

# Integrated Planar Multiband Antennas for Personal Communication Handsets

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**Abstract**—The advent of new, multistandard mobile phone devices is an important challenge for antenna designers, as they have to implement integrated antennas with multiband operation within a volume that is rapidly shrinking. In the paper, research results concerning the input return loss, radiation characteristics and efficiency of novel internal, planar, multiband patch antennas are presented.

**Index Terms**—Handset antennas, multiband antennas, small antennas.

## I. INTRODUCTION

THE constant evolution of the mobile phone market determines more stringent constraints for terminal antenna design, as the size of the terminals shrinks rapidly, while the functionalities of the handsets are ever increased. Multiband operation, which is nowadays almost a common standard, requires the use of enhanced radiating elements. Moreover, other aspects such as small size, weight, and integration have a great relevance for the final design, while material and assembling costs must be kept as low as possible [1].

The preferred antenna solution to deal with multistandard issues is the use of radiating patches with multiple resonances covering different bands, which are easily adapted to the shape of the handset, and can therefore be integrated within the back cover. The solution has a number of advantages: terminal designers can forget about the antenna when designing the external cover, the phone becomes more robust as there are no external radiating elements that could break off, and the antennas can be produced in a more cost-effective way. On the other hand, the antennas must operate in two or more frequency bands, but still be confined within a volume that becomes ever smaller, and the chassis acquires importance in the design process. Therefore, the up-to-date main challenge for the mobile antenna designer is to achieve the miniaturization of the radiating structure without loss of efficiency while keeping an adequate input return loss ( $< -6$  dB) within each band of operation.

Coverage of GSM900, GSM1800, PCS1900 and ISM2450 bands were reported in [2], [3]. multiband was achieved starting

from a dual-band design consisting of a PIFA antenna with an inserted slit at its shorting strip edge, following the C-patch basic design [4]. Four bands were covered with a total volume of  $36 \times 16 \times 9$  mm<sup>3</sup> and by two additional folded strips, which mainly controlled the higher resonance for the ISM2450 system. The additional strips, however, were located at different height levels and required orthogonal plate orientation between them. A volume reduction to equal that reported in [5] was achieved in [6] for both quad- and a five-band designs.

The reduction was possible by using a stub extending from the folded patch to enlarge GSM900 and GSM1800 bandwidths and also by inserting an additional folded direct-feed metal strip, both added to the basic antenna reported in [5], which was used as a starting point. A fifth resonance was achieved within the same volume by inserting an additional folded direct-feed metal strip that was required to be orthogonal to both the main patch and the first additional folded metal strip. In an ultimate effort, a six-band element to also cover the GPS band is reported in [7], wherein only an increase in 1 mm in width compared to previous designs was required. Unfortunately, no efficiency figures were provided for any of these quad-, five- or six-band elements.

Good results for a quad-band antenna were also reported in [8], yet occupying a  $38.5 \times 28.5 \times 8.5$  mm<sup>3</sup> volume. Excellent VSWR measured results were obtained for GSM900, GSM1800, PCS1900 and UMTS2000 with the use of a dual-band PIFA as a basic element, a wide V-shape slot and two end-positioned folded capacitive patch loads plus three quarter-wavelength parasitic shorted elements located around the main patch. Parasitic elements were shorted by shorting walls. One parasitic element helped increasing GSM900 bandwidth, while the other two helped increasing the UMTS200 band.

The location of the parasitic elements, surrounding the main radiator, is the reason for the increased size in comparison to other quad-band elements available in the literature [5], [6], [9]. Likewise, the end-positioned folded patches and the three parasitic patches shorted with shorting walls increase manufacturing costs compared to planar designs. Finally, good efficiency values above 69% were only computed. The quad-band design in [8] was further optimized to include a fifth resonance for WLAN5400 by a second slot etched perpendicular to the first slot in [10]. With a careful design the new band was accommodated without a decrease on any of the other bands performance, yet keeping the total occupied volume of  $38.5 \times 28.5 \times 8.5$  mm<sup>3</sup> and the end-positioned folded capacitive patch loads. Moreover, the time efficiency was measured using a Wheeler-cap technique, and measured efficiency values showed reduced results, although good efficiency over 60 % was achieved.

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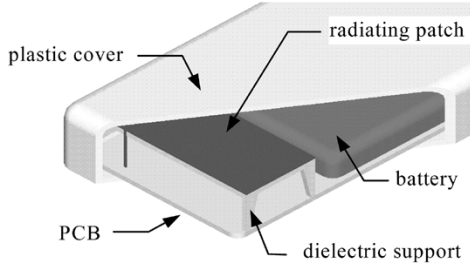


Fig. 1. Integrated antenna structure.

