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ULTRA-WIDEBAND PLANAR INVERTED-F ANTENNA (PIFA) FOR MOBILE PHONE FREQUENCIES AND ULTRA-WIDEBAND APPLICATIONS

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Abstract—A new planar inverted-F antenna with a very large bandwidth starting from 817 MHz to 11.5 GHz (VSWR $<$ 3) is proposed as an alternative for high performance mobile phones intended to cover the major part of the mobile phone frequencies worldwide as well as the ultra-wideband (UWB) frequency range. A prototype of the antenna was constructed and the reflection coefficient and radiation patterns were measured to demonstrate an adequate radiation performance. The antenna dimensions of $4 \times 2.5 \times 0.5\,\mathrm{cm}^3$ are compatible with the requirements imposed by the most recent commercially available smartphones. Besides, the easy construction without a matching network or a complicated geometry is an additional feature that can be reflected in low fabrication cost.

1. INTRODUCTION

The planar inverted-F antenna (PIFA) remains as one of the most popular antennas used in mobile phones today [1, 2]. It is extensively employed owing to its small size, low profile, excellent performance, simple fabrication and relatively low specific absorption rate (SAR) [3, 4]. However, a conventional PIFA has an inherent

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narrowband that has to be enhanced in order to fulfill the increasingly bandwidth requirements imposed by the new handsets. If a mobile terminal is designed for global coverage and international roaming, the antenna should be able to operate in dozens of frequency bands to cover the many 2G, 3G, and 4G networks around the world [2]. Achieving this is not an easy task considering that the new smartphones demand more space for the electronics associated to multiple functionalities that these terminals offer, leaving small room to accommodate the antenna system.

In the past, several techniques have been used to improve the bandwidth of PIFA antennas. The introduction of various resonant elements in order to create a multiband PIFA is a very common approach [4–6]. Another method calls for the addition of parasitic patches with resonant lengths close to the frequency band where the bandwidth improvement is required [7–9]. The inclusion of slots in the ground plane has also been used to enhance the bandwidth mainly in the lower frequencies of the spectrum allocated to mobile phone services [10–12]. The same type of slots can be employed in the main radiating structure to increase the bandwidth of some of the bands of interest [13, 14]. Other PIFA structures can use multilayers of resonators in order to increase the number of bands where the PIFA can operate [15–17]. Finally, a combination of the previous techniques is frequently utilized to add the effects of each method and increase the PIFA bandwidth.

The foregoing techniques have the ability to increase the number of bands in which a PIFA can operate or to enhance the bandwidth of some of the bands of interest. However, the total bandwidth enhancement is not enough to cover the great diversity of bands at which a mobile terminal should operate in many countries with different RF interface standards at different frequency allocations. An interesting new approach that is an alternative to the well-known techniques is to design a PIFA with a single but very large bandwidth that is capable of covering all the mobile phone bands within that single wideband. The antennas reported in [18, 19] utilize this new technique. The first antenna can cover any band between 1.6 and 5.3 GHz with $S_{11} < -10$ dB. The second is able to cover a wider bandwidth between 1.64 and 8.62 GHz with the same $S_{11} < -10$ dB. Both antennas are easy to construct and have dimensions that fall within the limits of many antennas for mobile devices. However, the height of the main radiator element above the ground plane in both antennas is 10 mm. That is a construction restriction that is not allowed in many new smartphones where the very low profile of the antenna system is imperative. Besides, these antennas cannot work on the very important bands of 800 and

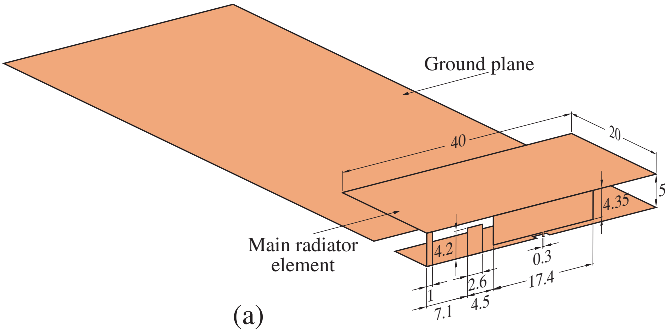
900 MHz where numerous mobile phone networks operate around the world.

