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Development and Application of a Channel Model for Intra-Device Communications at 300 GHz

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Abstract

In this contribution, propagation measurements and modeling for 300 GHz Intra-Device Communications are presented. In addition, the methodology for employing the achieved results in the derivation of a channel model for the Intra-Device application scenario of IEEE 802.15.3d as well as the utility of deriving further technical parameters based on this channel model are discussed.

1. Introduction

Recent development of media use shows that there is a clear trend towards ever increasing quality in consumed audiovisual content, with an increase in spatial and temporal resolution, color space and even dimensionality of the produced material. Along with this goes a dramatic increase in data rate that has to be transmitted, especially during the generation of said content. Another development lies in the constant shrinking of electronic devices and components, especially in the field of consumer electronics. Both of these observations lead to the need for a means of interconnection that provide data ranges in the range of tens or even hundreds of Gbit/s that allows for the reduction of wiring facilities and cost in the design of the associated devices. These considerations have already led to the definition of an intra-device application scenario in the IEEE P802.15.3 standardization process [7]. The concept of Terahertz communications is an ideal candidate to serve the introduced requirements, providing the capability of transmitting extremely high data rates while maintaining the flexibility of a wireless technology with very small possible transceiver designs compared to conventional radio solutions. This paper describes the process of developing the channel model for the intra-device application scenario and the use of that model during the system proposal evaluation in IEEE P802.15.3. After a brief description of the objectives, Section III introduces the components of the propagation research. In Section IV, the contributions of the propagation modeling to the channel model and the evaluation of system proposals is discussed before a summary is given in the final section.

2. Description of Objectives

Before the deployment of any wireless communication system, an understanding of the impairments from the environment that the system will be situated in to the radio channel is necessary. Thus, a description of the channel that is capable of producing realistic, reproducible data regarding the channel behavior is required. The overall objective of the works described in the following was the derivation of a stochastic channel model for THz intra-device communications for the evaluation of system proposals during the standardization process of IEEE P802.15.3d as well as to provide the manufacturers of corresponding equipment with a means to test their designs and to verify compliance to the standard requirements. Because of the limitations in measuring actual THz communication channels due to the current lack of actual small-scale transceivers and the difficulties arising when trying to evaluate the propagation characteristics using analytic numerical approaches [6], the general modeling approach in this study is based on ray-tracing (RT). In particular, the following steps have been performed: measurement of propagation effects such as reflection and transmission properties of materials, modification and calibration of the RT algorithm to account for these effects, derivation of a stochastic model from the RT simulations and finally evaluation of the system proposals based on the outputs of that model.

3. Propagation Research

The propagation channel for intra-device communications, especially when considered in the frequency range around 300 GHz, varies significantly compared to the usually considered outdoor or indoor-nomadic channels. Its characteristics are defined by a static environment built of materials such as plastic and metal comprising features in the order of only a few wavelengths. Moreover, the extremely high target bandwidths of up to 100GHz and the corresponding temporal resolution of a few tens of picoseconds make the channel temporally dispersive. In recent years, we have characterized the THz intra-device propagation channel by a modular approach. After Studying the impact of materials and geometric configurations separately [1,2,3,4], different modes of transmission such as direct links and directed non-line-of-sight links have been studied [5]. In addition, a conceptual study of propagation phenomena particularly in the vicinity or inside of structures has been performed based on the Finite Difference Time domain method [6]. All measurements described in the following have been performed using a Rohde & Schwarz ZVA50 vector network analyzer

(VNA) equipped with ZVA-Z325 frequency extensions and 20dBi standard gain horn antennas. For the plastic reflection and transmission measurements as well as for the reflection measurements from printed circuit boards (PCB), the frequency extensions have been mounted on a bi-static rotational stage to allow for accurate reflection measurements in specular and transmission measurements in boresight direction.