In the paper, some novel design concepts and measured results concerning novel triple and quad-band planar integrated antennas for mobile phones are presented.

## II. DESIGN METHODOLOGY

Printed antennas are nowadays an interesting alternative for mobile terminals, as current requirements are focusing on minimization of the size and weight of the handsets. Moreover, the development of new standards and the user's mobility requirements make it necessary to extend the operation of a handset to cover two or more standards. Thus, it becomes crucial to develop terminal antennas that implement different combinations of frequency bands. In many cases, one single feed point is required. Therefore, different resonant modes must be excited, each of them tuned to fit the centre frequency of the band of interest. Unfortunately, some of these bands overlap, like the GSM1800 and PCS1900 bands, thus requiring the use of radiating elements with broader bandwidth.

In the paper, a triple band and a quad-band antenna for mobile handsets will be presented. To keep a realistic configuration, the antennas were developed within the limits of a 16 mm × 36 mm rectangular area, with a height of 8 mm over a 36 mm × 100 mm ground plane of FR-4 material, as depicted in Fig. 1. The total volume reserved for the antenna is then 4.608 cm<sup>3</sup>.

There are two possible alternatives to cover two standards with overlapping bands. One can excite a single mode with a sufficient bandwidth or, alternatively, two mutually coupled modes. If the latter strategy is chosen, it is essential to be able to perfectly control the coupling mechanism, since any modification in the geometry of the patch can result in an important loss of bandwidth. The main concern is then how to tune one of the bands without interfering with the performance of the others. Indeed, to implement these integrated multiband antennas, it is common to use structures that include parasitic elements, or a combination of patches and radiating slots.

As the volume available is significantly reduced, quarter wavelength concepts are employed based upon the Planar Inverted-F Antenna (PIFA) [11], [12]. The performance of the designed antennas was first investigated with the FDTD-based field solver Empire [13], and then the input return loss of the prototypes was measured using a HP8719D network analyzer. To assure the mechanical stability of the structure, the antennas were attached to an 8 mm-thick foam block, which has no significant effect on the performance of the radiating structure.

In a multipath environment, and considering handsets with unknown spatial orientation, efficiency has become an impor-

tant matter when designing mobile phone antennas. Indeed, in order to optimize the use of the power available, high efficiency must be achieved. This represents an important parameter when determining the radiation performance of a mobile handset, as it gives the ratio between the power delivered to the antenna and the power that is actually radiated. A distinction should be made between radiation efficiency, determined by the patch itself, and the total efficiency, which includes the effect of matching losses. If the matching were perfect, both values would be identical.

The radiation efficiency  $\eta_{\text{rad}}$ , defined as the ratio between the radiated power  $P_{\text{rad}}$  and the power  $P_{\text{in}}$  delivered to the antenna [14], describes the losses in the structure, and it is given by

$$\eta_{\text{rad}} = \frac{P_{\text{rad}}}{P_{\text{in}}}. \quad (1)$$

The radiation efficiency can be calculated using the 3-D pattern integration method, for instance [15]. Yet, to include the effect of mismatching, the total efficiency  $\eta_{\text{tot}}$  must take into account the input return loss, and can be obtained from the radiation efficiency as

$$\eta_{\text{tot}} = \eta_{\text{rad}}(1 - |S_{11}|^2) \quad (2)$$

where  $S_{11}$  represents the return loss at the antenna feed point at the frequency of interest. In [16], [17], Wheeler presented a method, focus on antennas which are built over relatively large ground planes, like loops or patches, for determining the radiation efficiency of antennas.

When dealing with antennas integrated in personal communications devices, however, the size of the ground plane is reduced. With the antenna typically mounted on the top or the back side of the handset, the whole device acts as an active counter-pole for the antenna, and has to be considered in order to properly determine the radiation efficiency. Thus, an improved Wheeler-cap method [18]–[20] was employed to measure the efficiency of the novel elements described in the paper, wherein a sliding cap size is used to directly calculate the transmitted power and hence the radiation efficiency by measuring the antenna input return loss. A circle appears then in the Smith Chart, as depicted in Fig. 2. The radiation efficiency  $\eta_{\text{rad}}$  can thus be extracted from the transmission coefficient  $S_{21}$  as

$$\eta_{\text{rad}} = |s_{21}|^2 = \frac{2}{\frac{1}{\Delta S_{\text{max}}} + \frac{1}{\Delta S_{\text{min}}}}. \quad (3)$$

Where the coefficients  $\Delta S_{\text{max}}$  and  $\Delta S_{\text{min}}$  are determined from the input return loss with and without cap.