To overcome the above restrictions a new antenna with a very large bandwidth between 817 MHz and 11.5 GHz has been developed. The new antenna has a lower profile of 5 mm that is entirely compatible with the size restrictions imposed by smartphones. On the other hand, it can cover the cellular bands of 800 and 900 MHz as well as any band below 11.5 GHz. The penalty incurred by using a lower profile is that the figure of merit $S_{11} < -10$ dB is diminished to $S_{11} < -6$ dB (VSWR < 3). However, the last figure has become from some years ago in the most common criterion for mobile phone antennas where a part of radiation performance is sacrificed in sake of a lower volume [14, 20]. Nevertheless, the new antenna presented in this paper exceeds the criterion of $S_{11} < -10$ dB in important parts of its bandwidth. For example, between 860 MHz and 2.38 GHz, the new antenna complies with the stricter reflection coefficient requirement and therefore a very acceptable radiation performance is obtained in this range where many mobile phone systems are found.

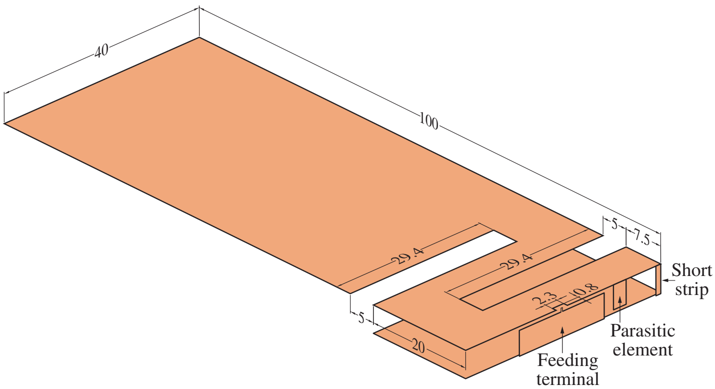
2. ANTENNA CONFIGURATION

A schematic diagram of the new antenna is shown in Figure 1. Unlike conventional PIFAs where the feeding terminal is very thin, the new antenna has a thick terminal that provides a single very large bandwidth [18, 19]. However, the use of a thick feeding terminal alone, does not create a bandwidth that includes the frequencies below 1.6 GHz, approximately. If the antenna is aimed to be employed for mobile phone terminals it should also cover the bands of 800 MHz and 900 MHz. To fulfill that goal another technique to increase the bandwidth from the ones discussed above has to be used simultaneously. In the present case, the addition of slots in the ground plane seems to be the most suitable. The use of slots in the ground plane has the purpose of electrically elongating the ground plane in such a way that a new low frequency electromagnetic mode will be excited and the antenna can work properly at the lower part of the mobile phone frequencies.

As seen from Figure 1, the ground plane size is $10 \times 4\,\text{cm}^2$, close to the dimensions commonly found in smartphones. If a conventional PIFA were designed to reach the frequencies around 800 MHz, the ground plane would be larger and that size would not be permitted in the vast majority of mobile phones. For that reason, the slots in the ground plane are very helpful to extend the electrical size without increasing the physical size. The size and position of the slots shown



(a)



(b)

Figure 1. Geometry of the proposed PIFA. All dimensions in mm. (a) Front view. (b) Back view.

in Figure 1 are obtained after an optimization process where the maximum bandwidth is obtained. Note that the slots are located just below the main radiator element although one of the slots exceeds the border of the main radiator element above. However, there is sufficient free space in the ground plane surface to place all the electronics needed in the mobile terminal. The slots increase the electrical size approximately to 0.4λ around 800 MHz, where it has been found that a low frequency mode is excited and the antenna can work properly in the lower part of the mobile phone bands [11].

