Compact multiband Planar Inverted F Antenna (PIFA)

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A small volume multiband planar inverted-F antenna (PIFA) with an electrically unconnected multi-strip ground plane is presented. The proposed antenna is low cost and easily fabricated, operates over a wide range of mobile communication standards with 3.57:1 and 2.32:1 VSWR at 0.89–2.48 and 3.1–10.6 GHz, respectively.

Introduction: Planar inverted-F antennas (PIFAs) are suitable for built-in handheld wireless equipment owing to their low profile [1]. Additionally, broadband antennas are desired since an increasing number of standards have become operative in recent years; such as GSM 900 (8.9–9.6 GHz), GSM 1800 or DCS (1.71–1.88 GHz), DECT (1.88–1.90), PCS (1.85–1.99 GHz), UMTS (1.9–2.2 GHz), WLAN (2.4–2.48 GHz), HiperLAN-2 (5.15–5.35, 5.47–5.725 GHz) and UWB (3.1–10.6 GHz). Conversely, PIFAs that are constructed over a standard continuous ground are narrowband [2]. A novel compact PIFA antenna realised using an electrically unconnected multi-strip ground plane is presented. The antenna achieves multiband operation at a measured 3.57:1 and 2.32:1 VSWR for the 0.89–2.48 and 3.1–10.6 GHz bands, respectively. Gains.22.82 dBi and omnidirectional-like measured radiation patterns are obtained.

Antenna design: Fig. 1 depicts the geometry of the proposed PIFA antenna. It consists of two etched planes separated by a substrate; the upper plane A, a radiating element incorporating meandering slots, the lower plane B, and an electrically unconnected multi-strip ground plane of 32.82 × 15.52 mm^2. Both planes are interconnected through a shorting wall C of 15.52 × 6.4 mm^2. A consists of a parasitic element A_a which couples with A_b and A_c. These are both connected to element Ad which is used for feeding purposes. B consists of 11 identical strips, B_a, of 15.52 × 2.47 mm2 each separated by a gap, B_b, of 0.6 mm. B has overall dimensions of 32.82 × 15.52 mm^2. Wall D of dimensions 12.48 × 3 mm^2 is electrically connected to A and is capacitively loaded by B. The FR4 substrate has a relative permittivity, εr, of 4.6 and height, h, of 6.4 mm. A solid ground plane, E, with a volume of 90 × 50 × 0.8 mm^3 (determined from a typical mobile handset PCB size) is optionally used. E connects to the PIFA via wall C at its half height line and causes an enhanced matched bandwidth (BW) for the lower resonance at 1.8 GHz. The antenna is fed at the upper plane element Ad, using the inner core of a 50 V SMA connector; the outer shield of the connector is attached to the shorting wall, C.

Multi-strip ground plane: The effects of PIFA elements over EBG/PBG materials and over protruded ground planes have been studied [2, 3]. The effects of a slotted PIFA antenna over an electrically unconnected multi-strip ground plane are presented in contrast to a reference PIFA. The reference antenna has the same feed and top conductor, but is mounted over a continuous ground plane with the same outer perimeter as the slotted ground.

The reference PIFA is designed to cover the UWB band as depicted in Fig. 2 and has a total volume of 32.82 × 15.52 × 6.4 mm^3, which equals the volume of the proposed PIFA. This multi-strip plane is demonstrated to perform as a high impedance surface (HIS), hereafter called frequency selective surface-strips or FSS-strips. The FSS-strips do not present the 1808 reflection phase cancellation encountered by a normally incident plane-wave at a perfect electric conductor (PEC). A series of simulations performed, Table 1, have shown that the FSS-strips can be adjusted in width and length for determining the best constructive phase shift to incident plane-waves. Using Zeland IE3D, parametric variation studies of the strip width w were carried out in steps of 0.30 mm. The FSS-strip thickness t and length l were held constant at 0.035 and 15.52 mm, respectively (the strip dimensions are defined in Fig. 1). Increasing width w caused the gap Bb to decrease and the corresponding simulated effect on antenna BW is shown in Fig. 2. An optimum value of

2.47 mm was found to give best S11 BW at 5.4 GHz which resulted in inter-strip spacing, Bb, of 0.6 mm. To test the frequency response of the frequency selective ground plane a microstrip line was mounted above an FSS-strip ground with optimised w, l and t dimensions as listed above. The measured transmission coefficient (S_{21}) had a stop band centred on 5.4 GHz with a 210 dB bandwidth of 22% relative to the centre frequency. The S21 of the final FSS-strip structure is shown in Fig. 2, where a lowpass filter (LPF) response with bandstops at ~5.5 and ~10.5 GHz can be observed. The manual optimisation procedure also maintained a match at 0.9 GHz increases BW by 100 MHz and reduces the operational frequency of the PIFA by 500 MHz. While the FSS-strips benefit BW at the 5.4 GHz resonance, it also adds BW to the overall S_{11} antenna response (Fig. 2). Owing to reduction of the operational frequency of the proposed antenna with regard to the traditional PIFA, there seems to be potential for antenna size reduction.

