60 GHz SIW horn antenna : off-body performance comparison with 4 GHz UWB monopole antenna

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***Abstract*—A 6.6 dBi-gain Substrate Integrated Waveguide (SIW) horn antenna is used for off-body channel measurement at 60 GHz. Statistical scenario-based measurements are more suitable to assess Body Area Network (BAN) communication since they include both the environment and the antenna behaviors. Measurements are performed for four scenarios and two antenna positions. Results are discussed and compared with measurements at 4 GHz using a SkyCross monopole antenna in terms of link outage probability using receiver performance from the literature. In particular, it is shown that in all considered scenarios, results at 4 GHz and at 60 GHz led to outage of less than 15% and less than 8% respectively.**

Keywords—millimeter wave; Ultra Wideband (UWB); SIW horn antenna; Body Area Network (BAN); off-body propagation

I. Introduction

Body Area Network (BAN) presents a high potential in future health-care and prevention. It will also be more and more involved in other applications such as multimedia entertainment, monitoring in sport, assistance for people with disabilities [1].

Although 60 GHz BANs are promising in terms of robustness against interference from other networks, further miniaturization of antennas, and large available frequency band, they suffer from high propagation losses.

In the context of BAN, once the antenna is located on the human body, its radiation properties change drastically. Available propagation channels that are measured in BAN context either depends on the antenna that have been used to perform the channel measurements [2] or take into account a part of human tissues as part of the radiating structure [3] in order to deembedd the antenna behavior from the channel. It was shown in [4] for a SIW (Substrate Integrated Waveguide) horn antenna that its gain and efficiency vary with the antenna-body spacing when simulated. Furthermore, due to body reflection, the antenna on-body radiation pattern is up-tilted, which makes off-body communication possible.

In this study, the antenna designed and characterized on body at 60 GHz in [4] is used for statistical off-body path loss measurement when mounted on a smartwatch position and on a mobile phone. Same configurations are investigated at 4 GHz to assess the potential of millimeter-waves with respect to other frequency candidate for Impulse-Radio Ultra Wideband (IR-UWB) BAN communications.

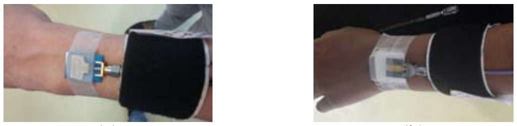
II. Off-body measurement setup

The SIW horn antenna in [4] is used as a receiver (RX) at 60 GHz located in the most likely places of central node for off-body BAN communications: on a wrist for a smartwatch and on a mobile phone. The transmitter (TX) was a remote base station located 1.25 m away from the subject and at a height of 1.16 m from the floor vertically (V) or horizontally (H) polarized using an open-ended WR15 rectangular waveguide (5.7 dBi gain).

The same configurations were considered at 4 GHz using commercially available Skycross SMT-3TO10M UWB antennas [5] for both TX and RX. This antenna exhibits a gain of 2.2 dBi in free space. As mentioned in [6], the measured S_{11} at 4 GHz is below -8 dB in free space and can go up to -3.5 dB when the antenna is touching the skin.

The measurements were conducted in Continuous Wave (CW) mode using an Anritsu Vector Network Analyzer (VNA). A 22 dB-gain amplifier was used at 60 GHz to enhance the measurement dynamic. The VNA IF (Intermediate Frequency) bandwidth was set at 10 Hz and the noise floor was consequently measured at about -80 dBm at 60 GHz and -97 dBm at 4 GHz.

Measurements have been conducted on two test subjects performing random movements in a standing up posture that includes position of line-of-sight (LOS) and non-LOS (NLOS) between the two antennas. The following off-body scenarios are performed: antenna on the wrist at a height h_T of 0 mm (scenario 1) and 5 mm (scenario 2) above the wrist (cf. Fig. 1.a, b); antenna attached to a mobile phone (scenario 3): user calling and typing text; antenna attached to a mobile phone placed in the pocket (scenario 4). Each set of measurement has been performed twice during approximately 60 seconds, which led to about 500 samples for each set.



