Multiband Fractal PIFA (Planar Inverted F Antenna) for Mobile Phones

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Abstract— **A novel Fractal planar inverted F antenna F-PIFA) based on the self affinity design is presented in this paper. The procedure for designing a Fractal Planar Inverted F Antenna is explained and the 2nd iteration of Sierpinski Carpet is chosen as an antenna for mobile phones. The F-PIFA has a total dimension of 27 mm x 27 mm and is designed and optimized to receive GSM (Global System for Mobile Communication) and UMTS (Universal Mobile Telecommunication System) and HiperLAN (High Performance Radio LAN). The frequency ranges are from 1900 MHz to 2100 MHz, 1885 to 2200 MHz for 3G and 4800 MHz to 5800 MHz for HiperLAN respectively. The antenna covered the GSM, UMTS and HiperLan frequency ranges with -6dB return loss and has an almost omni-directional radiation pattern. This antenna has been tested using a mobile phone model and the performance met all the criteria for a mobile phone application.**

I. INTRODUCTION

In the past, the common mobile phone antennas were the whip and monopole. Conventional monopole and whip antennas are simple, inexpensive with omni-directional pattern and gain that are suitable for mobile application. The design remained relatively large compared to the handset itself, and lacked shielding mechanisms. However, demand for small size mobile phone devices is increasing, and the requirement that the same mobile phone can operate at different frequency bands is also important. Currently at least five bands are assigned for world-wide mobile services (850, 900, 1800, 1900 and 2100 MHz) and high efficiency is required. These days, many mobile phones also have Bluetooth and Wireless LAN capability. By adding Bluetooth or WLAN at the mobile phone, data transfer can easily be made. Bluetooth or WLAN Communication Systems use frequency range from 2400-2483 MHz, hence the antenna designed must be able to operate in that frequency range.

The Planar inverted-F antenna (PIFA) is currently being used as an embedded antenna in many radiotelephone handsets [1-4]. It is one of the most promising antenna types since it is small and has a low profile, making it suitable for mounting on portable equipment. The planar inverted-F antenna is a microstrip antenna design that shows much promise in dealing with the shortcomings of the λ/4 monopole antenna in mobile communication applications [5-6]. The antenna also has a high degree of sensitivity to both vertically and horizontally polarized radio waves, thus making the Planar Inverted-F Antenna ideally suited to mobile applications. In addition, PIFAs can reduce the possible electromagnetic energy absorption by the mobile handset user's head, because of relatively smaller backward radiation toward the user. [7]

However, PIFA antennas have some disadvantages such as low efficiency, narrow bandwidth and no multiband capability. To overcome these drawbacks, especially narrow bandwidth, and to meet the miniaturization requirements of mobile units, the Fractal PIFA antenna has been proposed to achieve the design of internal compact and broadband microstrip patch antennas. Fractal antennas consist of elements patterned after self-similar designs to maximize the length, or increase the perimeter [8]. These have useful applications in cellular telephone and microwave communications. Furthermore, it is found that a small adjustment of the shape can make it work at the required resonant frequencies [9-11]. At the present time, there is no research into the combination of fractal to PIFA topology. Therefore, this paper proposes PIFA fractals, which can be used as an internal antenna solution with a wideband frequency response. In order to obtain a good fundamental antenna design, the initial studies were carried out theoretically, using CST Microwave Studio simulation software.

II. ANTENNA DESIGN

As mobile phones are becoming smaller with time, it is not feasible for separate antenna elements to be used to facilitate multiband operations. This paper proposes a novel design using a Sierpinski Carpet Fractal antenna as the patch for PIFA that is directly connected with a feed strip and is
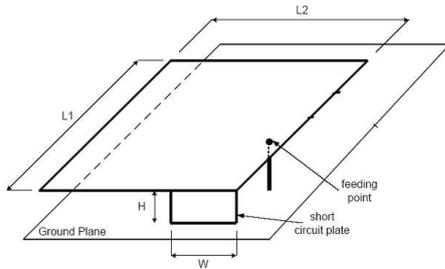
Fig. 1: Geometry of the proposed PIFA

positioned in a plane perpendicular to a ground plane. The antenna is designed using CST Studio Suit 2008 software.

