 40 × 6 (b) 160 × 140	1.92 – 2.17 GHz (12.2%)	4.0
Coplanar semi-disc [6]	(a) R_1 18.5 R_2 17 (b) 40 × 90	1.76 – 2.23 GHz (26.3%)	4.2

Dimensions: (a) Antenna design
(b) Ground plane
Note: * signifies the antenna measurement with RL20

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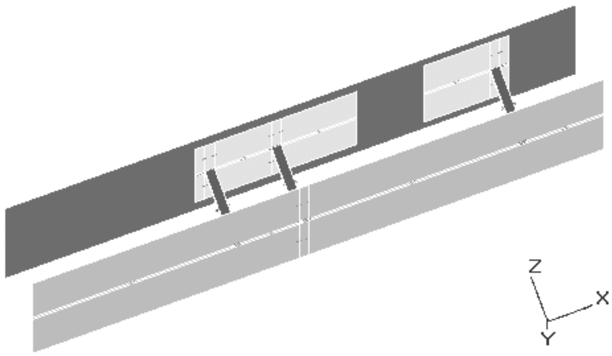
3.0 3G HANDSET ANTENNA DESIGNS

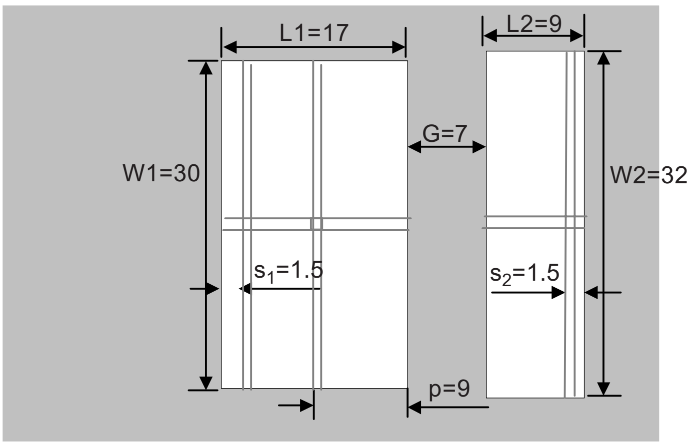
Section 2 has described and summarized a number of handset antenna design for 3G applications. For microstrip broadbanding techniques, we refer to an excellent reference by Garg *et al*. [7]. Arming with this knowledge, we present two improved handset antenna designs based on microstrip techniques. Our aim is to achieve the full 3G spectrum covering 1.885 - 2.2 GHz or a fractional bandwidth of 15.4% at 2.0425 GHz centre frequency with VSWR < 1.5 and a maximum gain of 4 dBi to mitigate multipath effect. The design is to meet the size requirement of a typical compact handset antenna dimension of 40 × 90 × 10 mm. To assist in our design, we make use of a commercial e-m software package *Zealand IE3D 8.2*.

3.1 Inverted Gap-Coupled Coplanar Rectangular Patches

Fig. 6 shows the configuration and dimension of a radiating edge gap-coupled coplanar rectangular patch antenna with shorting pins. Our design differs from Wang [6] in that



(a)



(b)

Figure 6 Configuration of the IGCC antenna (a) 3D view and (b) top view a dielectric layer (superstrate) is placed on top of the gap-coupled coplanar patch with an air filled substrate separating the conducting patch and the ground plane. We call this arrangement as the Inverted Gap-Coupled Coplanar rectangular patch antenna (IGCC). The use of an air-filled dielectric substrate in the design is to increase the patch bandwidth and its radiation efficiency while the application of a top-loaded dielectric substrate (superstrate) will increase the gain of the patch, in addition to protecting the patch from the environmental effect. In this design, the dimension of each coupled patch is 30 × 17 mm and 32 × 9 mm respectively, separated by a gap of 7 mm in width, giving an overall patch dimension of 33 × 32 mm. The thickness of the air filled substrate is 8 mm and the radius of each shorting pin is 1 mm. The feed point of the antenna is located along the centre axis between the two shorting pins. In this design, the Cuclad® UL1217 dielectric material with $\varepsilon_r = 2.17$ and h = 0.508 mm layer is used for the superstrate layer.