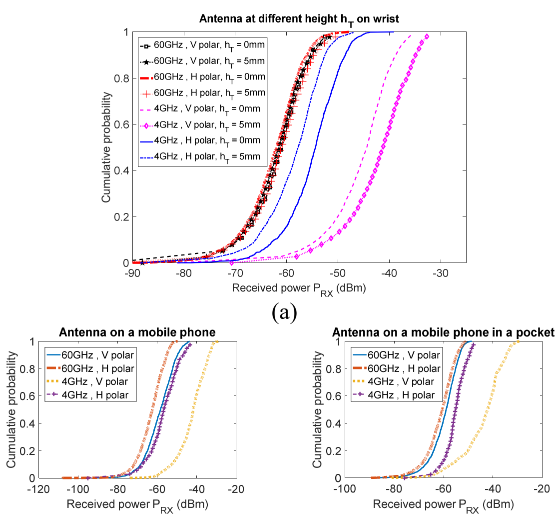
(a) (b)

Fig. 1. Antennas on left wrist **(a)** SkyCross at $h_T = 0$ mm on test subject 1 **(b)** 60 GHz SIW horn antenna at $h_T = 5$ mm above test subject 2 skin.

III. Results and Discussion

First, when setting the same EIRP (Equivalent Isotrope Radiated Power) at 19.7 dBm for both frequencies, it can be observed that as expected 60 GHz suffers from higher path losses than 4 GHz, about 10 to 30 dB (cf. Fig. 2). However, 60 GHz appears more robust to the change in TX antenna polarization than 4 GHz. Moreover, only the Skycross antenna is sensitive to the proximity of the body since it is not backed with a ground plane.

Next, normalization that takes into account regulation and suitable electronics has been applied. UWB technology is limited by an EIRP of about -15 dBm for a 500 MHz channel (as defined in the IEEE 802.15.6 standard [7]) while an EIRP of 25 dBm is worldwide accepted at 60 GHz [8]. Results are shown in terms of outage probability in Table 1 for different typical receivers that have been tested with IR communications in [9,10]. It is clear that at 4 GHz, a 100 Mb/s data rate cannot be reached. However, data rate of 16.7 Mb/s will exhibit an outage always less than 15% if the base station is horizontally polarized and less than 5% if vertically polarized. At 60 GHz, outage less than 8% are obtained in all considered scenarios. Consequently, under the assumptions of the considered electronics and measured scenarios, both 60 GHz and UWB appear to be suitable candidate for off-body communications.



(a)

(b) (c)

Fig. 2. Normalized received power distribution for EIRP = 19.7 dBm: **(a)** antenna on wrist - h_T = 0mm and h_T = 5 mm; **(b)** antenna on a mobile phone (calling and typing text); **(c)** Antenna on a mobile phone placed in a pocket.

TABLE I. Outage probability with regard to standardized EIRP and available receiver for different antenna position.

Frequency, data rate, EIRP, sensitivity	Scenario 1 (V/H)	Scenario 2 (V/H)	Scenario 3 (V/H)	Scenario 4 (V/H)
60GHz, 350 kb/s, 25 dBm,-67.8 dBm	4.6% / 5.3%	4.6% / 4.2%	3.6% / 7%	2.8% / 4.3%
4GHz, 16.7 Mb/s, -14.3 dBm, -99 dBm	1.1% / 0.5%	5.1% / 13.4%	0.4% / 15.2%	2% / 2.9%
4GHz, 100 Mb/s, -14.3 dBm, -50 dBm	100%	100%	100%	100%

IV. Conclusion

A moderate directivity SIW horn antenna was used for off-body channel measurement at 60 GHz. Different random scenarios are investigated experimentally at 60 GHz and at 4 GHz. Results show that for the same EIRP, the received power at 60 GHz is 10 to 30 dB lower than at 4 GHz. However, an EIRP of 25 dBm is allowed at 60 GHz where as -41.3 dBm/MHz is the maximum EIRP for UWB frequency. Considering a receiver sensitivity of -99 dBm at 4 GHz, outage of less than 5% to 15% were obtained. At 60 GHz, with a -67.8 dBm sensitivity receiver, an outage less than 8% was obtained for all considered scenarios. Further work will be done on theoretical analysis toward antenna-channel dissociation.

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