The configuration of the proposed PIFA is shown in Fig. 1. The rectangular radiating patch is printed on Rogers board (Rogers, RO4003C) with epsilon 3.38, and dimensions *L1xL2*. It is located in the centre of a 0.5 mm thick copper plate ground plane with dimensions *LgxWg*. The antenna height *h,* 8mm is filled with an air substrate (ε_r = 1.0). The shorting plate consists of a vertical conducting strip and it is used not only to connect between the patch and ground, but also to support the whole antenna. The 50Ω coaxial probe has a radius of 0.5mm and is fed on the centre line of the rectangular patch. The distance between the feeding position and the shorting plate varies depending on the fractal's iterations. The coaxial feed excites the PIFA's TM10 mode.

The operating frequency of a microstrip patch antenna is inversely proportional to its physical dimensions. For a standard, coax-fed, quarter-wave microstrip patch antenna, the operating frequency can be approximately determined from the length of antenna patch as follows:

$$f = \frac{c}{4(\lambda_d)} \qquad (1)$$

where λ_d is the wavelength inside the substrate (*L1 +L2*). The length *L1* and the width *L2* is subsequently optimized to obtain an improved frequency match by doing an optimization procedure through experimental trials. One method of reducing PIFA size is simply by shortening the antenna by adding a shorting pin. This approach affects the impedance at the antenna terminals such that the radiation resistance becomes reactive but this can be compensated with capacitive top loading. In practice, the missing antenna height is replaced with an equivalent circuit, which improves the impedance match and the efficiency. The ideal fractal antenna is obtained by iterating an infinite number of times. Fig. 2 shows the process of iteration for a Fractal design. The Fractal design is printed on a thin Rogers 4003 substrate of dielectric constant ε_r = 0.813 with thickness = 0.813 mm.
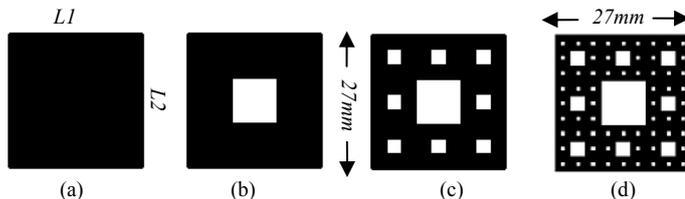

Fig. 2: Dimension for Fractal PIFA (a) 0 Iteration (b) 1ˢᵗ Iteration (c) 2ⁿᵈ Iteration (d) 3ʳᵈ Iteration

III. ANTENNA RESULT AND DISCUSSION

For the antenna results shown in Fig. 3, the measured bandwidths for -9.8dB return loss (2:1 VSWR) are as follows. For iteration 0 the bandwidth is 850MHz (1700-2550MHz), while for the 1ˢᵗ iteration it is 940MHz (1770-2710 MHz). The 2ⁿᵈ iteration gives a bandwidth of 590MHz (1630-2220MHz) in the lower band and 1520MHz (4780-5300MHz) in the upper band. For the 3ʳᵈ iteration, the bandwidth is 500MHz (1700-2200MHz) in the lower band and 400MHz (4830-5230MHz) in the upper band. These results are shown in Table I. It can be clearly seen that the 1ˢᵗ iteration produced a wider bandwidth compared to the other iterations, so the antenna has the capacity to cover GSM 1800, GSM 1900, UMTS 2000. As the number of iterations increases, the bandwidth becomes narrower but excite another resonant frequency at 5GHz. 2ⁿᵈ iteration achieves the bandwidth for 3G UMTS and HiperLAN. Thus, the F-PIFA design stops increasing the number of iterations and starts to study the behavior of F-PIFA at the 2ⁿᵈ iteration.

IV. F-PIFA AS INTERNAL ANTENNA

As the antenna design is completed, the next step is to evaluate the performance of this antenna in a complete phone model. This enables the evaluation of the coupling effects of neighboring object such as the battery, camera, as well as the influence of dielectric materials such as the housing and display screen. The Fractal Planar Inverted F Antenna was integrated and positioned in the space provided on a mobile phone circuit board as shown in Fig. 4. A 2mm x 60mm strip of copper plate was added in front of the F-PIFA in order to excite the 900 MHz resonance. The new Fractal Planar Inverted F Antenna covers the GSM800, 900, 1800 and 1900 MHz bands, together with Wireless LAN 2400MHz for the 802.11b and -g standards and 5000MHz for 802.11a standard.

Fig. 5 indicates the S_{11} result for the F-PIFA with and without the full phone model. The bandwidth of the antenna is calculated at -6 dB return loss by taking its limits at the upper frequency and lower frequency. Due to the fact that integrated antennas with a ground plane are known to radiate about 30% less power into the user's head, the bandwidth for a mobile phone is often calculated at -6dB [12]. It can be seen that when the antenna is covered with the mobile phone, the resonance is shifted to the left. The plastic housing will lower the resonant frequency due to dielectric loading, so the antenna has to be tuned to achieve the correct resonance. Thus the antenna length needs to be reduced slightly to move the resonance up until it resonates in the correct band. The changing resonant frequency can be observed using a network analyzer. This is the way to optimize the antenna.

