Study of a New Design of the Planar Inverted-F Antenna for Mobile Phone Handset Applications

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Abstract—**This paper suggests a new design of the PIFA antenna for mobile phone handset applications. In this context, we are interested in the development of new techniques based on the creation of slot matching for the improvement and miniaturization of a dual-band PIFA antenna operating at 900MHz and 1800MHz. Analysis of antenna parameters such as return loss (S11), radiation pattern, Voltage Standing Wave Ratio (VSWR), current distributions, gain, and the relation between them are performed in CST software. There is a good agreement between the results of simulation by CST and HFSS and those of measurement for the proposed antenna.**

Keywords-PIFA antenna; dual-band antenna; slots radiating element; CST microwave studio

I. INTRODUCTION

Wireless communication technologies have become an essential part of everyday life. Antennas are basic components of any telecommunication system and are connecting links between the transmitter or receiver and free space. The PIFA antenna is a good candidate for these applications because it meets certain technical requirements. Several researches have been focused on the diverse applications of the PIFA antenna [1-7]. This antenna can be printed on dielectric blocks, so the dielectric properties of the block can be used to miniaturize or to improve the performance at the lower band edge [8]. In [9, 10], diversity MIMO PIFA antennas, for multi-mode satellite navigation applications, have been modeled and realized. In [11-12], the authors proposed compact PIFAs operating at 2.45GHz for body communications and multi-input MIMO applications [13]. However, these techniques provide important information for the design of mobile antennas in the presence of the human body such as the reflection coefficient, the radiation pattern, the antenna impedance and the specific absorption rate. Currently, several research groups around the world have undertaken the assessment of technical requirements to verify the conformity of antenna design for mobile communication. The resonance characteristics of implanted PIFA antennas and their radiation signature inside and outside the body must be evaluated by numerical analysis and measurements. Among them, the PIFA [14] using a conductive plate, and carried out on a flexible dielectric substrate FlexPIFA to operate at 2.45GHz [15]. Other techniques have been proposed in [16]. In that case, the slot is not printed on the ground plane but integrated on PIFA geometry. This technique creates an additional mode which improves the bandwidth to the upper band covering of GSM900-1800 for original design at GSM900 and1800 for the design of the integrated slot. The multiband objectives of PIFA antennas can be found in [17]. In [18-19], authors present other solutions employing a monopole antenna, based on a low-profile multi-band handset designed only with slot antennas. The slots are not only useful for PIFA antenna design, but also for damping unwanted modes for EMC purposes.

A major interest area is the study of the effects of radiation on the organs of the human body. Therefore, it is important to realize a new PIFA antenna for mobile phones with the highest quality performance, with reduced electromagnetic exposure. In this context, a new compact PIFA antenna operating at different operational frequencies (900MHz and 1800MHz) is proposed. A parametric study was conducted on the antenna in order to ensure the required electrical and radiation performance. After the design and parameter defining and optimization, the simulation phase by using suitable software is a compulsory optimization step in order to save time and cost. It is also possible to take into account the dielectric parameters of the chosen low-cost materials. The chosen CST and HFSS electromagnetic simulation tools study and simulate complex structures for mobile terminals. The motivation for choosing a PIFA structure is that thus a larger band operation is achieved in the presence of a ground plane. In addition, antennas on a ground plane will be less affected by the presence of the human body. The antenna structures without a ground plane exhibit serious changes in the resonance frequency, depending on the distance of the body. Thus, the PIFA antenna is an attractive choice for many integration devices due to its low cost, simplicity of design and low profile.

II. ANTENNA DESIGN AND PARAMETRIC STUDY

In this part, we are interested in the simulation of a two-band rectangular PIFA antenna. We have added slots to the antenna at the top and bottom of the substrate to achieve the functioning for these bands for mobile phones. The proposed antenna elements were manufactured on the substrate FR4_Epoxy of relative permittivity $\varepsilon r=4.4$, $\tan\delta=0.0013$, thickness h=1.6mm, and the ground plane was made of FR4 ($\varepsilon r=4.4$, $\tan\delta=0.03$). The shorting pins and the feeding pin were

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made of short rectangular profile wires. They are part of connectors and their dimensions are defined in Table I. The coaxial probe was provided by a standard 50Ω connector of the SMA type. Figure 1 shows the built antenna.

