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Angle-Resolved THz Channel Measurements at 300 GHz in a Conference Room Environment

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Abstract

This paper introduces a correlative time-domain THz channel sounder supporting angle-resolved measurements. It operates at a center frequency of 300 GHz with a measurement bandwidth of 2 GHz. The channel sounder was used to collect impulse response data for a conference room environment to analyze the characteristics of the channel in terms of path gain, delay spread and angular spread. The evaluations show that with the chosen arrangement a good coverage can be achieved in the room and a large number of significant multipaths are received from various directions.

1 Introduction

Terahertz (THz) waves have frequencies extending from 0.1 THz up to 10 THz and fall in the spectral region between microwave and optical waves. The prospect of offering large contiguous frequency bands to meet the demand for higher data transfer rates in the terabits per second make it a key research area of 6G mobile communication. The current regulation considers identification of frequency bands within the frequency range between 275 to 450 GHz initially for future land mobile and fixed wireless service applications [1][2, p. 85 ff.]. Today only one technical standard IEEE's 802.15.3d 2017 targets the sub-THz frequency range from 252 to 330 GHz for wireless short range communication applications. Academia's and the industry's fundamental research focuses today on the D-Band (110 to 170 GHz), the G Band (140 to 220 GHz), and the H/J-band (220-330 GHz) based on granted experimental licenses. Indoor channel measurements in the H/J-band are evaluated concerning channel parameters in [3, 4]. To the authors' best knowledge, this paper is the first to introduce angle-resolved channel measurements at 300 GHz in an indoor environment under usage of a time-domain channel sounder.

2 Channel Sounder Setup

The used channel sounder is based on the principle of time-domain channel sounding, delivering channel impulse responses. In this measurement campaign, a stationary transmitter and a mobile receiver were used. The channel sounder is implemented by means of advanced test and measurement equipment operating in the microwave frequency range, which is extended by sophisticated front-ends enabling transmitting and receiving in the THz frequency range. The front-end's operating principle is documented in [5]. The channel sounder's block diagram is shown in Figure 1.

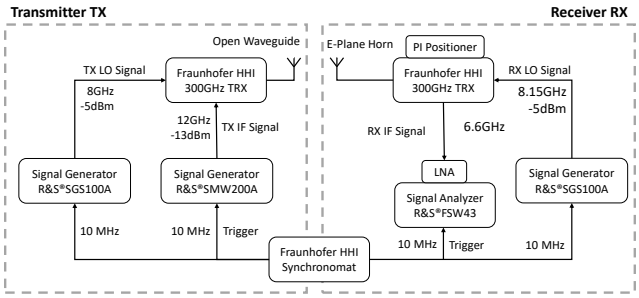

Figure 1. Block diagram of the developed channel sounder

Transmitter TX: A signal generator (R&S®SMW200A), a local oscillator (R&S®SGS100A) and a 300 GHz transmitter that was developed within the Fraunhofer Society form the transmitter (TX). The used transmit antenna is an open waveguide with horizontal polarization to grant a wide beam pattern. The waveguide's gain is 6 dBi, and its 3 dB opening angles are approx. 90° in the E-plane (azimuth plane) and H-plane (elevation plane). A precomputed Frank-Zadoff-Chu sequence [6] is used as the sounding sequence with a length of 100 µs and a bandwidth of 2 GHz. After the signal generator has been triggered once the periodic sounding sequence is provided continuously at an intermediate frequency (IF). An up-conversion of the IF signal to the carrier frequency (CF) is performed in the 300 GHz transmitter.

Receiver RX: A signal analyzer (R&S®FSW43), an external low noise amplifier (LNA), a local oscillator (R&S®SGS100A) and a 300 GHz receiver that was also developed within the Fraunhofer Society form the receiver (RX). As receiver antenna, a horizontally polarized E-plane horn was used. It has a gain of 20 dBi and an opening angle (3 dB angle) of approx. 15° in the E-plane (azimuth plane) and of approx. 90° in the H-plane (elevation plane). After down conversion of the received signal by the 300 GHz receiver to an IF, the signal is amplified by an external LNA and sampled by the signal analyzer. For each measurement,

it samples a set containing 500 sequence periods, which corresponds to a total acquisition time of 50 ms. To enable angle-resolved measurements in azimuth direction, the 300 GHz receiver is mounted on a precision rotation stage (Physik Instrumente M-061.DG) and rotated in steps of 15°, which corresponds to the antenna's beamwidth.

Synchronization: A Fraunhofer HHI Synchronomat provides a common 10 MHz high precision reference signal derived from an internal rubidium clock for all measurement instruments. It ensures frequency synchronization and coherent sampling between transmitter and receiver. In addition, the Synchronomat implements a triggering of the receiver which is coherent to the duration of the sequence.

