# Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

**Submission Title:** Link Level Simulations of THz-Communications
**Date Submitted:** 15 July, 2013
**Source:** Sebastian Rey, Technische Universität Braunschweig
Address: Schleinitzstr. 22, D-31806 Braunschweig, Germany
Voice: +49-531-391-2439, FAX: +49-531-391-5192, E-Mail: rey@ifn.ing.tu-bs.de

**Abstract:** A link level simulation environment for THz communications is presented based on broadband ray tracing channel modeling. Since THz indoor channels suffer from high free space path losses and inter symbol interference the impact of antennas is investigated with respect to system performance. Furthermore, some forward error techniques and the impact of phase noise are illustrated.

**Purpose:** Investigation of system aspects as input for THz system design

# Link Level Simulations of THz-Communications

Sebastian Rey[1], Sebastian Priebe[1], Thomas Kürner[1]

[1] Institut für Nachrichtentechnik, Technische Universität Braunschweig, Germany

# Outline

1. **Introduction**
2. Broadband ray tracing and link level simulation
   - Simulation environment
   - Scenario
3. System aspects and simulation results
   - Directive Antennas
   - Forward Error Correction
   - Phase Noise
4. Summary

# Introduction

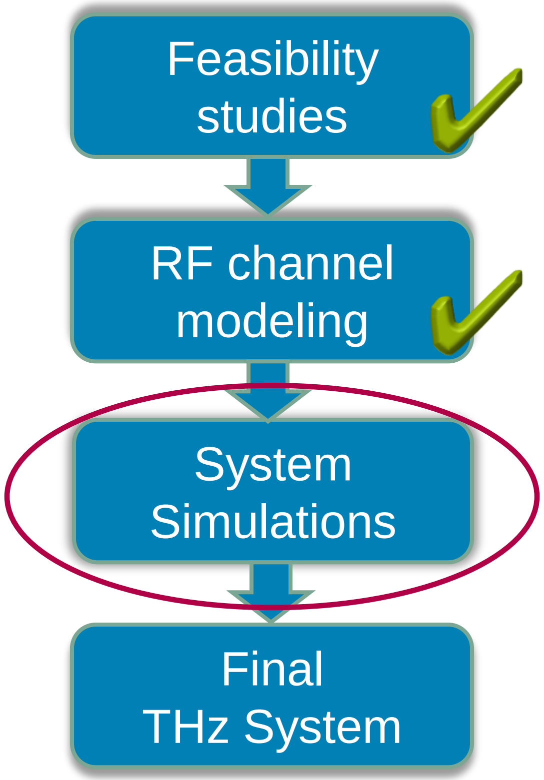
- Previous work:
  investigation of system performance based on channel propagation properties only

- Open issues:
  How does the THz channel influence the performance of a THz-communications system?

  Which requirements arise from system aspects as e.g. modulation schemes?

  What is the impact of RF impairments?

