35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Effect of the Antenna-Body Distance on the On-Ext and On-On Channel Link Path Gain in UWB WBAN Applications

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Abstract— **This paper investigates the effect of the operation distance (i.e., practical use) between an antenna and a human body on wireless body area network (WBAN) channel path gain. Different use cases in WBAN on-external (ext) and on-on links with different antenna-body distances for ultra wideband (UWB) technology are considered. These studies are carried out with two types of planar UWB antennas in the vicinity of a real human body. Corresponding scenarios are repeated by computer simulations, and differences between these environs (i.e., challenges in the modelling of the measurement situation) are analysed and discussed.**

I. Introduction

Wireless communications targeted to utilize around a human body have been industriously considered. Ultra wideband (UWB) technology is presented as one possible physical layer technology for wireless body area network (WBAN), which is an attractive solution for monitoring application in public health service [1], [2]. In 2012, the IEEE published an international standard 802.15.6 [3] for WBANs. Sensors of WBAN might be used between different communications such as on-on, on-external (ext) and on-in. When considering the on-body channels, the communication between devices is mainly through the creeping waves [4], [5]. For such on-on link, radiated electric (E)-field of the antenna should be normal to a body surface in order to achieve proper link performance, while in case of the on-ext link tangential E-field to a body surface is preferred. On-body propagation has shown huge interests during the recent years: Channel responses and modelling between different on-body sensor positions are reported, e.g., in [6]-[9], channel behaviour with different people is demonstrated in [10], [11], and the effect of an antenna or wave polarization on propagation is investigated in [12], [13].

In this paper, the main enthusiasm is to demonstrate how the practical antenna-body operation distance affects to the channel path gain via different propagation media. On the other hand, possible discrepancies between different antennas are of interest as well. Also the challenges of the computer-aided modelling of measurement scenarios are discussed. Investigations for on-ext and on-on channels are subdivided into two ensembles, while in both of them two types of antennas (antenna under test, AUT) and multiple AUT-body distances are considered. In the first phase, on-ext channels with different link angles, i.e., rotation angle referring to the direction of on-ext link relatively to the frontal body surface, are examined and compared with corresponding free space (FS) links. In the second phase, three on-on cases are involved for experimentations: (1) a line-of-sight (LOS) link along a body surface (abdomen-thorax), (2) a LOS link via FS (abdomen-hand), and (3) a non-LOS (N-LOS) link along a body surface (abdomen-spine). WBAN links are first measured in an anechoic chamber in the closeness of a real human body, and then the scenarios are repeated by simulating in reasonable positions in the vicinity of a whole body model, by using Computer Simulation Technology (CST) [14]. Arranging these studies is based on the IEEE802.15.6 recommendations [3], [15] for investigating the antenna characteristics and propagation close to a body.

Research is supported in part by the Finnish Funding Agency for Technology and Innovation (Tekes) through Enabling Wireless Healthcare Systems (EWiHS) project, Wireless Body Area Network for Health and Medical Care (WiBAN-HAM), Centre for Wireless Communications (CWC), and University of Oulu, Finland. Also Infotech Oulu Doctoral Program as well as Tauno Tönning, Emil Aaltonen, TES, Walter Ahlström and HPY foundations are appreciated for the financial support of this research work.

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II. Measurement and Simulation Setup

Fig. 1 compares on-ext and on-on link measurement and simulation setups. The height of the test person was 1830 mm and the whole body model 1880 mm, respectively. Measurements were carried out in an anechoic chamber by using a Rohde&Schwarz ZVA-8 (valid up to 8 GHz) [16] vector network analyzer (VNA) with four test ports and Sucoflex 104PEA [17] cables with the length of 8000 mm. The studied planar UWB antennas were dipole and double (slot) loop antenna shown in Fig. 1 f), which are described in [18] with more details. The distance *D* between the antenna and body was filled with a Rohacell 31 HF [19]. In measurements, the frequency spectrum covered a band of 2 – 8 GHz, while simulations were further extended to cover a band up to 11 GHz. 100 consecutive frequency responses were measured and the results presented here are showing their average behaviours. Table I collects all significant information for studied cases. For on-ext studies, the link distance was fixed to 1000 mm. The antenna-body distances *D* of 0 mm, 10 mm and 20 mm were considered while the rotation angle was varied between the values of 0°, 45° and 90° as in Fig. 1a). Corresponding FS links were measured as a reference for on-ext channels by positioning another pole to the place of a body as in Figs. 1 b)-c) both in measurements and simulations. For on-on investigations, different links were examined as specified in Table I. The distances of on-on links in Table I are measured when the AUT-body distance of 0 mm is used. In simulations, a sub-gridding scheme was used and the number of perfectly matched layers (PML) was adjusted to 4, as PML is the number of the absorber layers around the simulation space.

