Slotted PIFA for Mobile Communication Devices

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Abstract. *Slotted PIFA with capacitive loading for operation in the 880 ÷ 960 MHz band is presented. The PIFA is intended for mobile terminals in GSM mobile communication network. The antenna is placed on a ground plane with dimensions of an average handheld device. It is optimized by using electromagnetic simulator and a prototype is manufactured. Calculated and measured results agree very well. Input impedance matching with SWR < 3 in the whole band was achieved. Maximum gain of 3.2 dBi is measured. Preliminary studies of the influence of the user's head and hand on the antenna characteristics have been performed.*

Keywords

Small antenna, microstrip antenna, planar-inverted-F antenna, PIFA.

1. Introduction

The increasing interest for small and compact antennas is the consequence of the development of personal communications and handheld devices such as organizers, computers, navigation devices, etc. which are using wireless access points. For handheld wireless terminals the antenna is a necessary part. However, due to the market and end-user requirements, the antenna should not be visible. The answer to these conflicting requirements are small and compact antennas which can be integrated in the device body.

Antenna size and its performance are strongly linked together. The first fundamental results showing the link between antenna size and its maximum bandwidth and gain were presented in the late forties [1, 2].

The antenna size is not mainly determined by the technology used for its fabrication (like in electronic chips) but rather by physical laws. Good antenna performances are obtained when the antenna is resonant and when its size is comparable to the wavelength. At the operating frequencies of mobile communications and wireless networks this means that the antenna should be quite large. Several techniques and approaches have been introduced to reduce antenna dimensions and maintain good radiation properties [3–6]. Research and development on small and compact antennas is of great importance for all present and future wireless applications [4], [6]. Most frequently used small antennas are shorted patches and PIFAs [7–11]. Further reduction of antenna dimensions is obtained by modifications introduced in the patch [5], [12], [13]. However, the reduction in antenna dimensions is always made at the expense of bandwidth, gain and efficiency.

Another important issue for handheld device antennas is that these antennas radiate near the human (user's) body. This interaction should be considered in two ways: how the human body influences the antenna characteristics (input impedance, far field radiation pattern, gain and efficiency) and how the body tissue is affected by the RF energy radiated by the antenna [14].