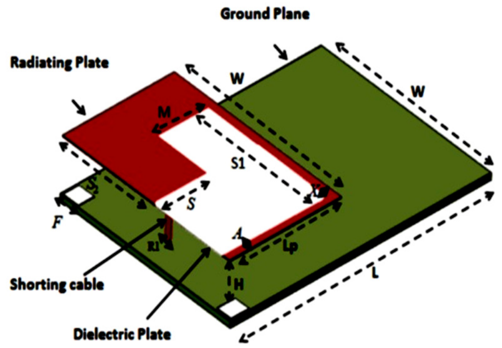


Fig. 1. Geometry of the proposed PIFA antenna

TABLE I. OPTIMIZED PARAMETERS OF THE PROPOSED ANTENNA

Parameters (mm)					
W	**L**	**Lp**	**S**	**S1**	**S2**
39.87	89.88	23.52	13	21.38	30
A	**M**	**F**	**R1**	**H**	**Hs**
2.7	6.88	1.86	0.05	6	1.6

The main objective of this part is to guarantee the resonant frequency at 900MHz and 1800MHz with the best possible adaptation and a high gain. It also includes a study of the effects of the geometric parameters of the antenna on the electrical and radiation characteristics (reflection coefficient, resonance frequencies, gain, and visualization of the radiation pattern). We first present the variation of some geometrical parameters of the slit and their influence on these characteristics. Then, the results of the simulations of the optimized structure are exhibited.

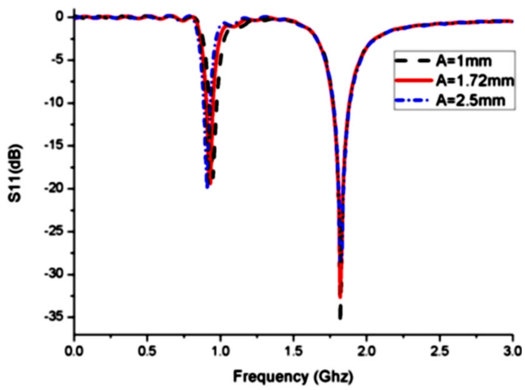


Fig. 2. Simulated reflection coefficient as a function of frequency for different values of A

Figure 2 shows the variation of the reflection coefficient as a function of the frequency for different values of parameter A. We note that when the parameter A is changed, the resonance frequency of the first bandwidth at 900MHz changes slightly, while the second band of the antenna at 1800MHz does not. The value 2.5mm for the parameter A is favored since it ensures a better adapted resonance frequency of 900MHz, while respecting a level of reflection coefficient as much as possible above -10dB. Figure 3 illustrates the variation of the reflection coefficient S11 as a function of the frequency for different values of the parameter S2. From the curves of Figure 3, it is obvious that the variation of S2 has a slight influence on the second resonant frequency of the antenna and also on its adaptation of the first band. When the value of this variable is equal to 27.45, the resonance frequency in the first band decreases and has a better adaptation. The same is true for the resonant frequency in the first band. Figure 4 illustrates the variation of the reflection coefficient S11 as a function of the frequency for different values of parameter X. It can be seen that when X varies, the resonance frequency and the bandwidth vary as functions of the frequency for the two GSM bands. The choice of X=1.42mm gives us the best performance of the antenna.

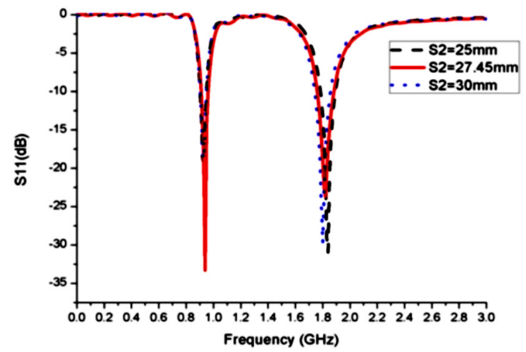


Fig. 3. Simulated reflection coefficient as a function of frequency for different values of S2

