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Evaluation of Human Body Communications Pathloss using Capacitive Coupling

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Abstract— Human Body Communications (HBC), standardized around 21 MHz by the IEEE 802.15.6 standard dedicated to Body Area Networks (BAN), are part of emerging techniques exploiting the human body as a propagation channel. HBC can use several coupling techniques, including capacitive coupling (HBC-CC). However, due to the sensitivity of this coupling type to the nearby environment, the determination of the signal attenuation using laboratory measuring equipment is difficult since they alter the propagation path. Therefore, to prevent parasitic coupling and properly evaluate pathloss, dedicated battery-powered portable devices have been developed. In this study, it is then proposed to model a transceiver prototype proposed in literature under the electromagnetic simulator software CST Studio Suite, and to compare for various configurations (emitter-receiver distance, ground electrodes size, and carrier frequency) simulated and measured pathloss obtained with this device. Finally, by following the methodology described in this work, it appears that simulation results are close the measured ones since a difference lower than 2 dB has been obtained.

Keywords—Human body communications (HBC), capacitive coupling, signal attenuation, electromagnetic simulation (CST)

I. INTRODUCTION

In 2012, the IEEE 802.15 Working Group has released a standard for low-power short-range wireless communication dedicated to Wireless Body Area Networks (WBAN): the IEEE 802.15.6 standard. This standard indicates that compatible devices must operate at very low emitted power, thereby reducing Specific Absorption Rate (SAR) in the body and increasing battery autonomy of these devices. One of the physical layers defined in the standard uses the human body as a propagation channel around 21 MHz: the Human Body Communication (HBC). HBC can rely on various types of coupling, including the capacitive coupling (HBC-CC), where electrodes act as antennas. As depicted in Fig. 1, four electrodes are used to create the capacitive coupling: two signal electrodes attached to the body, and two floating ground electrodes separated from the body. The body (direct path) and the nearby environment (return path) work then together as a transmission line [1]. However, the return path behaviour is also sensitive to the nearby environment, and it is difficult to estimate the pathloss using laboratory measuring equipment since they alter the propagation path.

Nevertheless, to properly design integrated HBC transmitters (resp. receivers) in terms of transmitted power (resp. sensitivity) while optimizing their energy consumption, it is essential to be able to estimate the signal attenuation. Furthermore, to ensure robust and reliable signal transmission using HBC, it is also necessary to understand the influence of various factors such as body posture and electrodes localizations, and the involved propagation mechanisms.

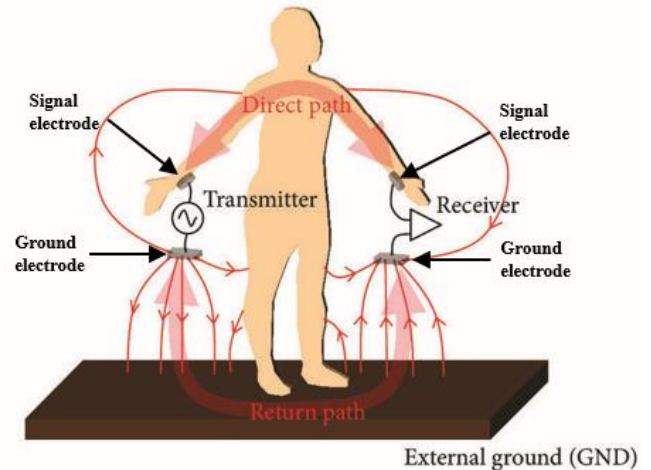


Fig. 1. Principle of capacitive Human Body Communications (HBC) [1].

In the literature, research works, examining many different factors affecting signal attenuation, have been conducted using simulation and measurement [2][3]. Regarding simulation, different human body electromagnetic models have been used.

In [2], a multilayer cylindrical model has been used to simulate a human arm (bone marrow, bones, muscle, fat, and skin) in an electromagnetic simulator (see Fig. 2). However, it is important to note that in this work, although the attenuation values are promising and consistent with experimental results, they highlight the limitations associated to the use of a Vector Network Analyzer (VNA) to characterize signal attenuation due to significant bias introduced by the VNA (parasitic coupling unintentionally enhancing the return path). Indeed, as demonstrated in [3], this result leads to a notable overestimation of attenuation due to the creation, via the metal housing of the VNA and cable shielding, of a more direct return path between the ground electrodes of the HBC transmitter and receiver. Therefore, the model proposed in [2] is not able to accurately estimate the signal attenuation.

