A Low Profile UWB Antenna for Wearable Applications: The Tripod Kettle Antenna (TKA)

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***Abstract*—A new low profile ultra-wideband (UWB) antenna for wearable applications is presented. Its structure is derived from the quadripod kettle antenna (QKA) [1], and is called tripod kettle antenna (TKA). The proposed antenna is very well suited for wearable applications due to its miniature size and low profile. Moreover, the antenna is completely encapsulated in a Polydimethylsiloxane (PDMS) substrate enabling a certain level of flexibility and a good robustness against different external influences (e.g. different weather conditions). The TKA is a broadband antenna with 70% coverage of the fractional UWB bandwidth (Federal Communications Commission, FCC). The antenna has a polarization perpendicular to the body surface with a quasi-omnidirectional radiation pattern in the plane orthogonal to the polarization. An antenna prototype has been built and characterized, and measured results are in a good compliance with the simulations.**

Index Terms*—Low profile and ultra-wideband, tripod-quadripod kettle antenna, PDMS, wearable antenna, polarization perpendicular to the body surface

I. INTRODUCTION

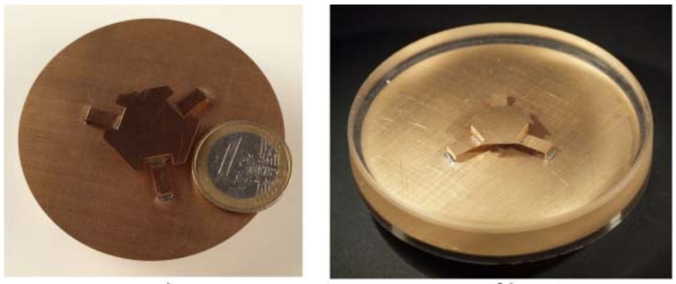
In recent years, wireless body area networks (WBAN) have received an increasing attention due to their wide use in different applications, like medical sensor systems, rescue service applications, military communication or personal entertainment [2]. WBANs consist of combinations of three different types of links: Off-Body links (Tx and Rx terminals are not on the same body), On-Body links (both terminals are mounted on the same body), and In-Body links (one of the terminals is embedded in the host body) [3].

The requested radiation features of wearable antennas are closely related to the type of communication they should provide. For example, for an Off-Body link the antenna is required to have a maximal radiation in a direction perpendicular to the body surface, while for an On-Body links maximal performance is needed in directions parallel to the body surface [4].

The polarization characteristics of wearable antennas play also an important role in the operation of the aforementioned communication links. A study presented in [5] shows important propagation differences for UWB antennas whose polarizations are either perpendicular or parallel to the body surface. Measurements confirm that the perpendicular orientation outperforms the parallel one. Indeed when the electric field is perpendicular to the body the EM fields tend to propagate along the body surface, while the EM penetration inside the body is small. For a polarization parallel to the body, the fields couple much more to the latter, thus enhancing the losses. Examples of antennas with dual polarization are also present in the literature, enabling both types of links at the same time [3]. The polarization is thus an important characteristic which determines whether a wearable antenna is suitable for certain type of communication.

Two examples of wearable UWB antennas with the polarization perpendicular to the host body surface are presented in [6]. The proposed antennas are so-called button antennas, due to their shape and easy integration into the clothes' buttons. Both antennas have nearly omnidirectional radiation pattern in the plane parallel to the body, and they are good candidates for On-Body communication. A more exhaustive overview of the state of the art in wearable UWB antennas can be found in [7].

In order to easily conform to the body surface, wearable antennas should be built using flexible substrates. Polydimethylsiloxane (PDMS) is a popular silicon based substrate for flexible electronics in general [8], and is a good candidate for wearable antennas, as shown for instance in [9].



a) b)

Figure 1: TKA UWB antenna

In this paper we propose a low profile UWB TKA antenna, with the polarization perpendicular to the body. The antenna is completely encapsulated in a dielectric based on PDMS [10]. Compared to the original dielectric-free version of this antenna [11], the dielectric slightly reduces the antenna performance, as the bandwidth is narrower than for an antenna in free space. However, an antenna immersed in PDMS is completely sealed and robust against different external influences (water, humidity, mud, etc.) Finally, the paper presents the TKA antenna prototype (depicted on Figure 1) together with its characterization in different operation scenarios.