3.2 Finite Ground Plane FS-PIFA

Figure 7 shows the design configuration of FS-PIFA. Our design is similar to He and Zhu [5] except with the implementation of a finite ground plane, hence called Finite ground plane FS-PIFA (FFS-PIFA). In this implementation, the dimension of the antenna is 33 × 32 × 6.5 mm with a ground plane size of 40 × 60 mm. The patch area and the ground plane sizes are chosen to be the same as the IGCC antenna for comparison purpose. The thickness of the strip conductor and the shorted wall are set to be 1 mm. The orientation and placement of the FFS-PIFA in this design has been optimised for better impedance bandwidth and its consideration for handset use.

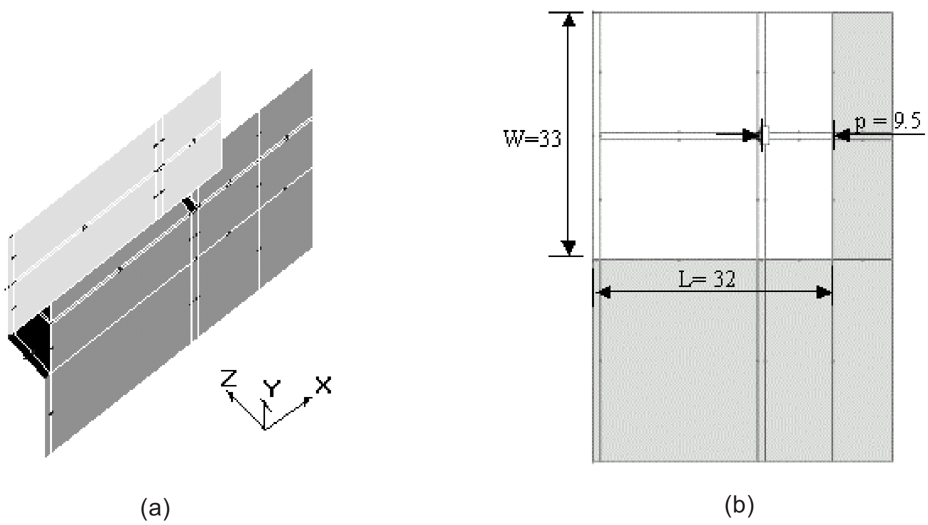


Figure 7 Configuration of the FFS-PIFA (a) 3D view and (b) top view

4.0 MEASUREMENT AND SIMULATION RESULTS

In this work, both the IGCC and FFS-PIFA are simulated using IE3D but only the IGCC antenna is fabricated using PCB techniques. Figure 8 shows the fabricated IGCC antenna. The antenna is supported by nylon spacers with an attach Perspex to hold the antenna for measurement. The IGCC antenna is measured in the open field using the Agilent E4403B Spectrum Analyzer, E4436B Signal Generator, E8358A PNA Network Analyzer, and a standard gain log-periodic antenna TDK LPDA-0803.