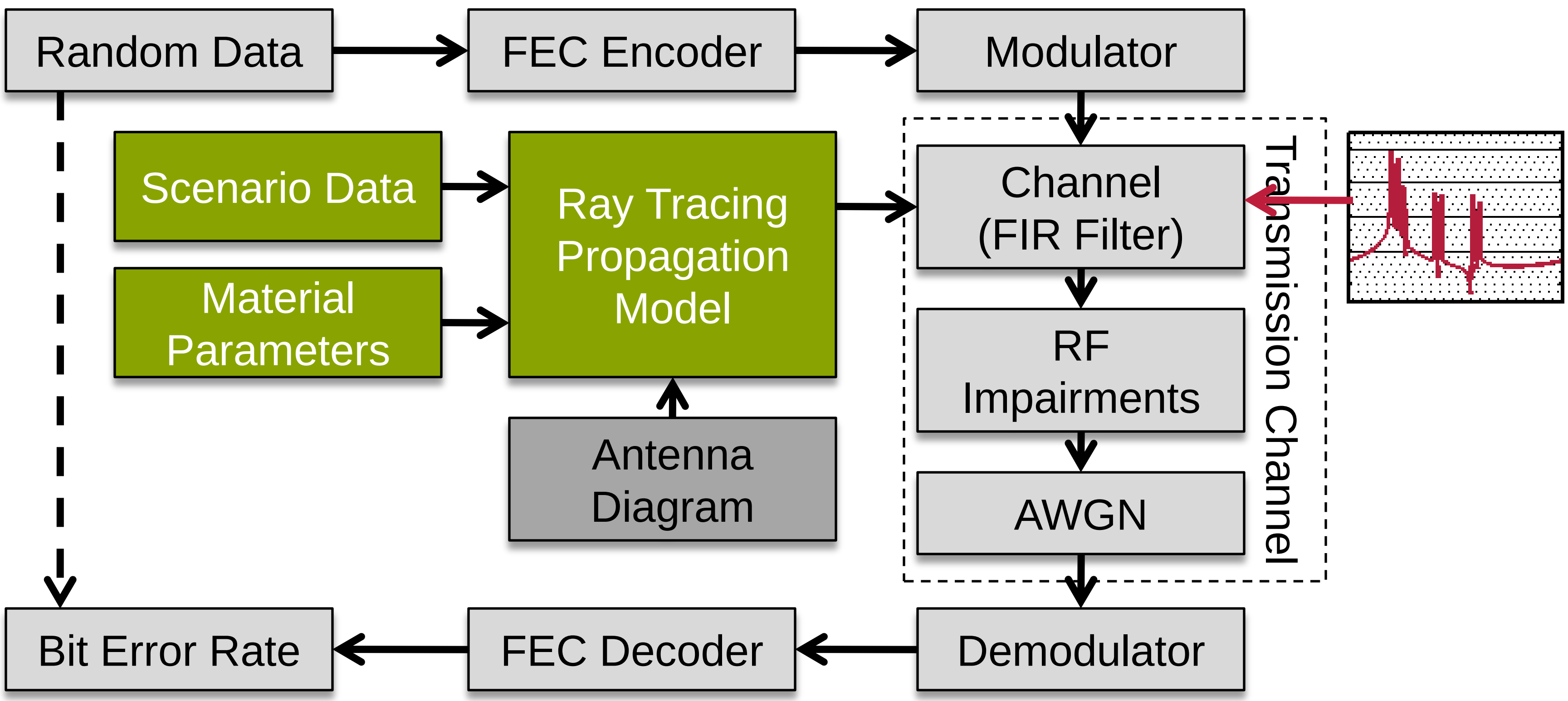
**THz Systems Development**



# Outline

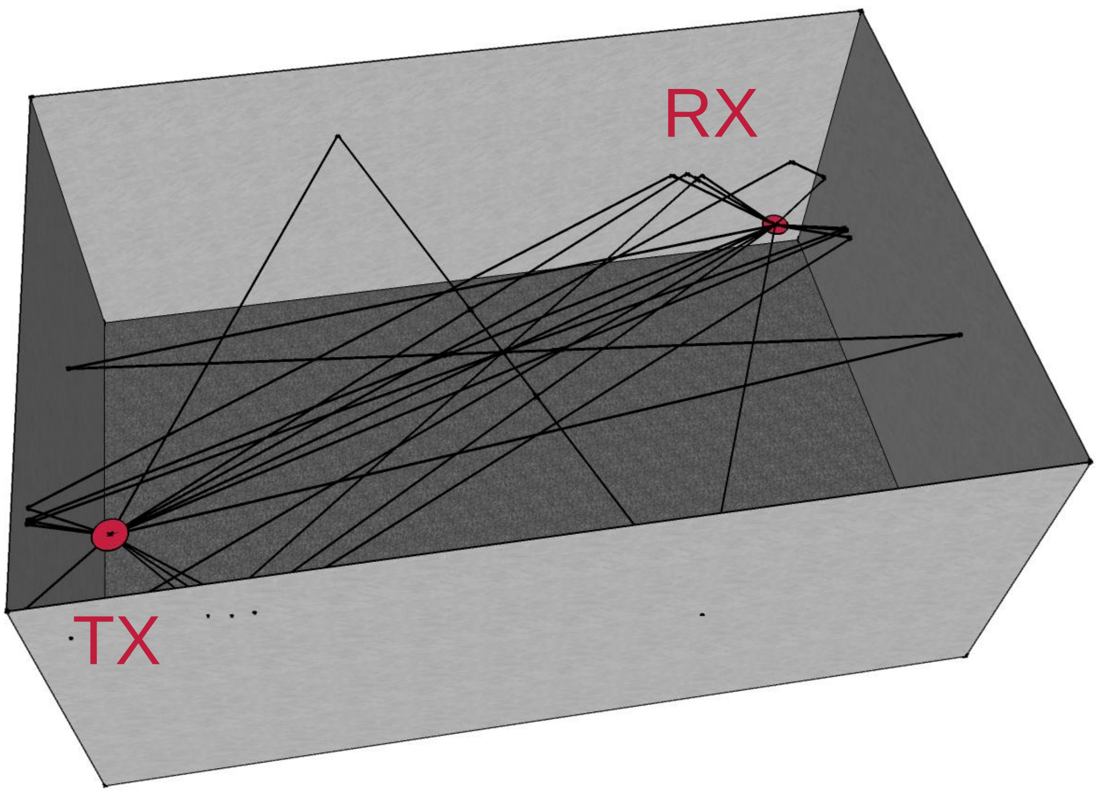
1. Introduction
2. **Broadband ray tracing and link level simulation**
   - **Simulation environment**
   - **Scenario**
3. System aspects and simulation results
   - Directive Antennas
   - Forward Error Correction
   - Phase Noise
4. Summary