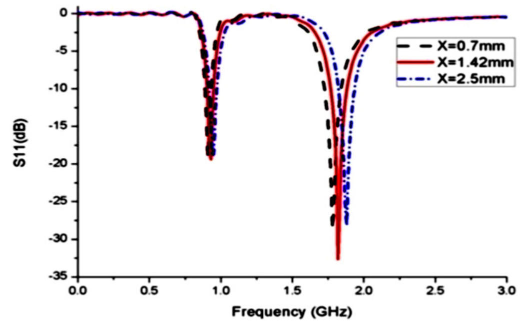


Fig. 4. Simulated reflection coefficient as a function of frequency for different values of X

Figure 5 illustrates the variation of the reflection coefficient S11 as a function of the frequency for different values of parameter H. From these results we can see that the variable H does not have any effect on the proposed antenna's characteristic. Figure 6 illustrates the variation of the reflection coefficient S11 as a function of the frequency for different values of parameter Hs. It can be seen that the variation of the parameter Hs influences the variation of the reflection coefficient. However, when Hs decreases, the resonance frequency increases for both bands (900MHz and 1800MHz). Figure 7 illustrates the variation of the reflection coefficient

S11 as a function of the frequency for different values of parameter R1. Unlike Hs, when R1 increases the resonance frequency increases for the second band, as it is best suited especially for R1=0.4mm.

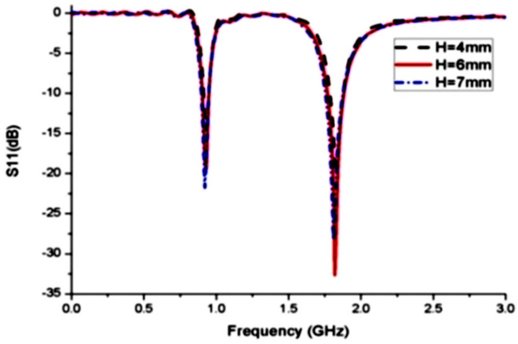


Fig. 5. Simulated reflection coefficient as a function of frequency for different values of H

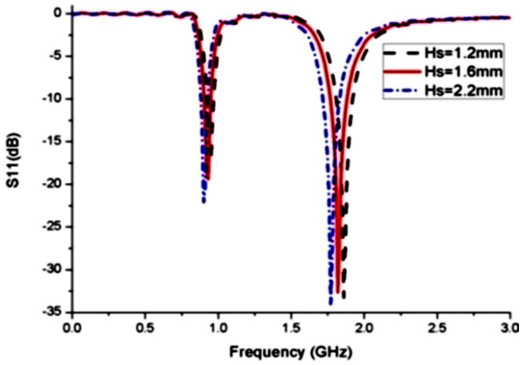


Fig. 6. Simulated reflection coefficient as a function of frequency for different values of Hs

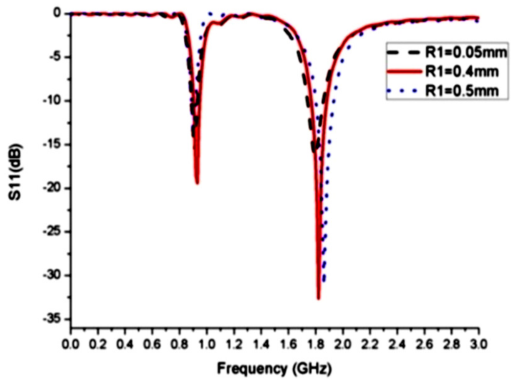


Fig. 7. Simulated reflection coefficient as a function of frequency for different values of R1

Figure 8 illustrates the variation of the reflection coefficient S11 as a function of the frequency for different values of parameter F. It is noted that when F reaches the value of 1.8mm, the resonant frequency and the remain almost constant. Also, the adaptation for the first band is improved when F increases. When F decreases to 1.5mm the resonant frequency changes for the first and the second band.