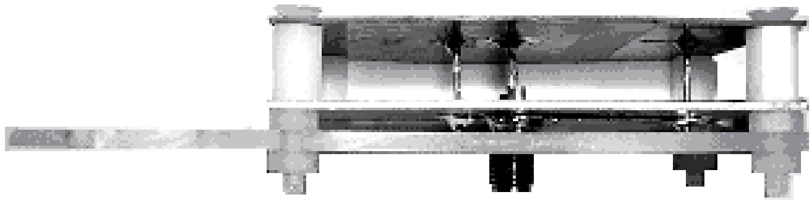


Figure 8 Fabricated IGCC with an attached Perspex plane

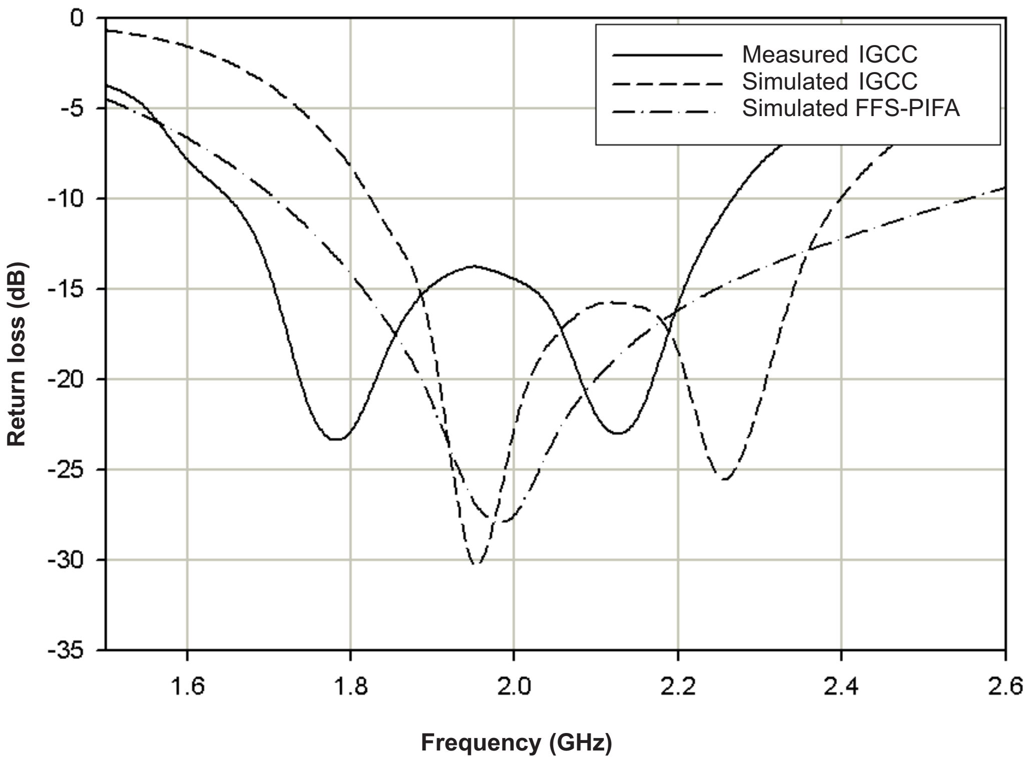


Figure 9 Return loss for IGCC and FFS-PIFA

Table 3 Comparison between IGCC and FFS-PIFA

Antenna design	**Frequency range / GHz [Bandwidth (MHz), %]**		**Resonant frequency / GHz**	**Gain /dBi**
	RL10	**RL15**		
IGCC	Simulated: 1.825 - 2.4 (575, 27.2) Measured: 1.64 -2.253 (613, 31.5)	Simulated: 1.875 - 2.34 (465, 22.1) Measured*: 1.65 - 2.21 (563, 29.0)	Simulated: 1.95/2.25 Measured: 1.79/2.13	Simulated: 4.0 Measured: 4.0
FFS-PIFA	1.7 - 2.52 (820, 38.9)	1.82 - 2.22 (400, 19.8)	2.0	4.0

Note: *signifies measurement for RL14

Figure 9 shows the simulated return loss of the designed FFS-PIFA and IGCC antennas. The fractional bandwidths for IGCC is 28.2% at RL10 and 23% at RL15 and for FFS-PIFA, the fractional bandwidth is 40.1% at RL10 and 19.6% at RL15. The patch dimensions for both the antennas are 33 × 32 mm with a ground plane size of 40 × 60 mm. The designs employed air filled dielectric substrate to increase the bandwidth and radiation efficiency similar to the designs employed by [5] and [6]. For the IGCC and FFS-PIFA the separation between the conducting plane and the ground plane is 8 mm and 6.5 mm respectively. As shown in Figure 9, the RL10 bandwidth for FS-PIFA is 22% wider than that of the IGCC. However, at RL15, the bandwidth for IGCC is 3.6% better than FFS-PIFA because of its dual resonance characteristic. The maximum gains for both antennas are 4 dBi. Measured data at RL10 bandwidth for IGCC is 1.65 - 2.27 GHz (31%), a 0.15 GHz offset from simulated results with maximum achievable gain of 4 dBi. Table 3 summarizes the measurement and simulation results of the designed antennas.

Figure 10 shows the simulated and measured E- and H-plane radiation patterns for the IGCC antenna. For the E-plane, the measured and simulated copolar patterns differ slightly at both resonant frequencies (1.8 and 2.15 GHz). However, the measured E-plane crosspolar patterns exhibit disoriented patterns. At 2.15 GHz, the E-plane crosspolar pattern increases by about 10 dB compared to the pattern at 1.8 GHz. As for the H-plane, the simulated and measured copolar patterns are similar, but the crosspolar patterns are relatively high. Figure 10 (c) gives the E-total patterns for both frequencies at phi angles of 0° and 90°. As shown in this figure, for phi = 0°°, the radiation pattern has a smaller lobe towards the user side.