The variation of the ratio  $l_{\text{cap}}/\lambda$  can be replaced by a frequency sweep, and the circle in the Smith chart can be obtained directly by measuring over a certain frequency range [21], which was the procedure chosen in this work, as it is easier to implement and leads to the same results.

## III. NOVEL ELEMENTS AND RESULTS

### A. Triple Band Antenna (GSM900/GSM1800/PCS1900)

The novel triple band antenna design consists of a probe-fed metal plate with a shorting pin, which provides a double reso-

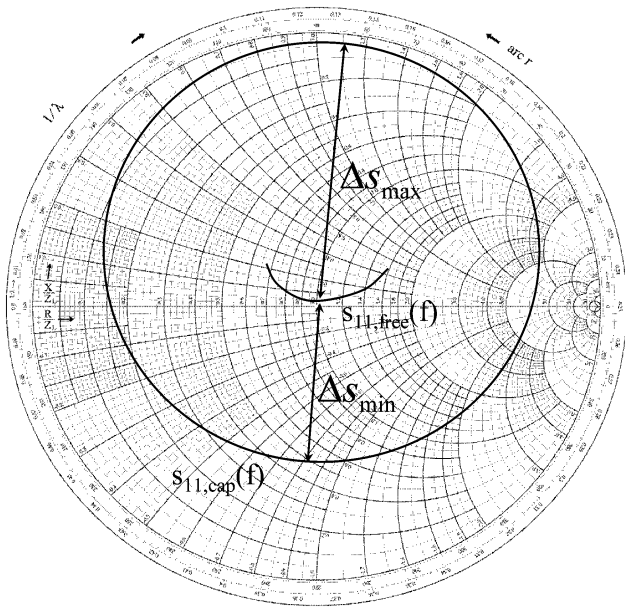


Fig. 2. Procedure for total efficiency measurement.

nance around 900 MHz and 1800 MHz. The antenna is based on previous dual-band concepts [21]–[23]. The shorted patch was designed for a resonant frequency of 1800 MHz. A spur-line filter embedded in its perimeter introduces a new resonant mode with a resonant frequency lower than that of the rectangular PIFA. The length of the spur-line filter is tuned to produce a new resonance at 925 MHz. The technique allows a dual-band operation without incrementing the total size of the antenna. Since the spur-line is made parallel to the patch edges, its influence upon the fundamental mode  $TM_{10}$  of the patch is not significant, while the new generated mode has similar characteristics to those of the main mode. The spur-line technique to obtain a dual-band operation was successfully applied to printed antennas of different shapes [24].

The resonant frequencies of the antenna can be further tuned by varying the position of the feed point and/or the shorting pin along the upper side of the patch. Earlier results available in the literature demonstrated the inherent narrowband nature of spur-line multiband antenna concepts [25], envisaging difficulties for common  $VSWR < 2$  requirements at mobile frequencies.

With the relaxation of the VSWR commercial requirements ( $VSWR < 3$ ) in exchange of an ever-decreasing available volume for the antenna designer, these concepts for multiband integrated antennas can be back into the scenario providing good total efficiency can be obtained. In addition to the dual-band patch used on those works, a shorted parasitic plate, capacitively coupled to the main radiator, was cut out of the main radiator in order to introduce a new resonance in the upper band, in a similar way to that described in [26], allowing thus to cover both the GSM1800 and PCS1900 standards. The final triple-band layout is depicted in Fig. 3.

Fig. 4 shows the simulated and measured input return loss of the triple band patch over the 36 mm × 100 mm FR-4 ground

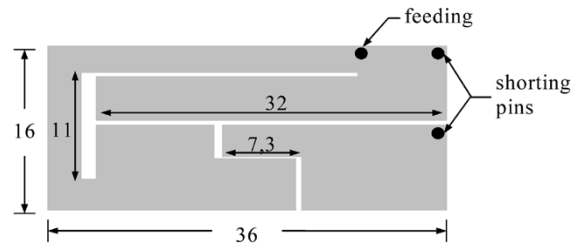


Fig. 3. Triple-band antenna layout (units in mm).

