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Analysis of the location impact on on-body antennas in BANs at 28 GHz

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Abstract

This paper presents a simulation-based study on the characteristics of a 28 GHz Body Area Network antenna at different body sites. The main objective is to evaluate the influence of the antenna position on the body on the performance of the antenna, The importance of using realistic human body models for accurate evaluations is emphasized. The head, torso, and hand components of the CST human model with tissue average properties is used for the study. In addition, assessments are carried out with multilayer tissue head model for comparison. The antenna characteristics are evaluated with these body models, both with and without an antenna holder, which allows the antenna prototype to be attached to the body during measurements.
The results show that the antenna location has a significant influence on the characteristics of the antenna, and the presence of the holder also has a significant effect on performance. These results emphases the need to simulate the antenna characteristics at specific intended locations in order to fully understand its performance.

1. Introduction

The millimeter-wave (mmWave) band has demonstrated significant potential for high-speed wireless communication, offering data rates in the gigabits/second range. This frequency band is increasingly being explored for Body Area Network (BAN) applications due to its short wavelengths, wide impedance bandwidth, and low signal interference [1-2]. However, the performance of mm-wave antennas in BAN applications can be significantly affected by the human body, posing challenges in maintaining stable connectivity and reliable data transfer [2-4].
The aim of this paper is to analyze the characteristics of a BAN antenna operating at 28 GHz across various body sites to understand the human body's impact on antenna performance. This simulation-based study uses a planar monopole antenna designed for wearable applications, featuring a 2 GHz impedance bandwidth and an 11 dBi realized gain [4].
Additionally, the study investigates the impact of the antenna holder which can be used to attach the antenna stably to the body during measurements. Furthermore, we explore the differences in antenna characteristics between a homogeneous head model and a tissue layer model. By addressing these aspects, we aim to provide a more comprehensive understanding of the characterization of the mmWave radio channel characteristics.
Understanding the impact of the human body on antenna performance is essential for accurately interpreting channel characteristics from BAN measurements. In general, a profound understanding of propagation characteristics is critical for advancing the field of wearable technology in practical, real-world scenarios.

2. Simulation model

The antenna used in the simulations, presented in Fig. 1a, is originally presented in [4] for 28 GHz BAN communications. The antenna's structure and dimensions are optimized to ensure minimal loss and maximum gain when placed in proximity to the human body. More details of the antenna can be found in [4]. The antenna holder model, presented in Fig. 1b, is developed to stably attach the antenna to different parts of the human body during antenna prototype measurements. The material is PLA having dielectric properties ε_r=2.55, tan loss= 0.018 [5].
The simulations are carried out using Dassault Simulia CST software [6] and its realistic shaped homogenous human model having average dielectric properties. This model is used to simulate the general interaction between the antenna and the human body without accounting for the complexities of different tissues hence saving the simulation time. In this study, we focus on the head, chest and hand areas of the model which are commonly considered locations for on-body antennas in several BAN applications [2]. For the simulations, only the relevant areas of the body model are considered to save simulation time. The simulation models for hand, chest and head are presented in Figs.1c-g, respectively. In the head area, two different locations are evaluated: Loc1, which is on the front of the ear and Loc2, which is partially on the ear.

Additionally, we also evaluate the antenna characteristics using a multilayer human head model which includes skin, fat, skull, and brain tissue layers as shown in Fig.1g. Each layer is assigned specific dielectric properties to accurately represent the electromagnetic behavior of the human head. This model is used to simulate the antenna's performance when placed near the head, providing insights into how different tissue layers affect the antenna's characteristics.

In this study, the following antenna characteristics are compared between different cases:

- Realized Gain: The effective gain of the antenna, accounting for losses.
- Radiation efficiency: Measure how effectively an antenna converts input power into radiated power.
- Total efficiency: includes both radiation efficiency and losses due to impedance mismatch.
- Main Lobe Magnitude: The peak value of the radiation pattern in the main direction.
- Main Lobe Direction: The angle at which the main lobe is directed.
- Angular Width: The angular span of the main lobe, typically measured at half-power points.
- Side Lobe Level: The relative magnitude of the side lobes compared to the main lobe.

