Applicability of Finite Integration Technique for the Modelling of UWB Channel Characterization

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***Abstract*— The objective of this paper is to verify applicability of Finite Integration Technique (FIT) based simulations in the modeling of Ultra Wideband (UWB) radio channel. A printed planar UWB monopole antenna, designed for Wireless Body Area Networks' (WBAN) on-body and off-body communications, is used in the experiments. The validation of the FIT-method is performed by comparing the simulation and measurement results in free space. The analysis was performed both in frequency and time domains. Furthermore, the channel behavior was explained with UWB antenna characteristics. The simulated and measured results are shown to have excellent correspondence both in frequency and time domain. All antenna simulations are done with Computer Simulation Technology (CST) Microwave Studio (MWS) software.**

Keywords-Ultra wide band (UWB) antenna; finite integration technique (FIT); radio channel measurement

I. INTRODUCTION

Wireless communication in medical and health care sectors have been under an intensive research and development within recent years. The aim is to get rid of wires, which connect patient's sensors to monitor device or access point, and further to data base, and replacing cables with a reliable and secure wireless communication link. This is a part of the general concept of Wireless Body Area Network (WBAN).[1] The standard for WBAN in medical application has been developed by the study group IEEE802.15.6 [2] and it will be released in the beginning of 2012.

The WBAN communication is classified into three categories: in-body, on-body and off-body communications. *In-body* communication covers the links between internal medical implants and sensors, which are attached on the body, *on-body* communication describes the links between sensor nodes on the patient's body, and *off-body* communication is related to the links between on-body devices and an external gateway, e.g., hospital room access point. [3]

In order to model the channel characteristics of the WBAN communication links, different channel models are presented, e.g., in [4] by the IEEE802.15.6. In general, Ultra Wideband (UWB) channel modeling for medical applications has been studied widely. However, according to the studies presented in [5], there are other measurement based channel models available which are more accurate than the IEEE802.15.6 channel model. Obviously, the use of measurement data in the simulations gives more realistic performance in a certain environment than the use of channel models, which, however, are always pure approximations of certain situations. Nevertheless, the use of measurement data is not always possible due to the laboriousness of the measurement campaigns. Besides, there are several challenges related to the inaccuracies and uncertainties of the measurements, but these are available also in channel models.

One option for modeling electromagnetic propagation is to solve Maxwell's equations in the given scenario by using numerical approaches, such as Finite Integration Technique (FIT) [6] or Finite-Difference Time-Domain (FDTD) [7] technique. In FIT and FDTD methods, the basic algorithms are similar, but the difference becomes from the form of Maxwell's equations used. FIT uses the integral form whereas FDTD uses differential form of Maxwell's equations. The main advantages of the FIT over the FDTD are high flexibility in geometric modeling and boundary handling [8]. Both techniques are widely used in antenna simulations, also in UWB context. Furthermore, FIT and FDTD have been studied in on-body channel modeling, e.g. in [9]. In on-body communication, impact of human body is significant on antenna properties and hence, dominates the channel characterization. Instead, in off-body communication with certain antenna arrangements, radio link can be considered more as a conventional radio link between the transmitting and receiving antennas. In ideal case, this link can be approximated as a free-space communication link.

The aim of this paper is to verify the applicability of FIT method in the modeling of UWB channel characteristics. The presented results are modeling a free space propagation, which can be considered as a preliminary study for an ideal off-body communication link. All antenna simulations are done with Computer Simulation Technology (CST) Microwave Studio (MWS) software [10].

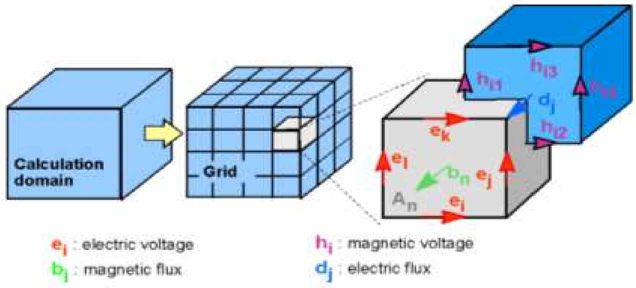

Figure 1. Principle of FIT calculation [11]

The paper is organized as follows: The basic idea of FIT is described in Section II. Section III presents a planar printed UWB monopole antenna used in the experiments. Simulation and measurement setups as well as numerical results are shown in Section IV. Summary and future works are discussed in Section V.