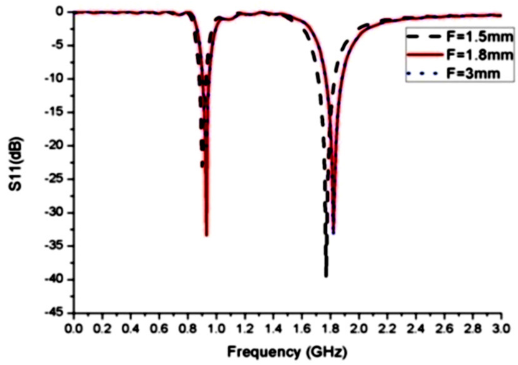
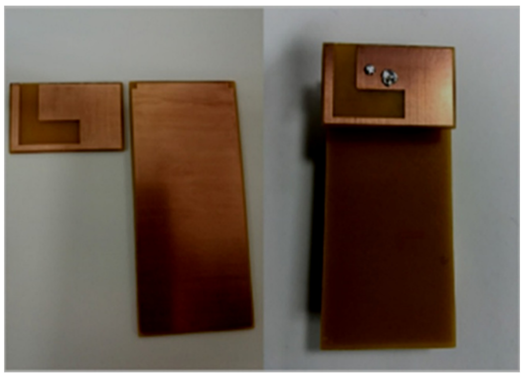


Fig. 8. Simulated reflection coefficient as a function of frequency for different values of F

The variation of the reflection coefficient S11 simulated by CST as a function of the reconfigurable slot antenna, gave an optimized antenna model intended in particular for GSM networks. It operates on two frequency bands of 900MHz and 1800MHz.

III. EXPERIMENTAL RESULTS AND DISCUSSION

To confirm our study, we realized the proposed PIFA antenna and the obtained measurement results were explained by a vector network analyzer. These measurements were focused on the reflection coefficient of the antenna in order to evaluate the actual performance of the designed antenna. Photos of the realized PIFA antenna, of dimensions 89.88×39.87×1.6mm³, are given in Figure 9. The antenna is printed on the substrate FR4_Epoxy of relative permittivity ε_r=4.4 and has a thickness h=1.6mm.



(a) (b)

Fig. 9. Photos of the realized PIFA antenna: (a) before and (b) after assembly

Figure 10 shows the variation of the reflection coefficient S11 simulated with CST, HFSS and measured as a function of frequency. According to Figure 10, there is almost an agreement between the simulated and the measured values of the reflection coefficients of the realized antenna. The simulation result by CST is almost similar to the measurement result for the first band. Also, the simulation result by HFSS is in accordance with the measurement result for the second band. Nevertheless, the adaptation of the reflection coefficient of the measurement result is somewhat reduced as compared to that of the simulation curves. This may be due to the losses in the line of excitation. The antenna has an adaptation of -35dB at 0.9GHz and -34dB at 1.8GHz respectively for the first and second band of operation with the CST simulator.

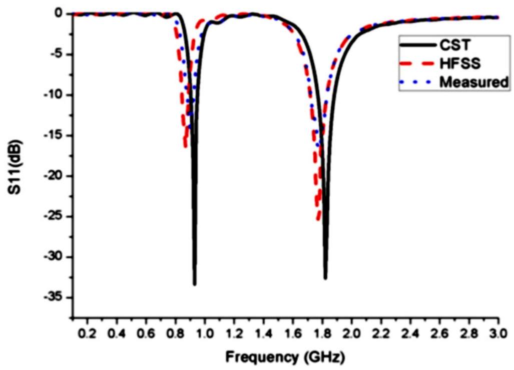


Fig. 10. Simulated and measured reflection coefficient as a function of frequency

Current distribution on the PIFA and electrical field on the slot has been computed using the CST simulator to give an extra physical insight into the behavior of this antenna. Figures 11 and 12 show the current distribution of the proposed antenna at 900MHz and 1800MHz.