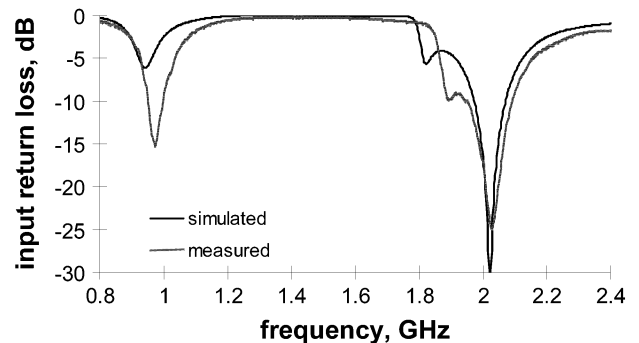


Fig. 4. Input return loss of the triple-band integrated antenna.

plane. The effect of the ground plane was taken into account for the design, as it has a major influence on the overall performance of the system [27]. Simulated and measured results are in good agreement, with slight discrepancies that can be attributed to the required discretization for practical simulation purposes.

In both cases, the triple resonance is clearly visible. Bandwidths of 93 MHz for the GSM900 band and 238 MHz for the GSM1800/PCS1900 band are obtained. The resonant frequencies lay slightly above the ones defined by the standards, to account for the effect of the plastic casing of the handset, which will slightly drop the resonant frequencies. Therefore, the antenna without cover is designed for higher frequencies, in order to minimize the utter need for tweaking.

Fig. 5 shows the electric and magnetic field distribution over the triple band antenna surface. It can be seen that the external branch of the patch is responsible for the GSM900 radiating mode. Coupling between the branch, the central part of the main patch and the parasitic patch produce an alternative double resonance covering GSM1800 and PCS1900 bands.

The measured radiation patterns of the antenna at the resonant frequencies of each frequency band are displayed in Fig. 6. Only the cuts through the azimuth plane are depicted here, normalized to their maximum value. The antenna shows a quasisymmetrical pattern, which is a desirable feature in a handheld personal communications device. The attained gains were 0.5 dBi in the GSM900 band, 0.1 dBi in the GSM1800 band, and 2.7 dBi in the PCS1900 band.

Regarding measured antenna efficiency, the results for the triple band antenna are displayed in Fig. 7. As radiation efficiency is higher, and more constant over frequency than total efficiency, bandwidth restrictions are not caused by the antenna

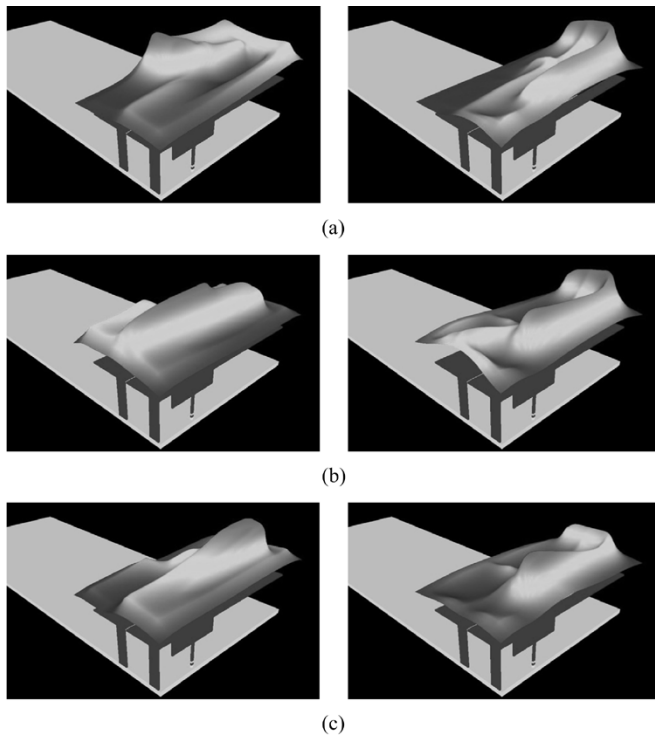


Fig. 5. Electric (left) and magnetic (right) field distribution for the triple-band integrated antenna for (a) GSM900 band, (b) GSM1800 band and (c) PCS1900 band.

design itself but rather by mismatching and chassis length. The effect is especially clear for the GSM1800 band.

In this case, the use of a passive matching network would enhance antenna efficiency. The efficiency performance of the antenna, however, can be classified as good since it remains above 60% for  $S_{11} < -6$  dB (VSWR < 3), which is consistent with other results available in the literature [1].