II. FINITE INTEGRATION TECHNIQUE

Finite Integration Technique provides a discrete reformulation of Maxwell's equations in their integral form suitable for computer calculations. It allows simulation of real-world electromagnetic field problems with complex geometries, both in time and frequency domains. In this study, FIT-based simulations have been conducted with CST MWS software [10]. The very basic principle of the simulation procedure is shown in Fig. 1 [11]. The first step in the simulations is the selection of calculation domain, which is then split by suitable mesh system into several small elements, called grid cells. Spatial discretization of Maxwell's equations is performed both in primary (grey box) and secondary (blue box) grid systems which are orthogonal to each other. The primary grid refers to the electric voltages **e** and magnetic facet fluxes **b**. The secondary grid gives the dielectric facet fluxes **d** and magnetic grid voltages **h**. [11]

The main benefit of FIT is the possibility to have two different materials within one grid cell, whereas in FDTD only one material is allowed within one grid cell. Due to this advantage, the mesh can be significantly sparser, and hence, less memory is required in FIT simulations, especially in the objects with complex geometry. [11]

III. UWB MONOPOLE ANTENNA

Fig. 2 presents the planar printed UWB antenna, which is exploited in this study. The designed UWB monopole antenna, which is having the ground plane on the same side of FR4 substrate than the monopole radiator is relatively easy to tune. Further, the small size of antenna make's it suitable and attractive for the WBAN applications.

The discrete port has been used in antenna simulations while in prototype measurements the feeding cable has been soldered over the ground plane in the direction of y axis. The relative permittivity of ε_r = 4.3 for FR4 substrate with thickness of 1.6 mm (in the direction of z axis) and loss tangent of *tan*δ = 0.025 from CST MWS material library has been used.

In Fig. 3, simulated and measured S_{11} in free space together with simulated realized maximum gain and total antenna efficiency have been presented. The antenna measurements were carried out in an anechoic chamber.

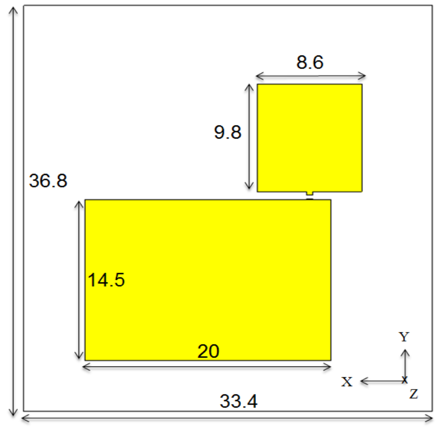

Figure 2. Detailed dimensions in mm for UWB monopole antenna

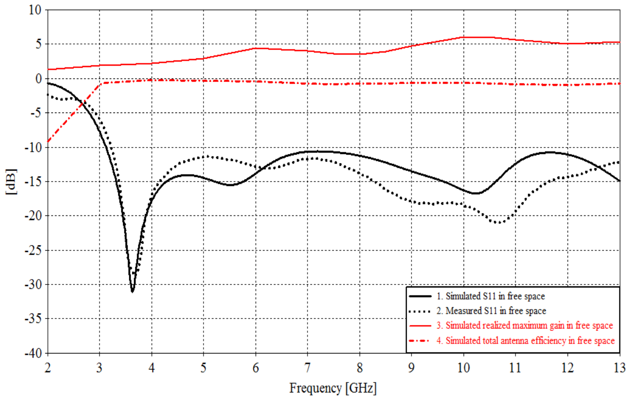

Figure 3. Simulated and measured S_{11} together with simulated realized maximum gain and total antenna efficiency in free space

Excellent agreement between the simulated and measured S_{11}'s were observed. Based on the simulated maximum gain and total antenna efficiency, the antenna can be concluded to have good radiation characteristics.