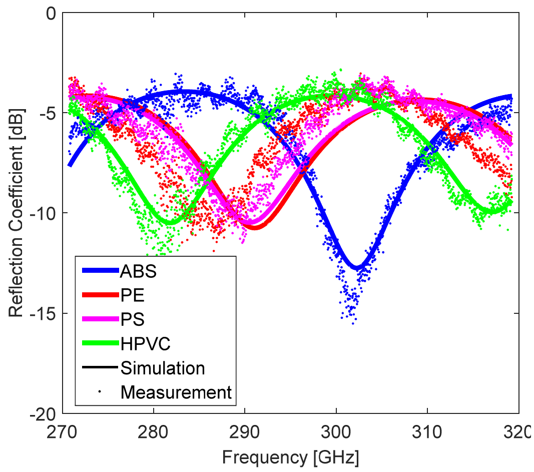

Figure 1. Reflection coefficient of plastic-sheets at an angle of incidence of 60° (based on [1])

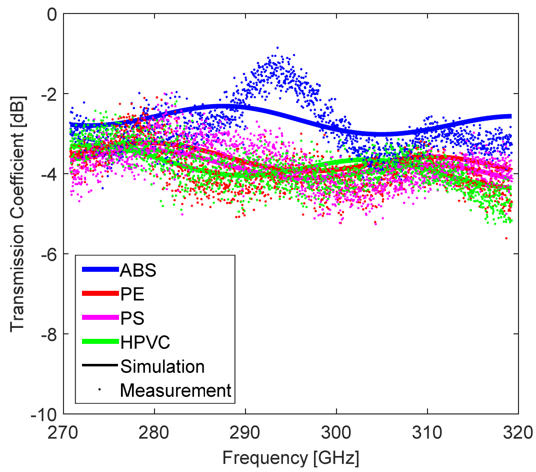

Figure 2. Transmission coefficient of plastic sheets at an angle of incidence of 60° (based on [1])

Figures 1 and 2 show the reflection and transmission coefficients over frequency of different 3mm thick plastic samples for two different angles of incidence. The coefficients have been modeled using the transfer matrix method as described in [1]. From the figures, it becomes obvious that transmission through plastic layers is a non-negligible effect even at THz frequencies and that the reflection coefficient of plastic surfaces shows a strong variation with frequency at such small wavelengths in the order of 1mm.

Another prominent feature of the propagation environment inside of consumer-electronic devices are printed circuit boards (PCB). Analogous to the reflection behavior of layered plastic surfaces, reflection from a PCB yields a signal corresponding to the superposition of a number of temporally delayed scattering processes. However, this time, the energy is scattered by the surface features of the PCB surface rather than from a single specular direction of reflection as illustrated in Figure 3.

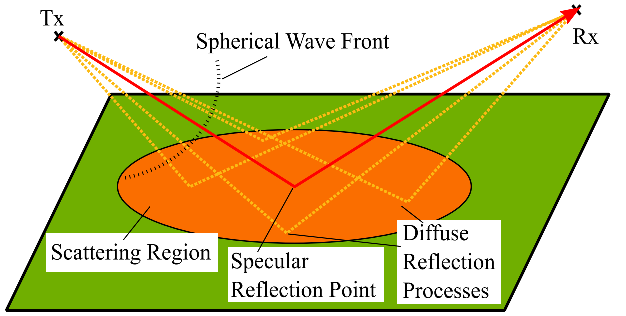

Figure 3. Geometry of the PCB scattering model (based on [3])

The reflection model is based on the assumption of a spherical wave front reaching the scattering features of the PCB surface at different time delays. The reflectivity of the scatterers along with their distribution throughout the plane of reflection are modeled based on set of four parameters that has been fitted to the measurements using a simulated annealing approach [3]. In addition to the analysis of these separate propagation mechanisms, channel measurements inside a compound structure resembling an intra-device environment have been performed. A photograph of the measurement procedure inside this so-called mock-up is shown in Figure 4.