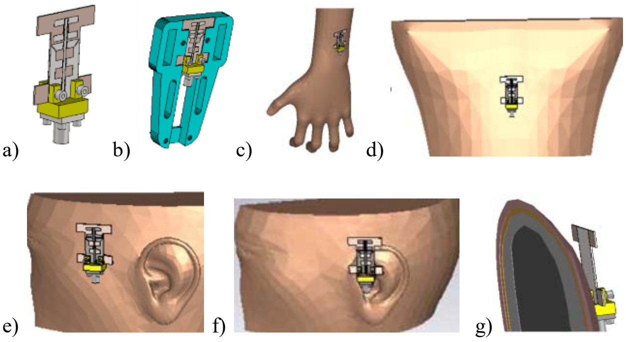

Figure 1. Simulation models for a) 28 GHz BAN antenna, b) antenna with the model of the holder used in the measurements, c) antenna mounted on the hand, d) chest, e) head, homogenous, Loc1; f) head, homogenous, Loc2; g) head, Multilayer, Loc1.

3. Results

3.1. Evaluations in Free Space

Firstly, the antenna characteristics are evaluated in free space, both with and without the antenna holder. Figs. 2a and 2b present 3D illustrations of the antenna's realized gain without the antenna holder (a) and with the antenna holder (b). Figs. 3c-e show the polar plots for Theta=90°, Phi=90°, and Phi=0° planes in both scenarios. As observed in the 3D illustrations and polar plots, the antenna holder introduces at certain angles noticeable notches in the radiation patterns, particularly in the Phi=90° plane in which the impact of the holder can cause over 10 dB difference (at Theta=60°). These notches can significantly impact the channel characteristics, especially if the off-body antenna is positioned slightly to the side of the on-body antenna. Table I presents a comprehensive comparison of the values for realized gain, efficiencies, main lobe magnitude and direction, angular width, and side lobe levels across all the evaluated scenarios. In the free-space results, the most significant differences between the holder and no-holder conditions are observed in the angular widths at the Phi=90° plane, with a variation of approximately 14 dB, whereas the differences are smallest at the Theta=90° plane. This phenomenon is attributed to the shape of the holder, as shown in Fig. 1b: in the vertical direction (z-direction), the holder does not create edges for the antenna, whereas in the horizontal direction (y-direction), the thick holder edges surround the antenna.

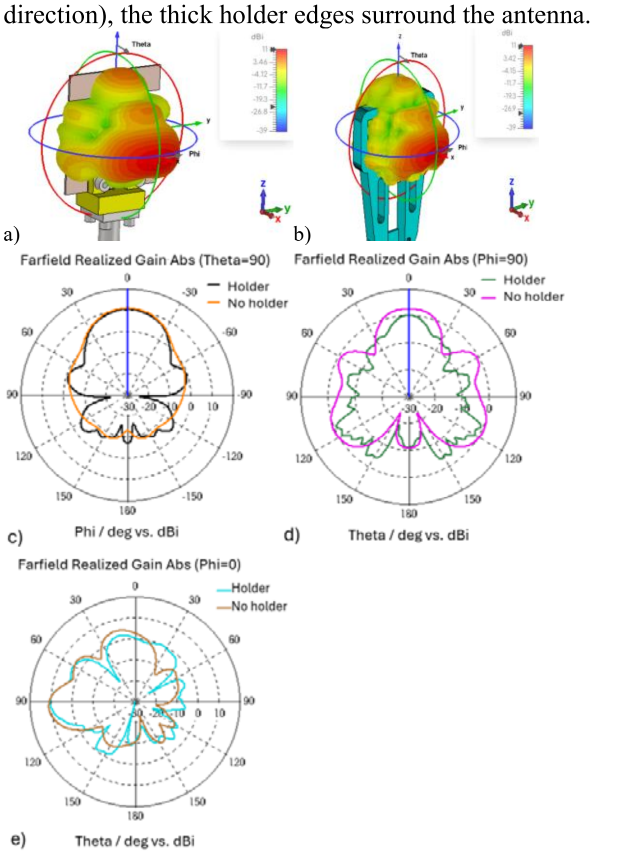

Figure 2. Impact of the antenna holder on the realized gains in free space: a) without the holder and b) with the holder; Polar plots for c) Theta=90°, d) Phi=90°, and e) Phi=0° planes.