2. Antenna Description

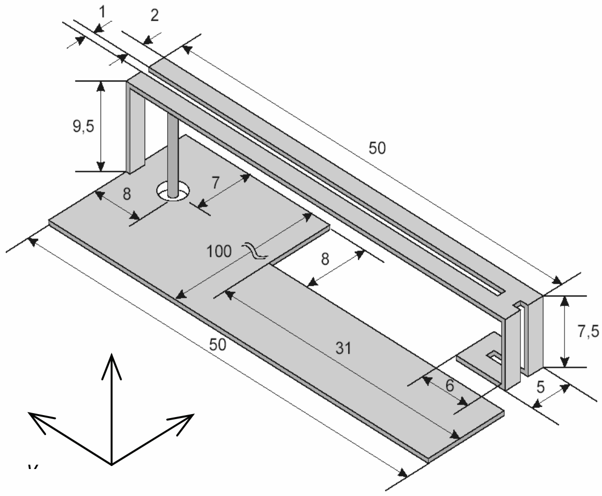
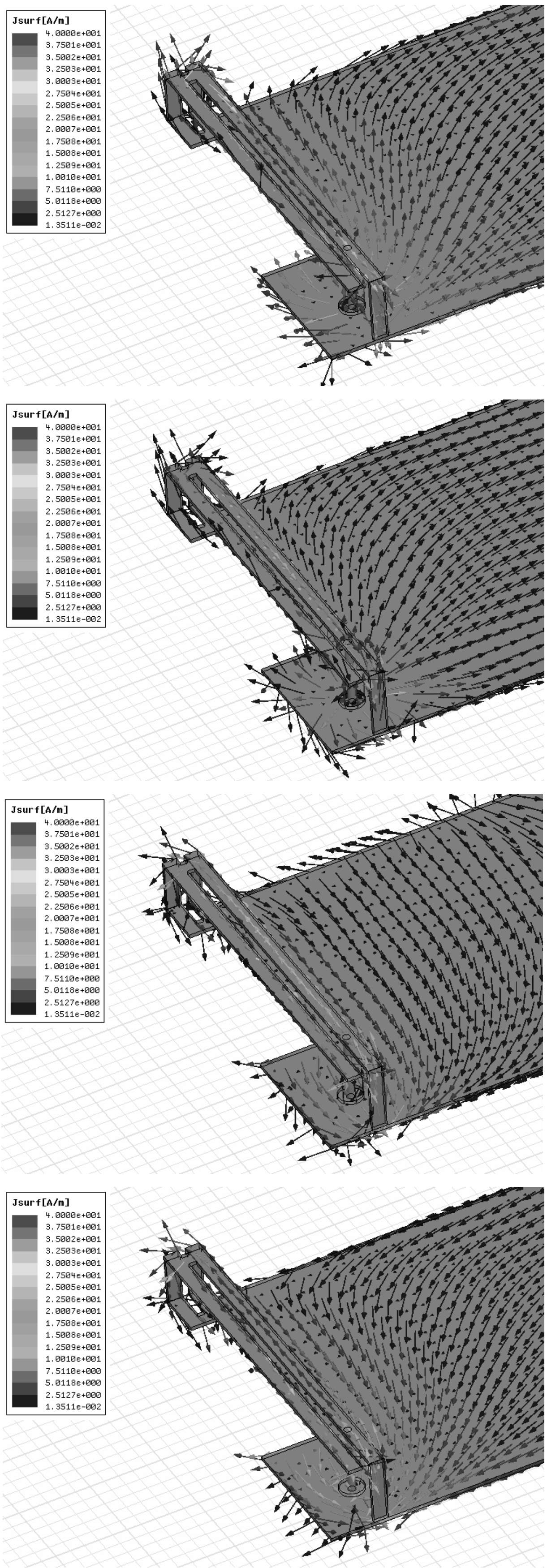


Fig. 1. Slotted PIFA (all dimensions in millimeters).

The antenna proposed in this paper is shown in Fig 1. The antenna was designed and optimized by using HFSS 3D full-wave electromagnetic field simulator by Ansoft [15]. The antenna is designed for operation in the 880 to 960 MHz band. Its resonant frequency is chosen roughly at the center of the frequency operating bandwidth.



a)
b)
c)
d)

Fig. 2. Calculated vector current density on the antenna at f = 920 MHz: a) t=0; b) t=T/8; c) t=T/4; d) t=3T/8; (T = 1 / f).

The antenna is placed on a 50 mm × 100 mm ground plane at one of the shorter edges. For simulation and testing purposes the antenna was excited by a coaxial probe and a SMA connector. However, in a real device, it would be excited directly from the T/R circuits on the printed circuit board placed bellow the ground plane. The ground plane size has been chosen to approximately match the size of a typical handheld device.

A slot was introduced in the PIFA to increase the path length of the surface current and reduce the size of the PIFA. Further length reduction was achieved by bending the end of the slotted PIFA towards the ground plane. This increased the capacitive loading at the antenna end. The introduced modification increased the antenna quality factor resulting in calculated input impedance bandwidth (SWR < 3) of only 51 MHz while the capacitive loading lowered the resonant frequency to 865 MHz. As satisfactory impedance matching over the design bandwidth could not be obtained by further modifications of the bent end of the PIFA, part of the ground plane bellow the antenna was removed. After this modification, calculations have shown that the resonant frequency was at 916 MHz, while the input impedance bandwidth was 109 MHz.

The calculated vector current density on the antenna at the center of the operating bandwidth (f = 920 MHz) is shown in Fig. 2. The vector current density has been calculated for four different moments during the first half of the signal period T (T = 1 / f). The plots for the second half of the period are omitted in Fig. 2 because the current intensity is the same while only the vector directions are opposite. The current flows around the slot in the PIFA, which increases the electrical length and allows size reduction. The current density maximum is at the middle of the excited part of the PIFA. The current density on the ground plane is low, but because of the ground plane size the total current is not negligible and it contributes to antenna radiation.