5.0 DISCUSSION

We have presented two improved designs for small, compact, and broadband handset antennas for 3G applications, the Inverted Gap Coupled Coplanar Patch antenna

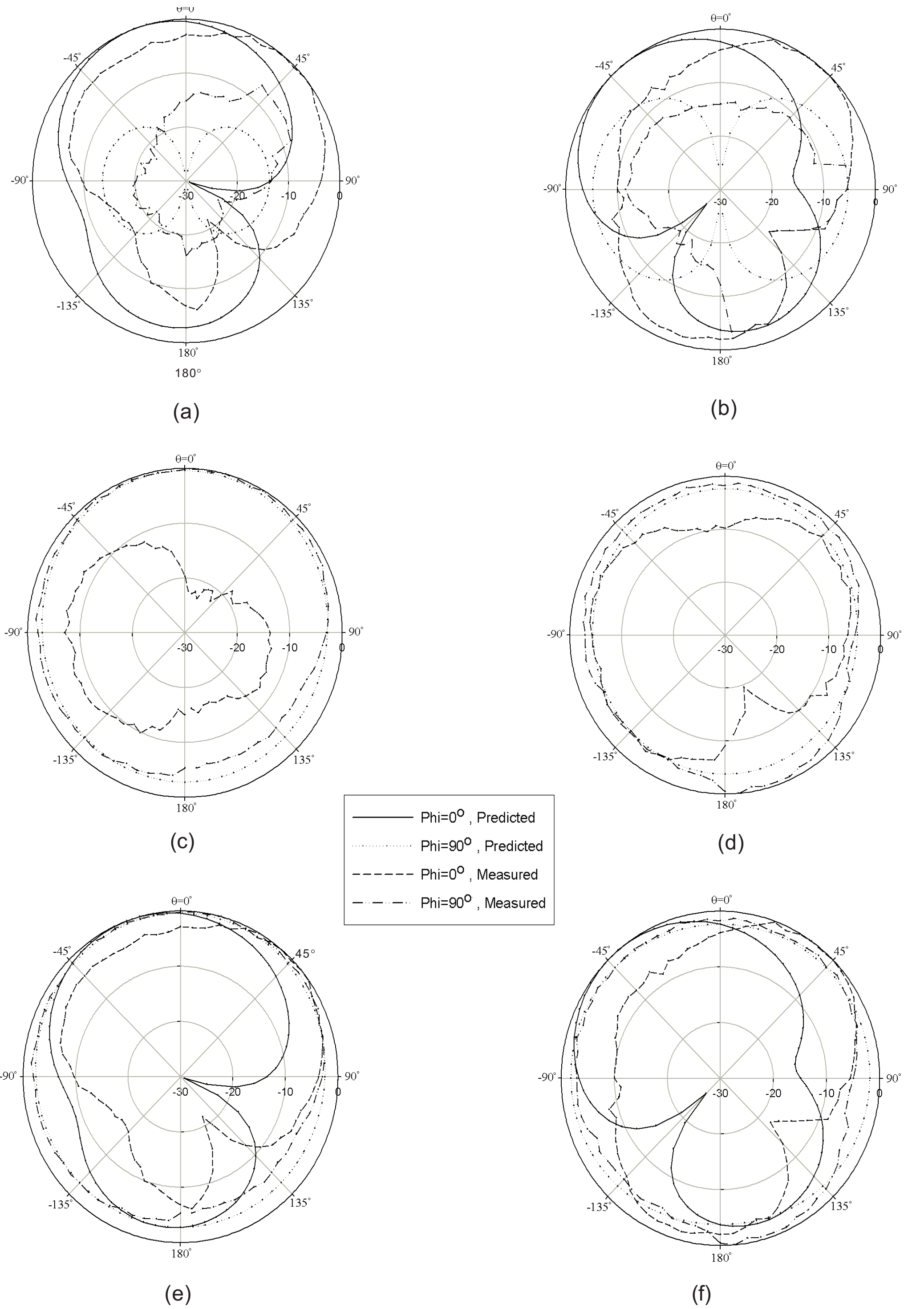


Figure 10 Far-field radiation patterns for IGCC (a) E-plane at 1.8 GHz, (b) E-plane at 2.15 GHz, (c) H-plane at 1.8 GHz, (d) H-plane at 2.15 GHz, (e) E_{total} at 1.8 GHz and (f) E_{total} at 2.15 GHz.

(IGCC) and Finite Full-shorted Planar Inverted-F antenna (FFS-PIFA). Simulation results are given for both designs and measurement results are given for the fabricated IGCC. The design concepts are adopted from Wang *et al*. [6] and He & Zhu [5] but with improvements in terms of fractional bandwidth and compactness.

