User Hand Influence on Properties of a Dual-Band PIFA Antenna

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Abstract. *This paper deals with the user hand influence on impedance matching and radiation pattern of a planar inverted-F antenna (PIFA). In the text, the PIFA structure is discussed in order to achieve broadband and multiband capability. Then, the dual-band PIFA antenna for operation at frequencies of GSM900 and GSM1800 systems is designed. In the next step we investigate the user influence in data mode (the user is typing a message or browsing with a phone). For this purpose the phantom hand was made of an agar based material. The first author's right hand was used as a template for the phantom. Numerical model was created by 3D scanning of the fabricated phantom. Finally, the comparison of the differences between simulations and measurement is presented.*

Keywords

Dual-band antenna, PIFA, user influence, human tissue, phantom hand.

1. Introduction

Nowadays, wireless communications devices are almost everywhere. Thanks to modern electronic components there is a continual trend of miniaturizing this equipment and similar demands are placed on their antennas. The radiation performance of small antennas is becoming more sensitive to the head and especially to the hand, since internal antennas were adopted into mobile devices.

In the data mode the index finger is mostly in close proximity of the antenna radiator. In order to evaluate the influence of the lossy dielectric object on the antenna performance, a hand model should be a necessary part of designing and testing of mobile devices. Due to hygienic limits, phantoms or numerical models are commonly used instead of real human hands. Several papers deal with this issue, but mainly covering only measurements or only simulations [1]–[4]. This paper deals with both, simulation and measurement, using a hand model and phantom which have precisely equal shape (corresponding with the first author's right hand). So the comparison of results is credible. The hand model is provided by scanning a phantom model using a 3D scanner. Agar was chosen as a tissue-equivalent material with additional water, whose dielectric properties are equivalent to biological muscle tissue [5].

The objectives of the paper are to design a dual-band PIFA antenna with the assistance of an electromagnetic field simulator, make a prototype and verify its properties by measurement. On this type of antenna, the user influence in data mode will be investigated. The phantom from the agar based material and its numerical equivalent will be used. Finally, the user hand influence on impedance matching, the radiation pattern and the radiation efficiency of PIFA, as well as SAR distribution in the hand will be presented.

2. Planar Inverted F-Antenna

PIFA is a commonly used antenna in mobile applications. It is called an inverted F-antenna because the side view of the antenna element is like the letter F with its face down.

The PIFA antenna is a modification of a conventional patch antenna. One of the main differences between them is their size. While the resonance length of an ordinary patch antenna is $\lambda/2$, PIFA reduces the resonance length to less than $\lambda/4$. It is accomplished by using a shorting pin located at the null-voltage point of a patch antenna.

It is known that planar antennas have a narrow bandwidth. This problem can be overcome by increasing substrate height, decreasing its ε_r or achieving multiband behavior of the antenna. In most cases, a thick air dielectric substrate is used. Multiband capabilities are often achieved by cutting slits on the patch.

2.1 Antenna Design

The aim of this chapter is to design a dual-band PIFA antenna for GSM900 and GSM1800 frequency ranges.

The first step of the antenna design is to determine approximate dimensions of the patch. The sum of width w and length l of the patch can be roughly expressed as follows [6]

$$w + l \approx \frac{\lambda}{4} \quad (1)$$

where λ is the first resonant wavelength. The initial cutting of the patch slit, for achieving the second resonance, was adopted from [6].

The patch is made of IsoClad933 substrate and the ground plane is made of FR-4 substrate. Separation between substrates is 1 cm, supported by plastic distance posts. The shorting pin has diameter 1 mm. Feeding is provided by an SMA connector through the ground plane.

Simulations were performed in the electromagnetic field simulator CST Microwave Studio based on the FIT numerical method. The designed dimensions of the patch are shown in Fig. 1. The ground plane dimensions are 50×120 mm^2. The final prototype of the antenna was fabricated (see Fig. 2).