Tabulated in Tables II and III are the results of efficiency and gain. Based on the results shown, this antenna is suitable for use as an internal antenna for mobile communication. As can be seen, the antenna radiation efficiency with the full phone model is still more than 50%. Even though the measured results with and without the full phone are slightly different, these results are still acceptable due to the minimal degree of difference, which is less than 10%. The degradation

is due to the reflection caused by the mismatch between antenna and its feed line and absorption by circuit and other component inside the handset.

RF energy is coupled into the drive circuit for loudspeaker, cameras and other component contribute losses by coupling energy although it is not close to the antenna. Fig. 6 shows the antenna position during the measurement taken inside an anechoic chamber; while Fig. 7 shows the 3D radiation patterns of the phone with and without a phantom head. Based on the results shown in Fig. 7, the radiation pattern is obviously influenced by the phantom head. The F-PIFA radiation pattern at the first, second and third frequency is almost omni-directional while the E-plane is linear. However, when the planar antenna operates at the fourth frequency which is 5000 MHz, the polarization becomes directional. Therefore the gain at this resonance is higher (3.57 dB) compared to the first and the second resonance as the antenna becomes more directional. Without a phantom head, an omni-directional radiation pattern is produced. However, the overall pattern shows an almost omni-directional radiation pattern, thus it is well suited for mobile phone applications.
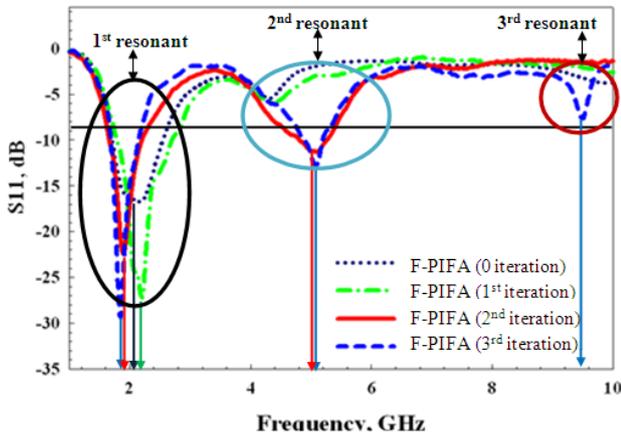

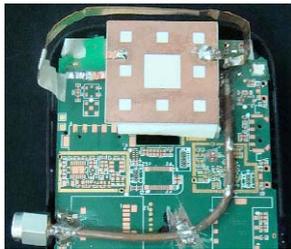Fig. 3: The measured S_{11} result for the designed antenna

Fig. 4: F-PIFA mounted on the candy bar phone.

TABLE I
BANDWIDTH FOR MEASURED OF F – PIFA.

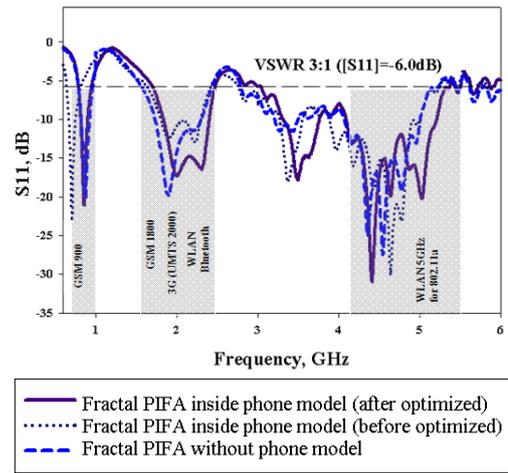| F - PIFA	Frequency Band (MHz)	Bandwidth (BW) (MHz)
0 Iteration	1700-2550	850 (42.5%)
1st Iteration	1770-2710	940 (47%)
2nd Iteration	1630-2220	590 (29.5%)
	4780-5300	520 (10.4%)
3rd Iteration	1700-2200	500 (25%)
	4830-5230	400 (8%)

Fig. 5: F-PIFA S_{11} result

TABLE II
TOTAL EFFICIENTCY RESULTS OF F-PIFA

Frequency (MHz)	Total Efficiency Measured (%)	Total Efficiency Simulated (%)
GSM 900 (824 – 960)	80 – 84	78 - 80
GSM 1900 (1710 – 2170)	80	75 - 78
3G (1885 – 2200)	80	75 -78
WLAN and Bluetooth (2400-2450)	80	78
HiperLAN (4800 - 5800)	72 - 78	68 - 75