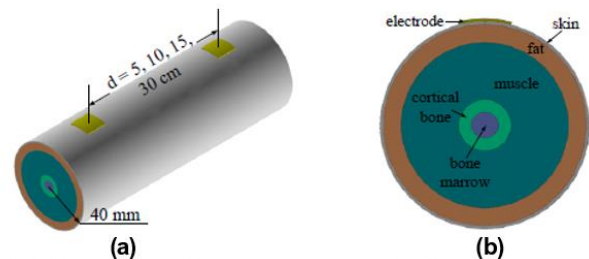


Fig. 2. 3-D view of human forearm (a) and a cross-sectional view (b) [2].

In [3], a 3D Finite Element Method (FEM) model using different biological tissues as materials and based on a 3D scan of a human has been proposed as illustrated in Fig. 3 (a). The simulation results obtained are once again consistent with those obtained in measurement (-42 dB for a distance of 20 cm). To minimize parasitic couplings as much as possible, measurements have been obtained using small battery-powered transmitter and receiver devices (see Fig. 3 (b)). However, only the transmitter-receiver distance of 20 cm was studied in [3].

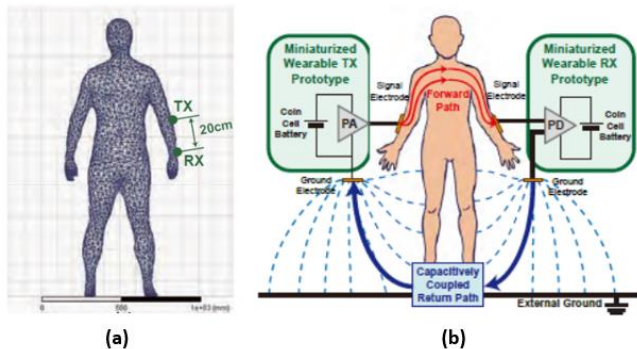


Fig. 3. Realistic human body mesh (a) and proposed measurement setup using the battery-operated wearable prototypes (b) [2].

Therefore, it is proposed here to also evaluate the attenuation experienced by the signal using electromagnetic simulations (CST software) and commercial human body model (Voxel Family) but for various transmitter-receiver distances (by changing the receiver location), various size of the ground electrodes, and two carrier frequencies. For this purpose, the battery-powered transmitter/receiver (transceiver) proposed in [4] dedicated to the estimation of the HBC signal attenuation has been modelled in the electromagnetic simulator. Then, the obtained simulation results have been compared with those obtained in measurement using the same device.

The paper is organized as follows. The setup of electromagnetic simulations is detailed in section II. Then, after presenting the metric used to characterize the pathloss, the signal attenuations obtained in simulation are compared to the ones obtained in measurement for various configurations in section III.

II. IMPLEMENTATION OF SIMULATION IN CST

A. CST configuration

The CST software used here is an electromagnetic simulation tool. It implements numerical methods such as the Finite Integration Technique (FIT) and the Finite Element Method (FEM), as well as realistic human body models such as the "Voxel Family" depicted in Fig. 4.

To conduct the study proposed here, the temporal solver of CST has been employed along with the FIT numerical method, as well as a human body model from the "Voxel Family". Finally, discrete ports have been used for system excitation.

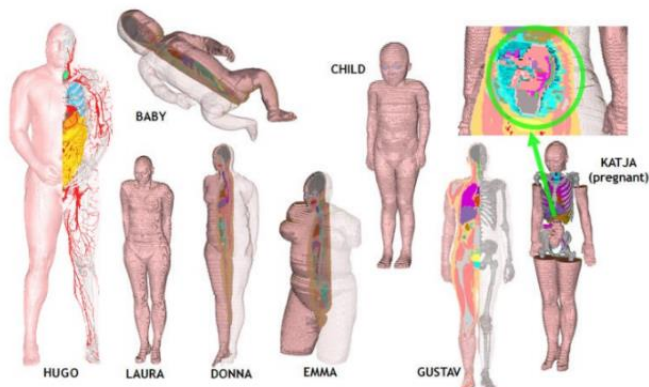


Fig. 4. Voxel model of the human body [5].

B. Transceiver and human body implementation

The transmitter-receiver considered in this study is described in [4]. It has been implemented on a double-sided Printed Circuit Board (PCB) measuring 52 mm by 52 mm, and manufactured using a FR4 substrate having a thickness of 1.6 mm and with copper layers having a thickness of 35 μm . Each PCB incorporates an 8 mm diameter standard self-adhesive medical electrode (Ag/AgCl) on the "bottom" side of the board, serving as the signal electrode applied to the skin (see Fig. 5 (a)). The ground electrode necessary for implementation of the capacitive coupling is formed by the ground plane located on the "top" side of the board (see Fig. 5 (b)). Finally, the whole system is powered by a CR2032 battery.