II. Antenna Concept

A. Idea

The concept at the origin of the proposed antenna goes back to 1976, when a Quadripod Kettle Antenna (QKA) was introduced by Tokumaru [1]. This antenna has an omnidirectional radiation pattern, but a relatively narrow bandwidth of 25% and a relatively large size. For a long time this type of antenna did not receive much attention from the research community, and further enhancement of the QKA antennas were presented only in the mid-nineties, [12][13].

B. Optimization and antenna prototype

The QKA served as an interesting starting point to develop a novel low profile UWB antenna, suitable for wearable applications and having a polarization perpendicular to the body surface. The bandwidth was greatly enhanced by reinforcing the circular symmetry of the antenna, going from four pods to three [11]. The antenna was optimized with respect to bandwidth and miniaturization using a commercial simulation tool (HFSS), leading to the Tripod Kettle Antenna (TKA).

The TKA consists of two stacked metallic plates connected by three supporting pods. Additional pods are used to connect the complete structure to the ground plane, as illustrated in Figure 2. Since the antenna is targeting wearable applications, an encapsulation in PDMS [10] was realized, leading to a further miniaturization of the antenna. All the conductive parts of the antenna are enclosed inside the PDMS, except for the SMA connector used to excite the antenna.

The used PDMS has stable electric characteristics over the entire UWB bandwidth, with a relative dielectric permittivity of 2.85 and a loss tangent of 0.01.

A number of simulations were run in order to optimize each of the antenna parameters. The final dimensions of the antenna were obtained after a complete parametric study of all the conductive parts. The final antenna is 24mm in diameter and 10mm in height. The ground plane of the antenna is 44mm in diameter and can be further miniaturized. It should be also mentioned that the ground plane can be made of flexible conductor in order to ease its conforming to the wearer.

The antenna was produced in several steps. Each of the antenna parts such as ground plane, and the lower & upper plate were built separately in bronze beryllium using etching techniques and then assembled and soldered to form the final antenna prototype. The antenna was mounted in the in-house custom prepared mold, and then filled with liquid PDMS [11]. After polymerization, the whole antenna body is embedded in a solid PDMS block, thus providing a hermetic sealing, as well as an enhanced robustness against different external influences (weather conditions, mechanical damages, etc.).

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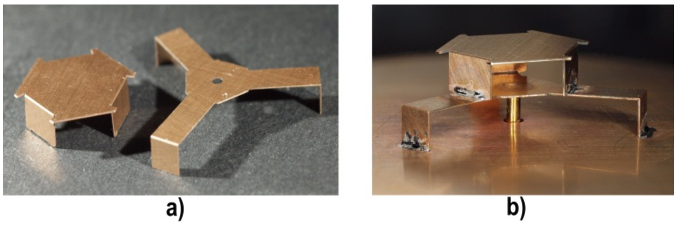


Figure 2: a) Two parts of the TKA before assembling, b) Assembled TKA antenna with the mounted connector

C. Antenna simulations and measurements in free space

The TKA was characterized in an anechoic chamber, and the measured results are in a good agreement with simulations. Figure 3 shows the input matching of the antenna. The antenna covers 68% of the fractional UWB as defined by FCC.

The polarization of the antenna is perpendicular to the body surface (E field perpendicular to the ground plane). The antenna has a quasi-omnidirectional radiation pattern in the plane parallel to the body surface, with a deep null in the orthogonal direction, Figure 4 and Figure 5. In the terms of radiation, the TKA is similar to a monopole antenna, but has a lower profile. The vertical polarization of the TKA antenna makes this antenna an interesting candidate for different types of wearable applications. Indeed, most UWB wearable antennas presented in literature have a polarization parallel to the body, so having an antenna with orthogonal polarization present two advantages: we have seen that the losses are lower [5], but also it provides us with the possibility to use polarization diversity by combining with a classical wearable UWB antenna.