# Link level simulation environment




- Equivalent baseband model

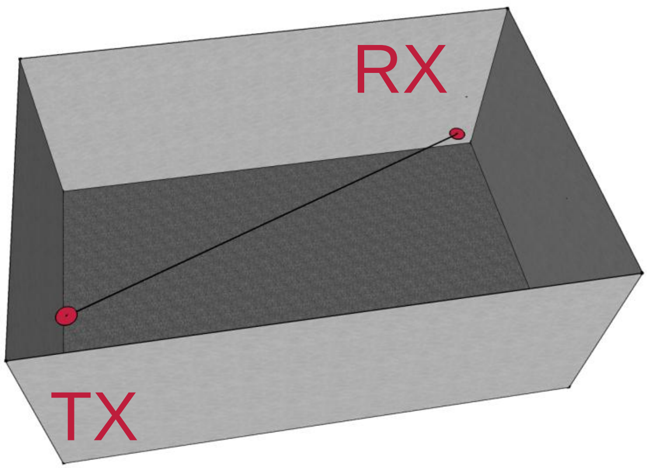
# Scenario for simulations




- Empty room
  6 m x 4 m x 2.5 m
- Height:
  Transmitter (TX) 2.3 m
  Receiver (RX) 0.8 m
- 25 propagation paths
  1 direct path
  4 with 1 reflection
  8 with 2 reflections
  12 with 3 reflections

# Link budget for direct path

| | | | |
|---|---|---|---|
| SNR = | 10 | dBm | transmitter power (baseband) |
| - | 7.4 | dB | conversion loss |
| + | $G_{tx}$ | dBi | antenna gain (transmitter) |
| - | $L_{FSL}$ | dB | free space loss |
| + | $G_{rx}$ | dBi | antenna gain (receiver) |
| - | 7.6 | dB | noise figure |
| - | $P_n$ | dBm | thermal noise |

