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Planar Inverted-F Antennas Integrated into Small Multi-Standard Handsets

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Original scientific paper

Three small multi-band planar inverted-F antenna (PIFA) elements are presented. They have been developed to be used in future small multi-standard handsets. Mobile communication (GSM1800, UMTS), wireless local area network (WLAN) (IEEE 802.11b, HiperLAN2) and wireless personal area network (WPAN) (Bluetooth) standards have been envisaged. A double layer structure with an air gap is used, to provide the required large bandwidth. Small ground planes with 100 × 40 mm^2 and 60 × 40 mm^2 are used representing nowadays one piece and two pieces small handsets. Prototypes have been designed, fabricated and tested. Good agreement has been obtained between numerical simulations and experimental results.

Key words: handset, microstrip patch antenna, PIFA, small antennas, multi-standard antennas

1 INTRODUCTION

The need of multi-band antennas has been created mainly by the nowadays overwhelming importance of the mobile communications market and the recent explosion of WLAN and WPAN services. The terminals for 3G mobile communication systems must be 2G compatible. In Europe that means support of, at least, both GSM1800 and UMTS. Furthermore the growing importance of WLAN and WPAN services is already demanding specific attention. Therefore operation with other standards, for instance IEEE 802.11a/b, Bluetooth and HiperLAN2 has to be supported. From the antenna point of view the most challenging terminal is the handset. On top of very tight specifications (bandwidth, radiation pattern, gain, etc.) the antenna has to be compact enough to fit into the small handsets.

This paper describes three PIFA elements developed to be integrated into small future multi-standard handsets. Two of them envisage GSM1800, UMTS and IEEE 802.11b/Bluetooth systems. The third one aims at GSM1800, UMTS and HiperLAN2/IEEE 802.11a systems. The multi-resonance effect is created by the use of an L-shaped slot, two shorting pins and two U-shaped slots, respectively. The antenna configurations have been optimized taking into account a small ground plane. Similar antenna configurations have been recently proposed [1–5] for other combinations of frequency bands or different ground plane sizes.

Antenna prototypes have been designed, fabricated and tested. The good agreement obtained between numerical simulation and experimental results has provided validation of the design procedure.

2 ANTENNA CONFIGURATIONS

Nowadays two main types of handsets are used; single piece handsets with typical dimensions 100 × 40 mm^2 and two pieces handsets. The two pieces of the handsets have typical dimensions 60 × 40 mm^2 and can be folded on top of each other.

The PIFA elements considered in this paper are printed over small ground planes with the dimensions 100 × 40 mm^2 and 60 × 40 mm^2 indicated above. The patches are printed on a 1.575 mm thick Duroid 5880™ substrate ($\varepsilon_r = 2.20$) over an air gap which separates the substrate from the ground plane. The air gap is necessary to increase the (impedance) bandwidth of the antennas. A 50 Ohm coaxial feeding probe is used. Frequency specifications of the standards under consideration are indicated in Table 1.

The PIFA elements have been designed to provide an input reflection coefficient below −6 dB

Table 1 **Frequency specifications**

Standard	Central Freq.	Bandwidth	
	MHz	MHz	%
GSM1800	1795	170	9.5
UMTS	2035	270	13.3
IEEE 802.11b Bluetooth	2442	83.5	3.4
HiperLAN2	5250	200	3.8

and radiation patterns with low directivity in the required frequency bands. As usually in wireless communication system applications no polarisation restrictions have been considered. ENSEMBLE software tool [6] has been used for the simulations.

The geometry of the PIFA element with an L-shaped slot is shown in Figure 1 (dimensions in mm). The width of the L slot is 1.5 mm, and it has a short side with 9.6 mm, and a long side with 21.1 mm. The patch is placed 4 mm below the substrate top border, and it is centred along the short dimension of the ground plane. The air gap is 13 mm thick.

The dimensions of the PIFA element have been chosen to provide operation at the GSM1800, UMTS and IEEE 802.11b/Bluetooth frequency bands (1.710–2.484 GHz) [7].