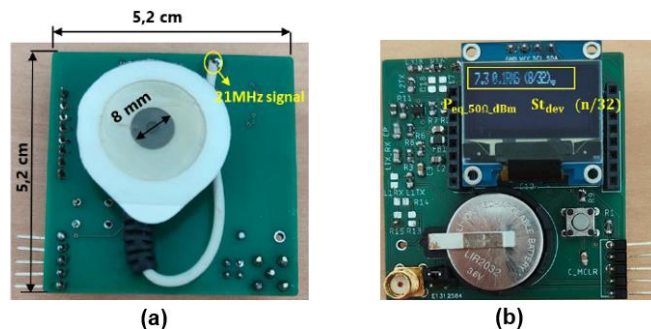


Fig. 5. Transmitter-receiver proposed in [4].

The transceiver circuit described in [4] has been reproduced in the electromagnetic simulator CST. Unlike the experimental setup, the signal electrode, the ground electrode, and the battery are modelled as Perfect Electric Conductors (PEC). The assembly shown in Fig. 6 also includes a PEC ground plane measuring 52 x 52 mm and a flat cylinder with a diameter of 20 mm and a thickness of 3.2 mm which represents the CR2032 battery (the association of both constituting the ground electrode).

On both the emitter and receiver sides, the discrete port has been connected to the signal electrode wire on one side and to the battery on the other side (see Fig. 6). It is worth noting that the ground plane is connected to the battery via a wire not shown in Fig. 6. Finally, a Voxel Family human body model representing a 38-year-old male measuring 176 cm with a resolution of $2.08 \times 2.08 \times 2.0$ mm has been used.

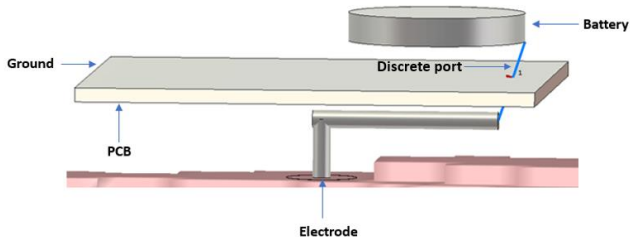


Fig. 6. Transmitter-receiver model in CST.

C. Emitter and receiver locations

To evaluate the signal attenuation between the transmitter and the receiver under various conditions and compare them to measurement results, the transmitter has been positioned on the wrist of the right arm. Then, as illustrated in Fig. 7, the receiver has been placed at four different positions labelled from B to E to assess the influence of the transmitter-receiver distance on attenuation. The corresponding distances are approximately 20 cm (A-B), 40 cm (A-C), 60cm (A-D), and 120 cm (A-E).

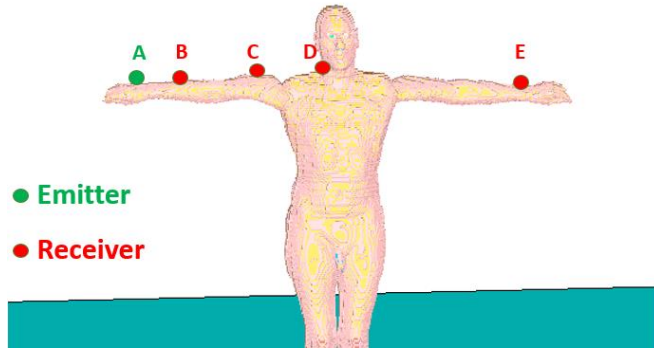


Fig. 7. Transmitter and receiver positions.

III. RESULTS

Regarding simulations, the evaluation of the pathloss has been computed from the obtained S-parameters. Indeed, as described in both [3] and [4], impedance matching circuitry was utilized at both the transmitter and receiver ends to optimize path loss (ratio of the received and emitted powers). Therefore, the best-suited metric to determine in simulation the signal attenuation is the maximum transducer power gain (denoted as G_{Tmax}), where a perfect impedance matching at both the transmitter and receiver sides is assumed. This gain can be calculated from the S-parameters as follows [3]:

$$G_{Tmax} = \frac{|S_{21}|}{|S_{12}|} \left(K - \sqrt{K^2 - 1} \right) \quad (1)$$

with:

$$K = \frac{1 + |\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{12}||S_{21}|} \quad (2)$$

and:

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad (3)$$

where the S_{xy} are the obtained S-parameters.

Finally, it must be underlined that experimental results presented below are the averages of the results obtained with three persons.