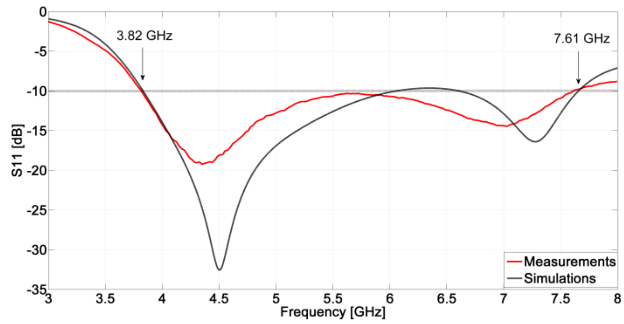


Figure 3: Input reflection coefficients

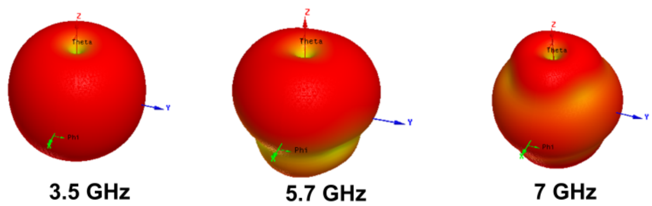
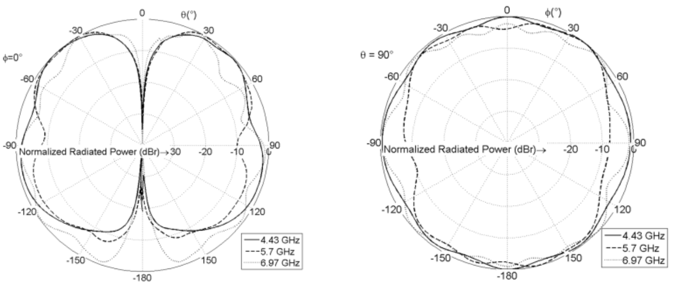


Figure 4: Simulated radiation patterns at three different frequencies. 3D plots, with coincident ground and *xy* planes



a) b)

Figure 5: Measured far field radiation patterns, 2D cuts along elevation or E-plane (a) and azimuth or xy plane (b)

D. Antenna simulations (on a body phantom) and measurements on a human hand

Since the TKA is intended to operate as a wearable antenna, additional simulations were performed on a simplified single-layer body phantom. The model used for the body phantom has a cylindrical shape, centered below the ground plane of the antenna. In the model there is a 0.2mm gap between the body phantom and the antenna structure. This gap represents the fact that in a real body scenario the antenna will be always detached from the body (e.g. clothing tissues). The radius of the phantom is 131mm while the height 40mm. The relative dielectric permittivity is 52.66, and the loss tangent 0.242 [7]. The complete structure is depicted in Figure 6.

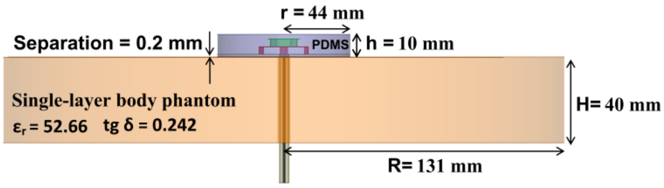


Figure 6: Cross section of the antenna HFSS model with the body phantom below

The inclusion of the body phantom in the simulation model of the TKA has been found to be a delicate issue. In fact, the large ratio between the relevant dimensions of the TKA itself and those of the body phantom has led to a significant increase of the computational resources required to simulate the structure in Figure 4 with a satisfactory level of accuracy. The doubts raised by this unexpected problem of accuracy force us to be very cautious with regard to the assessment of the corresponding simulation results. Instead, as a check of the robustness of the antenna operation with regard to the presence of a wearer, we present measurement results.

The input reflection coefficient of the TKA has been measured using a vector network analyzer while the antenna is held in the hand, for two different postures of the hand. This realistic body scenario is depicted in Figure 7.

Looking at Figure 8, we see that the antenna performance is very slightly affected by the way it is held. In general, the fact that the differences introduced by the presence of the human hand are very limited is attributed to the polarization of the antenna (that is normal to the hand surface) and the presence of the ground plane. When the antenna is held in a "fist" manner, Figure 7 b) there is a small deviation of the input reflection coefficient when compared to the case where the antenna is measured in free space. The differences are due to the complex lossy nature of the human hand. However, the presence of the ground plane prevents a more significant alteration of the antenna behavior due to the hand.

a) b)

Figure 7: TKA antenna measured while held in the hand. Over the open hand surface (a) and over the closed fist (b)

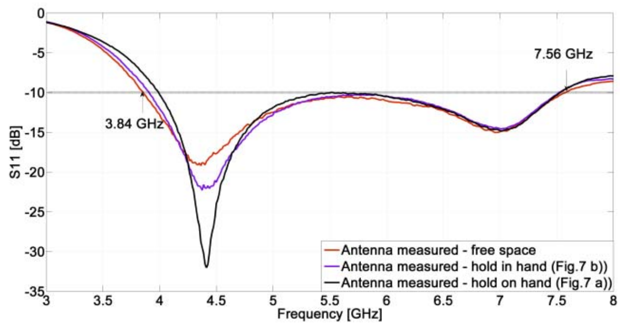


Figure 8: Comparison of the input reflection coefficients for the antenna measured in free space and in realistic body environment

In the situation when the antenna is held on the top of the open hand, Figure 7 a) a wider area of the human hand is not covered by the antenna ground plane, which stresses the influence of the hand. A better input matching is due to the increased losses form the exposed hand area, yielding an unchanged bandwidth.