The simulated radiation patterns in free space for the XZ and ZY –planes, which are the most informative cutting planes, at frequencies 3, 7, and 10 GHz are presented in Fig. 4. Relatively omnidirectional radiation patterns were observed for the entire UWB band with the presented antenna.

IV. NUMERICAL RESULTS

A. *Simulation Setup*

In this study, FIT-based simulations are conducted for the UWB monopole antenna illustrated in Fig. 2. In the simulation setup, two antennas were placed perpendicularly against each others; such the antenna feeding points were located in the same proper axis. Distance between the antennas was swept from 0.5 m to 2.5 m in the steps of 0.5 m. The sub-gridding scheme, which allows different levels of mesh to be used for different solids in the model, was used. The open Perfectly Matched Layer (PML) boundary properties (amount of layers) were increased to the level of 20 to receive reliable channel operation, i.e., similar results than in the measurements.

B. *Measurement setup*

In order to verify the capability of FIT-based computer simulations in the realistic UWB antenna evaluation, measurements were carried out with the prototypes

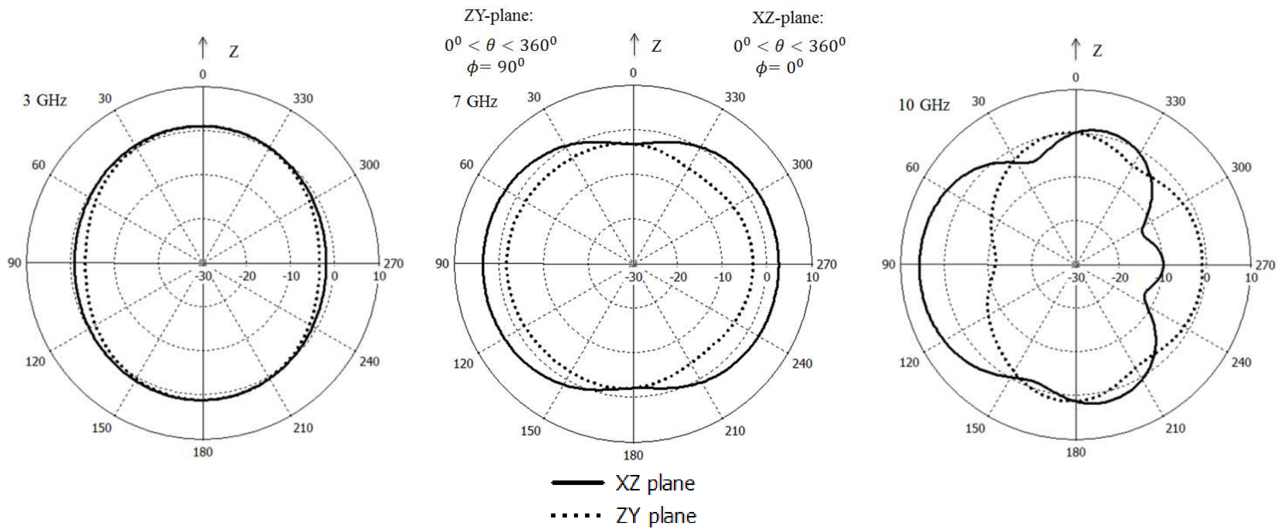

Figure 4. Simulated radiation patterns (plots of realized gain) at frequencies 3, 7, and 10 GHz in XZ- and ZY-planes

Figure 5. Measurement setup in an anechoic chamber

described in the previous section. Figure 5 presents the measurement setup constructed in an anechoic chamber, having floor space of 2.4 m x 3.85 m, and height of 3 m.

Both two UWB antennas were placed on the top of the plastic stake, at the height of 2 meters. Agilent 8720ES Vector Network Analyzer (VNA) [12] was used for antenna measurements. The measured frequency band was between 2 GHz and 13 GHz. Free-space measurements were taken with the antenna distances *d* ranging from 0.5 m to 2.5 m, in the steps of 0.5 m..