3.2. Evaluations with body models

Next, the antenna characteristics are evaluated at different parts of the human model (hand, chest, and head) with and without the antenna holder. Figs. 3a-b show realized gains as polar plots in Theta=90° plane, without and with the holder, respectively. Similarly, Figs. 3c-d present results in Phi=90° plane and Figs 3e-f show the Phi=0° plane.

Differences in realized gains are observed across different body parts. Without the holder, variations of 2 to 6 dB are mainly seen at certain angles of Theta=90° and Phi=0° planes. At Phi=90°, differences are more pronounced, reaching up to 10 dB at Theta=32°. With the holder, differences increase significantly, up to 20 dB in the Phi=90° plane. Differences are also observed in the values of overall realized gain, efficiencies, main lobe magnitude and direction, angular width, and side lobe levels, as summarized in Table I.

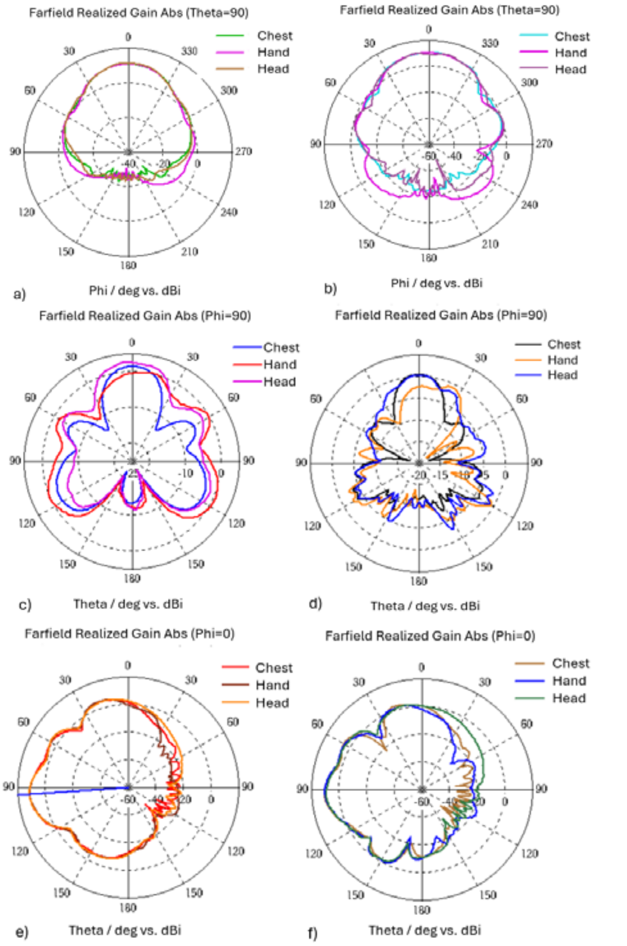

Figure 3. Comparison of realized gains obtained with simulations on chest, hand and head. Polar plot illustrations without (left) and with (right) the antenna holder for: a-b)Theta=90°, c-d) Phi=90°, and e-f) Phi=0° planes.

Next, the impact of the antenna holder is studied in the case of the hand model. Similar to the free-space evaluations, the realized gains are presented as 3D illustrations and polar plots in Fig 3. It is observed that the presence of the body model amplifies the differences caused by the antenna holder. Also in this case, the differences are most pronounced in the Phi=90° plane, with variations reaching up to 20 dB at Theta 60°. Table I compares the differences in realized gain, main lobe magnitude and direction, angular width, and side lobe levels. Also, the differences in these values are more pronounced than in free space, with the largest variations occurring in the main lobe direction and angular widths in the Phi=90° plane.

A similar trend is observed when evaluating antenna characteristics using the chest model; however, the differences are less minor than with the hand model. For brevity, the realized gain plots are left out from this paper and the results are only summarized in Table I. In this case, the largest difference is in the angular widths of Phi=90° plane, approximately 4 dB. The larger differences observed in the hand model is due to human model geometry: hand is significantly smaller than chest and head, which will affect on overall radiation characteristics.