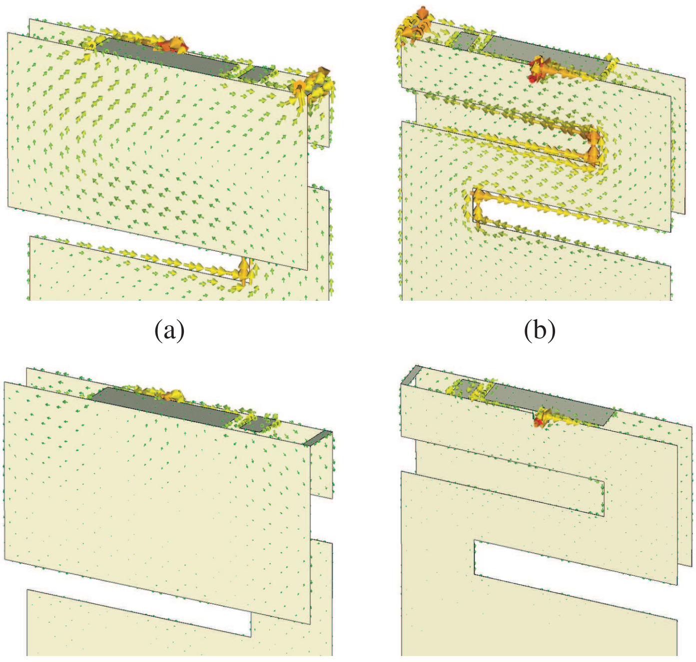
From Figure 1 it is also noted that the shorting strip between the main radiator element and the ground plane is located in one corner of the antenna structure. This short-circuit is not different from the ones used in conventional PIFAs.

Additionally, there is a parasitic element that is used to increase the bandwidth at higher frequencies [18, 19]. This element is very simple and gives a particular capacitive coupling between the ground plane and the main radiator element to enhance the response at the upper part of the bandwidth.

3. SIMULATED AND MEASURED RESULTS

The new antenna proposed in this paper was developed and optimized with the assistance of the CST Microwave Studio® software package. The structure of Figure 1 was introduced into the simulations along with a model of an SMA connector to consider the external feeding of the actual antenna. The distance between the short and the feeding terminal, the size and position of the slots, the height of the parasitic element and other important dimensions were optimized to maximize the bandwidth with the lowest possible reflection coefficient.

To provide a physical insight of the PIFA behavior, Figure 2 shows the current distributions on the antenna surface for a couple of frequencies. Figures 2(a) and 2(b) show strong currents well distributed along the surface of the main radiator and the slots of



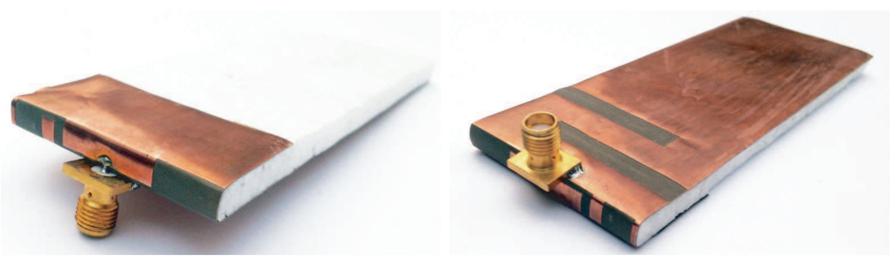
(a) (b) (c) (d)

Figure 2. Current distributions at 845 MHz and 10.39 GHz. (a) Front view at 845 MHz. (b) Back view at 845 MHz. (c) Front view at 10.39 GHz and (d) Back view at 10.39 GHz.

the ground plane at 845 MHz. It is important to have currents not so concentrated in specific zones of the antenna in order to have a better wideband [21]. For that reason, the optimization process demonstrated that a thicker slot in the ground plane was better in terms of wideband at the lower frequencies. On the other hand, Figures 2(c) and 2(d) show that the ground plane is no longer a main contributor to radiation at 10.39 GHz. Instead, the main radiator element have modes excited at this frequency, as well as the parasitic element, where it can be noted a relatively strong current flowing through it. In Figure 2 it is also observed that the currents are well distributed along the feeding terminal. That is not the case of a conventional PIFA that has a thin feeding terminal and the currents concentrate more in a smaller area at certain frequencies within a narrowband. The effect of the thick feeding terminal in this PIFA is similar to that of a vertical monopole planar antenna with a special trident shaped feeding terminal as reported in [21].