C. *Frequency domain analysis*

First, the measurement and simulation results were analyzed in the frequency domain by studying the frequency response of the channel. This corresponds to the scattering parameter S_{21}, i.e., the isolation between antenna 1 and antenna 2. Figure 7 represents the frequency response obtained from the measurements (solid) and simulations (dash-dot) in the frequency range 2-13 GHz when the distances between the antennas were 0.5 m and 2.5 m. Furthermore, the measured and simulated S_{11}-parameters are included in Fig. 7. It is noted that there is an excellent agreement between the simulated and measured results in the cases of S_{21}, as well as in S_{11}. The shape of the measured and simulated S_{21} curves can be explained by studying the S_{11} curve, as well as the radiation patterns presented in Section III. The presented UWB antennas have almost omnidirectional patterns for the entire UWB band, as presented in Fig. 3. However, at the frequency of 7 GHz there exists a smallish zero. In addition, from S_{11} curves two resonances in the lower and higher ends of UWB band can be seen.

When comparing the simulated and measured responses, slightly better results are obtained by the simulations. This is natural due to the unidealities always present in the measurements. For instance, simulation software uses two completely identical antennas, whereas in practice, it is not even possible to produce two antenna prototypes having exactly identical properties. In the simulations, two antennas are always exactly the same (copy-paste of each other) and positioned exactly in the right places from the channel point of view. However in measurements, the antenna feeding cables in prototypes (semi rigids soldered to the ground plane) and the angle of gradient of plastic stakes together make the difference between the measurement and simulation results. In order to clarify this issue, measured scattering parameters S_{11} and S_{22} are compared in Fig. 6. For the sake of reference, simulated S_{11} (which is same as simulated S_{22}) is showed. As it can be seen, measured S_{11} and S_{22} are slightly different.

Similar good agreement between the simulated and measured S_{21} were also noted with the distances 1 m, 1.5 m and 2.0 m, but the figures were not included here due to the lack of the space. Furthermore, these experiments were also carried out using another UWB monopole antenna. The simulated and measured parameters matched well also in that case.

D. *Time domain analysis*

Next, the simulated and measured data were analyzed in time domain by studying the impulse responses of the measurement and simulated data. For this, Inverse Fast Fourier Transform (IFFT) was performed for the simulated frequency response. Measured impulse response was obtained from the VNA, which can carry out the transformation directly.

The simulated and measured impulse responses are shown in Fig. 8. As it can be seen, FIT can model well the timing and strength of the channel impulse when exceeding the background noise level. Side lobe levels are found to be slightly different. This is due to the Hamming-windowing performed by VNA, whereas in the impulse responses obtained from simulations, no windowing was included.