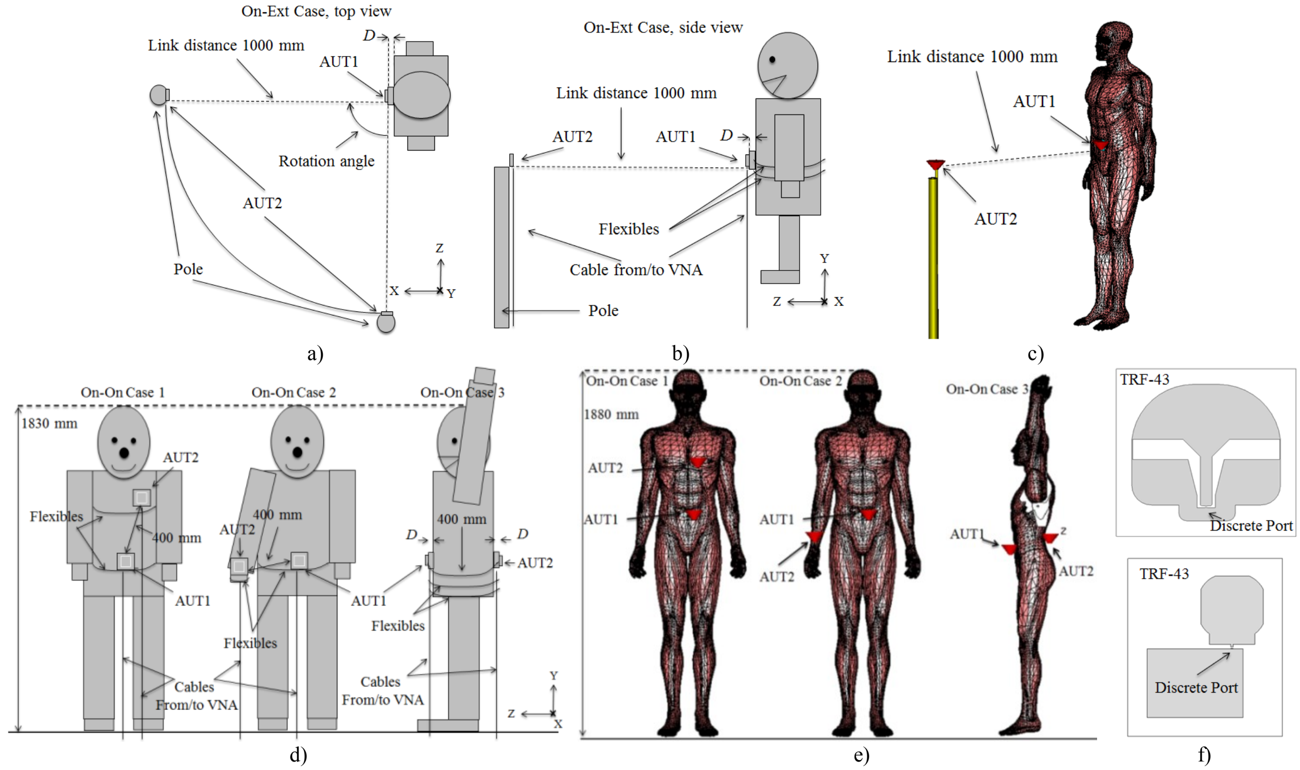

Figure 1. a)-b) Measurement and c) simulation setup for WBAN on-ext cases, d) measurement and e) simulation setup for WBAN on-on cases, and f) antennas (dipole below and double loop above) with TRF-43 substrate in investigations. Measurements are carried out in an anechoic chamber.