#### B. Quad-Band Antenna (GSM900/GSM1800/PCS1900)

In order to be able to use the antenna on third generation multiband terminals, a fourth resonance at UMTS frequencies is also required. In an ultimate antenna design effort to bring bandwidth to its maximum without increasing antenna volume, a slot was etched within the perimeter of the main patch of the triple band antenna, as shown in Fig. 8. The slot has a dimension of  $\lambda/2$  for the UMTS band and has a width of 0.5 mm, which does not disturb the GSM900 mode excited in the branch of the patch. The novel element can in this way cover the frequency bands of four different standards, namely GSM900, GSM1800, PCS1900 and UMTS (FDD), without increasing the overall size of the structure. For UMTS, only the downlink frequency band was considered, as the uplink band overlaps with the PCS1900 band.

Fig. 9 shows a comparison between the 3D electromagnetic simulation and measured results. A good prediction of the resonant frequency was obtained for the GSM900, GSM1800 and PCS1900 bands.

Yet, a frequency shift between simulated and measured results appears for the UMTS band, which corresponds to the operating principle of the inserted slot. This is explained by both

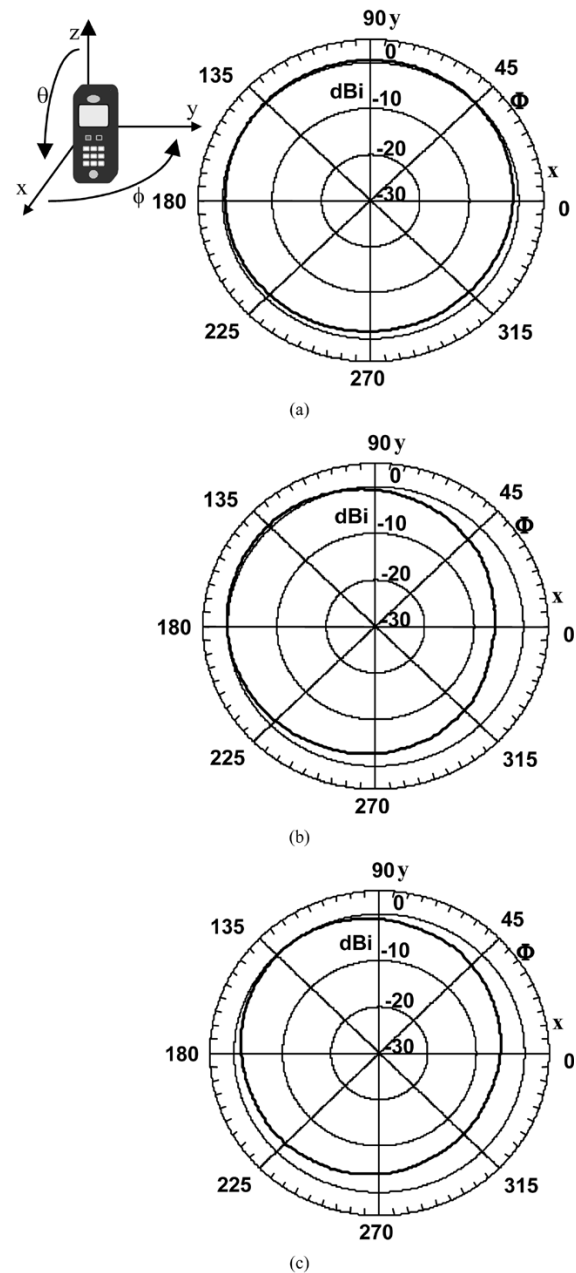


Fig. 6. Measured radiation patterns of the triple-band integrated antenna in the azimuth plane for (a) GSM900 band, (b) GSM1800 band and (c) PCS1900 band.

the discretization of the structure, which was fine enough to give an approximate estimation of the behavior of the slot mode, but not so detailed as to predict the exact resonance frequency, and to the use of Perfectly Matched Layer (PML) walls as boundaries for the simulation space, which have more influence on this mode than on other patch resonances.