A. Signal attenuation with respect to transmitter-receiver distance

As indicated earlier, the transmitter (Tx) has been placed on the right wrist and the receiver (Rx) has been positioned at four positions. Whatever the considered position, simulation results are close to the measurements with a maximum deviation of about 2 dB only as shown in Fig. 8. Moreover, the same trend is observed for simulated and measured pathloss, namely a significant degradation (from A-B to A-D configurations) followed by an improvement. Thus, when moving from an inter-electrode distance of 20 cm to 60 cm, there is a degradation of -15 dB in simulation and approximately -12 dB in measurement. Beyond 60 cm, the attenuation value no longer degrades since an improvement of about 7 dB in simulation and 2.5 dB in measurement is observed instead. It is noteworthy that for a 20 cm distance, the attenuation is close to the one obtained in [3] (-42 dB). Moreover, the highest attenuation is observed at 60 cm which may be due to the presence of neck bones directly under the skin.

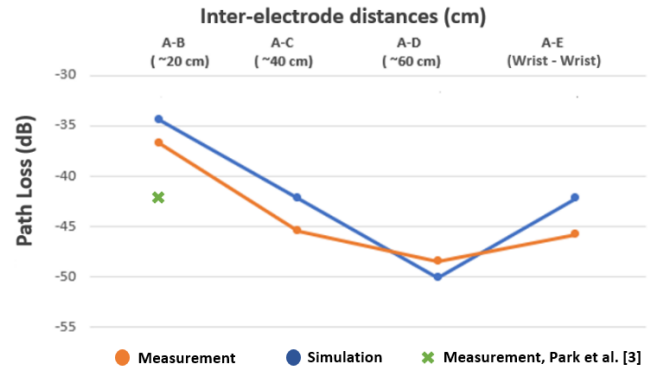


Fig. 8. Attenuation results variation for measurement, simulation and as reported in [3] across different inter-electrode distances.

B. Signal attenuation with respect to frequency

To assess the impact of a change in carrier frequency (21 MHz) on pathloss, simulations and measurement have been conducted with a carrier frequency of 42 MHz for a transmitter-receiver distance of 20 cm. The simulation results indicate a degradation of approximately 3 dB in attenuation when the frequency changes from 21 MHz to 42 MHz, while the measurements indicate a lower degradation as shown in TABLE I.

TABLE I. SIMULATED AND EXPERIMENTAL RESULTS OF THE ATTENUATION OBTAINED AT A DISTANCE OF 20 CM FOR A CARRIER FREQUENCY OF 21 MHz AND 42 MHz.

Frequency (MHz)	Simulation (dB)	Measurement (dB)
21	-34.2	-36.8
42	-37.5	-37.5

In comparison with other works, notably those of [6] which has also showed a degradation of approximately 3 dB at 42 MHz, the observations reported in [3] and [7] present a different trend. Indeed, in these two studies, a significant improvement of the signal attenuation, approximately 5 dB and 6 dB, respectively, have been noted when going from a

frequency of 21 MHz to 42 MHz (see TABLE II.). These results suggest the existence of factors influencing the HBC signal propagation at higher frequencies which have not been yet identified. Thus, this divergence in literature highlights the importance of a thorough analysis and the consideration of as many factors as possible when evaluating pathloss in the context of HBC.

TABLE II. COMPARISON OF PATHLOSS VARIATION BETWEEN 21 MHz AND 42 MHz.

Author(s)	Distance Tx/Rx (cm)	Attenuation (dB) @ 21 MHz	Attenuation (dB) @ 42 MHz	Attenuation Variation (dB)
Park et al.[3]	20	-42	-37	+ 5
Vasić et al. [7]	28	~ -26	~ -20	+ 6
Ruiz et al. [6]	20	~ -15	~ -18	- 3
Simulation	20	-34.2	-37.5	- 3.2
Measurement	20	-36.8	-37.5	- 0.7

C. Signal attenuation with respect to the ground plane size

To assess the impact of the ground plane size (which acts with the battery as the ground electrode) on the attenuation value, four prototypes have been tested both in simulation and measurement for an emitter-receiver distance of 20 cm with a carrier frequency of 21 MHz. These prototypes exhibit a progressive reduction of the ground plane size, ranging from GP Type I to GP Type IV, as depicted in Fig. 9. GP Type I has the maximum ground plane size, 52.5 by 52.5 mm, while GP Type II measures 37.12 by 37.12 mm (in other words half of the surface area of GP Type I). GP Type III has an area of 26.25 x 26.25 mm (half of the GP Type II area), and GP Type IV does not have a ground plane (though it still retains the ground plane associated to the battery surface to serve as the ground electrode).