These realistic body environment measurements give us an initial idea about the performance of the TKA antenna when it will operate in a real wearer scenario. Even if the antenna is mounted on some other parts of the body (e.g. shoulders, wrists, chest, etc.) no significant bandwidth shift is expected, thus making the TKA antenna a very convenient candidate for broadband wearable applications.

III. CONCLUSIONS AND FUTURE WORK

The TKA is an excellent and original UWB antenna with an almost omnidirectional radiation pattern and covers 70% of the fractional UWB bandwidth as defined by FCC. The antenna has a low profile and it is completely encapsulated in PDMS, and is thus completely protected from a potentially harsh environment. Its polarization is orthogonal to the mounting surface, which has the advantage to diminish the coupling to the latter and, when combined with a more classic antenna with a polarization parallel to the wearer, it can provide polarization diversity.

Further work will explore the accuracy issues observed here for the inclusion of the body phantom in the simulation model, the time domain characterization of this antenna in free space and in conjunction with a wearer in the frame of impulse radio, along with the study and implementation of space and polarization diversity when combined with other antennas.

REFERENCES

[1] S. Tokumaru, "Multiplates: Low profile Antennas," in *IEEE, Antennas and Propagation Society International Symposium*, 1976, pp. 1–4.

[2] Y. Hao, A. Alomainy, P. Hall, Y. Nechayev, C. Parini, and C. Constantinou, *Antennas and Propagation for Body-Centric Wireless Communications*, vol. 50, no. 2. Artech House, 2006, p. 291.

[3] D. Ma and W. X. Zhang, "A Dual-band Dual-polarized Antenna for Body Area Network," in *European Conference on Antennas and Propagation (EuCAP)*, 2010, no. 2, pp. 1–5.

[4] N. Chahat, M. Zhadobov, R. Sauleau, and K. Ito, "A Compact UWB Antenna for On-Body Applications," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 4, pp. 1123–1131, 2011.

[5] H. B. Lim, D. Baumann, J. Cai, R. Koh, E. P. Li, and Y. Lu, "Antennae Polarization for Effective Transmission of UWB Signal around Human Body," in *IEEE International Conference on Ultra-Wideband, ICUWB*, 2007, pp. 220–224.

[6] B. Sanz-Izquierdo, J. C. Batchelor, and M. Sobhy, "UWB Wearable Button Antenna," in *European Conference on Antennas and Propagation*, 2006, pp. 9–12.

[7] P. S. Hall, "Small Antennas for Body Centric Applications," in *Handbook on Small Antennas*, Ll. Jofre, M. Martinez-Vazquez, R. Serrano, and G. Roqueta, Eds. 2012, pp. 583–597.

[8] Q. Liu, K. L. Ford, R. Langley, A. Robinson, and S. Lacour, "Stretchable Antennas," in *European Conference on Antennas and Propagation*, 2012, pp. 10–13.

[9] J. Trajkovikj, J.-F. Zürcher, and A. K. Skrivervik, "Soft and Flexible Antennas on Permittivity Adjustable PDMS Substrates," in *LAPC, UK*, November, 2012.

[10] "184 Silicone Elastomer, datasheet," 2012. [Online]. Available: dowcorning.com.

[11] J.-F. Zürcher, "TOLPA (Tripod Omnidirectional Low Profile Antenna): A Vertically Polarized Antenna with 90% Bandwidth," Accepted in *Microwave and Optical Technology Letters*, 2013.

[12] M. Mattes, "QKA Bericht," Internal LEMA report, 1995.

[13] P. Gay-Balmaz, J.-F. Zürcher, and J. R. Mosig, "Analysis and Measurement of QKA Antennas," in *IEEE Antennas and Propagation Society International Symposium*, 1997, pp. 460–463.