Fig. 10 shows the electric and magnetic field distribution over the patch surface for the different modes excited in the quad-band antenna. The GSM900, GSM1800 and PCS1900 bands portrait similar distributions than in the triple-band structure. Only the slot effect located in the GSM900 branch is significant. Nevertheless, capacity coupling does not suffer significant differences from that of the triple band antenna, and quad-band

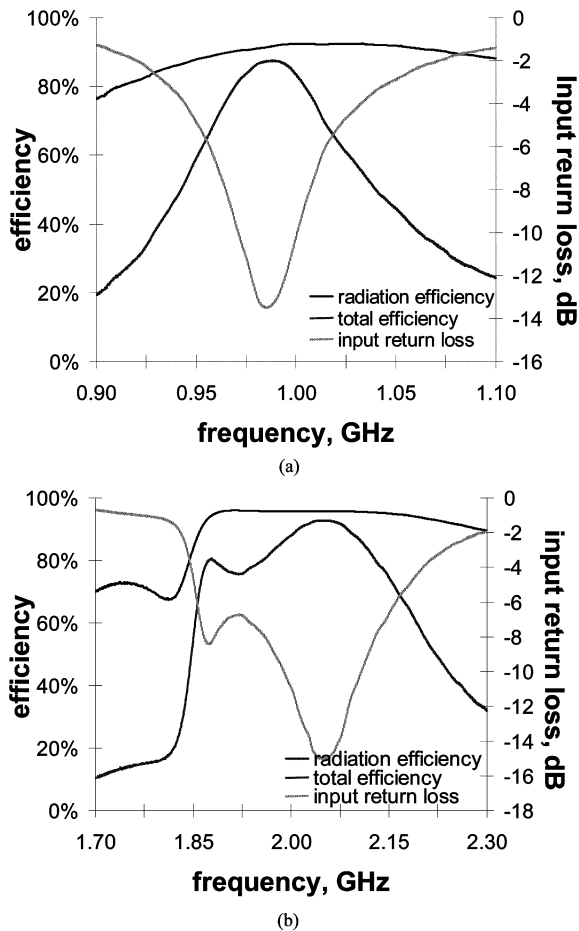


Fig. 7. Antenna efficiency versus input return loss for the triple-band integrated antenna for (a) GSM900 band and (b) GSM1800 and PCS1900 bands.

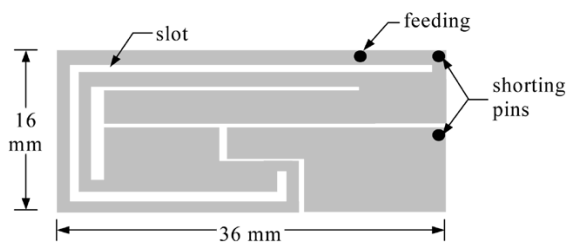


Fig. 8. Quad-band integrated antenna layout.

antenna performance at the GSM900 band is similar. Fig. 10(d) shows the new mode created by the slot introduced in the patch to cover the UMTS band. It is clearly demonstrated that the slot dominates the resonant mode.

Fig. 11 shows the measured radiation patterns of the antenna at the resonant frequency of each frequency band. Since the introduction of the slot along the perimeter does not significantly alter the field distributions, the antenna depicts similar characteristics to those of the triple band antenna in the GSM900, GSM1800 and PCS1900 frequency bands, with nearly omnidirectional patterns in the azimuth plane.

The antenna performance at UMTS frequencies features a more irregular radiation pattern, due to the shape and the orientation of the slot. Nevertheless, this is not a main drawback for its use in mobile terminals, since their spatial orientation is totally arbitrary. The measured gain for the UMTS band is 2.8 dBi.

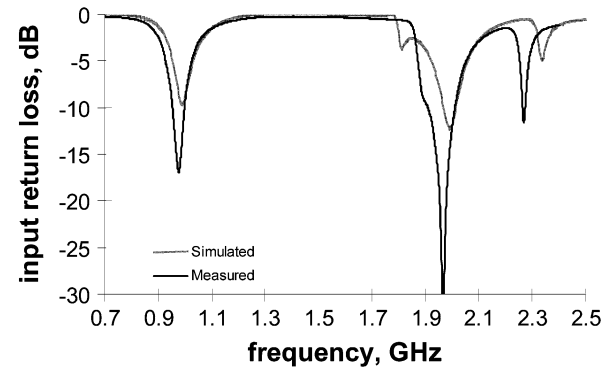


Fig. 9. Input return loss of the quad-band integrated antenna.