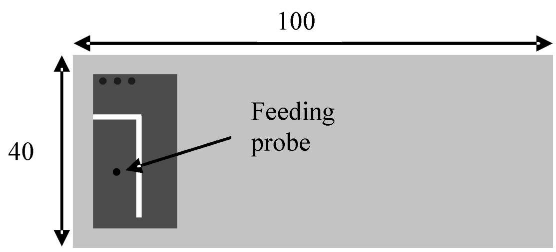

Fig. 1 Geometry of the PIFA element with an L-shaped slot (dimensions in mm)

The geometry of the PIFA element with two coupled shorting pins is shown in Figure 2. In this case the air gap is 10 mm thick. The dimensions of the patch, the location of the shorting pins and the feeding point have been chosen also to provide operation at the GSM1800, UMTS and IEEE 802.11b/Bluetooth frequency bands (1.710–2.484 GHz) [8].

The geometry of the PIFA element with two U--shaped slots is shown in figure 3 (dimensions in mm). The air gap is also 10 mm thick. The dimensions of the patch and of the two U-shaped slots

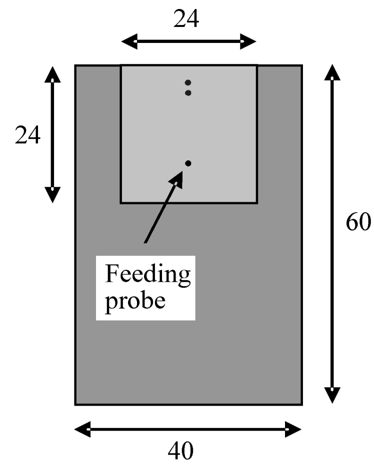

Fig. 2 Geometry of the PIFA element with 2 coupled shorting pins (dimensions in mm)

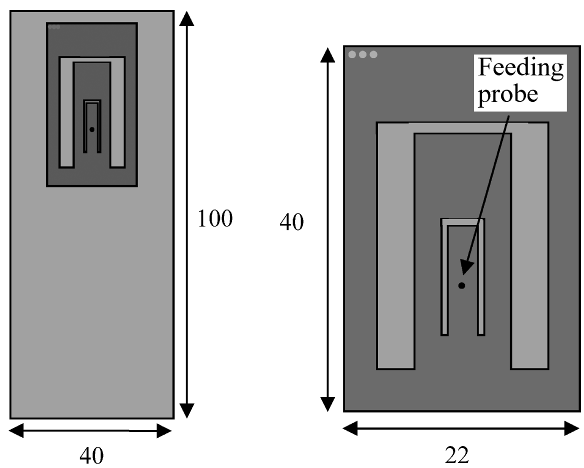

Fig. 3 Geometry of the PIFA element with 2 U shaped slots (dimensions in mm)

have been chosen to provide operation at the GSM1800, UMTS and HiperLAN2 frequency bands (1.710–2.170 GHz and 5.150–5.350 GHz) [9].

3 CURRENT DISTRIBUTION

ENSEMBLE software tool [6] can provide the current distribution on the patch and ground plane metallic surfaces. The current distribution is important for the diagnosis of the antenna operation and physical insight of the radiation mechanism.

The current distribution on the PIFA element with two U-shaped slots is shown in Figures 4, 5 and 6. The results correspond to the centre frequencies of the GSM 1800 (1.795 GHz), UMTS (2.035 GHz) and HiperLAN2 (5.250 GHz), respec-

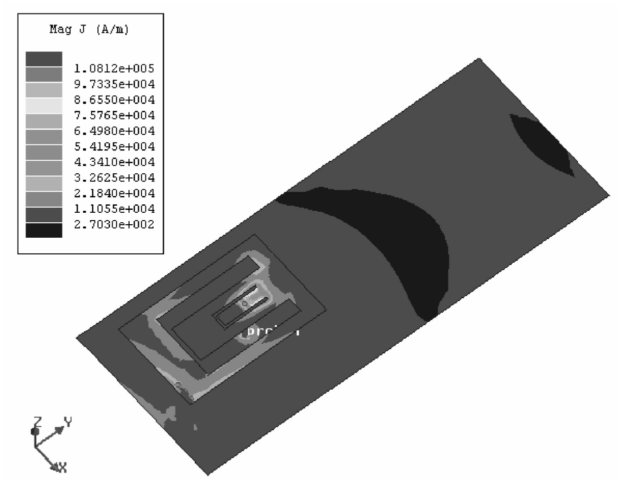

Fig. 4 Current distribution of the PIFA element with an L--shaped slot at 1.795 GHz