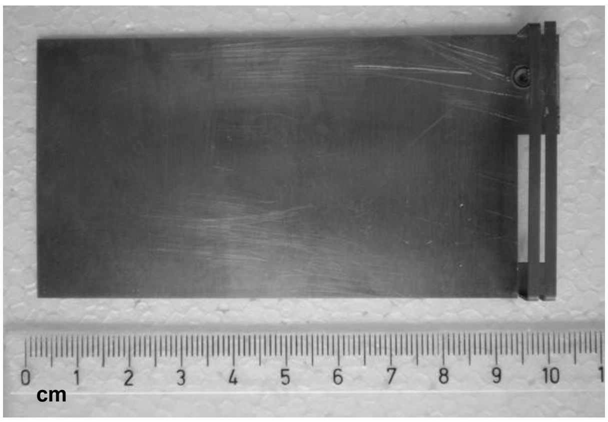


Fig. 3. Slotted PIFA on 50 mm × 100 mm ground plane.

When the simulation and optimization process has been completed, the antenna prototype was manufactured. The antenna on the ground plane is shown in Fig. 3. Fig. 4 shows construction details of the prototype.

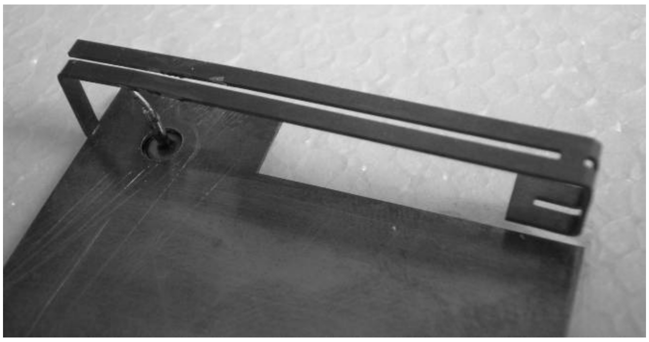


Fig. 4. Prototype detail.

3. Calculated and Measured Results

The comparison of the calculated and measured reflection coefficient at the antenna input is shown in Fig. 5. The resonant frequency is around the center of the desired operating bandwidth. In the operating bandwidth of 880 ÷ 960 MHz, both the calculated and measured reflection coefficient magnitudes are bellow –6 dB (SWR < 3) which is generally accepted limit for antennas used in handheld devices [5], [13].

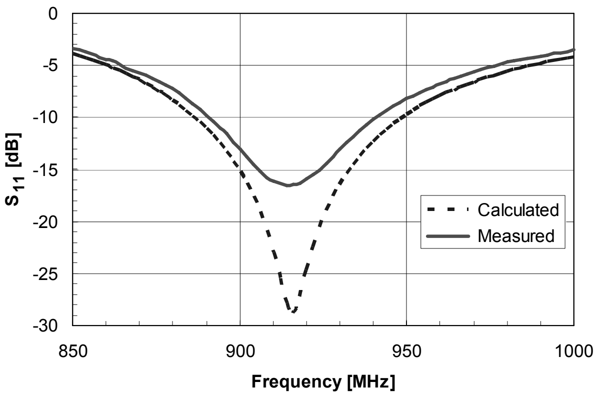


Fig. 5. Calculated and measured reflection coefficient at the antenna input.