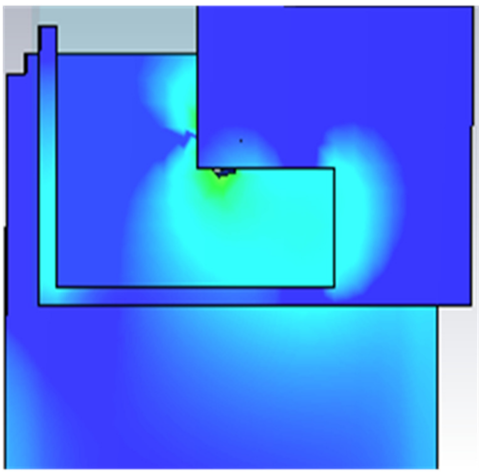


Fig. 11. Current distributions at resonant frequency 900MHz

It can be seen that the current distribution reaches maximum density mainly on the L shaped stub in the same phase as shown in Figure 12. The resonance behavior of antennas can be better understood by considering the current distribution. From the Figures, it can be concluded that the resonance at 1800MHz is due to the slit in the ground plane because it shows a maximum along the length of the slot. The resonance at 900MHz is due to the modified patch because it shows the current minimum on the patch. It should be also noted that that the PIFA is highly excited at 1800MHz (larger branch at Figure 12) whereas it is weakly excited at 900MHz (short branch at Figure 11). The PIFA modes for both resonances are the fundamental ones, the maximum of current distribution is at the feeding/short area and its minimum is at the open edge.

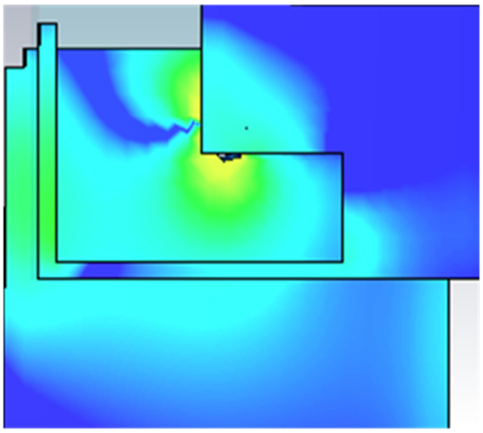


Fig. 12. Current distributions at the resonant frequency of 1800MHz

The VSWR value determines the matching properties of the proposed antenna (Figures 13-14). It indicates how efficiently the antenna is transmitting or receiving the electromagnetic waves over GSM900MHz-1800MHz band frequencies. It describes the amount of power reflected by this antenna. The VSWR should be between 1 and 2 for little reflection losses.

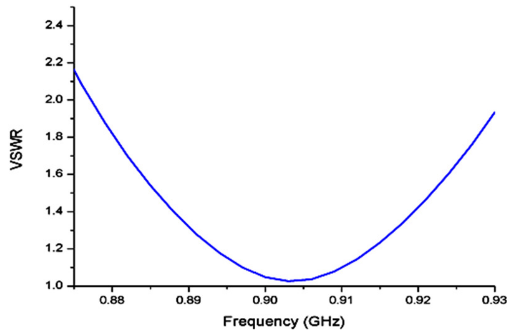


Fig. 13. Simulated VSWR value vs frequency for the GSM900 band

Based on Figures 13 and 14, we found that the VSWR value is 2.15 and 1.65 respectively at 900MHz and 1800MHz. As an explanation we might say that that the GSM900MHz band of the proposed antenna during the phase of transmission and reception of the electromagnetic wave is more efficient than the GSM1800MHz band. The same thing stands for the amount of power reflected by this antenna. The VSWR investigation shows that dual frequency operation at 900MHz and 1800MHz is obtained by the parasitic element effects. The dual-frequency operation is revealed as a function of slot position above a ground plane. As the height of slot decreases, the separation of resonance frequency is higher. It also shows a better impedance matching of load to the characteristic impedance of the transmission line carrying radio frequency signals.

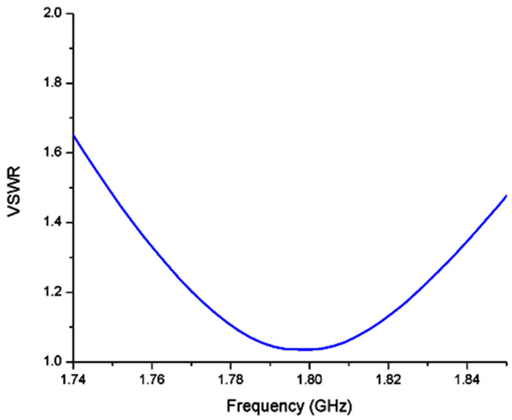


Fig. 14. Simulated VSWR value vs frequency for the GSM1800 band.