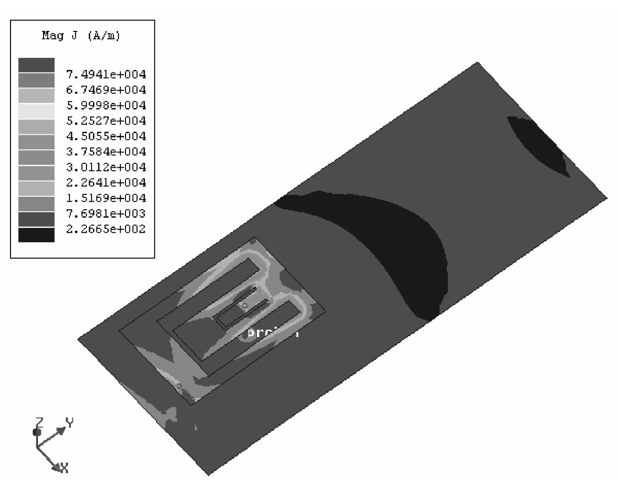

Fig. 5 Current distribution of the PIFA element with an L--shaped slot at 2.035 GHz

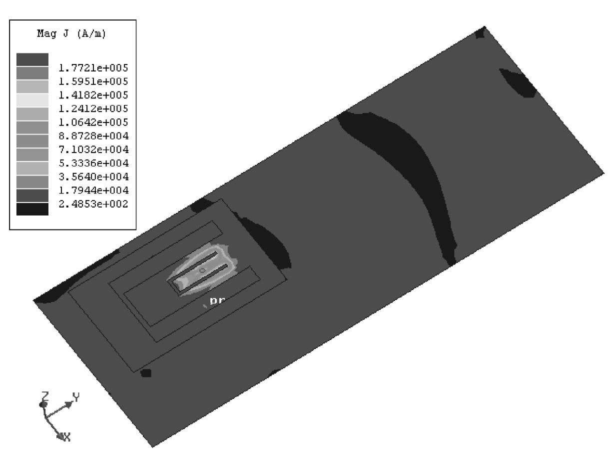

Fig. 6 Current distribution of the PIFA element with an L--shaped slot at 5.250 GHz

tively. The current on the ground plane is very small for all the three frequencies depicted. This is a very important feature because it allows minimisation of the interaction with the user hand. However, as expected, the current distribution shows a different pattern for each of the three frequencies. At 1.795 GHz, the current flows mainly around the patch borders. At 2.035 GHz, the current flows around the borders of the U-shaped external slot. Finally at 5.250 GHz, the current flows almost exclusively around the U-shaped inner slot.

4 EXPERIMENTAL RESULTS

Using conventional photolithography printing circuit technology a prototype of each antenna has been fabricated and tested. Photographs of the antenna prototypes are shown in Figure 7.

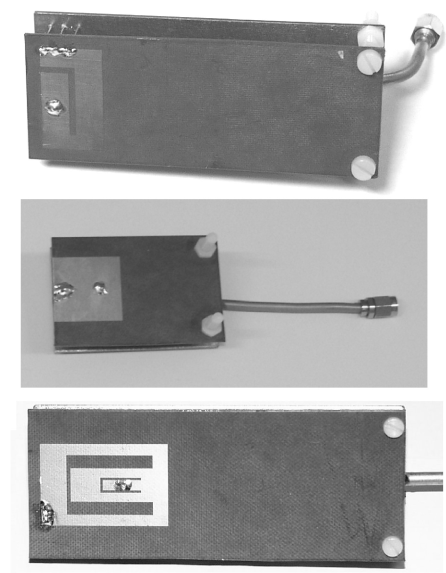

Fig. 7 Photographs of the antenna prototypes

4.1 Input Reflection Coefficient

The input reflection coefficient of the PIFA prototypes has been measured with a vector network analyser. The corresponding results are shown in Figures 8, 9 and 10.

As shown in Figure 8, the S_{11} of the PIFA with an L-shaped slot is below −6 dB (VSWR ≤ 3) in the frequency range 1740–2530 MHz, corresponding to a 790 MHz bandwidth (37 %). There has been a small 30 MHz shift towards higher frequencies. However this shift can be easily compensated by a small translation (around 0.3 mm) of the L-shaped slot.