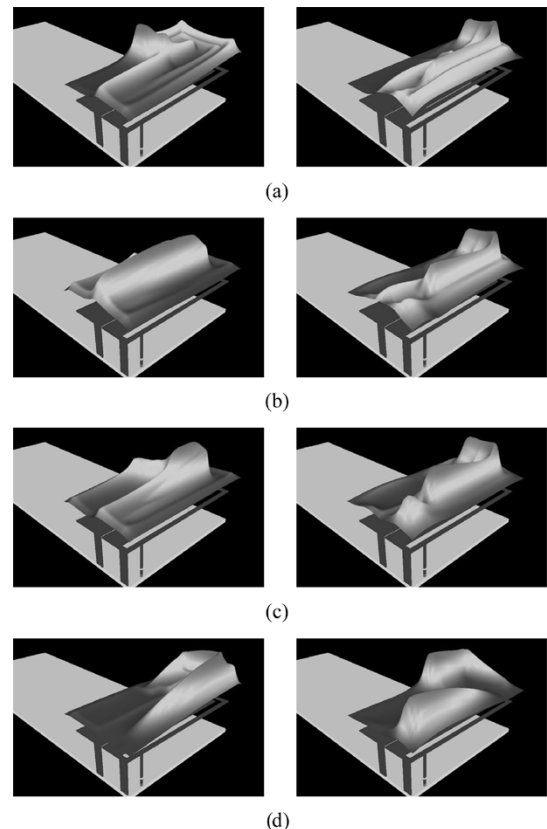


Fig. 10. Electric (left) and magnetic (right) field distribution for the quad-band integrated antenna for (a) GSM900 band, (b) GSM1800 band, (c) PCS1900 band and (d) UMTS band.

The efficiency of the quad-band antenna was also measured, and results are presented in Fig. 12 without the casing. Again, the total measured efficiency remains over 60% in the GSM900, GSM1800, and PCS1900 bands, which correspond to the patch spur-line operating modes, and do not differ significantly from those of the triple band antenna. A slightly worse matching performance is observed for UMTS FDD frequencies. Worse matching values lead to a lower total efficiency. Nonetheless, total efficiency remains above 40%. The effect of the plastic casing reduces measured efficiency in a 5%. This is also consistent with the fact that when bandwidth reaches its maximum for the same available space, a decrease in radiation efficiency is expected [28], making the use of both impedance bandwidth

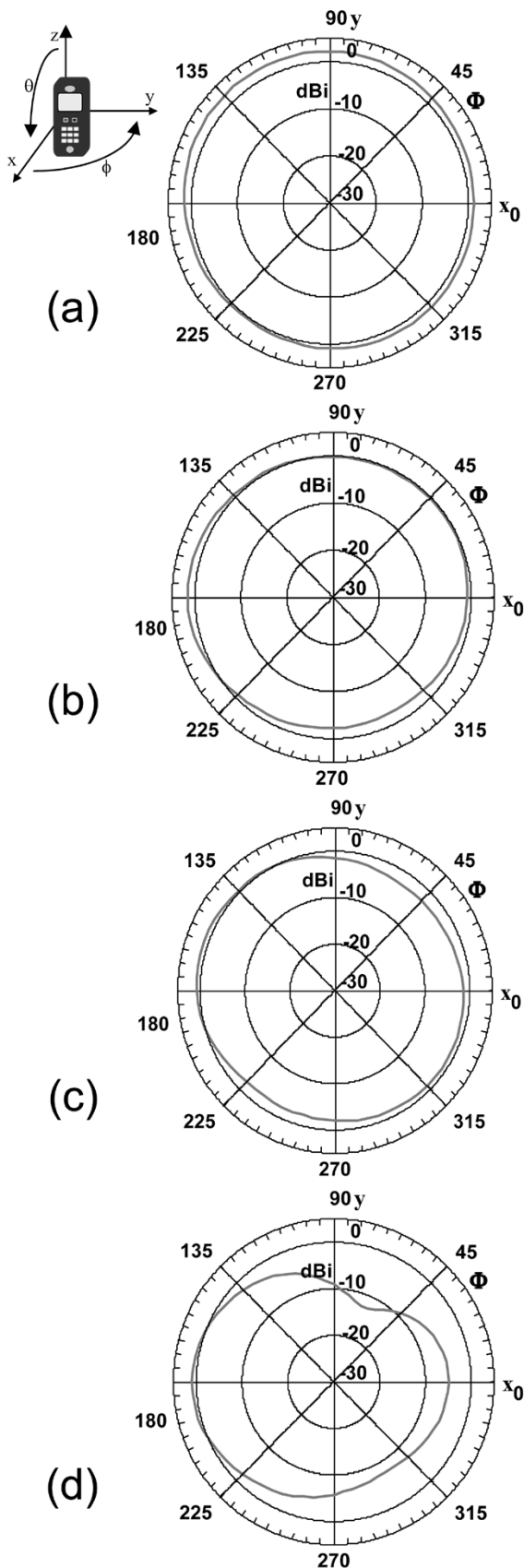


Fig. 11. Measured radiation patterns of the quad-band integrated antenna in the azimuth plane for (a) GSM900 band, (b) GSM1800 band, (c) PCS1900 band and (d) UMTS band.

and efficiency including mismatch losses essential for a proper antenna evaluation.