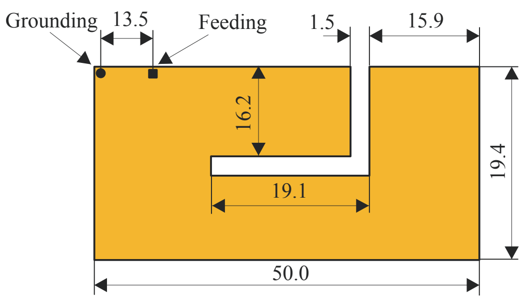

Fig. 1. Dual-band PIFA dimensions.

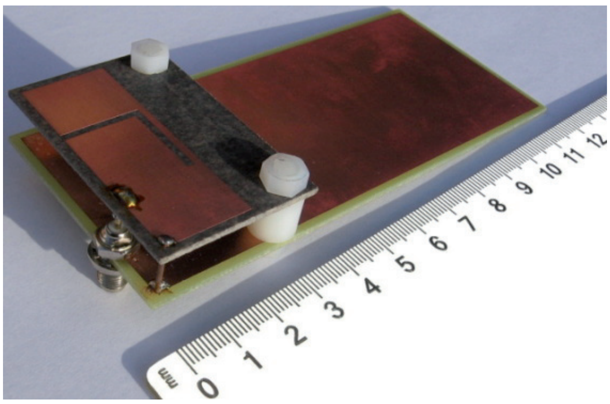

Fig. 2. Photo of the dual-band PIFA prototype.

2.2 Antenna Parameters

The impedance match measurement of the fabricated PIFA was carried out by the vector network analyzer Rohde&Schwarz ZVL3. For eliminating unwanted asymmetric currents flowing over the outside shield of the coaxial cable, ferrite chokes were used.

The comparison of the computed and measured frequency response of the reflection coefficient is shown in Fig. 3. Both characteristics show good impedance match in the required frequency bands, but some disagreement between them is obvious. Frequency shifts are caused mainly by inaccurate soldering of the connector and shorting pin.

In Fig. 4 the computed 3D radiation patterns for vertically and horizontally polarized waves are compared. It is obvious, considering antenna position in Fig. 4, that vertically polarized waves play a dominant role in antenna radiation. For vertically polarized waves at 925 MHz, antenna radiation is practically omnidirectional (like a dipole); at 1795 MHz, the antenna radiates primarily downwards. Horizontally polarized waves at 925 MHz are strongly suppressed; at 1795 MHz, the radiation pattern is approximately omnidirectional with gain around 0 dBi.

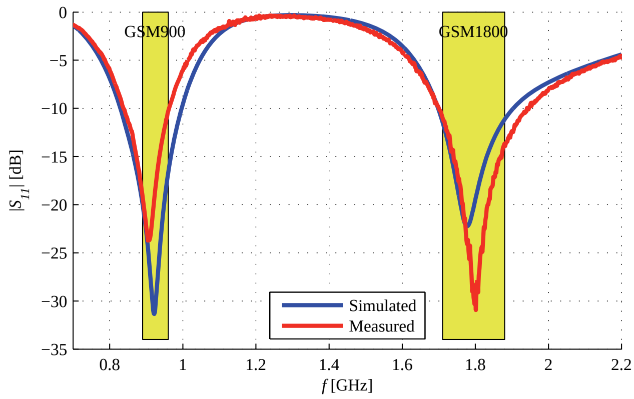

Fig. 3. Simulated and measured frequency response of the reflection coefficient of the PIFA.

