Sensitivity Analysis of a 280 – 312 GHz Superheterodyne Terahertz Link Targeting IEEE802.15.3d Applications
Dominik Wrana
1st International Workshop on Metrology for THz Communications, Braunschweig, 28 June 2022
Agenda

1. Motivation
2. Transmit and Receive Chipsets for THz Wireless Communication
3. Sensitivity Analysis
4. Conclusion
1. Motivation

Metrology for THz communication systems

Link-Level → Component-Level → Circuit-Level

chip-level non-idealities cause signal distortion!

→ device characterization + sensitivity analysis to define link capabilities and optimum operation points
**Tx / Rx Chipsets for Wireless THz Communication**

**MMIC Architecture**

1. **METERACOM-specific Tx and Rx MMICs** (adopting a specification-driven top-down design approach)

![Novel BOEL 300 GHz Tx and Rx MMICs](image)

2. **Superheterodyne Tx and Rx MMICs** (specifically developed within the ThoR project)

![Superheterodyne Tx and Rx MMICs](image)

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www.meteracom.de
2. Superheterodyne Tx / Rx Chipset for Wireless THz Communication

Frequency Response

**Tx**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Power</th>
<th>LO Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 GHz</td>
<td>70 GHz</td>
<td>80 GHz</td>
</tr>
<tr>
<td>P_{RF} = -10 dBm</td>
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<td>P_{RF} = -32 dBm</td>
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<td>f_{LO} / GHz</td>
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<td>-16</td>
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**Rx**

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<tbody>
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<td>P_{RF} = -32 dBm</td>
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</tr>
<tr>
<td>f_{LO} / GHz</td>
<td>-10</td>
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<tbody>
<tr>
<td>70 GHz</td>
<td>72 GHz</td>
</tr>
<tr>
<td>P_{RF} = 3 dBm</td>
<td></td>
</tr>
<tr>
<td>f_{IF} / GHz</td>
<td>-10</td>
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3. Sensitivity Analysis
Measurement Setup

- **Goals:**
  I. Characterization of H-band Tx / Rx chain to find optimum operation points for wireless demonstration
  II. Analysis of the influence of chip-level impairments on signal quality
- Tx – Rx chain in back-to-back configuration neglecting all air channel impairments
- Custom E-band frequency extensions
- Coherent LO generation
3. Sensitivity Analysis
CW Measurements – Tx Linearity / Rx Sensitivity

**Tx Linearity**

- IP1dB = -4 … -2 dBm
- OP1dB = -6 … -4 dBm

**Rx Sensitivity**

- CG = 2 … 6 dB
- IP1dB = -24 … -21 dBm
3. Sensitivity Analysis
Modulated Signal Measurements

- Higher order modulation schemes require higher back-off from IP1dB due to higher peak-to-average power ratio (PAPR)
- Measured back-off in good accordance with theoretical derivation
- Manual adjustment of RF attenuation limits accuracy of Rx sensitivity measurement
3. Sensitivity Analysis
Selected Results – Max. Data Rate / Spectral Efficiency / IEEE802.15.3d

<table>
<thead>
<tr>
<th>Channel ID</th>
<th>Maximum performance</th>
<th>IEEE802.15.3d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>$f_{IE,center} / \text{GHz}$</td>
<td>79.1</td>
<td>79.25</td>
</tr>
<tr>
<td>$f_{RE,center} / \text{GHz}$</td>
<td>301.2</td>
<td>304.25</td>
</tr>
<tr>
<td>Bandwidth / GHz</td>
<td>8.64</td>
<td>1.35</td>
</tr>
<tr>
<td>Data Rate / Gbit/s</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>Modulation Scheme</td>
<td>32-QAM</td>
<td>256-QAM</td>
</tr>
</tbody>
</table>

- Maximum data rate of 32 Gbit/s (BW limited by E-band freq. extension)
- Sufficient linearity to support up to 256-QAM
- Compliance with the IEEE802.15.3d frequency standard

EVM / dB: -23.6, -30.8, -20.9, -21.4, -27.1, -30.5
SNR / dB: 19.6, 26.3, 20.6, 19, 23.5, 25.6
3. Sensitivity Analysis
Analysis of Spurious Tones in the RF Domain

- Measured RF spectra at output of Tx module
- Conditions:
  \[ f_{\text{LO,in}} = 73.5 \, \text{GHz} \]
  \[ f_{\text{IF,in}} = 72.125 \, \text{GHz}, \ P_{\text{IF,in}} = -18 \, \text{dBm} \]
  \[ f_{\text{RF,out}} = 3 \cdot f_{\text{LO,in}} + f_{\text{IF,in}} = 292.625 \, \text{GHz} \]

\[ f_{\text{LO,3rd}} = 220.5 \, \text{GHz}, \ f_{\text{LO,4th}} = 294 \, \text{GHz} \]

**no BPF**

**with IF BPF**

**with IF + LO BPF**
3. Sensitivity Analysis
Analysis of Spurious Tones in the RF Domain – LO Generation with X8 Module

Blockdiagram

Output Spectrum

2.92mm
WR-10

X8 WG Module
X2
X2
X2
AMP

IN
OUT

P_{out} 7^{th} Harmonic

Output Frequency / GHz

Input Power / dBm

P_{out} 8^{th} Harmonic

Output Frequency / GHz

Input Power / dBm

P_{out} 9^{th} Harmonic

Output Frequency / GHz

Input Power / dBm

P_{out} = 0 \text{ dBm}

f_{out} = 74.4 \text{ GHz}

8th harm. (wanted)

7th harm.

9th harm
3. Sensitivity Analysis
Analysis of Spurious Tones in the RF Domain

- Measured RF spectra at output of Tx module
- Conditions:
  \[ f_{LO,in} = 73.5 \text{ GHz} \]
  \[ f_{IF,in} = 72.125 \text{ GHz}, P_{IF,in} = -18 \text{ dBm} \]
  \[ f_{RF,out} = 3 \cdot f_{LO,in} + f_{IF,in} = 292.625 \text{ GHz} \]
  \[ \rightarrow f_{LO,3rd} = 220.5 \text{ GHz} / f_{LO,4th} = 294 \text{ GHz} \]

- even with spectrally pure IF and LO input signals unwanted spurious tones are present!
3. Sensitivity Analysis
Analysis of Spurious Tones in the RF Domain – Effect on Transmission Quality

- Short-range wireless transmission experiment using E-band modems
- Full-duplex link
- Channel bandwidth of 2 GHz

- 4th harmonic of freq. tripler causing severe in-band interferences in channels 16, 17, and 18.
- Channel center frequencies: 286.2 / 288.36 / 290.52 GHz
- Used corresp. f_LO: 71.358 / 72.078 / 72.798 GHz
- Resulting 4th harm. frequencies: 285.43, 288.31 and 291.19 GHz
4. Conclusion

• Fully-integrated superheterodyne Tx / Rx chipset was shown

• Performed sensitivity analysis indicates
  I. optimum operation points
  II. Max. achievable data rate
  III. use of higher order modulation schemes is possible
  IV. Feasable link distance for long-range demonstration

• severness of spurious tones arising from non-ideal LO and IF signal generation demonstrated in wireless transmission experiment
Thank you very much for your Attention

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