After the optimization, a prototype was built as shown in the pictures of Figure 3. Since all the antenna elements are planar, the construction is very simple. One side of a flexible laminate Taconic FF27$^{\mathrm{TM}}$ was used to print all the antenna elements. The substrate permittivity is 2.7 and its thickness is 0.13 mm. The substrate flexibility was preferred for the prototype because the construction is simplified just folding the laminate to shape the antenna structure. The only element that was welded was the SMA connector. In this way, reducing the manual welding of elements, some errors in the distances and positions of the antenna elements are reduced as well. Finally, a block of expanded polystyrene (EPS) foam was used to provide mechanical support to the structure without modifying the electromagnetic behavior of the prototype because the dielectric constant of the EPS is near to that of the air (1.03 approximately).

The simulated and measured reflection coefficient curves of the



(a) (b)

Figure 3. Pictures of the prototype. (a) Front view. (b) Back view.

new antenna are shown in Figure 4. Note that the prototype satisfies the criterion of $S_{11} < -6$ dB in the whole band, from 817 MHz to 11.5 GHz, except in the interval from 3.36 to 3.72 GHz where $S_{11} < -5.5$ dB. It is a small difference of 0.5 dB respect to the simulated curve but located in the very limit of -6 dB. This part of the band was the most complex to optimize and so the simulated values are near the limit. A new design with more tolerance to strictly satisfy the -6 dB criterion will be the object of further study.

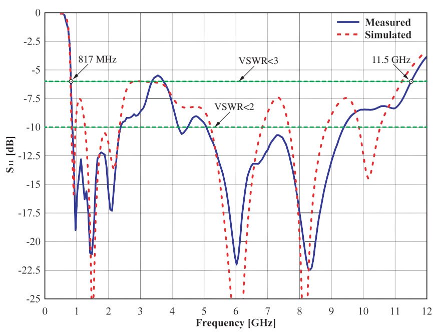


Figure 4. Measured and simulated reflection coefficient.

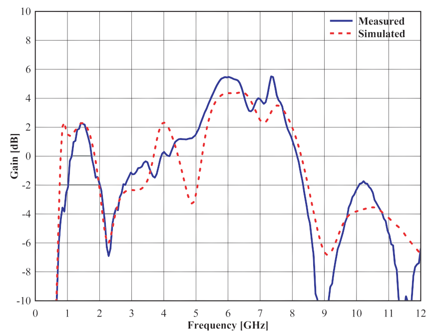


Figure 5. Measured and simulated gain at $\theta = \varphi = 0°$.

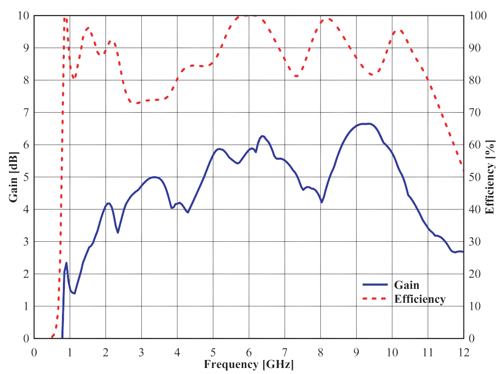
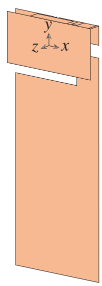


Figure 6. Simulated maximum gain and total efficiency.