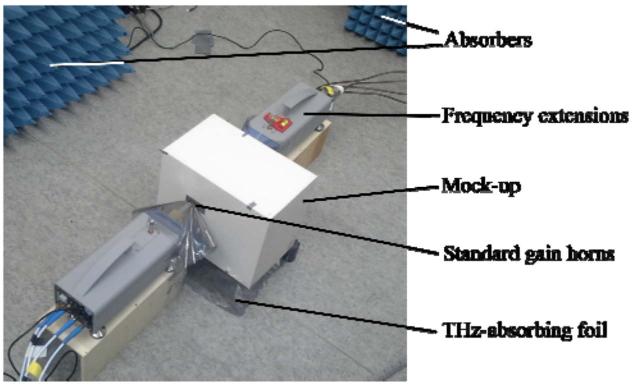

Figure 4. Procedure of the compound structure measurements (based on [5])

The mock-up has been designed in a modular approach, with the possibility to assemble different box-sizes with varying front- and back-sides. With the measurements, it could be shown that the THz intra-device radio channel is strongly influenced by the dimensions of the propagation environment as well as the presence of printed circuit boards, especially in the case of non-line-of-sight transmission [5].

4. Contributions to the IEEE P802.15.3d Standardization Process

4.1 Contributions to the Channel Model

The results of the introduced studies regarding the various propagation aspects for intra-device communications have been incorporated into a ray-tracing based propagation modeling algorithm. This algorithm in turn has been utilized for calibrating a channel generator capable of generating channel transfer functions (CTF) based on the antenna configuration and scenario size as input data [8].

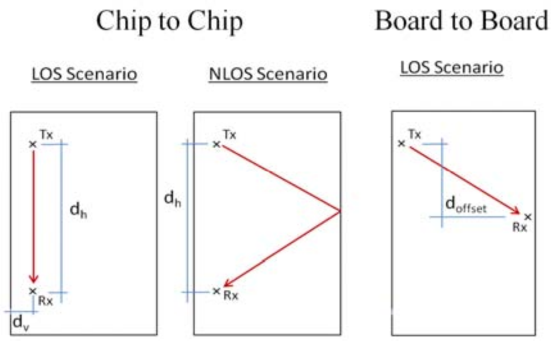

Figure 5. Operational modes for intra-device communications in IEEE 802.15.3d (based on [8])

The TG3d channel modeling document (CMD) identifies three different application cases for intra-device communications which are illustrated in Figure 5.
In the development of the CMD it has been decided to compose a set of CTFs with varying antenna profiles for each application case in order to provide concrete data for development engineers to test the capabilities of their system designs regarding TG3d channels. Propagation simulations have shown that the radio channel for these three operational modes varies significantly.

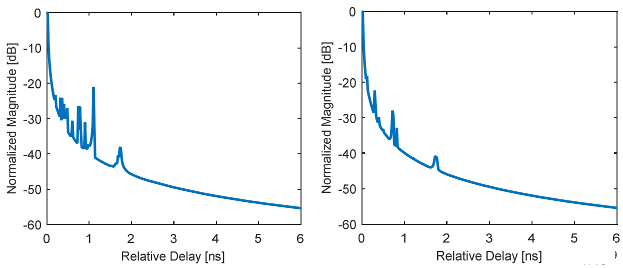

Figure 6. Envelope of the CIRs for board-to-board communication in vertical (left) and circular (right) polarization (based on [8])

Exemplarily, Figures 5 and 6 show the envelope of all generated CIRs of the chip-to-chip application scenario under NLOS condition and the envelope of the CIRs corresponding to the board-to-board configuration, respectively. It is easy to see that the channel for the NLOS case exhibits much more adverse propagation conditions in terms of temporal dispersion. Moreover, it can be seen that the usage of circularly polarized antennas strongly reduces the impact of multipath propagation for both application cases.

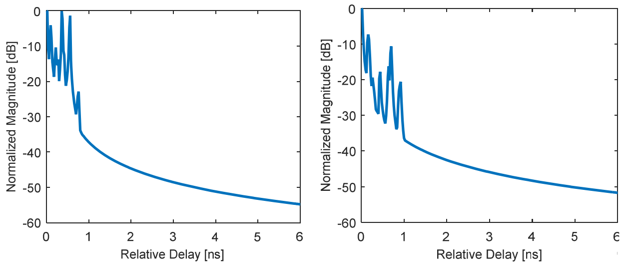

Figure 7. Envelope of the CIRs for NLOS chip-to-chip communication in vertical (left) and circular (right) polarization (based on [8])

4.2 Evaluation of System Proposals

Based on the CTFs generated for the TG3d CMD, link-level simulations have been performed to evaluate the performance of various modulation and coding schemes (MCS). The results of these simulations provided a basis for deciding which of the MCS to incorporate into the draft proposal for the standard. As an illustrating example, Figures 8 - 10 show the performance of the simulated board-to-board scenario utilizing 6dBi and 18dBi antennas with BPSK modulation in contrast to that of an AWGN channel.