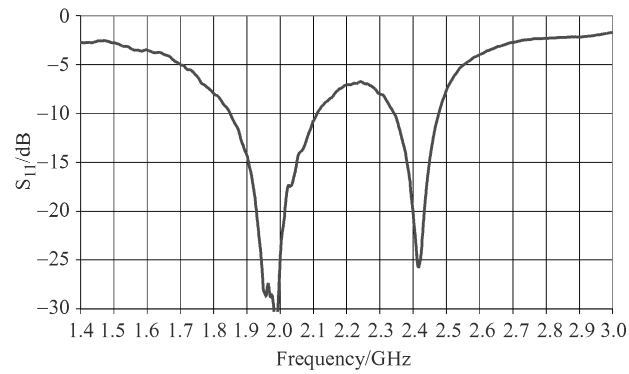

Fig. 8 Measured S_{11} of the PIFA element with an L-shaped slot

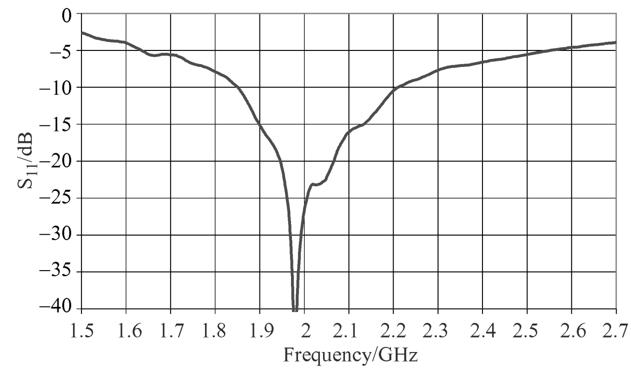

Fig. 9 Measured S_{11} of the PIFA element with 2 coupled shorting pins

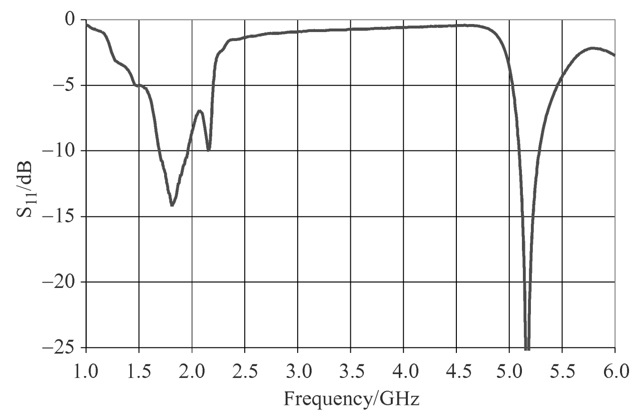

Fig. 10 Measured S_{11} of the PIFA element with 2 U-shaped slots

As shown in Figure 9, for the PIFA with two coupled shorting pins, $S_{11} \leq -6$ dB in the frequency range 1680–2450 MHz (770 MHz or 37.3 % bandwidth). The bandwidth is enough to cover the envisaged standards. However a shift of 33.5 MHz, toward high frequencies, has to be implemented. This can be easily done by decreasing the patch length about 0.4 mm.

As shown in Figure 10, for the PIFA with two U-shaped slots, $S_{11} \leq -6$ dB in the frequency range 1605–2195 MHz (590 MHz or 31.1 % bandwidth) and 5050–5405 MHz (355 MHz or 6.8 % bandwidth), which fulfils completely the bandwidth specifications.

4.2 Radiation Pattern

The far field radiation pattern has been measured in an anechoic chamber. Examples are shown in Figures 11 through 16.

Very similar radiation pattern results have been obtained for the three prototypes at the GSM1800 and UMTS bands. Figures 11 and 12 show the radiation pattern of the PIFA with two coupled shorting pins, and the PIFA with two U-shaped slots, respectively. Moreover, as shown in Figures 13, for the PIFA element with and L-shaped slot, the same type of radiation pattern has been obtained at the IEEE 802.11b/Bluetooth band. As shown in Figure 14, at this frequency (2.442 GHz) the PIFA element with two coupled shorting pins has a very similar radiation pattern.

As shown in Figure 15, a different type of radiation pattern has been obtained, for the PIFA with two U-shaped slots, in the HiperLAN2 band. However the shape is still acceptable if the two orthogonal polarisations are combined together.

The cross-polarization level is quite high for the three PIFA elements. This is usually not a problem in wireless communication applications, especially in urban scenarios, as the multiple reflections and scattering change dramatically the polarisation of the incoming electromagnetic waves.