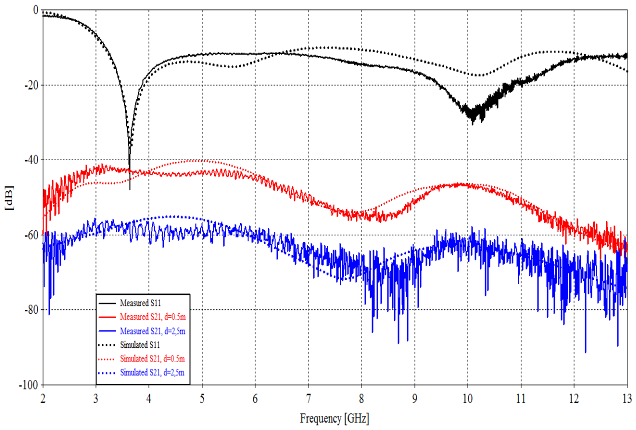

Figure 6. Simulated and measured S_{11} and S_{21}

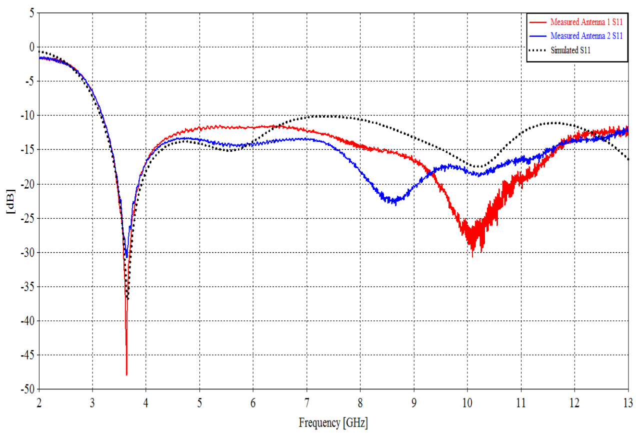

Figure 7. Comparison of measured S_{11} and S_{22} parameters

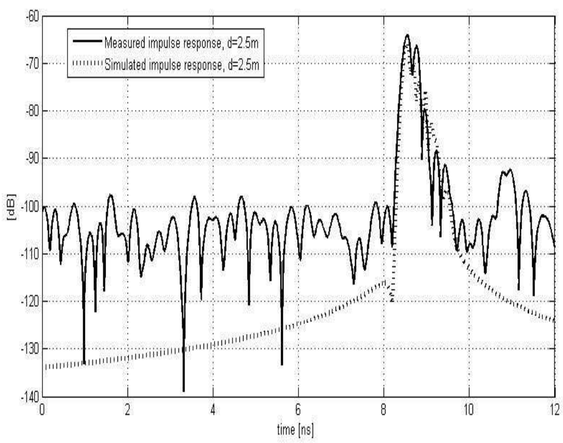

Figure 8. Comparison of measured and simulated impulse responses

V. SUMMARY AND FUTURE WORK

In this paper, the applicability of FIT-based simulation method for modeling the UWB channel characteristics was studied. The printed planar UWB monopole antenna, which can be used for on-body and off-body communication links was used in the experiments. Simulated and measured S_{11} and S_{21} were presented to have good agreements both in frequency and time domain. Furthermore, challenges in the channel modeling and measurements were discussed.

This was a preliminary study for the usability of FIT in WBAN off-body communication link modeling. The study is related to an ideal case, in which there is a small gap between the human body and the antenna of the on-body device, i.e., the human body does not have an impact on antenna radiation and thus does not affect the propagation characteristics. The next phase is to include the human body in the study and use these results as a reference.

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REFERENCES

[1] M. Hämäläinen, J. Iinatti, R.Kohno, “Wireless Communications in Healthcare, Recent and Future Topics”, 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL), Oct 2011.

[2] IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs). TG6 Body Area Networks (BAN) draft standard IEEE P802.15-10-0245-06-0006. 2010.

[3] P. S. Hall, Y. Hao, “Antennas and Propagation for Body-Centric Wireless Communication”, Artech House 2006.

[4] IEEE P802.15 (WPANs), Channel model for BAN, 2010.

[5] H. Viittala, M. Hämäläinen, J. Iinatti, ”Different Experimental WBAN Channel Models and IEEE802.15.6 models: Comparison and Effects”, ISABEL 2009, Nov. 2009.

[6] T. Weiland, “A Discretization Method for the Solution of Maxwell’s equations for six-component fields,” Electronics and Communication (AEU), Vol. 31, p. 116, 1977.

[7] K. S. Yee, “Numerical solution of initial boundary value problems involving Maxwell’s equations in isotropic media,” IEEE Trans. on Antenna and Propagation, Vol. 14, No. 3, pp. 302-307, May 1966.

[8] T. Weiland, M. Timm, I. Munteanu, “A Practical Guide to 3-D Simulation,“ IEEE Trans. on Microwave Magazine, pp. 62-75.

[9] Y. Zhao, Y. Hao, A. Alomainy, C. G. Parini, “Two novel FDTD Based UWB Indoor Propagation Model”, Proc. IEEE Int. Conf. Ultra-Wide-band, Sept. 2005.

[10] *CST Microwave Studio*, [Online]. Available: http://www.cst.com.

[11] CST User Manual,CST AG, Darmstadt, Germany.

[12] *Agilent, [Online]. Available: http://www.home.agilent.com/agilent/home.jspx?cc=FI&lc=fin.*