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DESIGN AND MEASUREMENT OF A 2.45 GHZ ON-BODY ANTENNA OPTIMIZED FOR HEARING INSTRUMENT APPLICATIONS

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Abstract

A balanced PIFA-inspired antenna design is presented for use with the 2.45 GHz ear-to-ear radio channel. The antenna is designed such that the radiated electric fields are primarily polarized normal to the surface of the head, in order to obtain a high on-body path gain ($|S_{21}|$). The antenna structure can be made conformal to the outer surface of a hearing instrument, such that the bandwidth of the antenna is optimized given the available volume. The radiation patterns, ear-to-ear path gain and available bandwidth is measured and compared to the simulated results. It is found that the antenna obtains a relatively high ear-to-ear on-body path gain, as well as a bandwidth that is large enough to cover the entire 2.45 GHz ISM-band.

Keywords: Antenna Design, Ear-to-ear, Bandwidth, Body-centric, Measurement, On-Body, Polarization, WBAN.

1 Introduction

Ear-to-ear on-body path gain ($|S_{21}|$) at 2.45 GHz has received much attention in the literature in recent years, e.g. [1–4]. This is due to both commercial interest from manufacturers of Hearing Instruments (HI), and academic interest in the challenges that are involved in the design of small on-body antennas. Many of the previous studies have focused on propagation effects, and it has been found that the antenna polarization is the key to obtain a high on-body path gain. However, most of these studies describe simple loop or monopole type antennas. Only few studies have focused on the design of 2.45 GHz antennas that are suitable for application in HIs such as [5–7]. This paper presents a new PIFA-inspired antenna that is optimized for high ear-to-ear on-body path gain and high bandwidth. The radiated electric field is normal to the surface of the head in order to obtain optimum on-body path gain. In addition, the antenna structure is made conformal to the outer shell of a Behind-the-Ear (BTE) HI for best use of the available volume, thus obtaining a larger bandwidth. The antenna bandwidth is required to be at least 80 MHz in order to cover the 2.45 GHz ISM-band. A larger bandwidth can in practice be used to compensate for detuning effects that may be different from person to person. The proposed antenna is analyzed in terms of prototype measurements as well as Ansoft HFSS simulations. The antenna input impedance and on-body radiation patterns are presented. The ear-to-ear on-body path gain between the two antennas mounted at the ears is evaluated in terms of electromagnetic isolation [8], and the obtainable

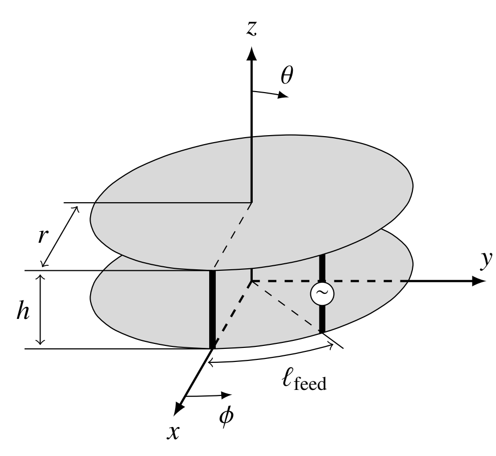


Figure 1: Geometry of the proposed on-body antenna. The antenna consists of two parallel, concentric circular plates that are connected by a shorting pin, and a balanced feed. The design parameters are listed in Table 1.

Table 1: Design parameters for the proposed antenna. The antenna design is outlined on Figure 1.

r	(mm)	10.0
h	(mm)	5.0
ℓ_{feed}	(mm)	3.5

bandwidth of the antenna structure is estimated from the antenna impedance [9]. The head phantom that was used in the simulations was modeled as a homogenous material with the dielectric parameters $\epsilon_r' = 50$ and $\tan\delta = 0.5$.