5 CONCLUSIONS

Three compact multi-band PIFA elements have been presented. They have been developed to be used in the small multi-standard handsets of future mobile communication and WLAN/WPAN systems. Two handset sizes (60 × 40 mm and 100 × 40 mm) and a combination of 2G and 3G mobile communication standards (GSM1800 and UMTS) with two different WLAN standards (IEEE 802.11b and HiperLAN2) have been considered. Three antenna prototypes have been designed, fabricated and tested. Good agreement has been obtained between numerical simulations and experimental results, providing validation of the design procedure, and demonstrating feasibility of the proposed antenna elements.

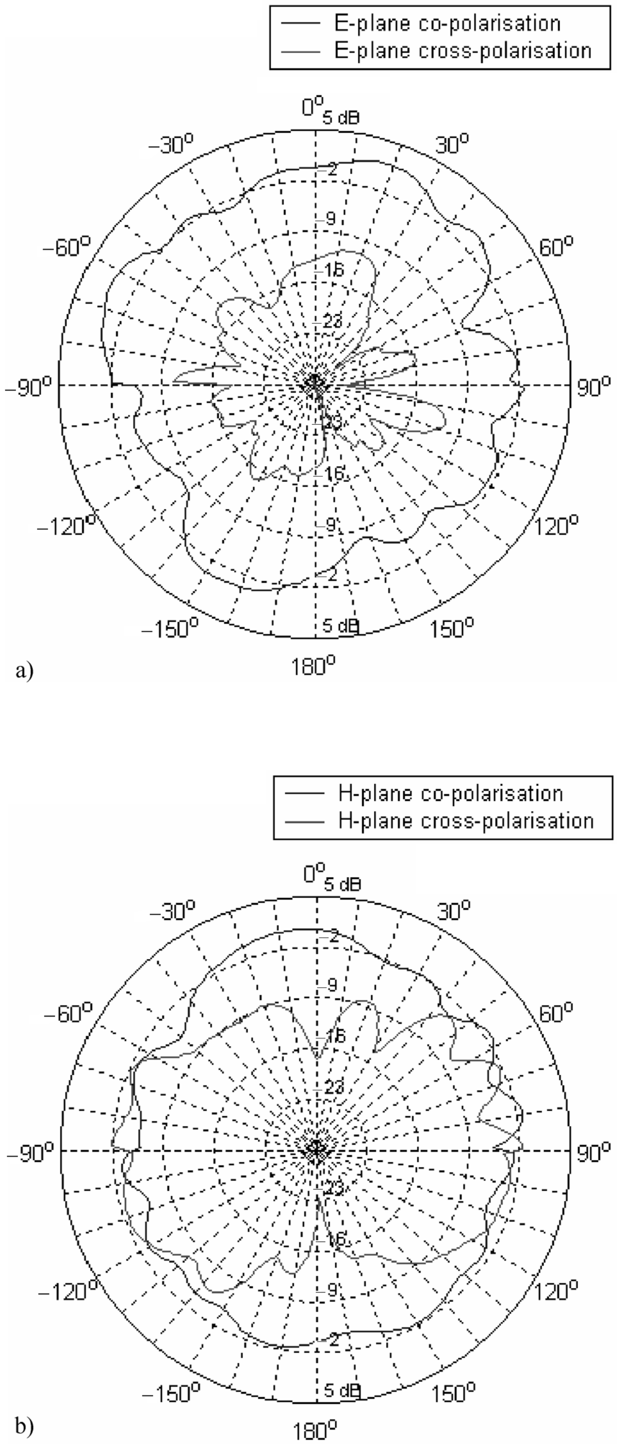

Fig. 11 Measured radiation pattern (gain scale) of the PIFA with 2 coupled shorting pins (2.035 GHz); a) E-plane, b) H-plane