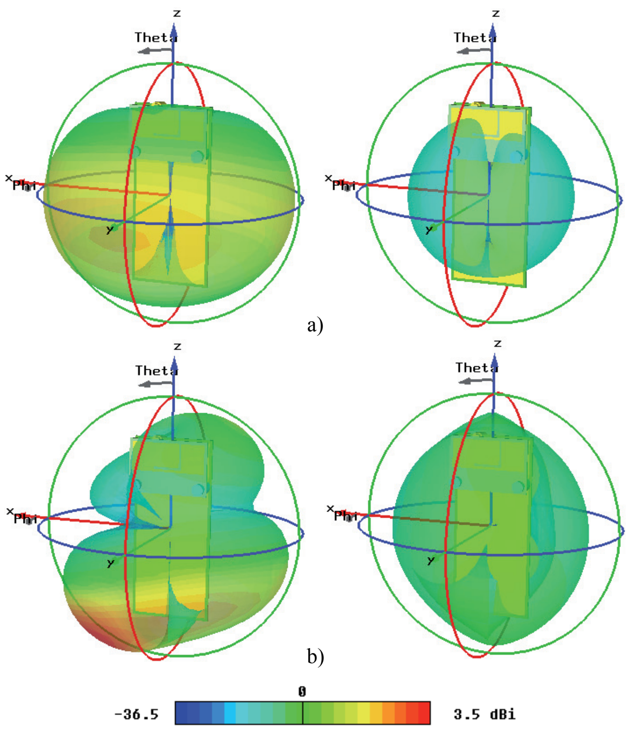

Fig. 4. Simulated radiation patterns at a) 925 MHz and b) 1795 MHz of the PIFA. Left pictures represent vertically polarized waves, the right pictures are computed for horizontally polarized waves.

3. Hand Models

This chapter deals with the description of hand models used for investigating user hand influence. The first author's right hand was used as a template for the models.

3.1 Phantom Fabrication

It is necessary to mold a cast from suitable material for creating a phantom hand with consistent shape of the original hand. This material should couple to the electromagnetic field produced by the device in the same way and to the same extent as a real human hand.

The first step was creating a plaster cast of the hand using a material named Efkocrea. Efkocrea is an elastic material, specially designated for making molds. After the cast dried out, the mold was destroyed and the plaster cast was varnished.

A reusable mold was divided into 7 horizontal layers. The separate layers were made by the product Lukopren N [7]. It is a silicone rubber which becomes vulcanized after being mixed with a catalyst.

The material for the phantom hand should have the required dielectric properties over a wide frequency range, be shapeable, and sturdiness is also desirable. Target values for the phantom hand material, i.e. the average permittivity and conductivity of dry and moistened palm skin, have been reported in [8] and are shown in Tab. 1.

f [MHz]	ε_r [-]	σ [S/m]
900	36.2	0.79
1800	32.6	1.26

Tab. 1. Average permittivity and conductivity of all tissues of the hand published in [8].

f [MHz]	ε_r [-]	σ [S/m]
900	50	0.4
1800	50	1.0

Tab. 2. Measured dielectric properties of agar based material.

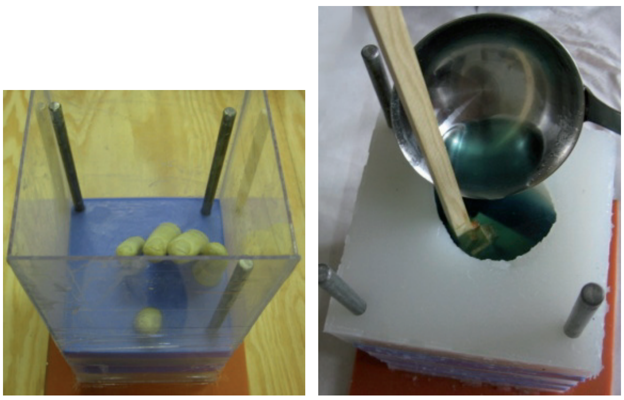

Fig. 5. Fabrication process of reusable seven layer mold (left) and casting process of agar based material to this mold (right).

An available tissue-equivalent material suitable for phantom hand fabrication is agar, whose dielectric properties are equivalent to biological muscle tissue. Better agreement with this tissue can be performed by increasing the water content of agar [5]. The selected ratio of agar to distilled water is 3:4. Agar was melted down and mixed together with water in the chosen ratio. The measured parameters for the produced mixture are shown in Tab. 2. For the sake of high proportion of water in the mixture, a load-bearing structure of spruce wood was glued together to provide mechanical support. The process of fabricating the phantom based on agar is shown in Fig. 5.