2 Antenna Design

The proposed on-body antenna is shown in Figure 1, where the $xy-$plane is parallel to the surface of the head, such that the $z-$axis is normal to the surface of the head. The antenna consists of two parallel, concentric circular plates of radius r that are separated by the vertical distance h that corresponds to the height of the antenna. A shorting pin is used to connect the two parallel plates at a location along their circumference, which is seen at the $x-$axis in Figure 1. The antenna is excited by a balanced feed at a distance, ℓ_{feed}, from the shorting pin measured along the circumference of the antenna. The antenna input impedance Z_{A} is tailored by adjusting the feed distance ℓ_{feed}, as for an Inverted-F antenna (IFA) or a Planar-IFA (PIFA). The best on-body performance is obtained when the circumference of the antenna is half a wavelength $\lambda/2$, such that there is a resonant current path along the circumference of the antenna. This requirement results in a large impedance bandwidth, and strong currents are induced on the shorting pin normal to the surface of the head. The currents in turn are effective in launching an on-body surface wave. Thus, the antenna radius is given by

$$r = \frac{\lambda}{4\pi}\,, \tag{1}$$

which is approximately $r = 10\,\mathrm{mm}$ at 2.45 GHz. The antenna height, h, represents the width of a HI and as such it is assigned the somewhat arbitrary value $h = 5\,\mathrm{mm}$ in this work, which is a realistic dimension of a BTE HI. If the antenna is designed according to (1), the distance between the feed and the short will affect the antenna impedance such that

$$\lim_{\ell_{\mathrm{feed}}\to 0} Z_{\mathrm{A}} = 0 \quad \text{and} \quad \lim_{\ell_{\mathrm{feed}}\to \lambda/4} Z_{\mathrm{A}} = \infty. \tag{2}$$

By experimentation it was found that the antenna impedance provides a good impedance match to $50\,\Omega$ when $\ell_{\mathrm{feed}} = 3.5\,\mathrm{mm}$ for the given r and h of the antenna. The antenna design parameters are listed in Table 1. A photo of a constructed antenna prototype is shown in Figure 2. The prototype is constructed from one piece of copper tape that is glued to a machined cylinder of $\epsilon_r' = 1.05$ and $\tan\delta < 0.0002$ material (ROHACELL® HF) with radius r and height h. The antenna is fed by the use of a coaxial cable with a quarter-wave bazooka balun mounted, in order to reduce spurious currents induced on the coaxial cable. It should be noted that the antenna can be realized in a different shape than circular, such that the parallel plates of the antenna can be conformal to the sides of a BTE HI. In this way the volume that is available to the antenna can be used optimally, although the antenna circumference should still approach $\lambda/2$ for the best results.

Figure 2: Photo of the constructed antenna prototype.

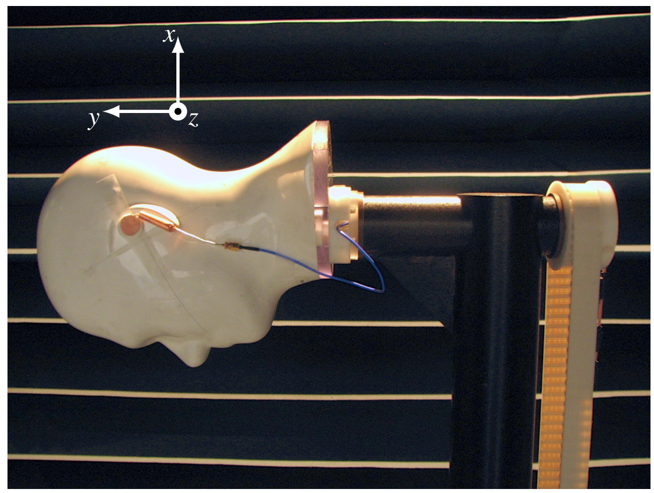


Figure 3: Photograph of the measurement setup. The orientation of the antenna coordinate system is indicated in the figure.

3 Measurement Setup

The measurement setup for the antenna on-body gain radiation pattern is illustrated in Figure 3. The constructed antenna prototype was mounted centered at the side of the head