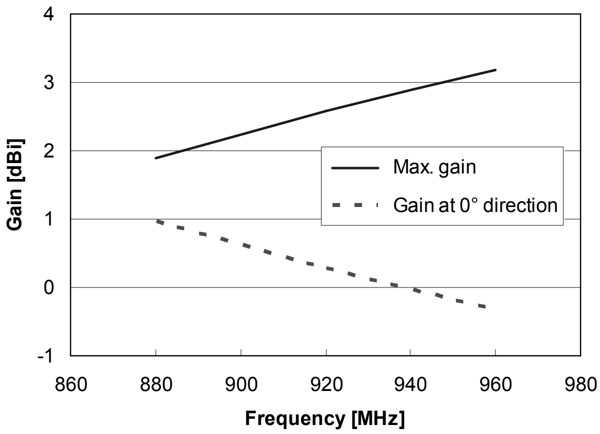


Fig. 6. Measured gain.

The measured gain is shown in Fig. 6. The gain was measured at 0° direction (perpendicular to the ground plane) and at the beam maximum. As it can be seen in Fig. 6, the maximum gain increases with frequency, and the maximal value of 3.2 dBi is measured at 960 MHz. On the other hand, the gain at 0° decreases with frequency, as the beam maximum shifts from the 0° direction. At 960 MHz it is slightly bellow 0 dBi.

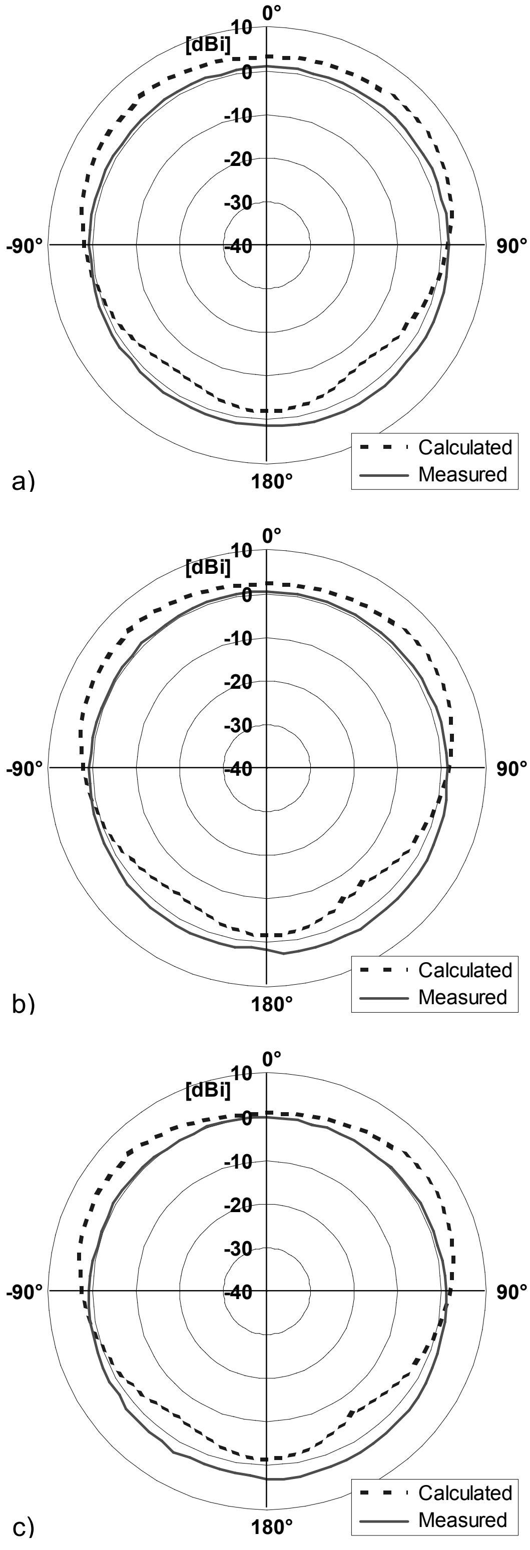


Fig. 7. Calculated and measured co-polarization gain patterns in *x-z* plane: a) 880 MHz, b) 920 MHz; c) 960 MHz.