In Section 2.0, the advantages of microstrip-based antenna designs for handset applications are clearly illustrated. As in Table 2, we notice a large ground plane size is needed for the linear external antennas, e.g. DRA and sleeve due to their inherent need of an infinite ground plane. Microstrip antennas, for example FS-PIFA has better current concentration on the antenna itself giving better independency from the ground plane size. Apart from its small dimensions in both antenna and ground plane at microwave frequencies, microstrip antennas also provide good aesthetics design and the required effective radiation pattern that is directed away from the user's head and hand, thus giving small Specific Absorption Rate (SAR). An apt solution to the radiation effects concern of handset users.

A long list of PIFA designs and discussions can be found in open literature especially for handsets. FS-PIFA is derived by using a shorting wall of the same length as the width of a PIFA, hence giving a broad impedance bandwidth. We noticed that the resonant frequency varies as the probe moves along the centre axis, and as the probe moves closer to the shorting wall, the impedance bandwidth will increase exponentially.

A comparison between He & Zhu's infinite FS-PIFA [5] and our finite FS-PIFA with reference to Table 4 shows that a finite ground plane does significantly affect the impedance bandwidth of the antenna. Our FFS-PIFA, gives approximately twice the bandwidth of He & Zhu's FS-PIFA with a 20.6% reduction in antenna volume and a decrease in ground plane size of about 89%. This account has been speculated by He & Zhu [5].

Table 4 Comparison between FFS-PIFA and HE & ZHU for FS-PIFA

Antenna design	Dimensions / mm length × width × thickness (volume/cm^3)	RL10 frequency range / GHz bandwidth (%)	Gain / dBi
FFS-PIFA	(a) 32 × 33 × 6.5 (6.86) (b) 60 × 40 (24)	1.7 – 2.52 (40.1)	4
He & Zhu [5]	(a) 36 × 40 × 6 (8.64) (b) 160 × 140 (224)	1.91 – 2.18 (25.0)	4

Dimensions: (a) Antenna
(b) Ground plane

Gap coupling two patches in a gap-coupled patch antenna increases its bandwidth than that of a single patch, but this inherently increases its lateral size. On the other hand, introducing a shorting pin along the centre y-axis of each gap-coupled patch can reduce its lateral size [8]. For this geometry, the coupling along the radiating edges of the two patches creates two resonant frequencies where the lower and higher resonance are determined by the driven patch and overall patch area respectively [6].

The application of a top-loaded substrate on the conducting patch as in the IGCC design decreases the resonant frequency [9]. This in effect allows further reduction in lateral size without compromising the bandwidth. A 29% of antenna volume reduction with respect to [6] has been achieved in our IGCC design (Table 5). The superstrate layer with $\varepsilon_r = 2.17$ was chosen in our design since it is sufficient to cover the IMT-2000 band. Unlike the FFS-PIFA where impedance bandwidth and resonance can be both adjusted by optimising the probe position along the centre axis, this technique only affects the resonant frequency for the IGCC.

H-plane cross polarization for the IGCC as shown in Figure 10 is relatively high, similar to the results of [6] and [8], but this is not a major concern for mobile cellular handset application since most of these fields will diffract of the edges of a small finite ground plane within the handset [8].

Table 5 Comparison between IGCC and Wang *et al.* [6] for gap-coupled coplanar rectangular patches

Antenna design	Dimensions / mm length × width × thickness (volume/cm^3)	RL10 resonance f_1/f_2 (GHz) bandwidth (%)	Gain / dBi
IGCC	(a) 32 × 33 × 8 (8.45) (b) 60 × 40 (24)	1.95/2.25 (28.2)	4.0
Wang *et al.* [6]	(a) 33 × 36 × 10 (11.88) (b) 90 × 40 (36)	1.92/2.06 (20.0)	4.0

Dimensions: (a) Antenna design
(b) Ground plane

6.0 SUMMARY

A number of third generation handset antenna designs had been reviewed, discussed and compared in this paper. Two improved designs based of gap-coupled patch antenna and FS-PIFA, i.e. the IGCC and FFS-PIFA have been described and the results showed that the antennas are promising for IMT-2000 handset application. Measured IGCC gave an impedance bandwidth of 27.5% at VSWR<1.5 @ 1.95 GHz centre frequency and with the achievable gain of 4 dBi. The dimension of the IGCC is 32 × 33 × 8 mm (8.45 cm^3) for the antenna and 60 × 40 mm (24 cm^2) for the ground plane.

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