TABLE I. MEASUREMENT AND SIMULATION PARAMETERS

Parameter Information	***Measurements***	***Simulations***
Frequency band	2 to 8 GHz	2 to 11 GHz
Number of points	1601	1601
Link distances in on-on case 1	≈ 400 mm	≈ 270 mm
Link distances in on-on case 2	≈ 400 mm	≈ 330 mm
Link distances in on-on case 3	≈ 500 mm	≈ 310 mm
IF bandwidth of the VNA	100 kHz	-
Sweep time	288 ms	-
Transmit power	10 dBm	-
Consecutive samples recorded	100	-
Cable loss at 2 GHz	6.9 dB	-
Cable loss at 8 GHz	10.8 dB	-

III. RESULTS

This section presents the measurement and simulation results in terms of transmission coefficient S_{21}. Channel path gain behaviour in frequency domain is contemplated. One of the motivations is also to investigate, whether it is possible to find out the link characteristics by simulating them with CST using finite integration technique (FIT) instead of on-site measurements.

A. *The Effect of Practical Operation Distance between an Antenna and Human Body on Channel Path Gain*

Figs. 2 – 3 collect some measurement and simulation results. In Figs. 2 b)-d), S_{21} coefficient for on-ext links of 1000 mm for rotation angles of 0°, 45° and 90° (i.e., is in a direction normal to a body surface) with D = 0 mm is depicted. The FS performance is described in Figs. 2 a) and c) as a reference, in order to further demonstrate the influence of the proportion of a body to channel gain. As it is obvious from the pictures, path gain in FS cases stays rather stabile. In corresponding cases with a body, roughly the total of 20 dB variation of path gain can be observed in some frequencies due to the different rotation angles. This is due to the fact that when an antenna is operated very close to a body, the body effect will cause the antenna patterns to appear relatively directive in a direction normal to a body surface, which has been concluded with pictures previously in [20], [21]. A rather short increase on antenna-body distance enables a clearly wider beam of patterns in the direction of tangential body surface. This improvement is clearly notable in channel path gain at different angles due to larger antenna-body distances, especially in higher frequencies.

The results for some on-on links with use cases 1-3, described in Figs. 1 d)-e), are depicted in Fig. 3. In total nine different combinations for each case is considered such that AUT1 and AUT2 can receive any value D = 0 – 20 mm in steps of 10 mm. For the better visibility, some interesting combinations were decided to present for each case. The main observations from the results of cases 1 and 2 in Figs. 3 a)-d) are that 1) the measured channel path gain in cases 1 and 2 is roughly, practically on the same level, even though the propagation medium between these scenarios is quite different, and 2) a clear improvement to the channel performance with D = 10 mm or even D = 20 mm can be attained instead of the use on contact with tissues. Figs. 3 e)-f) compares the on-body links of the case 3. It can be concluded that AUT-body distances over 10 mm should be applied in order to avoid obtaining to record continuous noise. Based on the considerations in frequency domain, it seems that the measured data on these channel paths is mainly noise. This will be confirmed as a future work when performing time domain characterization.