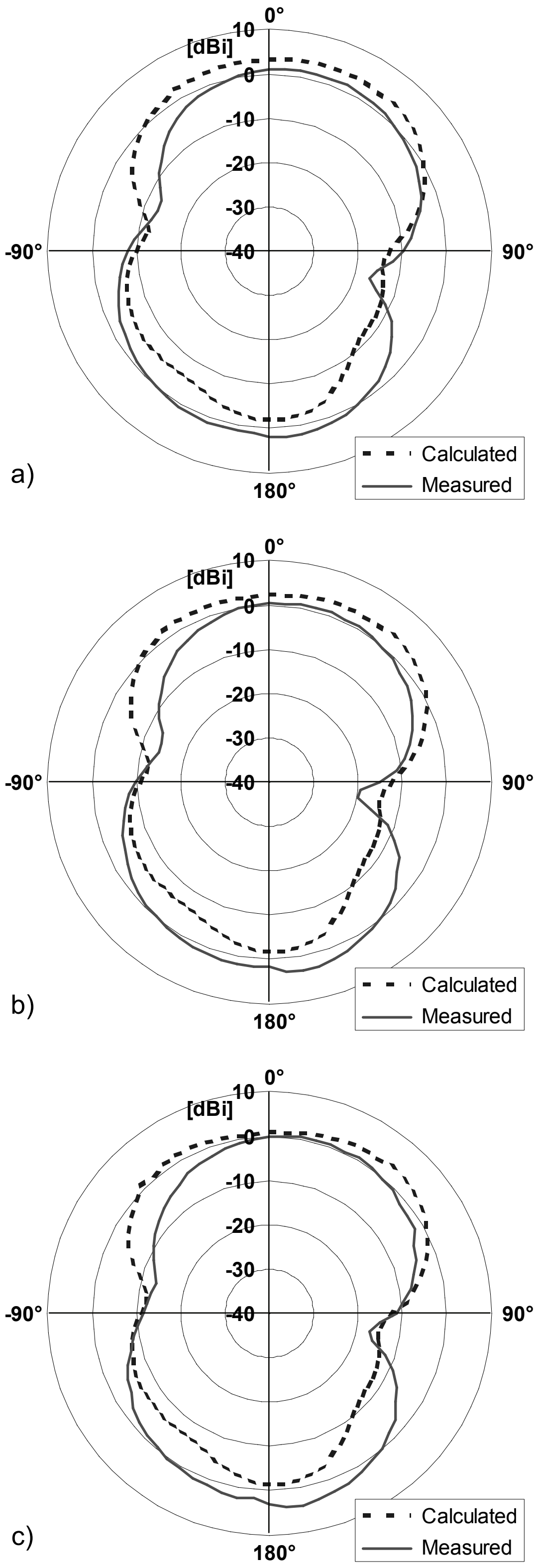


Fig. 8. Calculated and measured co-polarization gain patterns in *y-z* plane: a) 880 MHz, b) 920 MHz; c) 960 MHz.

Comparison of the calculated and measured co-polarization gain patterns are shown in Figs 7 and 8. The antenna is linearly polarized. The patterns are measured at both ends as well as at the center of the operating frequency bandwidth. The measurement planes, *x-z* and *y-z*, are defined with coordinate system shown in Fig. 1. The *x-z* patterns are almost omnidirectional, while the *y-z* patterns have two broad maxima. The patterns do not change significantly with frequency.

Although simulation results predict very low density of the current flowing in the ground plane (Fig. 2), measurements show that the contribution of these currents to the radiation is significant.

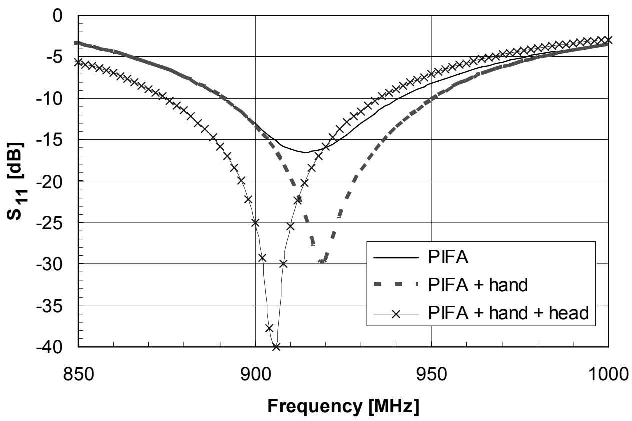


Fig. 9. Measured reflection coefficient at the antenna input for the PIFA alone, for the PIFA with hand phantom, and for the PIFA with hand and head phantoms.