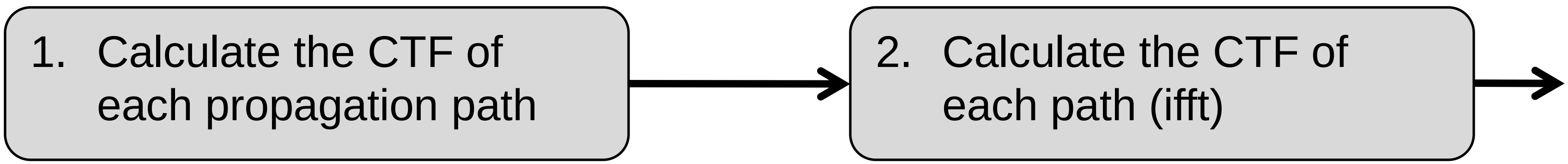


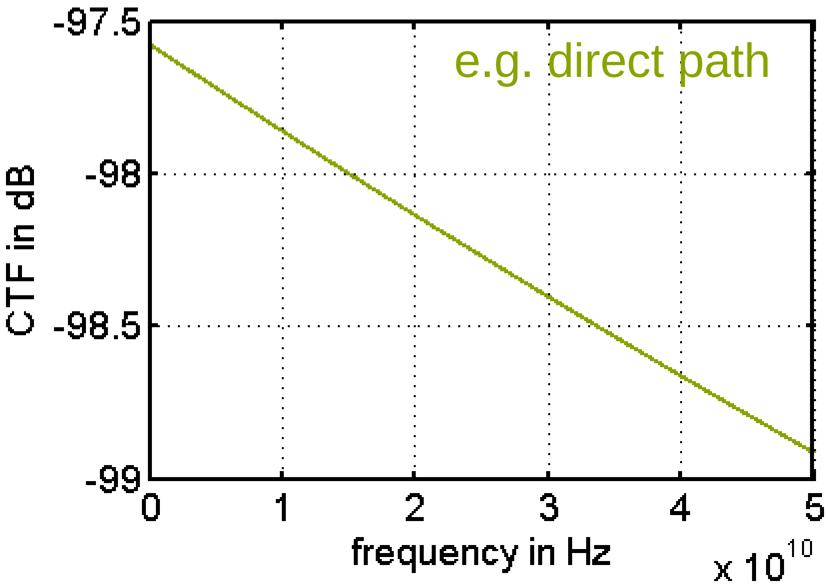

Carrier frequency: 325 GHz

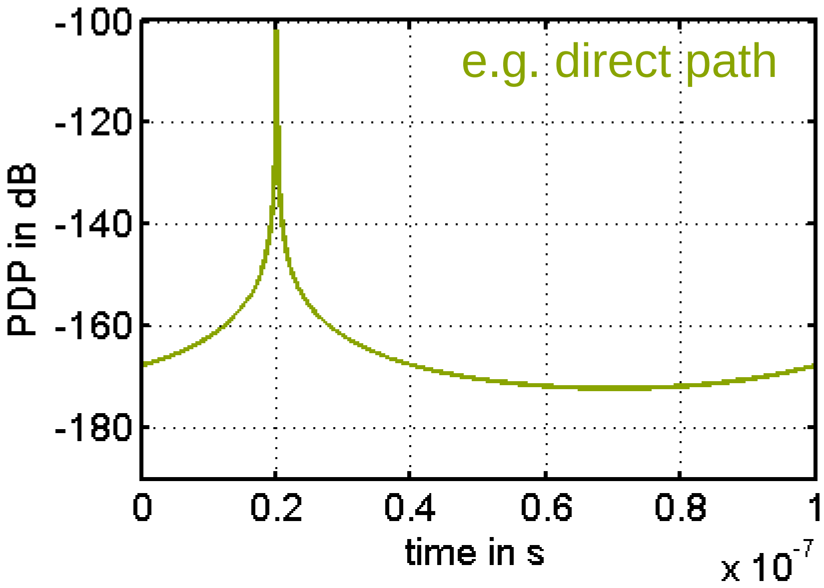
Bandwidth: 50 GHz

For the direct path only:
- 98.2 dB free space loss
- 46.4 dBi antenna gains
  for a SNR = 10 dB