3.2 Numerical Model Creation

The numerical model was created by 3D scanning of the plaster cast which was made beforehand. It is the best solution for precisely preserving the phantom dimensions and shape. The resolution of the model was reduced, in 3D editor, for maintaining lower computational demands. The final model consists of approximately 10 thousand triangles. After that, the file was imported into CST Microwave Studio, where it was located at the desired position relative to the antenna. A simplified wooden load-bearing structure was also modeled. The resulting structure is shown in Fig. 6.

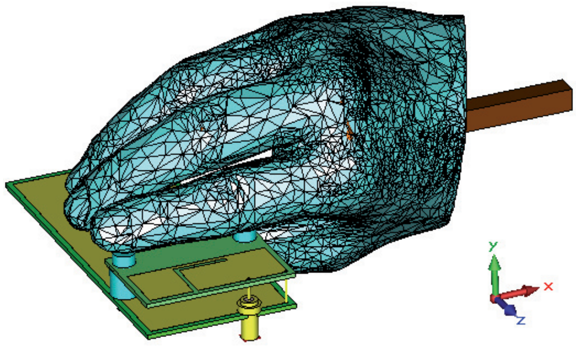

Fig. 6. Numerical model of the antenna with the phantom hand in the desired position.

4. The Effects of the User Hand

The effect of the user hand on impedance match was measured using the phantom hand described above. The phantom was placed in a typical position relative to the antenna in data mode (the same as in Fig. 6), which is shown in Fig. 7.

The comparison of the measured frequency response of the reflection coefficient between the antenna in free space and with phantom influence is shown in Fig. 8. It can be seen that the presence of the agar phantom brings slight impedance matching deterioration for both frequency bands. At the GSM900 band, it is also noticeable that the resonant frequency shifts towards the lower value, and that the higher resonant frequency is practically unchanged.

The simulation results with agar setting material prove sufficient agreement with measurements in the

GSM1800 band; in the GSM900 band, faint disagreement can be seen. The variance is probably due to big measurement error of the material parameters at low frequencies.

The comparison of the simulated frequency response of the reflection coefficient between materials (average from Tab. 1. and agar based) is also shown in Fig. 8. The correspondence between plots is obvious, which proves that the agar based material is properly selected.

Fig. 7. Photo of the phantom prototype during antenna impedance match measurement.

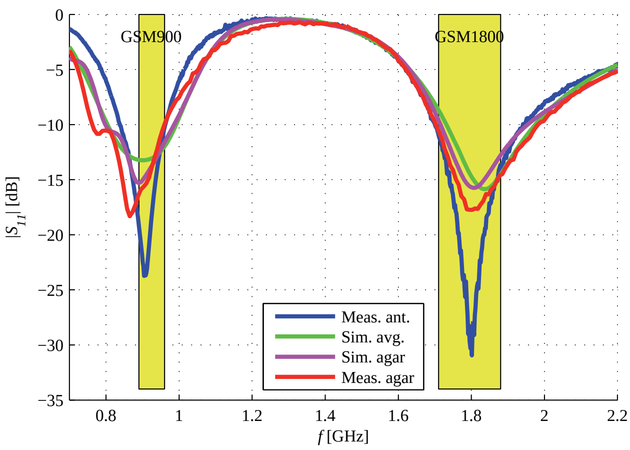

Fig. 8. User hand influence on impedance matching of the PIFA.

Figure 9 compares the computed radiation patterns between antenna in free space and with phantom influence for the xy plane. The xy plane is normal to the ground of the antenna as well as parallel with the fingers (see Fig. 6). Rotation angle corresponds to the angle Phi in Fig. 4, the antenna position, with respect to the Earth's surface, also agrees with Fig. 4.