Preliminary measurement results of the reflection coefficient at the antenna input for the presented PIFA in the proximity of human hand and head phantoms are shown in Fig. 9. For the measurements of the PIFA with only the hand phantom, the hand phantom was covering approximately 8 cm of the bottom part of the antenna ground plane. For the measurements of the PIFA with the hand and head phantom, the position of the hand phantom was the same while the head phantom was placed 2 cm behind the ground plane. The first case simulates the application of the handheld device used with earphones, while the second simulates the case where the handheld device is placed near the user's ear. Measurement results in Fig. 9 show that better impedance matching than the one shown in Fig. 5 can be expected. To enable the comparison, the measured results from Fig. 5 are repeated on Fig. 9. The presence of the hand phantom and especially the presence of both the hand and head phantoms shift the resonant frequency of the PIFA (Fig. 9). However, in both cases the requirement for impedance matching at the antenna input (SWR < 3) is satisfied in the desired operating bandwidth of 880 to 960 MHz. Nevertheless, the influence of the user's hand and head on the antenna should be reduced. It is expected that the influence of the user's head can be reduced by further shaping of the removed part of the ground plane in order to lower the radiation in the direction of the user's head. The influence of the user's hand can be reduced by reducing the RF currents flowing on the ground plane by RF chokes. Both issues are important not only for obtaining better radiation properties of the antenna but also for protecting the user of the exposure to EM fields generated by the handheld device.

Better impedance matching for the PIFA loaded with hand and head phantoms is due to the losses in the dielectric material simulating the human tissue. However, increased losses implicate gain reduction. Also distortion of the radiation patterns is expected. These two issues will be considered in our future work.

4. Conclusion

A slotted PIFA with capacitive loading for operation in the 880 ÷ 960 MHz band was presented. The modifications introduced in the PIFA allowed reduction in size. The PIFA was realized over a ground plane which dimensions approximately matched the size of a typical handheld device. The antenna was optimized and the prototype was fabricated. The input impedance as well as the radiation patterns and gain were measured. The measured and calculated results agree reasonably well.

Preliminary results of the influence of human head and hand phantoms on the antenna characteristics show the need of reducing the radiation of the antenna in the direction of the user's head and hand. This will make the antenna less sensitive to its surrounding during operation and it will reduce the user's exposure to the electromagnetic fields generated by the handheld communication device.

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Davor BONEFAČIĆ was born in Zagreb, Croatia, in 1968. He received his Dipl.Ing., Mr.Sc. and Dr.Sc. degrees from the Faculty of Electrical Engineering and Computing, University of Zagreb in 1993, 1996, and 2000, respectively. Since 1993, he has been with the Department of Wireless Communications, Faculty of Electrical Engineering and Computing, University of Zagreb. From 1993 to 2002 he worked as a research assistant and from 2002 to 2006 as assistant professor. Currently he is associate professor at the same Department. His teaching activity includes several subjects on microwave engineering and radar systems. In 1996 he was a visiting researcher at the Third University of Rome, Rome, Italy. In 1996 he was awarded with the silver plaque "J. Lončar" for outstanding master thesis. Since 2004 he is a collaborating member of the Croatian Academy of Engineering. He is co-author of more than 60 journal articles and conference papers. Besides teaching and research his professional activity includes measurement of field distribution and estimation on health risk of mobile communication base stations and radar installations, technical inspections of radio broadcasting stations, and calibration and conformity verification of RF measurement equipment. His research interests include active integrated antennas and arrays, spatial power combining, electronic beam scanning, small and compact antennas for wireless communications, and wideband antennas.

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