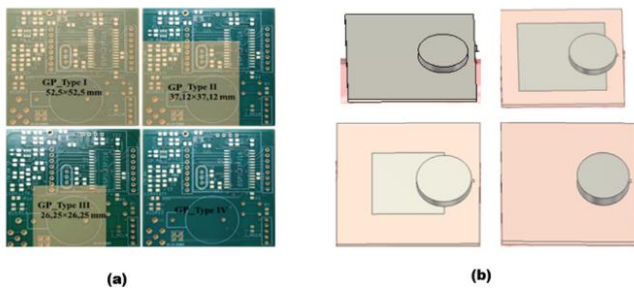


Fig. 9. Geometry of the ground planes tested in measurement (a) and in simulation (b).

The results presented in TABLE III. indicate that the GP-Type IV prototype (smallest ground area), offers the most favorable conditions in terms of attenuation in simulation and in measurement. However, a degradation of less than 1 dB has been obtained in simulation when moving from GP Type I to GP Type IV, whereas in measurement, a difference of 4.5 dB has been observed between the most favorable and the least favorable configurations. These results suggest that the configuration with the smallest ground area may unexpectedly offer more favorable performances in terms of pathloss under

certain conditions and require further investigations to understand the cause.

TABLE III. SIMULATED AND EXPERIMENTAL RESULTS OF THE PATHLOSS OBTAINED AT A DISTANCE OF 20 CM FOR A CARRIER FREQUENCY OF 21 MHz AND CONSIDERING 4 GROUND PLANE SIZES.

Ground plane type	Simulation (dB)	Measurement (dB)
GP type I	-34.2	-36.8
GP type II	-34.4	-38.4
GP type III	-33.9	-40.7
GP type IV	-33.4	-36.2

IV. CONCLUSION

In this paper, the setup of electromagnetic simulations to estimate the signal attenuation in the context of capacitive Human Body Communications has been presented in the CST software and the commercial human body model Voxel Family. The simulation results have been compared with those obtained experimentally (results averaged over 3 persons) for different configurations using a dedicated battery-powered transceiver which have been modelled in the electromagnetic simulator. It appears that using a complex human body model, such as the one used in [3] or in this work (Voxel Family), seems more relevant than the cylindrical multilayer model proposed in [2]. Indeed, it seems that this enables to achieve simulation results that are closely aligned with those observed experimentally using battery-operated devices, which are assumed to introduce a minimal bias [3][4] in contrast to the results acquired using a Vector Network Analyzer such as in [2]. Finally, the influence on the pathloss of the emitter-receiver distance has been evaluated (ranging from -35 dB to -50 dB at 21 MHz depending on the distance), as well as the signal frequency (degradation on the order of 3 dB when transitioning from 21 MHz to 42 MHz) and the ground plane size (the ground plane size seems to have a limited impact for the considered small prototypes at 20 cm and for a frequency of 21 MHz).

REFERENCES

- [1] D. Naranjo-Hernández et al., "Past results, present trends and future challenges in intrabody communication", *Wireless Communications and Mobile Computing*, Vol. (2018), p. 9026847, Mar 2018. [Online]. Available : <https://doi.org/10.1155/2018/9026847>
- [2] R. Xu et al., "Circuit-coupled fem analysis of the electric-field type intra-body communication channel", in *2009 IEEE Biomedical Circuits and Systems Conference*, 2009, pp. 221–224.
- [3] J. Park et al., "Channel modeling of miniaturized battery-powered capacitive human body communication systems", *IEEE Transactions on Biomedical Engineering*, vol. 64, no. 2, pp. 452–462, 2017.
- [4] R. A. B. Mefteh et al., "Design of a battery-powered emitter dedicated to the characterization of human body communications", in *2020 15th Design Technology of Integrated Systems in Nanoscale Era (DTIS)*, 2020, pp. 1–5.
- [5] "CST Voxel Family". [Online]. Available: https://space.mit.edu/RADIO/CST_online/mergedProjects/3D/common_tools/common_tools_biomodels.htm#Voxel_Family.
- [6] J. Ruiz et al., "Propagation characteristics of intra-body communications for body area networks", in *CCNC 2006. 2006 3rd IEEE Consumer Communications and Networking Conference*, 2006., vol. 1, 2006, pp. 509–513.
- [7] L. Vasić et al., "A capacitive intrabody communication channel from 100 khz to 100 mhz", in *2011 IEEE International Instrumentation and Measurement Technology Conference*, 2011, pp. 1–4 .