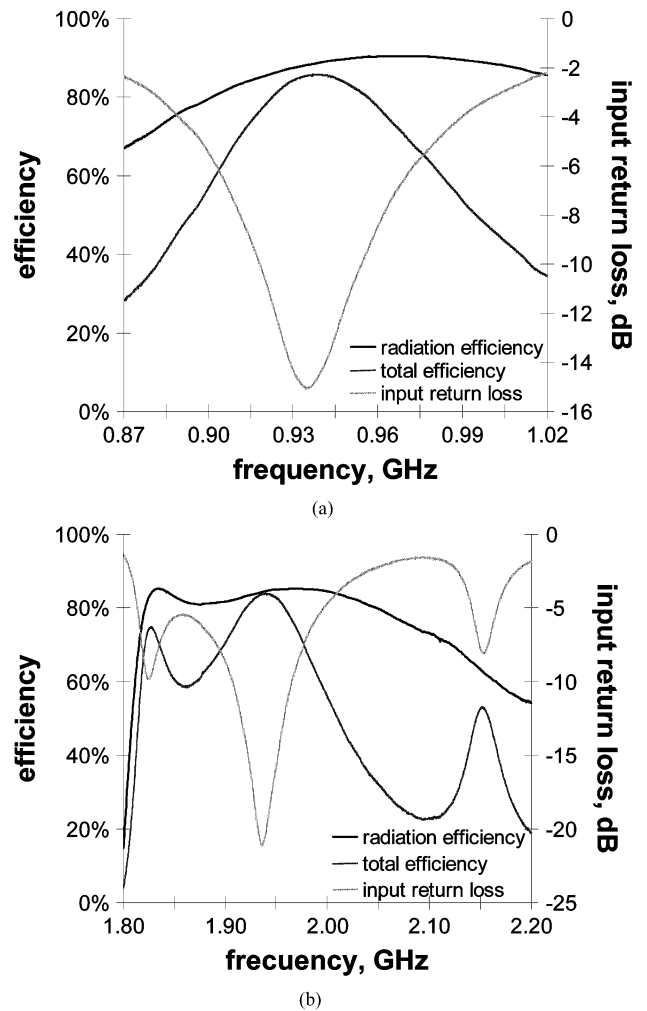


Fig. 12. Antenna efficiency versus input return loss of the quad-band integrated antenna for (a) GSM900 band and (b) GSM1800, PCS1900 and UMTS bands.

#### IV. CONCLUSION

Two novel integrated planar multiband antennas for small personal communications handsets have been presented, which could be used to cover the frequency bands of three and four standards, respectively. Triple multiband operation was achieved by combining spur-line techniques with active and parasitic patches, while the use of an additional slot introduces a fourth resonance with acceptable performance without increasing antenna volume so that a quad-band antenna is obtained. The measured results show a good behavior of the novel antennas, regarding matching, radiation properties and efficiency.

The new planar quad-band design has inherent lower manufacturing cost than other reported elements which make use of multilevel orthogonal parasitic patches, single-level parasitic shorted patches with shorted walls or end-positioned capacitively folded patch loads, while demonstrating similar efficiency and radiation patterns performance.

The design flexibility of the spur-line slot-combined planar multiband strategy introduces the concept of frequency-agile integrated antennas, making the antenna ideal for Bluetooth, WLAN or other wireless applications like Distributed Smart

Monitoring Services (DSM), where devices are able to memorize different events that may happen during part of the lifetime of a moderately complex object or even an entire system. Other possible applications is on Secure Mobile Systems (SMS) or Distributed Intelligent Automotive Control (DSAC), for which additional performance tests are required to evaluate the ability of these novel elements to conform to the strict thermo-mechanical stress specifications of the abovementioned applications, with operating temperatures sometimes in excess of 150°C and harsh electromagnetic environments.

For applications regarding ambient intelligence, the Specific Absorption Rate (SAR) performance of the novel antennas is currently under evaluation.

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