In Figure 15 the radiation patterns of the proposed PIFA antenna for two resonance frequencies of 0.9GHz and 1.8GHz in the case of phi=0deg and phi=90deg are presented. From Figures 15 and 16, it is noted that the radiation of the antenna is concentrated in four different directions for each resonant frequency with the appearance of a certain level of undesirable radiations. These are negligible in comparison with the main radiation lobe which justifies the multi-directional aspect of this antenna. We note that this has a gain greater than 7dB for each resonant frequency, which is an important value for a single element antenna.

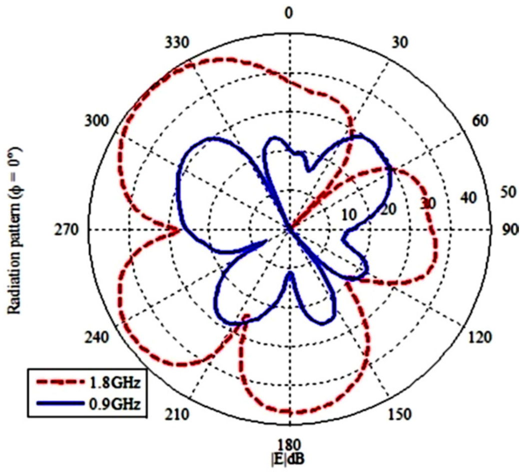


Fig. 15. Radiation pattern for frequencies 0.9GHz and 1.8GHz, phi=0deg

In Table II, a comparison of various parameters to verify the performance of the antenna is carried out. The proposed antenna is resonant at two frequencies, 902MHz and 1800MHz. It has been analyzed using CST Microwave Studio in terms of return loss (S11) plot, current distributions, gain (dBi), radiation efficiency, radiation pattern, VSWR, and bandwidth (MHz). From Table II, it can be seen that the proposed antenna is more compact, has a wider impedance bandwidth and an acceptable peak gain for GSM applications.

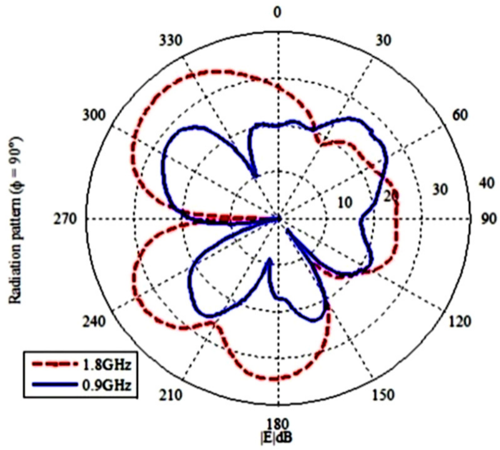


Fig. 16. Radiation pattern for frequencies 0.9GHz and 1.8GHz, phi=90deg

TABLE II. CHARACTERISTICS OF THE PROPOSED ANTENNA

Frequency (Mhz)	Gain (dBi)	Radiation efficiency (%)	Frequency range (GHz)	Bandwidth (MHz)
902	7.32	67.5	0.889-0.928	39
1800	8.16	72.14	1.752-1.87	118

IV. CONCLUSION

In this work, a new dual-band PIFA antenna that covers GSM bands at 900MHz and 1800MHz was designed. The technique of modifying the geometry of the radiating element, in particular the creation of the slots and the use of the localized elements was exploited. This antenna is characterized by a good adaptation of the reflection coefficient for its two resonant frequencies, multi-directional radiation and a gain greater than 7dB for each resonant frequency. The results found a good compromise between all the parameters and there is a good agreement between the simulated and the measured results. So, this realized antenna is a good candidate for GSM applications. This study establishes the foundation of a new future project that could revise the effects between the GSM network and its associated equipment and the organs of the human body and propose practical solutions to reduce the effects of electromagnetic radiation on humans.

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