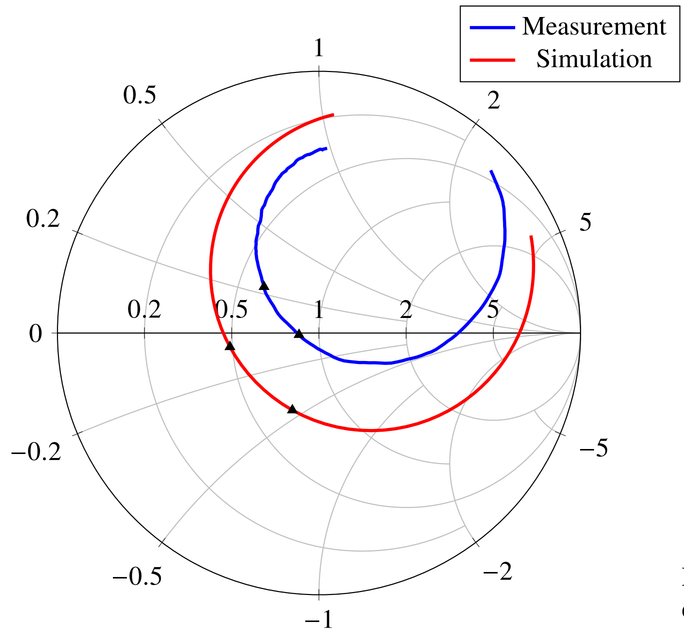


Figure 4: Smith chart normalized to 50 Ω with the measured (blue) and simulated (red) antenna input impedance from 2 to 3 GHz. The triangular markers (▲) indicate the band edges of the 2.45 GHz ISM-band.

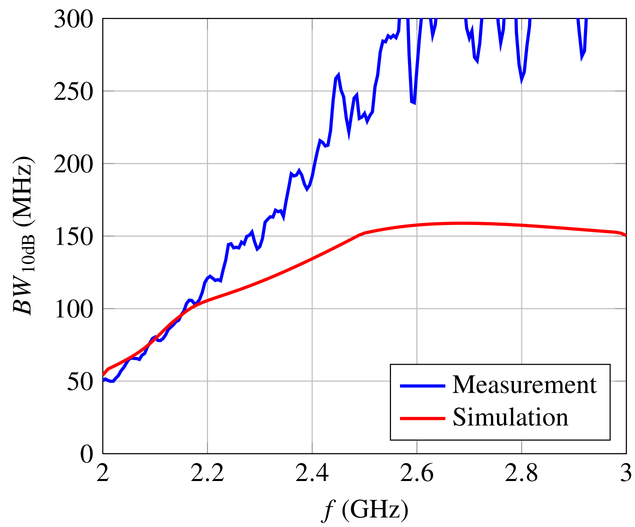
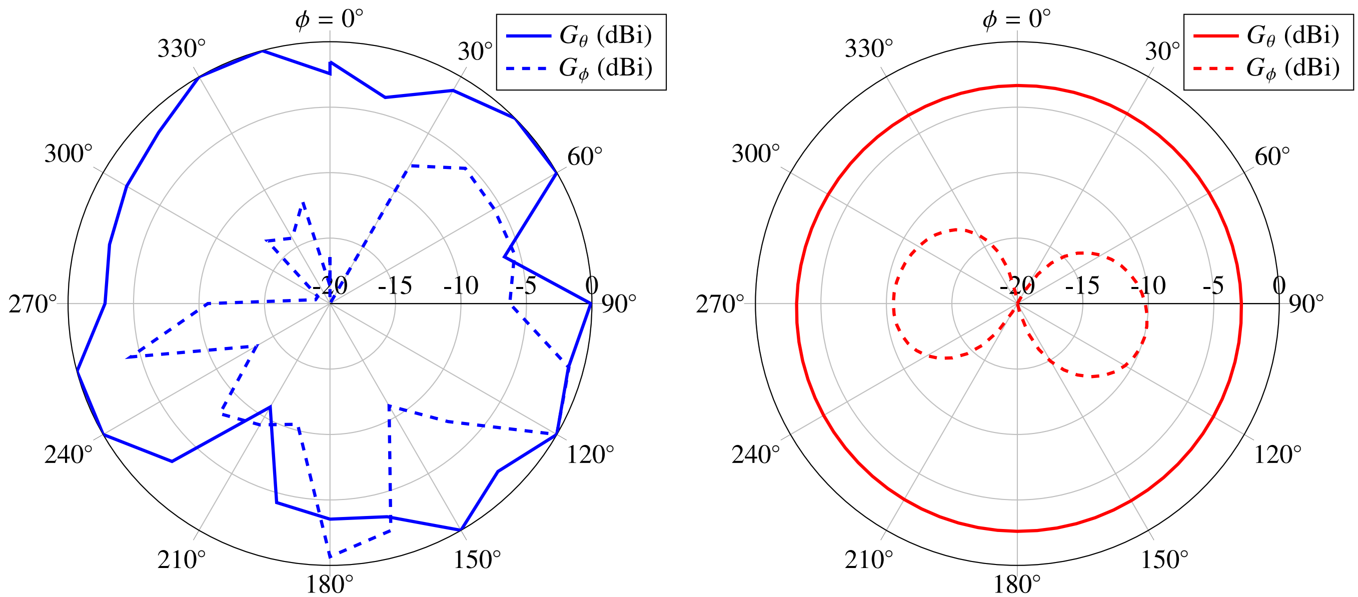