3 Measurement Scenario and Procedure

The measurements were conducted in a conference room with a floor area of 4.7 m by 7.8 m and a ceiling height of 2.9 m (see Figure 2). The north side of the room was dominated by a window facade. The eastern wall to the adjacent office was mainly glass. The remaining two walls (south, west) were made of concrete/bricks. The predominant interior consisted of a large table and corresponding seating furniture (office chairs) in the room's center. Additionally, a large TV screen and magnetic boards decorated the southern and western wall, respectively. In order to represent an access point, the transmitter (TX) was placed in one corner of the room at a height of 1.86 m and aligned to the room's center (Figure 3). The rotatable receiving front-end (RX) was set up on the table at typical user equipment (UE, e. g. laptop) positions (height above ground: 0.93 m). During this campaign, measurements were carried out at eight different measurement positions (MPs), each comprising 24 azimuth pointing angles to cover a full rotation of 360°. TX location as well as measurement positions with indicated orientation are shown in Figure 2.

At each measurement position, the receiver was placed on the table with 0°-orientation according to the direction indicated in Figure 2. The automatic 360° measurement procedure was as follows: The receiver's front-end orientation was set to the initial angle of $-180°$ and sequentially rotated by steps of 15° over a full revolution. Each time after reaching the target orientation, the data acquisition was started and after its completion the next angle was approached. When arriving 180°, the procedure was stopped and the front-end was set up at the next measurement position.

4 Measurement Evaluation and Results

Data Processing: The accumulated raw measurement data of all approached angles at each measurement position is processed and evaluated by the following steps: The first step comprises an estimation and correction of phase drift - mainly caused by phase noise of the system - for each recorded set of sequence periods. The phase deviation is

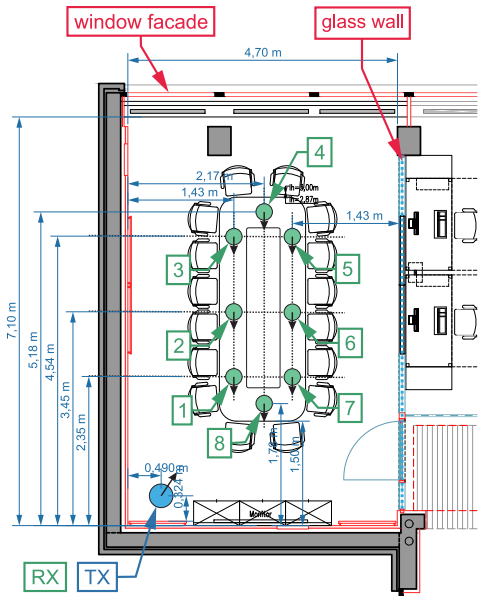

Figure 2. Conference room floor plan. Transmitter (TX) and measurement positions (green, numbered) with indicated orientation and 0°-direction, respectively (black arrow).

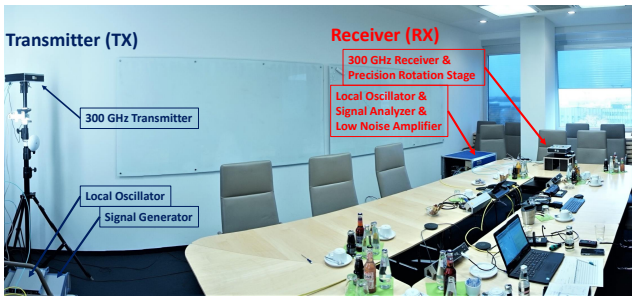

Figure 3. Measurement scenario and arrangement for receiver position MP 4.

estimated by observing the phase values of the main peaks of the individual cross correlation functions between received and transmitted signal for each of the 500 sequences within the set. Since the measurement scenario was static within the acquisition time (50 ms), phase variations of adjacent cross correlation functions are solely caused by noise and impairments of the measurement system and should be compensated for. The second step is the calculation of the channel impulse response (CIR) for each angle. It is based on averaging of the phase-corrected sequence periods within the set and the correlation with prerecorded back-to-back calibration data. In the third step, the estimated CIRs are windowed in the frequency domain to reduce side lobes in time domain caused by the hard (rectangular) band limitation of the measurement system. The windowing function needs to be adapted to the expected dynamic range. Here, a Kaiser-Bessel window with parameter $\beta = 6$ is used. Since the further evaluations are based on the peak values of the CIRs, a normalization of the windowing function with respect to equal amplitudes is performed. Figure 4 shows a

superposition of three instantaneous power delay profiles (IPDPs) for different angles for the first measurement position. The blue line corresponds to the line-of-sight (LOS) path whereas the red and yellow line correspond to paths with strong multipath components. Observing an exceptionally low noise floor of around −130 dB leading to a dynamic range of 60 dB, a noise threshold of −120 dB is chosen for further calculations. The fourth step implements a path estimation by identifying local maxima within each set of IPDPs (two dimensional peak search jointly in delay and angle direction).