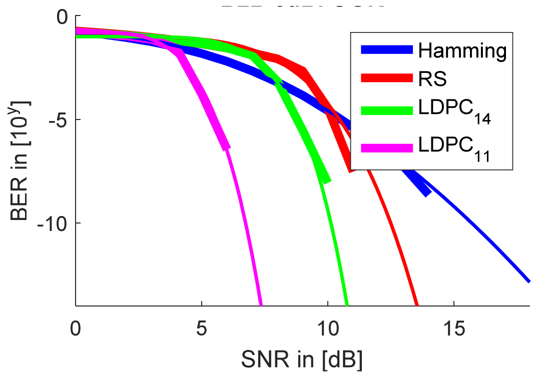

Figure 8. FEC performance of BPSK in the board-to-board scenario with 6dBi antennas (based on [9])

Comparing the achievable bit-error rates in the cases of the 6dBi and 18dBi antennas, it can be seen that varying antenna directivities, corresponding to different beam widths and degrees of spatial filtering, also have an impact on link performance. For the 18dBi case, all of the FEC types show an improvement by about 2dB in terms of required SNR to reach a bit error rate of 10^{-12}. However, a further increase of antenna directivity will not lead to an additional increase of performance. Having a look at Figure 10 it can be seen that the results for 18dBi already match those of the AWGN channel, which is a best-case scenario compared to any wideband impulse response + noise. Throughout the further applications analyzed in the frame of the IEEE P802.15.3d standardization process, many examples can be found where an appropriate antenna configuration even enables quasi-error free data transmission at all [9].

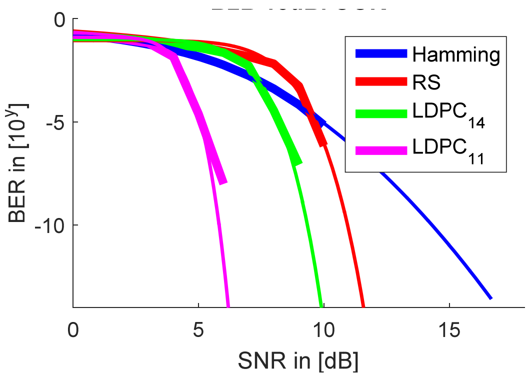

Figure 9. FEC performance of BPSK in the board-to-board scenario with 18dBi antennas (based on [9])

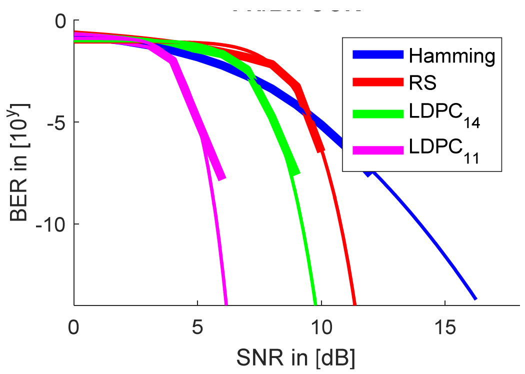

Figure 10. FEC performance of BPSK in the AWGN-channel (based on [9])

The presented BER performances provided, amongst others, the basis for the definitions of system design requirements for the standard [9,10]. The minimum receiver sensitivities have been calculated based on the performance of the various modulation and coding schemes in the AWGN channel. The achievable link distances have been determined from the SNR values calculated for realistic channels from the channel model for the varying antenna configurations.

5. Summary

In this summary paper, an overview on the systematic analysis of propagation effects, derivation of a channel model and application of the model to the design in the IEEE P802.15.3d project was presented. Based on channel measurements, a propagation modeling algorithm has been developed and verified. Using this algorithm, a channel generator has been configured for generating channel transfer functions exhibiting the characteristics of the intra-device propagation environment. The so developed channel description has provided valuable insights and concrete data for the design of the operational parameters of the standard.

6. References

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