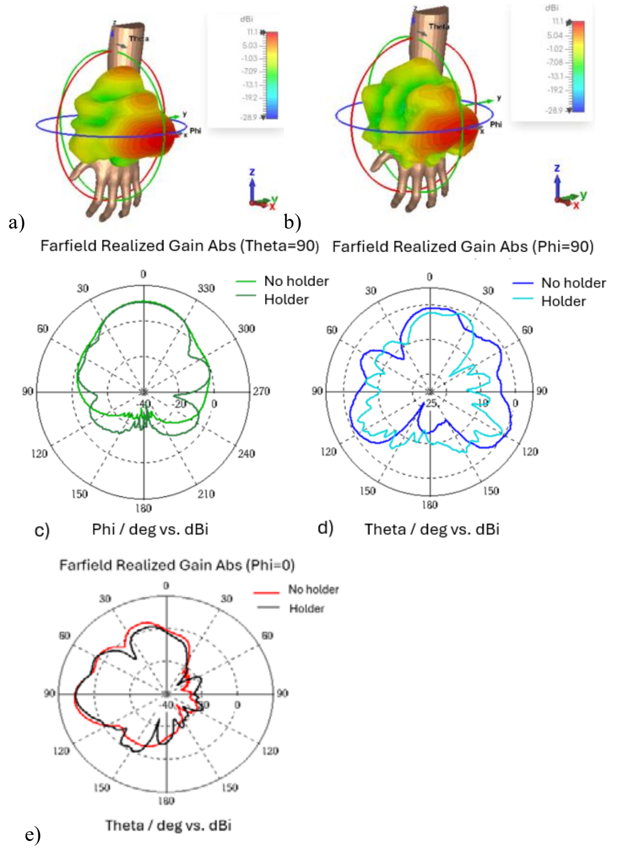

Figure 4. Impact of the antenna holder on the realized gains with the hand model: a) without the holder and b) with the holder; Polar plots for c) Theta=90°, d) Phi=90°, and e) Phi=0° planes.

3.3. Comparison with head locations and models

Finally, the antenna characteristics are evaluated and compared at two different head locations (Loc1 and Loc2). Additionally, the antenna characteristics are compared using homogeneous and multitissue layer head models. Similarly to previous cases, the largest differences are observed at the Phi=90° plane. Therefore, only this plot is presented here for brevity: the case without the holder is shown in Fig. 5a, and with the holder in Fig. 5b.

In the case without the holder, the differences between the models are minor. The most noticeable difference between Loc1 and Loc2 is approximately 4 dB at Theta = 35°. The difference between the antenna characteristics obtained with the homogeneous head model and the multitissue layer model is mostly insignificant, with a maximum difference of 2 dB at Theta = 30° and 4 dB at Theta = 80°. This is expected due to the small propagation depth at 28 GHz, which is only a few millimeters.

Consequently, there is no significant difference whether a homogeneous or multitissue layer model is used. In the presence of the holder, the differences between antenna characteristics obtained at Loc1 and Loc2 are larger at certain angles, as shown in Fig. 5b. The difference is up to 10 dB at Theta = 32°. The difference between the homogeneous and multitissue layer model is also slightly larger at certain angles, with a maximum of 5 dB at a few specific angles.

Table I Antenna characteristics at different body sites, body models and with and without the antenna holder