However, it is worth mentioning that in extensive parts of the antenna bandwidth the stricter criterion of $S_{11} < -10$ dB is achieved. In the measured curve, those regions correspond to the bands from 860 MHz to 2.38 GHz and from 5.07 GHz to 9.39 GHz. Therefore, a very adequate radiation performance is expected in sub-bands where important services are allocated, such as cellular (800–900 MHz), GPS (1.22 and 1.57 GHz), DCS (1.8 GHz), PCS (1.9 GHz), LTE (except the North American 700 MHz band and the frequencies between 2.4 and 2.6 GHz), the 5 GHz WLAN and a considerable part of the UWB frequencies. Even at the zone where services as important as WiFi and Bluetooth are allocated in the 2.4–2.5 GHz band, the new antenna would comply with $S_{11} < -9.5\,\text{dB}$ which is more than acceptable for



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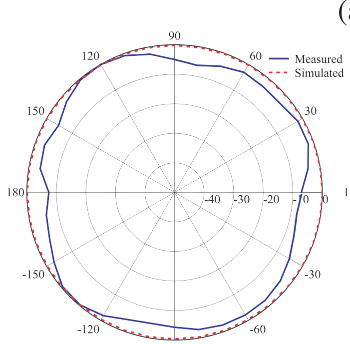

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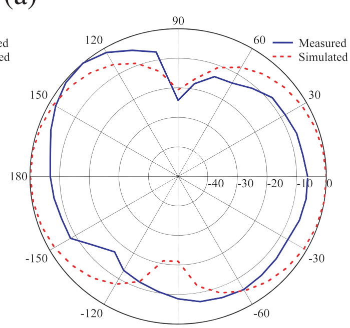

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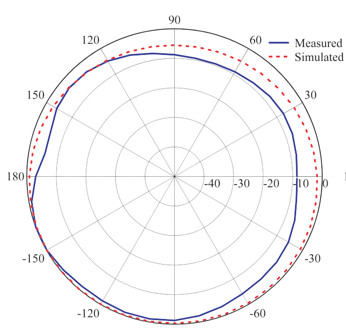

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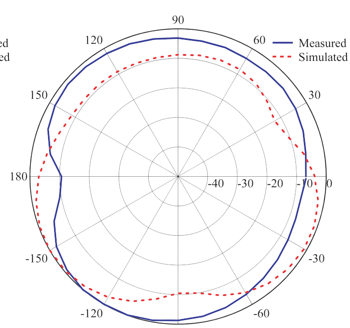

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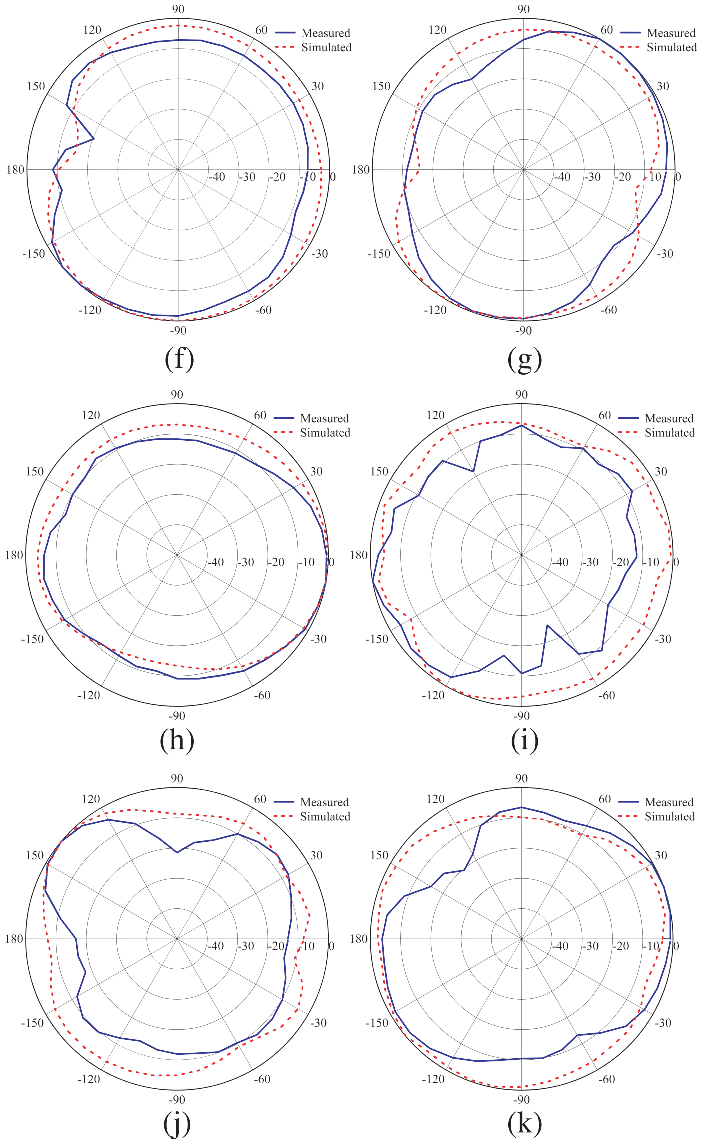