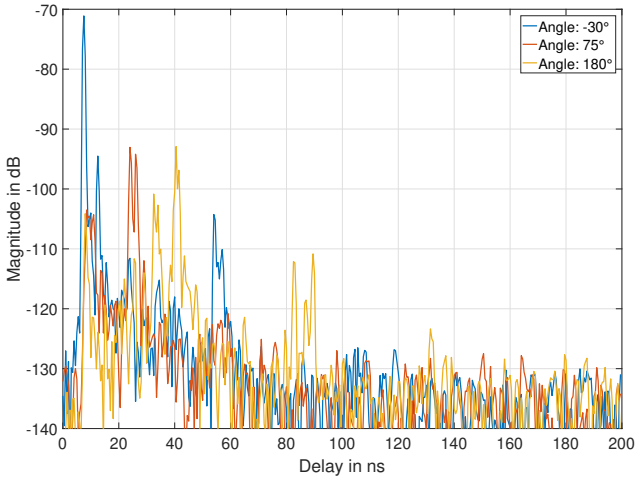

Figure 4. Superposition of three IPDPs at MP 1 corresponding to three different angles.

Evaluation of Results: The data processing results in a set of IPDPs and estimated propagation paths for each measurement position. Figure 5 illustrates the set of IPDPs with all nearly 100 estimated propagation paths for the first measurement point. Synthesized omni-directional IPDPs were derived by superimposing the paths from all directions. The synthesized omni-directional IPDPs for all MPs are illustrated in figure 6. The figure reports that the strongest path corresponds to the LOS path. However, strong multipath components can also be observed. This observation is also reflected in figure 7 that illustrates the overall omni-directional path gain (PG) as well as the "directional" PGs of the three most dominant paths for each MP. Besides the PGs, the synthesized omni-directional IPDPs were used as basis to calculate the delay spread (DS) and angular spread (AS). In case of DS and AS, an additional evaluation threshold of 30 dB below the strongest component has been applied. This relative threshold was well above the absolute noise threshold of −120 dB for all measurement positions, as can be seen in Figure 6. Table 1 summarizes the results of the root-mean-square (RMS) DS and AS as well as the overall omni-directional PG. The table reports an expected course for the PGs of MP 1 to MP 4. After that the, PG values fluctuate. Interestingly, DS and AS show lowest values for positions with highest TX–RX distances, i. e. MP 4 and MP 5. To the best of the authors' knowledge, there are no other DS values publicly reported for 300 GHz at an indoor office or conference room scenario. When comparing these results with data obtained at lower sub-THz frequencies for indoor office scenarios at 150 GHz [7] and 190 GHz [8], the examined DS values are in a comparable range (between 4 and 11 ns). That being said, this experiment's lowest DS values of around 2 ns deviate most from the reported values from aforementioned publications. The AS results are also comparable with ray tracing results from 190 GHz, but, despite that, are well above the results reported from the experiments at 150 GHz, showing values at 30° for smaller distances, and up to 60° for higher distances. However, in contrast to this paper's setup, both TX and RX side were equipped with directional horn antennas and rotated sequentially, respectively, thus analyzing synthetic omni-directional antennas on TX and RX side.

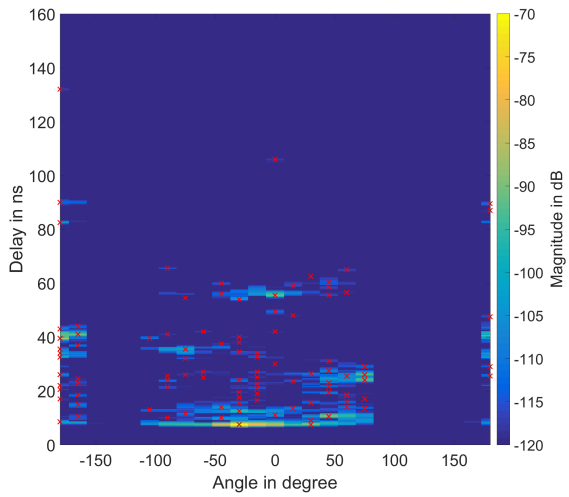

Figure 5. Heatmap illustration of IPDPs for MP 1 plotted as colored pixels in the angle-delay-domain. All estimated paths in form of local maxima above the −120 dB noise threshold are marked by a red cross.

Table 1. Path gain (PG), rms delay spread (DS), and angular spread (AS) for each measurement position (MP).