TABLE III
MEASURED AND SIMULATED GAIN RESULTS OF PIFA

Frequency (MHz)	Gain Measured (dB)	Gain Simulated (dB)
GSM 900 (824 – 960)	1.5 -1.8	2
GSM 1900 (1710 – 2170)	2 – 2.6	2.6 - 3
3G (1885 – 2200)	2 – 2.6	2.6 - 3
WLAN and Bluetooth (2400-2450)	2.8 -3	3
HiperLAN (4800 - 5800)	2.7 - 3.6	3.2 - 3.67

TABLE IV
MATERIAL PARAMETERS OF THE SAM PHANTOM.

SAM Material	Frequency [GHz]	Relative Permittivity (εr)	Conductivity [S/m]	Density [kg/m^3]
SAM Liquid	2.0	40.0	1.40	1000
SAM Shell		3.5	0	1000

Fig. 6: Position of the antenna during measurement in an anechoic chamber.

A final test for the mobile phone is to evaluate it in the presence of a human body with particular emphasis on the human head in terms of a unit referred to as specific absorption rate (SAR). The SAR value used in the assessment of mobile phones measures the amount of EM (ElectroMagnetic) energy absorbed by biological tissue. The SAR value is obtained by measuring the electric field in the simulated human tissues in close proximity to the device and is calculated ebove equation (2) [13]. Table IV shows the electrical properties of the brain.

$$SAR = \frac{\sigma}{\rho}|E|^2 = \frac{J^2}{\rho\sigma}[W/kg] \qquad (2)$$

E: rms value of the electric field strength in the tissue [V/m];
J: Current density [A/m];
σ: conductivity of body tissue [S/m];
ρ: density of body tissues [kg/m3]

Fig. 8 shows the SAR calculation using a SAM Phantom Head. The position of the PIFA mounting headset is tilted by 30º and is 0.5 mm away from the SAM Phantom Head. The SAR is calculated over 10 grams of the human tissue mass. The antenna is facing in the opposite direction from the human head. Fig. 7 shows that the PIFA radiation plots have a high Front to Back Ratio, which indicates a low SAR value of less than 2 W/kg. According to Swiss Regulations, the international SAR limit recommended for mobile phones is 2.0 watts per kilogram (W/kg) over 10 grams of tissue. For the United States Government, the SAR level is required to be at or below 1.6 W/kg taken over a volume of 1 gram of tissue. However, SAR depends on the frequency of operation, antenna type and distance between the antenna and the human body. It increases as the frequency of operation increases and this is due to the penetration depth and the fact that at higher frequencies, more power is absorbed on the surface. Table V indicates the value of the maximum SAR that is simulated using CST software.
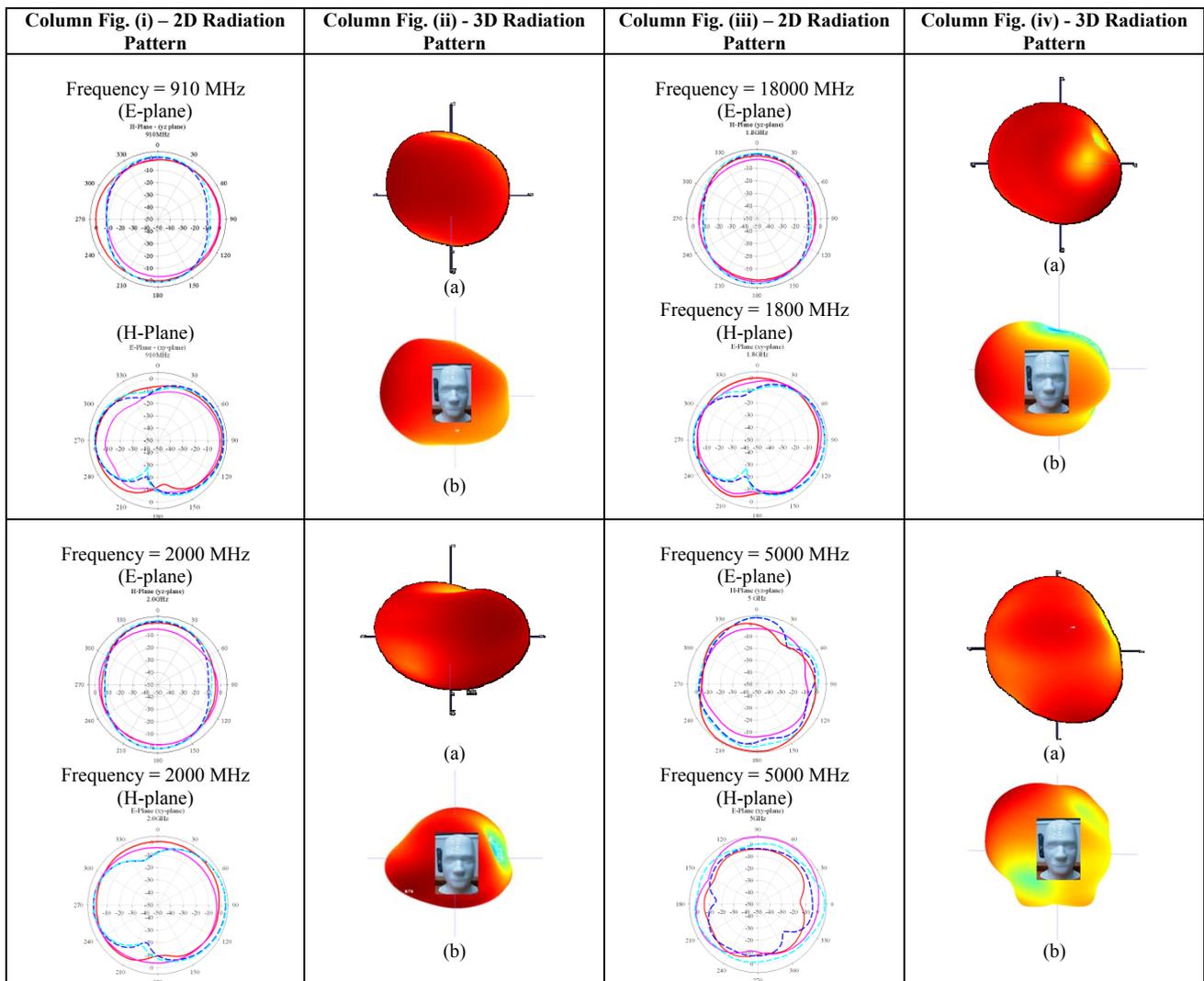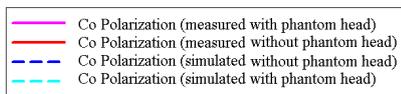