Figure 7. Measured and simulated radiation patterns at 845 MHz, 1.88 GHz, 2.45 GHz, 5.79 GHz and 10.39 GHz (Unit: dB). (a) Antenna coordinates. (b) Horizontal 845 MHz. (c) Vertical 845 MHz. (d) Horizontal 1.88 GHz. (e) Vertical 1.88 GHz. (f) Horizontal 2.45 GHz. (g) Vertical 2.45 GHz. (h) Horizontal 5.79 GHz. (i) Vertical 5.79 GHz. (j) Horizontal 10.39 GHz. (k) Vertical 10.39 GHz.

a mobile terminal antenna.

The antenna gain at the frontal direction of $\theta = \varphi = 0°$ was also measured. The measured gain curve is plotted in Figure 5 along with the simulated one. From the figure, it is observed a resemblance between curves with some differences that could be attributable to the construction tolerances and some limitations of the test setup. Some of the antenna gain values obtained in this particular direction are not the ones expected even for a mobile phone antenna. However, they are adequate considering the direction where the gain is maximum.

In Figure 6 it is shown the simulated maximum gain as well as the total efficiency. Actually, the efficiency is a more useful parameter for a mobile phone antenna because it is not classified as a directional antenna where the gain parameter is more relevant. As seen from Figure 6, the gain is above 1.3 dB while the efficiency is higher than 65% in the whole bandwidth. Both parameters are very acceptable for a mobile phone antenna and validate an adequate radiation performance besides the very large bandwidth.

Finally, the radiation patterns at several important frequencies are depicted in Figure 7. The approximated omnidirectional characteristic of this new PIFA can be seen from the different horizontal ($\varphi = 0°$) and vertical ($\varphi = 90°$) patterns. Some nulls are observed but not as profound and extensive as in directional antennas, especially at lower frequencies where the patterns are simpler and more similar to a dipole. The fluctuations and some unexpected nulls in the measured patterns could be caused mainly by restrictions and non-ideal conditions during measurements. However, the new PIFA is confirmed in its basic behavior as an acceptable omnidirectional radiator.

4. CONCLUSIONS

A new ultra-wideband PIFA antenna, which covers the frequencies between 817 MHz and 11.5 GHz and complies with $S_{11} < -6$ dB (VSWR <3), has been proposed. Extensive parts of this bandwidth achieves a better parameter of $S_{11} < -10$ dB. This PIFA covers almost all the frequency bands where mobile phones operate in every part of the world. It can even cover the high frequencies of the future ultra-wide band (UWB) services. As far as the authors' knowledge, this new antenna has the largest bandwidth designed for a mobile phone antenna with acceptable characteristics of size and radiation performance. The new antenna is planar and has a simple geometry that can be implemented at low cost. Its size of $4 \times 2.5 \times 0.5\,\mathrm{cm}^3$ is within the limits permitted in many terminal models, including the most recent smartphones.

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