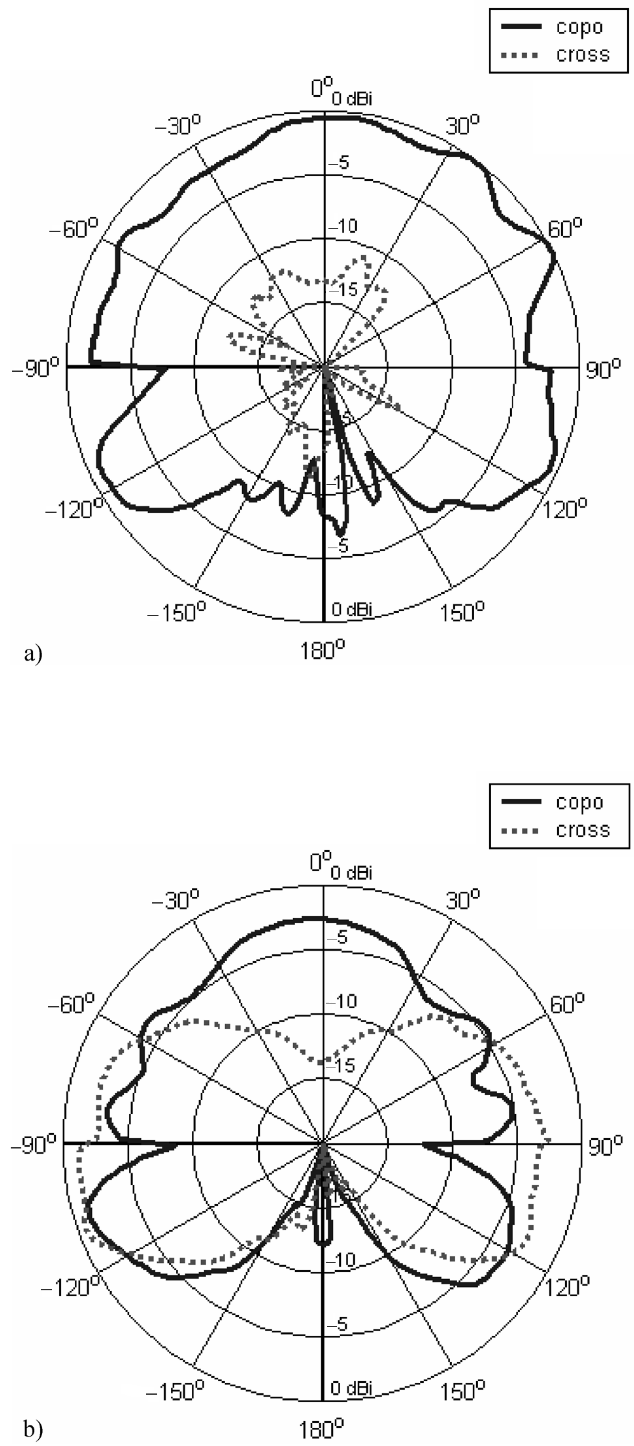

Fig. 12 Measured radiation pattern of the PIFA with 2 U-shaped slots (2.035 GHz); a) E-plane, b) H-plane