Comparison of large continuous and frequency selective ground planes: Fig. 2 shows measured reflection coefficients (S_{11}) for the proposed PIFA using FSS-strips compared with the reference antenna with a continuous conducting ground. Also shown is the S_{11} curve for the proposed slotted PIFA connected to a large continuous ground plane, E according to Fig. 1a. The results show an antenna with better matching over a wider frequency range, in the 0.89–0.96, 1.71–2.48, 3.1–5.725 and 8.1–10.6 GHz bands for the proposed antenna over the traditional PIFA. Adding E causes the resonance frequencies of the slotted PIFA to fall at the cellular bands. With E present, the measured S11 ~ 25 dB (VSWR ~ 3.57:1) BWs of the new slotted
PIFA are 12 and 49% at 900 MHz and 1.8 GHz, respectively. With S_{11} defined to be ~ 28 dB (VSWR ~2.32:1) the BW is 110% for the 3.1–10.6 GHz FCC ultra-wideband (UWB). This indicates that the proposed antenna is sufficient to encompass bands for the GSM 900, GSM 1800 (also called DCS), DECT, PCS, UMTS, WLAN (Bluetooth), HiperLAN-2 (including WiMAX) and UWB communication standards.

Measured far-field radiation patterns for the relevant bands are depicted in Fig. 3. The patterns are essentially omnidirectional, with some front-to-back ratio increase at the upper bands. Simulated directionality is given in Table 2 which shows similar directionality for both the traditional and the proposed PIFA, however, there is a slightly higher directionality for the traditional PIFA. There is also a slightly higher front-to-back ratio of _0.05 dB in the 5.15–10.6

GHz band range for the proposed PIFA, and 0.5 dB in the 0.9–5.15 GHz for the traditional PIFA in the elevation plane; no significant variation is encountered in the azimuth. This is because traditional PIFAs use continuous ground planes (in essence reflectors); the plane of the traditional

PIFA had the same overall dimension (32.82 _ 15.52 mm2) radiator top layer of the proposed antenna. The maximum simulated gains of the proposed antenna and the traditional PIFA are given in Table 3.

As expected, the FSS band-stop which results using the slotted ground plane improves gains in the 5.15–10.6 GHz range. The higher gains presented indicate that the FSS-strips have alleviated the field cancellation caused by the 1808 reflection phase encountered by a normally incident plane-wave at a perfect electric conductor (PEC). The difference between directivity and gain (efficiency) is the result of a physically compact antenna.

Conclusion: A compact multiband PIFA type antenna with a ground plane incorporating an FSS-strip structure proficient for mobile equipment applications in the GSM 900, DCS, DECT, PCS, UMTS, WLAN, HiperLAN-2 and UWB bands has been proposed and investigated. The FSS-strips incorporated into the ground plane offer an improved response over a traditional PIFA. The front-to-back ratio of the new antenna might be seen as indicating offering reduced SAR benefits for head absorption.

References

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3 Zhao, Y., Hao, Y., and Parini, C.G.: ‘Radiation properties of PIFA on UC-EBG substrates’, Microw. Opt. Technol. Lett., 2005, 44, (1), pp. 21–24

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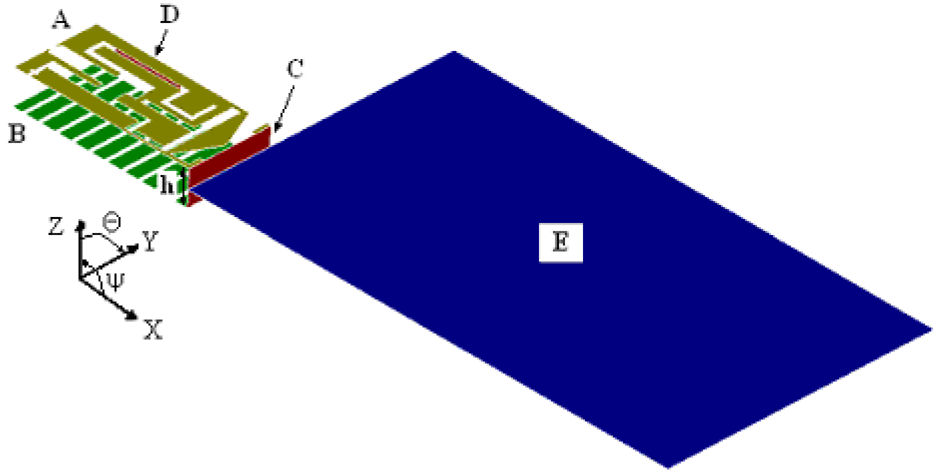
Figure captions:

Fig. 1 Geometry of the proposed PIFA
a isometrical view
b unfolded planar view of conductors

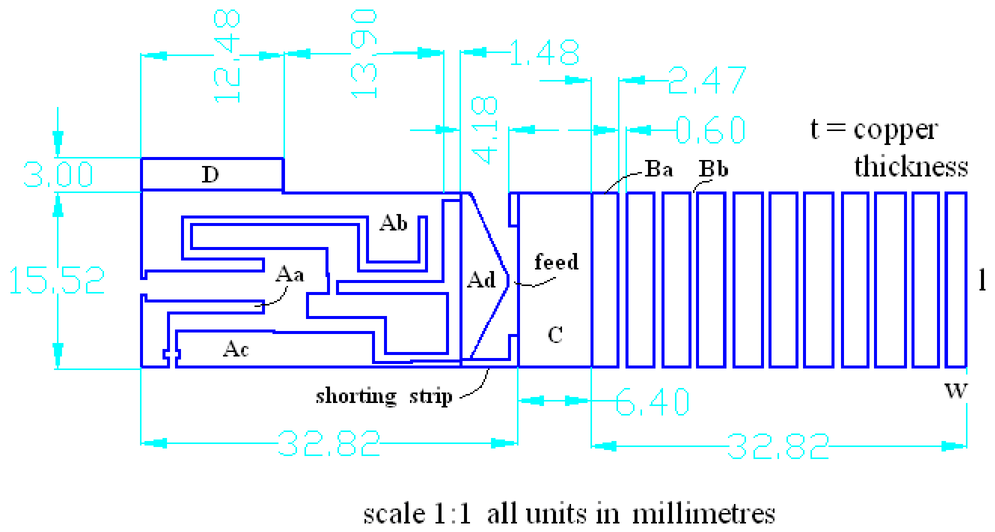
Fig. 2 Reflection coefficient (S11) of the PIFA
- - - - traditional PIFA with PEC
—— proposed PIFA
– – – proposed PIFA with added ground plane

Fig. 3 Radiation patterns of the proposed PIFA
a co-pol, azimuth, y-z plane
—— 0.9 GHz
- - - - 2.5 GHz
······ 4.4 GHz
– · – 5.7 GHz
– ·· – 7.9 GHz
b co-pol, elevation, x-z plane
—— 0.9 GHz
- - - - 2.5 GHz
······ 4.4 GHz
– · – 5.7 GHz
– ·· – 7.9 GHz

Figure 1

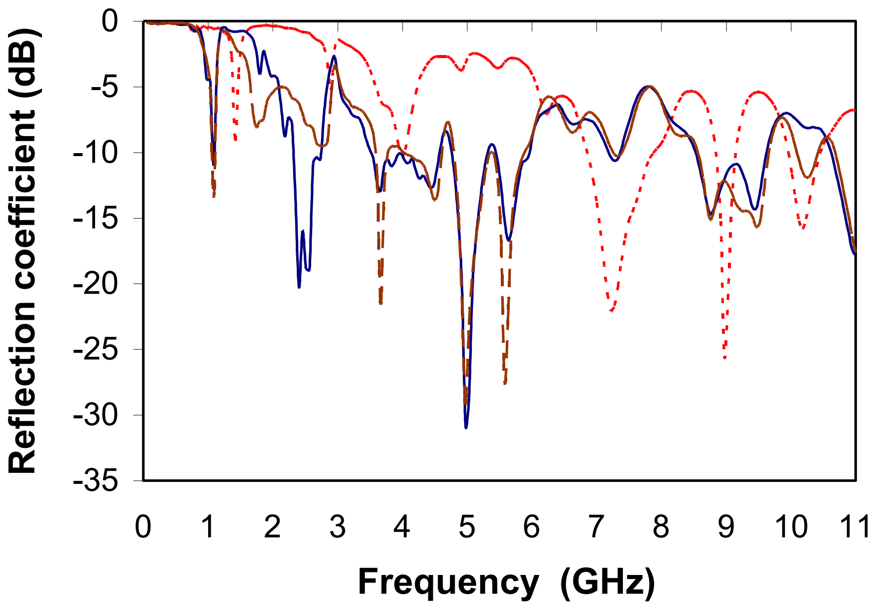

A
D
C
B
h
Z
Θ
Y
Ψ
X
E

(a)