Figure 5: Available bandwidth, $BW_{10\,\mathrm{dB}}$, of the antenna estimated from the measured (blue) and simulated (red) antenna input impedance.

on a standard SAM phantom for the measurement of the radiation pattern. The antenna coordinate system was oriented such that the feed cable runs parallel to the y-axis in Figure 1 that points towards the top of the phantom head. Hence, the x-axis points towards the back of the head, and the z-axis is normal to the surface of the head. For the measurement of the antenna impedance and the ear-to-ear path gain, two antenna prototypes are worn behind the ears of an actual person. In this measurement setup the feed cables of the antenna prototypes exit along the z-axis of the respective antenna coordinate systems, normal to the sides of the head. The measurements were done by the use of a Vector Network Analyzer (VNA). The test person was sitting in an indoor environment with approximately 3 m height to a metallic roof.

4 Results

The measured antenna impedance is shown in the Smith chart in Figure 4 along with the simulated antenna impedance. It is observed that the general characteristics of the traces are in good agreement, as the antenna impedance is very person-specific due to the proximity of the body. The limits of the 2.45 GHz ISM-band are indicated by the black triangular markers (▲). The proposed antenna is seen to provide a good match to 50 Ω. The available bandwidth of the antenna can be estimated from the antenna input impedance, as described in [8, 9]. The procedure is applied to both the measured and the simulated antenna input impedance. The result is shown in Figure 5. It is seen that both the antenna prototype and the simulated antenna provides more bandwidth than is required for the 2.45 GHz ISM-band. There is a significant discrepancy between the measurement and the simulation at higher frequencies which is may be due to ineffectiveness of the balun at those frequencies. The variation at the high frequencies of the measurement is due to the derivative of the the antenna impedance that is part of the procedure. The small variations in the measured antenna impedance at higher frequencies thus becomes large variations in the estimated antenna bandwidth. The antenna on-body radiation patterns in the on-body xy-plane ($\theta = 90°$) are shown in Figure 6. Both the co-polar (θ-component) and cross-polar (ϕ-component) antenna radiation patterns are shown. It is seen that the antenna is omni-directional in the on-body plane, and that the co-polar θ-component is much stronger than the cross-polar ϕ-component. The ear-to-ear in-body path gain ($|S_{21}|$) was measured and the electromagnetic isolation of the two antennas ($|S_{21}^{\mathrm{EMI}}|$) can be found by the procedure that is outlined in [8]. The electromagnetic isolation is the S_{21} that would be obtained at each frequency, if the antennas were perfectly matched at that frequency. It can be viewed as the maximum realizable path gain at each frequency if the antennas were matched at that frequency. The maximum realizable path gain is shown in Figure 7. An excellent agreement between the measurement and the simulation is observed, except for the frequency ripple in the measurement. The ripple is due to reflections from the room, similarly to observations in [2, 4].



(a) (b)

Figure 6: Measured (a) and simulated (b) antenna gain radiation pattern in the $\theta = 90^\circ$ plane (xy-plane) tangential to the surface of the head. Both the G_θ co-polar (line) and G_ϕ cross-polar (dashed) components are shown in dBi.