For vertically polarized waves at the frequency of 925 MHz, attenuation due to the presence of the hand in the direction of the x axis is well observed. In this way, the antenna is surrounded by a hand which absorbs part of the radiation. On the contrary, at the frequency of 1795 MHz, the gain is larger in the x direction.

At the frequency of 925 MHz, horizontally polarized waves are not as strongly suppressed as in free space. At the frequency of 1795 MHz, also attenuation in the direction of the x axis is observed.

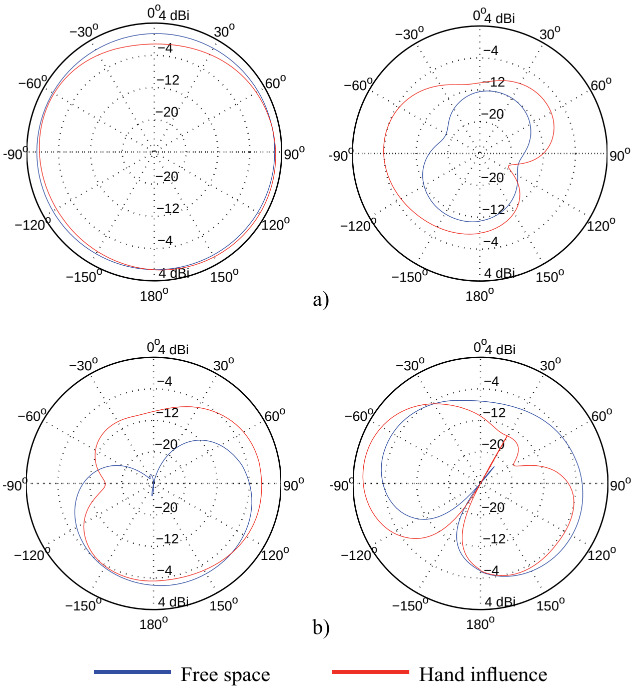

Fig. 9. Comparison of the calculated radiation characteristics of PIFA for the xy plane (see Fig. 6.) with the characteristics simulated in phantom hand presence at a) 925 MHz and b) 1795 MHz. Rotation angle corresponds to the angle Phi in Fig. 4. The left pictures represent vertically polarized waves, the right pictures are computed for horizontally polarized waves.

The comparison of the calculated radiation efficiency between the antenna in free space and with hand influence is shown in Tab. 3. It is obvious that the presence of human hand brings radiation efficiency decrease for both frequency bands. At the GSM1800 band, the decrease of radiation efficiency is more significant than that at the GSM900 band.

	f [MHz]	890	925	960	1710	1795	1880
PIFA	e_{cd} [%]	98.8	98.8	99.0	98.3	98.7	99.0
PIFA + hand	e_{cd} [%]	66.5	68.9	69.2	46.6	49.5	52.5

Tab. 3. Radiation efficiency (e_{cd}) calculation for only the PIFA and the PIFA with the hand model present. Lower, center and upper frequencies are selected for both GSM bands.

Figure 10 shows the simulated SAR distribution in the hand for the antenna in data mode. SAR is 10 g averaged, calculated for the same radiated power of 1 W, for both frequency bands.

Energy absorbed by the biological tissue mass is larger at the frequency of 1795 MHz, but all values meet the defined maximum limits very well. For mobile phones, the SAR limit (in Europe) is 2 W/kg averaged over the 10 g of tissue absorbing the most signal, [6].