12.48
13.90
1.48
2.47
4.18
0.60
t = copper
thickness
3.00
D
Ba
Bb
Ab
15.52
Aa
Ad
feed
l
C
Ac
shorting strip
W
6.40
32.82
32.82
scale 1:1 all units in millimetres

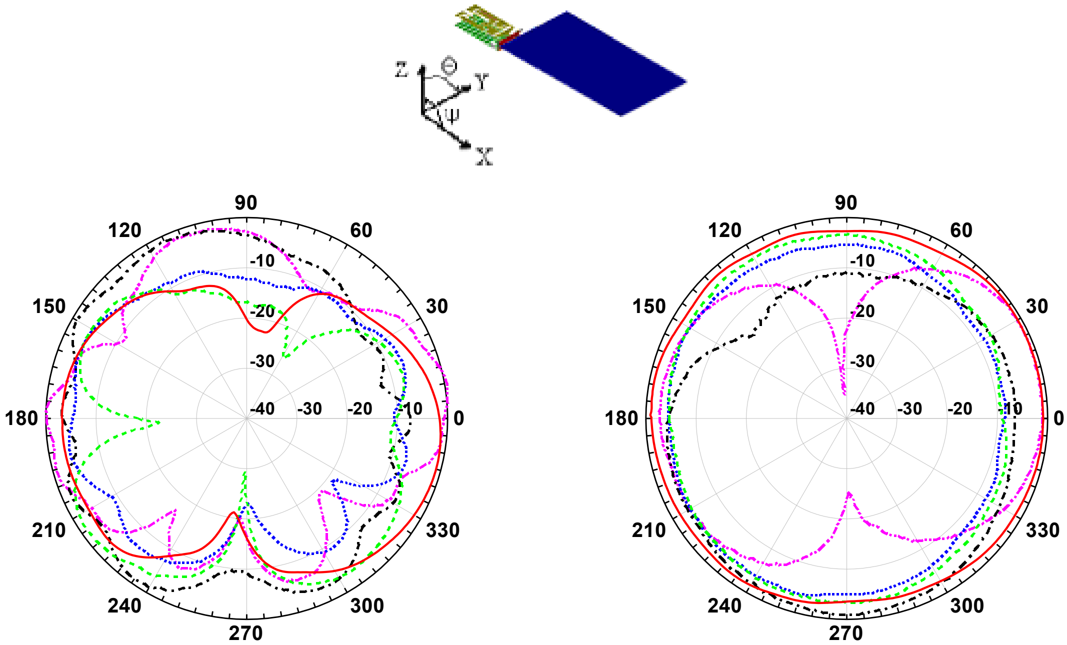
(b)

Figure 2



Reflection coefficient (dB)
0
-5
-10
-15
-20
-25
-30
-35
0
1
2
3
4
5
6
7
8
9
10
11
Frequency (GHz)

Figure 3


Z
Θ
Y
Ψ
X
90
120
60
150
30
180
0
210
330
240
300
270
-10
-20
-30
-40
-30
-20
-10

a

b

Table 1

Frequency (GHz)	Proposed PIFA Directivity (dBi)	Traditional PIFA Directivity (dBi)
0.9	3.33	2.39
1.8	4.15	5.77
1.9	4.31	5.93
2.1	4.96	6.34
2.5	4.90	6.46
4.4	7.23	7.30
5.2	7.03	7.04
5.4	7.18	7.18
5.7	6.32	7.72
7.9	6.23	6.24

Table 2

Frequency (GHz)	Proposed PIFA Gain (dBi)	Traditional PIFA Gain (dBi)
0.9	0.91	-20.48
1.8	-2.82	-10.66
1.9	-2.25	-9.39
2.1	-1.62	-6.72
2.5	-1.89	0.15
4.4	-2.25	-2.26
5.2	-0.54	-0.88
5.4	+0.38	-0.16
5.7	-2.27	-3.08
7.9	-0.68	-0.69