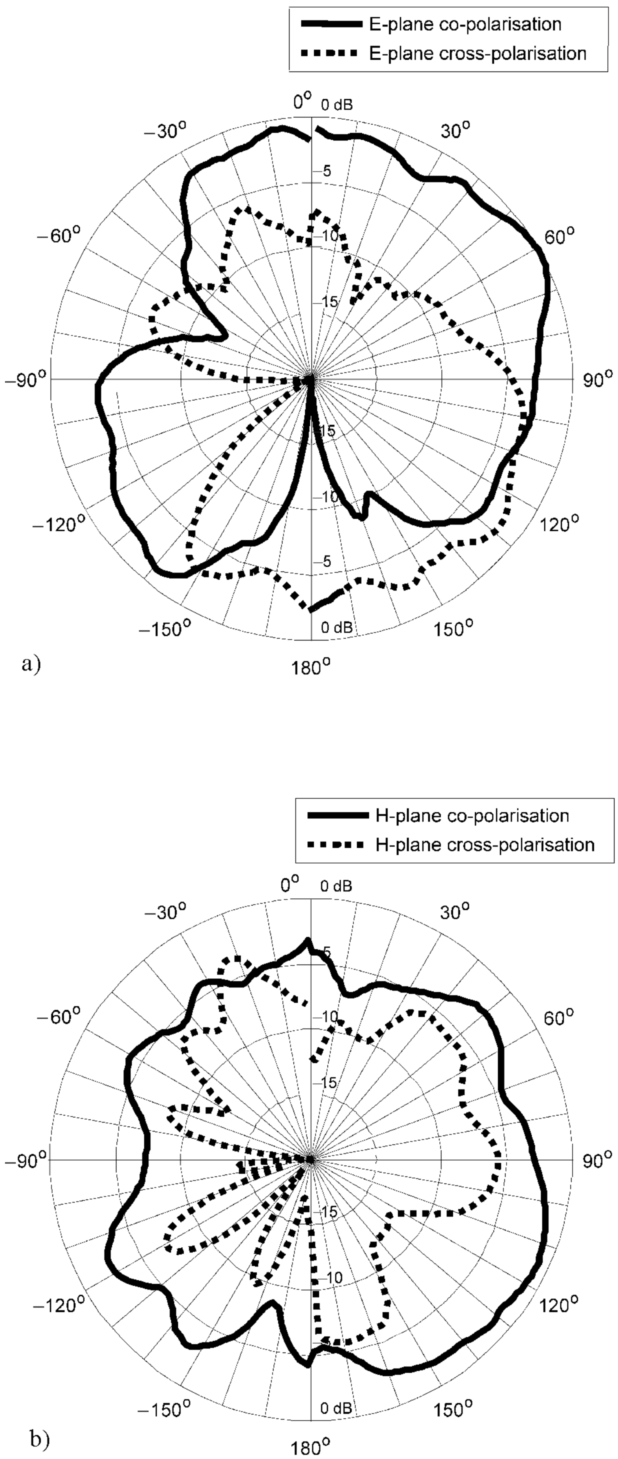

Fig. 13 Measured radiation pattern of the PIFA element with an L-shaped slot (2.442 GHz); a) E-plane, b) H-plane

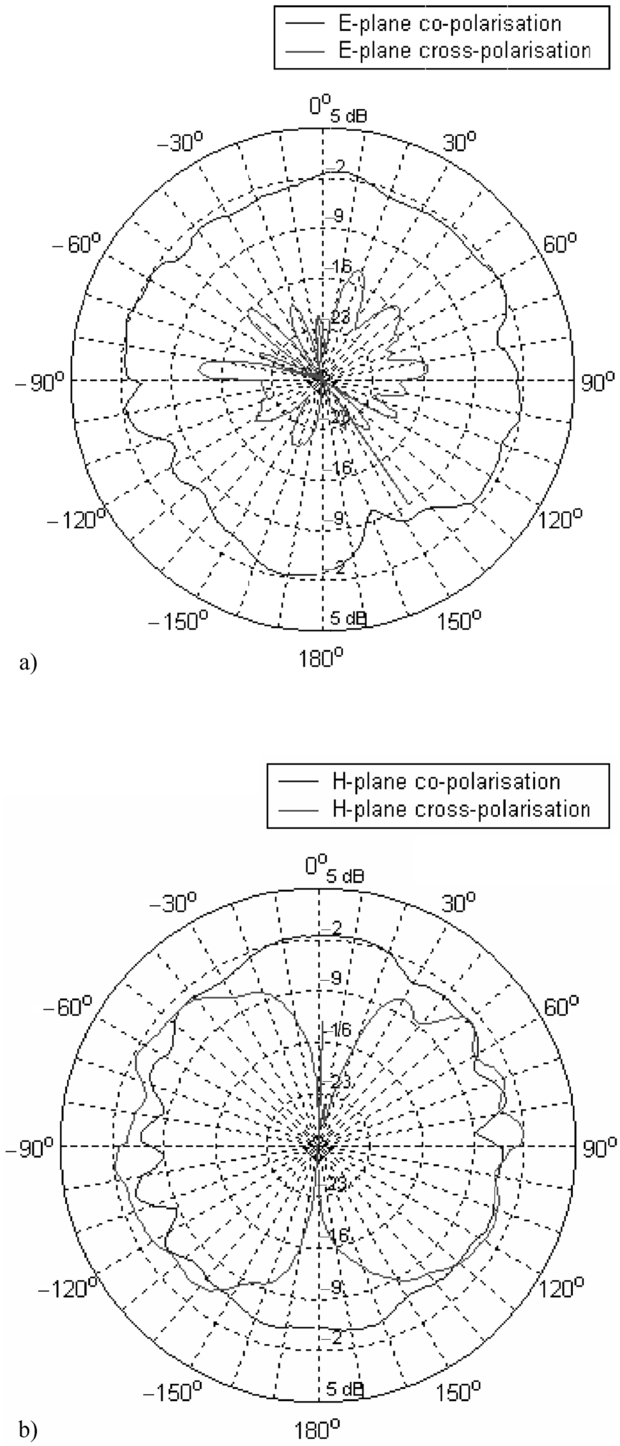

Fig. 14 Measured radiation pattern (gain scale) of the PIFA with 2 coupled shorting pins (2.442 GHz); a) E-plane, b) H--plane