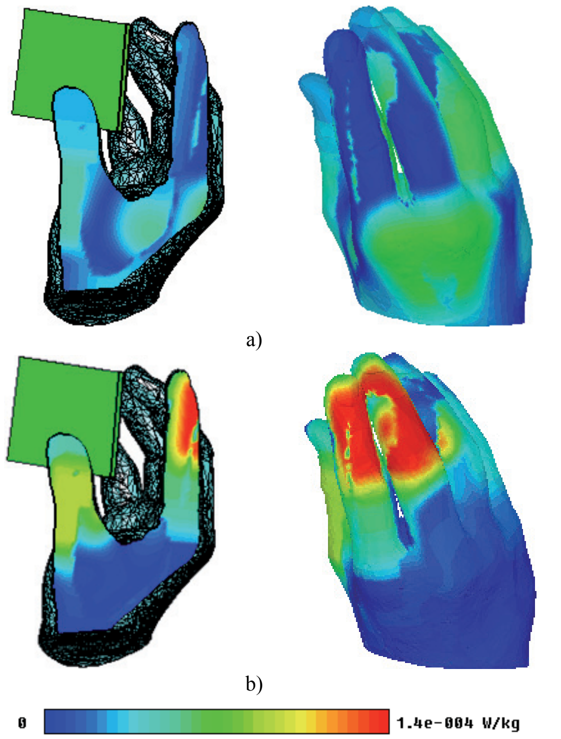

Fig. 10. Simulated SAR distribution in the hand at a) 925 MHz and b) 1795 MHz. Left pictures represent absorption inside the hand, the right pictures are 3D views to the surface of the hand.

5. Conclusion

The user hand influences on the properties of dual-band PIFA antennas are studied in this paper. The antenna covers the frequency bands of communication systems GSM900 and GSM1800 with impedance matching $|S_{11}| < -10$ dB at both bands.

The effect of the user hand on the antenna was measured using a hand model placed in a typical position of antenna in data mode. For this study, a phantom hand (corresponding to the first author's hand) and its equivalent numerical model were made. A suitable material of agar base has been developed and verified for phantom fabrication.

The presence of the phantom hand, in the measured position, brought slight impedance matching deterioration for both frequency bands. At the GSM900 band, it is evident that the resonant frequency shifts towards the lower value. The impact of the user hand on the radiation characteristics is quite different for both frequencies and polarizations. The radiation efficiency is influenced by the hand quite significantly, especially at the GSM1800 band. SAR distribution inside the hand meets the defined maximum limits very well.

This study examined the effect of a hand on one particular antenna. However, the presented methods, phantom made or numerical model, can serve well in the design and testing of any antenna.

Acknowledgements

The research was supported by the grant of the Czech Science Foundation no. P102/12/1274 and by the COST Action IC1102 (the grant no. LD12012). Measurements were performed in the laboratories supported by the SIX project; the registration number CZ.1.05/2.1.00/03.0072, the operational program Research and Development for Innovation.

References

[1] SAROLIC, A., SENIC, D., et al. Influence of human head and hand on PIFA antenna matching properties and SAR. In *19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, 2011.

[2] LI, C. H., OFLI, E., CHAVANNES, N., KUSTE, N. Effects of hand phantom on mobile phone antenna performance. *IEEE Transactions on Antennas and Propagation*, 2009, vol. 57, no. 9, p. 2763–2770.

[3] DAVOODI, D., SHARIFZAD, S. A Numerical study of the interaction between handset antennas and human head/hand in GSM 900, DCS, PCS and UMTS frequency bands. In *Progress in Electromagnetics Research Symp. Proc.* China, 2010, p. 733–737.

[4] BOYLE, K., YUN, Y., LIGHTHART, L. Analysis of mobile phone antenna impedance variations with user proximity. *IEEE Transactions on Antennas and Propagation*, 2007, vol. 55, p. 364–372.

[5] ZAJICEK, R., OPPL, L., VRBA, J. Broadband measurement of complex permittivity using reflection method and coaxial probes. *Radioengineering*, 2008, vol. 17, no. 1, p. 14–19.

[6] ZHANG, Zhijun. *Antenna Design for Mobile Devices*. 1st. ed. Singapore: John Wiley & Sons, 2011. ISBN 978-0-470-82446-7.

[7] Lukopren N products. [Online] Cited 2013-05-14. Available at: http://www.lucebni.cz/en/Produkty/Lukopren%20N.

[8] GABRIEL, C. Tissue equivalent material for hand phantoms. *Physics in Medicine and Biology*, 2007, vol. 52, p. 4205–4210.

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