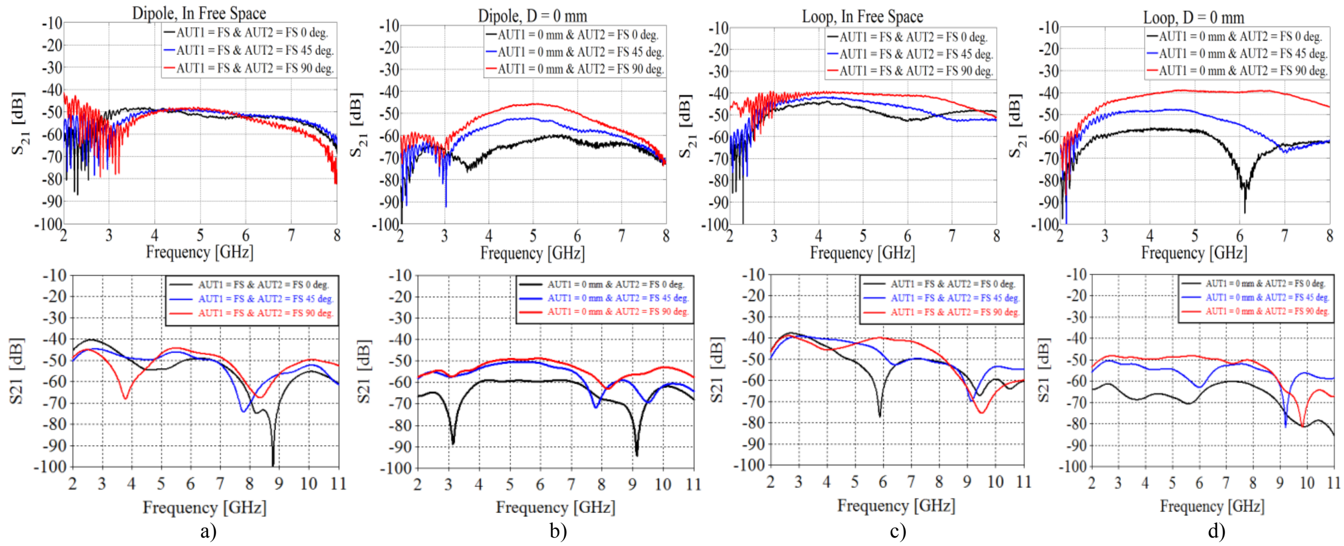

Figure 2. Some on-ext path gains in free space and in contact with body ($D = 0$ mm): a)-b) for dipole and c)-d) for loop. Measurements results shown above are processed with Matlab while simulations below plotted with CST. Figures show the variation of the channel path gain with the rotation angle.