MP	**PG** (dB)	**DS** (ns)	**AS** (°)
1	96.7	7.3	61.21
2	99.0	7.9	61.82
3	98.8	5.5	50.76
4	101.9	1.8	50.29
5	97.6	2.4	20.59
6	101.4	10.6	63.92
7	99.7	6.2	119.94
8	101.2	4.1	59.33

5 Conclusion

In this paper we presented results from a conference room channel measurement campaign under the usage of a time domain channel sounder in the 300 GHz band with a measurement bandwidth of 2 GHz and an exceptionally high

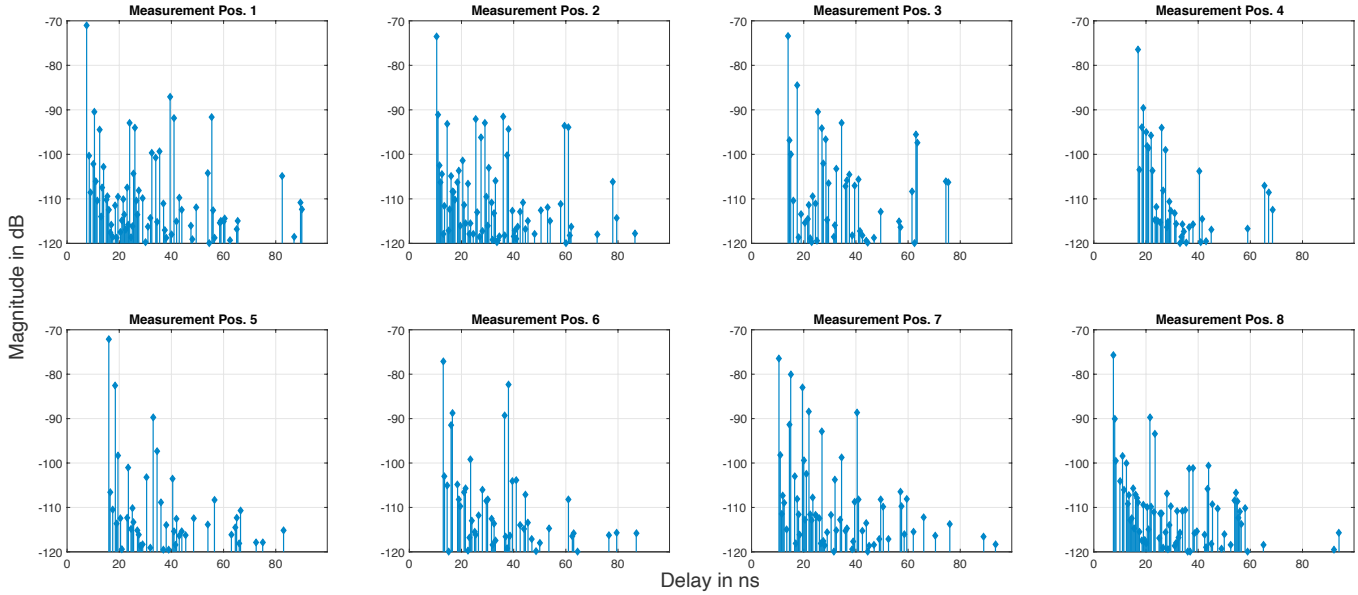

Figure 6. Synthesized omni-directional IPDPs derived from superimposing estimated propagation paths from all receive directions.

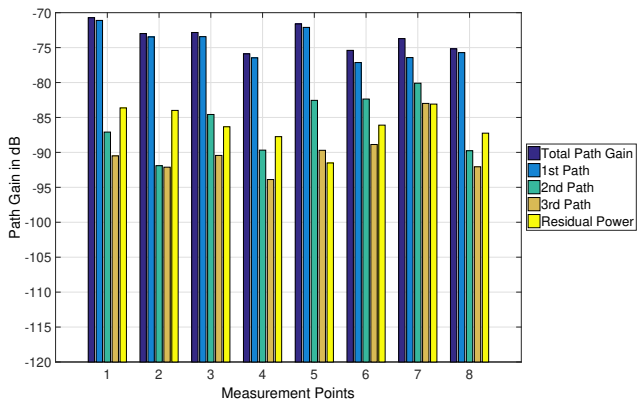

Figure 7. Bar plot illustrating the path gains for all MPs, divided into the total path gain, path gain of the three strongest paths, and the residual power.

dynamic range of more than 60 dB. They comprise angle-resolved measurement data with a resolution of 15° for eight measurement points. To the authors' best knowledge, these were the first angle-resolved channel measurements at 300 GHz in an indoor environment under usage of a time-domain channel sounder. Both strong line-of-sight and significant multipath components were observed and analysed. Regarding angle-resolved channel parameters, an average PG of 73.54 dB, an average DS of 5.65 ns and an average AS of 60.98° were obtained.

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