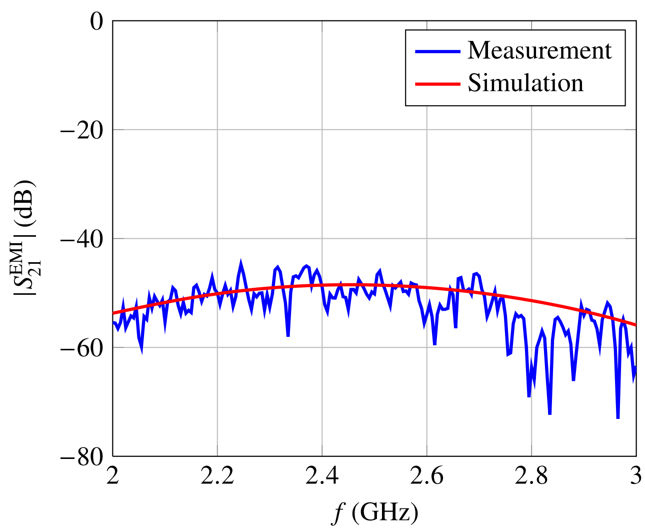


Figure 7: Maximum realizable ear-to-ear on-body path gain ($|S_{21}^{\mathrm{EMI}}|$) in dB. An actual person was used for the measurement (blue), while a phantom head including ears was used for the simulation (red).

It is seen that a path gain better than −50 dB can be obtained, which is superior to previously reported results [5, 7]. The results are summarized in Table 2.

Table 2: Summary of the measured and simulated bandwidths and maximum ear-to-ear on-body path gains at 2.45 GHz for the proposed on-body antenna.

		Measurement	Simulation
$BW_{10\,\mathrm{dB}}$	(MHz)	240	143
$BW_{10\,\mathrm{dB}}$	(%)	9.8	5.8
Path Gain	(dB)	−50	−48

5 Conclusion

A balanced-fed antenna that is suitable for ear-to-ear on-body communications has been presented. The antenna can be made conformal to the outer shell of a HI, to achieve the best utilization of the available volume. Furthermore, the radiated electric field is normal to the surface of the head, and thus provides a high on-body path gain. A prototype of the antenna has been constructed and the measurement results agree with the simulations. The antenna can achieve a 10 dB bandwidth that is large enough to compensate for person-specific detuning effects. The ear-to-ear path gain has been measured at −50 dB, which is better than previously reported results.

References

[1] R. Chandra and A. J. Johansson, “Influence on the Ear-to-Ear Link Loss from Heterogeneous Head Phantom Variations,” in *5th European Conference on Antennas and Propagation*, Rome, Italy, Apr. 2011, pp. 1–4.

[2] S. H. Kvist, J. Thaysen, and K. B. Jakobsen, “The Effect of the Head Size on the Ear-to-Ear Radio-Propagation Channel for Body-Centric Wireless Networks,” in *Antennas and Propagation Conference (LAPC)*, Loughborough, UK, Oct. 2010, pp. 345–348.

[3] ——, “Investigation of the Ear-to-Ear Radio Propagation Channel,” in *5th European Conference on Antennas and Propagation*, Rome, Italy, Apr. 2011, pp. 3640–3644.

[4] A. Vasylchenko, C. Hennemann, and R. Dubrovka, “Characterization of The Ear-to-Ear Propagation Channel Using Microstrip Dipole Antennas,” in *VIII International Conference on Antenna Theory and Techniques*, Kyiv, Ukraine, Sep. 2011, pp. 202–204.

[5] S. H. Kvist, J. Thaysen, and K. B. Jakobsen, “Polarization of Unbalanced Antennas for Ear-to-Ear on-Body Communications at 2.45 GHz,” in *Loughborough Antennas and Propagation Conference (LAPC)*, Loughborough, UK, Oct. 2011, pp. 1–4.

[6] L. Huitema, S. Sufyar, C. Delaveaud, and R. D’Errico, “Miniature Antenna Effect on the Ear-to-Ear Radio Channel Characteristics,” in *6th European Conference on Antennas and Propagation*, Prague, Czech Republic, Mar. 2012, pp. 1–5.

[7] S. H. Kvist, S. Özden, J. Thaysen, and K. B. Jakobsen, “Improvement of the Ear-to-Ear Path Gain At 2.45 GHz Using Parasitic Antenna Element,” in *6th European Conference on Antennas and Propagation*, Prague, Czech Republic, Mar. 2012, pp. 1–4.

[8] J. Rahola, “Bandwidth potential and electromagnetic isolation: Tools for analysing the impedance behaviour of antenna systems,” in *3rd European Conference on Antennas and Propagation*, Berlin, Germany, Mar. 2009, pp. 944–948.

[9] A. D. Yaghjian and S. R. Best, “Impedance, bandwidth, and Q of antennas,” *Antennas and Propagation, IEEE Transactions on*, vol. 53, no. 4, pp. 1298–1324, Apr. 2005.