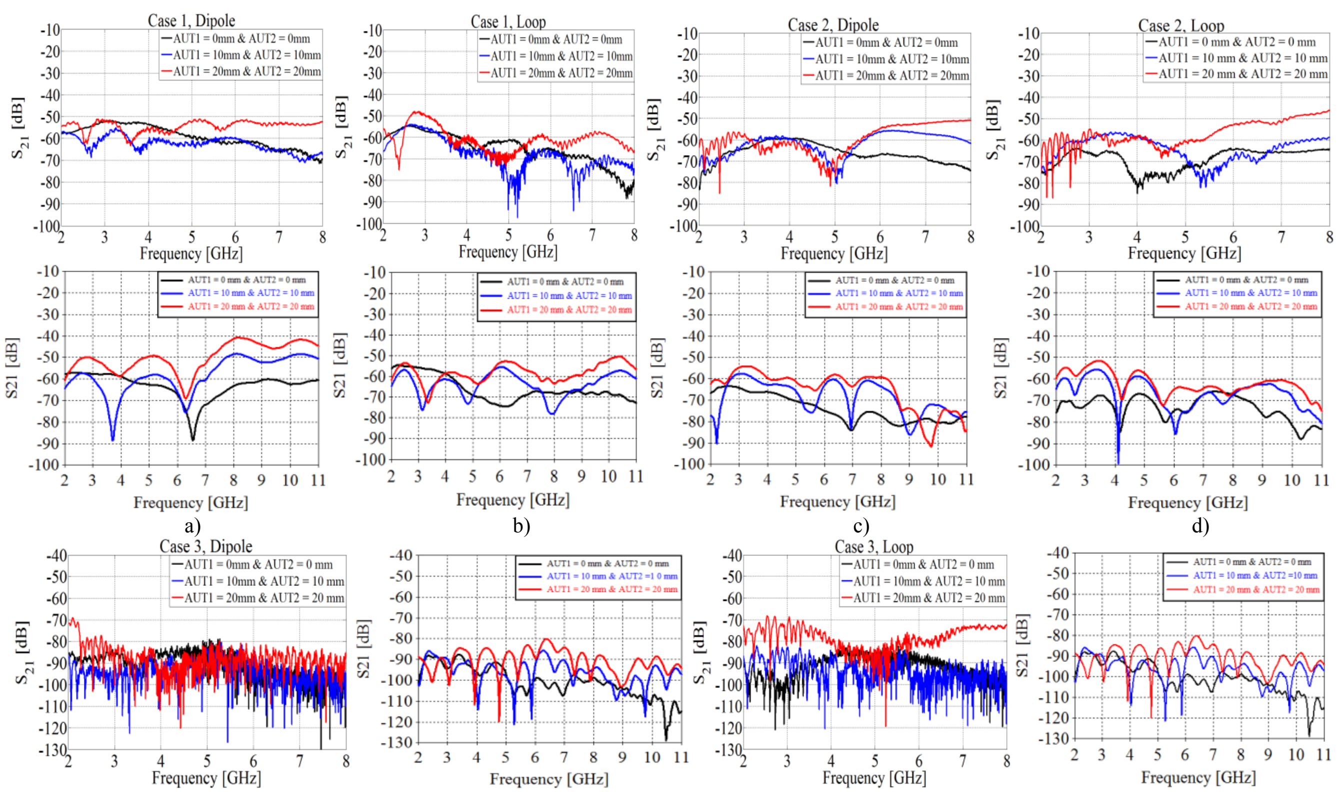

Figure 3. Some on-on channel path gains of cases 1, 2 and 3: a) and c) are for dipole, while b) and d) are for loop in cases 1 and 2 (measurements above, simulations below). e) and f) describes some results for the on-on case 3 (left: measurements, and right: simulations).

Also the operation of different antenna types was compared, and it was observed that no significant differences were attained between these two antennas in these configurations. Generally, the studied double loop antenna was observed to slightly outperform the dipole in FS scenarios and WBAN on-ext situations when contrasting the absolute path gain. However, when both antennas were operated close to body, the better absolute path gain in most scenarios of cases 1 and 2 was achieved with the dipole. On the other hand, the loop seems to work better for the case 3 when the propagation around the body surface is aspired. These findings are explained due to the antenna characteristics: the differences on the polarization properties of studied antennas.

B. Some Differences between Simulation and Measurement Scenarios

Differences between measurements and simulations due to uncertainties are generally known. We want to emphasise that even though these diversities exist, those environs can be modelled to be very close to each other.

First of all, one issue is differences between the numerical body model and an actual human body. This issue can be mitigated using a dispersive model. The cable effect is another issue affecting differences between measurements and simulations. In measurements, the antenna feed is implemented by soldering a semi-rigid cable to the prototype which has a different influence on the antenna properties than simulations where a discrete port is used for the antenna feeding. The cable and port connectors can be modelled in simulations, but there still exist differences. Further, it should not be ignored that antennas are always exactly identical copies of each other in simulations. In real life, it is obviously very difficult to generate two antenna prototypes fed with semi-rigid cables that are exactly equivalents, especially when manually soldered.

One of the most significant differences comes from the polarization properties of antennas at a link level, as inspected at a theoretical level, e.g., in [22]. In simulations, antennas are accurately placed for certain positions, for instance, at on-body cases. Practically, when antennas and cables are positioned on a real human body with an elastic strap, the antenna positions (referring to their tilt angles) relatively to a body surface normal between antennas are not exactly ever the same. This may have the effect of reducing the advantage of the larger AUT-body distances found in practical measurements, even though the improvement could be substantiated by theoretical simulations. Nonetheless, tilt angles can be also varied and adjusted in simulations. On the other hand, a large tilt angle might cause issues for generating logical mesh for simulation environment around antenna feedings (should be equal in the proximity of each antenna).

IV. Summary

The effect of operation distance D between the antenna and body for on-ext and on-on path gain was demonstrated, and the discrepancies between measuring and modelling these scenarios were discussed. Path gain was concluded to clearly improve when both antennas have distances $D > 10$ mm. In case of on-ext channels, the rotation angle has significant impact on the achieved path gain due to the directive effect of a body on patterns when operated very close to a body. Basically, the estimation of WBAN channel path gain by computer simulations was observed to be highly suitable by using FIT.

Corresponding time domain investigations will be provided as a next step of this work. Further, more dense AUT-body distances will be considered as a future work in order to give answers whether there is some specific distance that dictates a clear improvement for the path gain. Also on-on case 3 will need deeper considerations in order to verify the propagation phenomena in that case.

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