Calibration and Verification of Multidimensional Channel Sounder for THz Applications
D. Dupleich, S. Semper, M. D. Al-Dabbagh, A. Ebert, T. Kleine-Ostmann and R. Thomä
Presenter: Giovanni Del Galdo
1st International Workshop on Metrology for THz Communications, Braunschweig, 28 June 2022
Goal and Motivation

Goal
• Realize an OTA artifact

Purpose
• Test the calibration of a channel sounder
• Test resolution capabilities of a channel sounder
• Validate the performance of its full chain (i.e., hardware and signal processing)

Features
• OTA to include the antennas
• Designed to generate multipath components with varying directions, delay times and (Doppler shifts)
Table of Content

1. The Over-the-Air Multipath Artifact
2. Measurement Set-up
3. Frequency Response Calibration and Parameter Estimation
4. Results
5. Conclusions
OTA Multipath Artifact and Ground Truth

TX  
\[ \theta  
\]

\[ d = 0.3 \text{ m} \]

S1  
\[ d_{1,1}(\theta) \]

\[ r_1 = 0.41 \text{ m} \]

\[ \phi_{TX/RX} = 65^\circ \]

RX  
\[ d_1(\theta) \]

\[ d_2(\theta) \]

\[ \phi_1(\theta) \]

\[ \phi_2(\theta) \]

\[ d_{1,2}(\theta) \]

\[ d_{2,2}(\theta) \]

\[ r_2 = 1 \text{ m} \]

\[ \theta_1 \]

\[ \theta_2 \]

\[ \theta_3 \]

\[ \phi_1 \]

\[ \phi_2 \]

DoD, DoA(deg)

Rotation of artefact \( \theta \) (deg)

0 25

-20 0

-40 -20

-60 -40

Propagation distance (m)

Rotation of artefact \( \theta \) (deg)

0 1.7

-10 0

-20 -10

-30 -20

S1  
\[ S_1 \]

\[ \phi_1(\theta) = d_{1,1}(\theta) + d_{1,2}(\theta) \]

S2  
\[ S_2 \]

\[ d_2(\theta) = d_{2,1}(\theta) + d_{2,2}(\theta) \]
Table of Content

1. Over-the-Air Multipath Artifact
2. Measurement Set-up
3. Frequency Response Calibration and Parameter Estimation
4. Results
5. Conclusions
TUIL Dual-polarized UWB THz Channel Sounder

Baseband
- UWB 12-bit MLBS M-Sequence baseband units
- **7.5 GHz** bandwidth (null-to-null) → **4 GHz** after frequency response calibration
  - Imperfections (e.g., notch) in the frequency response of the system $H_{OTA}(f)$
  - Spurious peaks in the time domain $h_{OTA}(\tau)$

RF
- Up- and Down-converters at 190 GHz
- Two parallel RX channels to simultaneously sample the two polarizations
- A switch at the TX to alternatively transmit the different polarization

Antennas
- Dual-polarized 15° HPBW horn antennas at both sides
Characterization of the Reference Scatterers

Point scatterer
- Ideal: sphere (polarization independent) $\rightarrow$ Hard to implement
- Practical: wires (polarization dependent)

Scatterers: metal wires
- 1.5 mm diameter $\approx \lambda$
- 10 cm length

Measurements
- Dual-polarized measurements of the reflection loss of the scatterers
- Illumination angle $\beta$ changed from 60° to 145°

Results
- Mean reflection loss of approx. 27.5 dB
- Constant in vertical polarization
- Illuminating angle dependence in horizontal polarization
Table of Content

1. Over-the-Air Multipath Artifact
2. Measurement Set-up
3. Frequency Response Calibration and Parameter Estimation
4. Results
5. Conclusions
Signal Processing and Parameter Estimation

**FFT-based processing (non-parametric): peak-detector**
- Inherent resolution of the measurement system → Resolution of MPCs depends on the bandwidth
- Sensitive to the quality of the frequency response calibration → spurious peaks, side-lobes, etc.

**Model-based processing (parametric) → RiMAX**
- Modified implementation of RIMAX: the system frequency response $H_{OTA}(f)$ is incorporated in the data-model $H(f)$
- Performance depends on the data model

$$
\sum_{l=1}^{L} y_l \delta(\tau - \tau_l) + n(\tau) \rightarrow \sum_{l=1}^{L} y_l h_{OTA}(\tau - \tau_l) + n(\tau) \quad H(f)
$$

$$
H(f) = \sum_{l=1}^{L} y_l H_{OTA}(f) \exp(j2\pi f \tau_l) + n(f)
$$

$$
\min_{L, y_l, \tau_l, \tau \leq L} \|H(f) - H_{\text{meas}}(f)\|_2^2
$$
Frequency Response Calibration

- Calibration by deconvolution carried out in the frequency domain with reference OTA back-to-back frequency response measurement $H_{\text{OTA}}(f)$ in pure LOS (in anechoic chamber at TX – RX distance $d_{\text{ref}}$)

- Raw $H_{\text{OTA}}(f)$

$$H_{\text{cal}}(f, \theta) = \frac{H_{\text{meas}}(f, \theta)}{H_{\text{OTA}}(f)} \exp \left( -j2\pi f \frac{d_{\text{ref}}}{c_0} \right) W(f) \bullet h_{\text{cal}}(\tau, \theta)$$

- Spline interpolated $\tilde{H}_{\text{OTA}}(f)$ (to minimize the effects of the notch)

$$\tilde{H}_{\text{cal}}(f, \theta) = \frac{H_{\text{meas}}(f, \theta)}{\tilde{H}_{\text{OTA}}(f)} \exp \left( -j2\pi f \frac{d_{\text{ref}}}{c_0} \right) W(f) \bullet \tilde{h}_{\text{cal}}(\tau, \theta)$$
Table of Content

1. Over-the-Air Multipath Artifact
2. Measurement Set-up
3. Frequency Response Calibration and Parameter Estimation
4. Results
5. Conclusions
Raw Measurements

Legend
Background: measured CIR
Ground-truth
Verification of the FR Calibration

Legend
Background: measured CIR
○ Ground-truth

FFT-based processing

FR calibrated (non-interpolated)

FR calibrated (interpolated)
FFT-based Estimation: Peak Detector

Legend

Background: measured CIR

- Ground-truth
- Estimated delays

FFT-based processing

- FR calibrated (non-interpolated)
- FR calibrated (interpolated)
FFT-based and Model-based Estimation

FFT-based processing
- FR calibrated (interpolated)

Model-based processing
- Raw measurements

Legend
- Background: measured CIR
- \( \bigcirc \): Ground-truth
- \( \times \): Estimated delays

### FFT-based and Model-based Estimation

- **1 GHz**
- **2 GHz**
- **4 GHz**

- Propagation distance (m)
- Rotation of artifact \( \theta \) (deg)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Propagation Distance (m)</th>
<th>Rotation of Artifact ( \theta ) (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 GHz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Raw measurements
- FR calibrated (interpolated)
# Table of Content

1. Over-the-Air Multipath Artifact  
2. Measurement Set-up  
3. Frequency Response Calibration and Parameter Estimation  
4. Results  
5. Conclusions
Conclusions

OTA multipath artifact
• Can be used to test the channel sounder calibration and validate its performance

FFT-based processing (non-parametric)
• Very sensitive to the frequency response calibration
• Resolution highly depends on the measurement bandwidth

Model-based (parametric estimation)
• More accurate
• Less sensitive to bandwidth

Future work
• Extension to Doppler and DoA/DoD
Thank you very much for your Attention

E-Mail: t.kuerner@tu-bs.de