Fig. 7: 2D and 3D radiation pattern of F -PIFA. (a) 3D radiation pattern without phantom head, (b) 3D radiation pattern with phantom head

TABLE V
SAR RESULTS AT DIFFERENT OPERATING FREQUENCIES

Freq (GHz)	SAR (W/kg)
0.9	0.255
1.6	0.817
2	0.996
2.5	1.08
4.8	1.47
5	1.55
5.8	1.59
1.6	0.996


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Type         SAR (rms)
Monitor      SAR (f=2) [1] (10g)
Maximum-3d   0.995761 W/kg at 71.5233 / 113.797 / -133.188
Frequency    2
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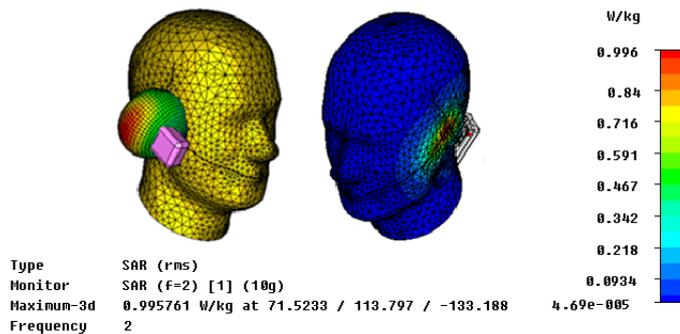
Fig. 8: Simulated SAR with SAM Phantom Head using CST simulation tools

V. CONCLUSION

The presented PIFA antenna covers the required operating frequency range for mobile phone application which are GSM 900 MHz, 1800 MHz, UMTS, WLAN and HiperLAN. An additional strip of copper is added to excite a low frequency resonance for GSM900. This antenna has also been applied in mobile phones and the 3D radiation patterns, gain and efficiency were measured using an anechoic chamber and were discussed. It is observed that the radiation pattern is omni-directional, thus, this antenna is extremely suitable for applications in mobile communication devices. Its sensitivity to both the vertical and horizontal polarization is of immense practical importance in mobile cellular communication applications because the antenna orientation is not fixed. This satisfies the requirements in wireless communication.

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