	Real.gain [dBi]	Efficiency (rad. / tot.)	Main Lobe magnitude [dBi] (Theta90°/Phi90°/Phi0°)	Main lobe direction (deg.)	Angular width (deg.)	Side lobe level (dB)
Free-space, no holder	11.0	-0.8 / -0.8	10.8 / 2.6 / 11.1	0.0 / 0.0 / 93.0	46.4 / 41.6 / 23.3	-19.0 / -2.2 / -6.3
Free-space, holder	10.4	-1.0 / -1.1	10.4 / 0.2 / 10.4	0.0 / 0.0 / 91.0	45.9 / 27.4 / 20.8	-11.1 / -1.1 / -6.6
Hand, no holder	10.9	-1.1 / 1.1	10.7 / 0.5 /11.0	1.0 / 114.0 / 94.0	45.5 / 37.9 / 24	-11.2 / -1.1 /-6.0
Hand, holder	10.2	-1.8 / -1.9	10.3 / 0.9 / 10.2	3.0 / 120.0 / 91.0	47.7 / 11.5 / 21.4	-10.8 / -1.4 /-5.1
Chest, no holder	11.1	-1.2 / -1.2	10.7/ 1.4 /11.2	0.0 / 0.0 / 94.0	47.0 / 35.3 / 24.3	-10.0 / -4.3 / -6.0
Chest, holder	10.4	-2.0 / -2.1	10.5 / 0.3 / 10.6	358.0 / 1.0 / 92.0	48.7 / 34.8 / 20.3	-12.0 / -4.1/ -3.2
Head, Loc.1, no holder	11.4	-1.1 / -1.1	11.1 / 2.6 / 11.4	3.0 / 4.0 / 94.0	43.6 / 45.1 / 22.4	-8.7 / -4.2 / -6.2
Head, Loc.1, holder	10.6	-1.7 / -1.8	10.3 / 0.2 / 9.1	9.0 / 1.0 / 94.0	45.7 / 55.9 / 23.9	-10.7 / -1.5 / -5.0
Head, Loc.2, no holder	11.2	-1.1 / -1.1	11.2 / 2.8 / 10.0	6.0 / 5.0/ 92.0	49.6 / 44.4 / 20.1	-11.5 / -3.9 / -5.5
Head, Loc.2, holder	10.7	-1.6 / -1.7	10.7 / 0.0 / 10.4	4.0 / 0.0 / 90.0	42.3 / 28.2 / 22.0	-10.3 / -2.1 / -6.5
Head, multilayer, Loc2 no holder	11.3	-1.0 / -1.0	11.0 / 2.9 / 11.3	1.0 / 6.0 / 90.0	44.2 / 47.3 / 23.5	-9.9 / -3.6 / -6.4
Head, multilayer, Loc2 holder	10.4	-1.6 / -1.6	10.4 / 0.9 / 10.0	6.0 / 0 / 92.0	49.6 / 30.2 / 20.1	-11.5 / -0.9 / -5.5

Overall, the minor differences between the homogeneous and multilayer model results are encouraging, since the use of the homogeneous model significantly reduces simulation time. This is particularly relevant for mmWave simulations, where complexity can rapidly increase with more complex models having different material properties.

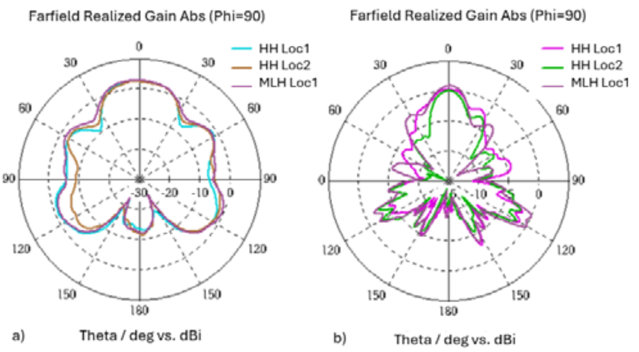

Figure 5. a) Comparison of realized gains obtained with homogeneous head model (HH) at locations 1 and 2 and multilayer head (MLH) model at Phi=90° plane: a) without the holder and b) with the holder.

4. Conclusions

This simulation-based study provides a comprehensive analysis of the characteristics of a 28 GHz BAN antenna at different body sites, including the head, chest, and hand. The results clearly show that the location of the antenna has a significant impact on the radiation characteristics. This emphasizes the need to evaluate the performance of the antenna at the specific body location where it is intended to be used.

Additionally, the impact of the antenna holder on the radiation characteristics was investigated. The results show that the presence of the holder clearly influences the performance of the antenna, underscoring the importance of considering the holder's influence during realistic evaluations. Furthermore, no significant difference was found between the homogeneous and multilayer head models. This is attributed to the small propagation depth at 28 GHz, which minimizes the influence of different tissue layers on the antenna's performance.

Overall, these results emphasize the critical importance of simulating antenna characteristics at specific intended locations and considering the practical aspects of antenna deployment, such as the use of holders, to achieve a thorough understanding of the antenna's performance.

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