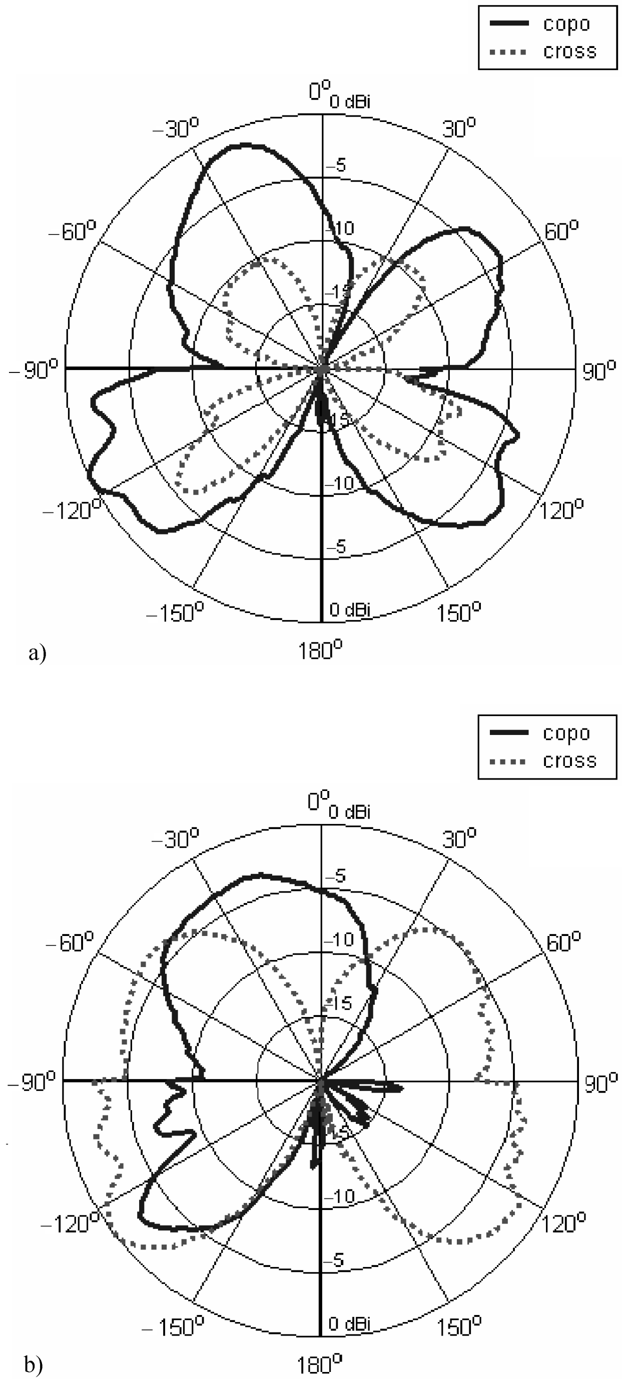

Fig. 15 Measured radiation pattern of the PIFA with 2 U-shaped slots (5.250 GHz); a) E-plane, b) H-plane

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Planarne male višefrekvencijske antene oblika invertiranog F za ručne pokretne komunikacijske uređaje. U radu su prikazane tri izvedbe planarnih malih višefrekvencijskih antena oblika invertiranog F. Antene su razvijene za primjenu u ručnim uređajima za pokretne komunikacije koji će raditi u više različitih radijskih komunikacijskih sustava. U razmatranje su uzeti sustavi pokretnih komunikacija (GSM1800, UMTS), radijske lokalne mreže (WLAN) (IEEE 802.11b, HiperLAN2) i radijske mreže za osobne potrebe (WPAN) (Bluetooth). U izvedbi antena primijenjena je dvoslojna izvedba ispunjena zrakom kako bi se postigla željena širina pojasa. Antene su smješene na osnovne uzemljene površine s izmjerama 100 mm × 40 mm i 60 mm × × 40 mm što odgovara izmjerama nepreklopivih i preklopivih ručnih komunikacijskih uređaja. Sve su tri antene projektirane, izrađene i ispitane mjerenjima. Postignuto je dobro podudaranje izračunanih i izmjerenih vrijednosti parametara antena.

Ključne riječi: ručni komunikacijski uređaj, mikrotrakasta antena, planarna antena oblika invertiranog F, male antene, višefrekvencijske antene

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