# Channel Impulse Response (CIR)



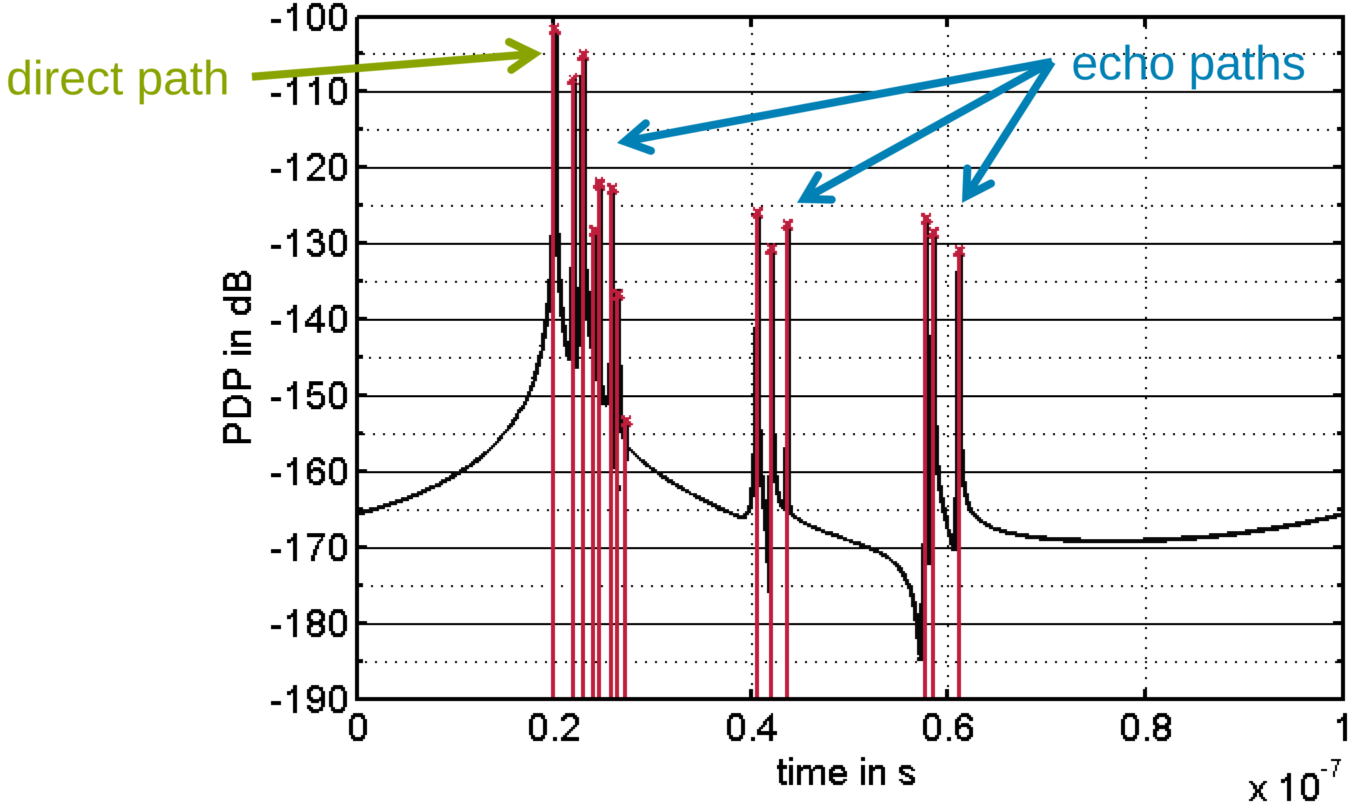



# Channel Impulse Response (CIR)

3. Sum all CIR of the propagation paths

4. Extract peaks; sync and normalize (not shown)



# Outline

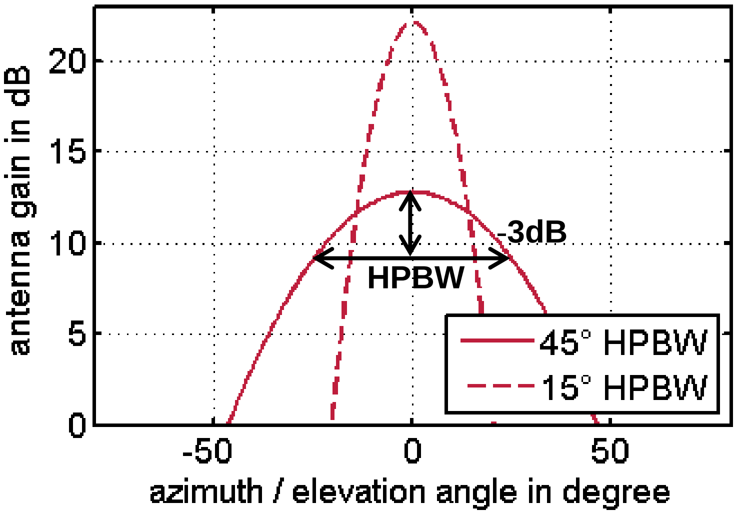
1. Introduction
2. Broadband ray tracing and link level simulation
    - Simulation environment
    - Scenario
3. **System aspects and simulation results**
    - **Directive Antennas**
    - **Forward Error Correction**
    - **Phase Noise**
4. Summary

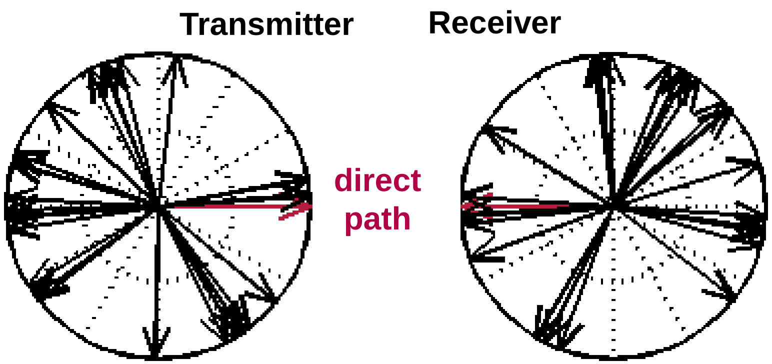
# Directive antennas – shapes and gain

- Antenna gain of 46.4 dBi required
- Assumption of Gaussian beam shape (azimuth and elevation) with the same Half Power Beam Width (HPBW), c.f. IEEE 802.15-15-12-0102-00-0thz.
- Examples, same antenna for the transmitter and the receiver:

| HPBW | gain |
|---|---|
| 1,5° | 84.2 dBi |
| 10° | 51.2 dBi |
| 15° | 44.2 dBi |
| 45° | 12.8 dBi |

BUT: Inter Symbol Interference ?

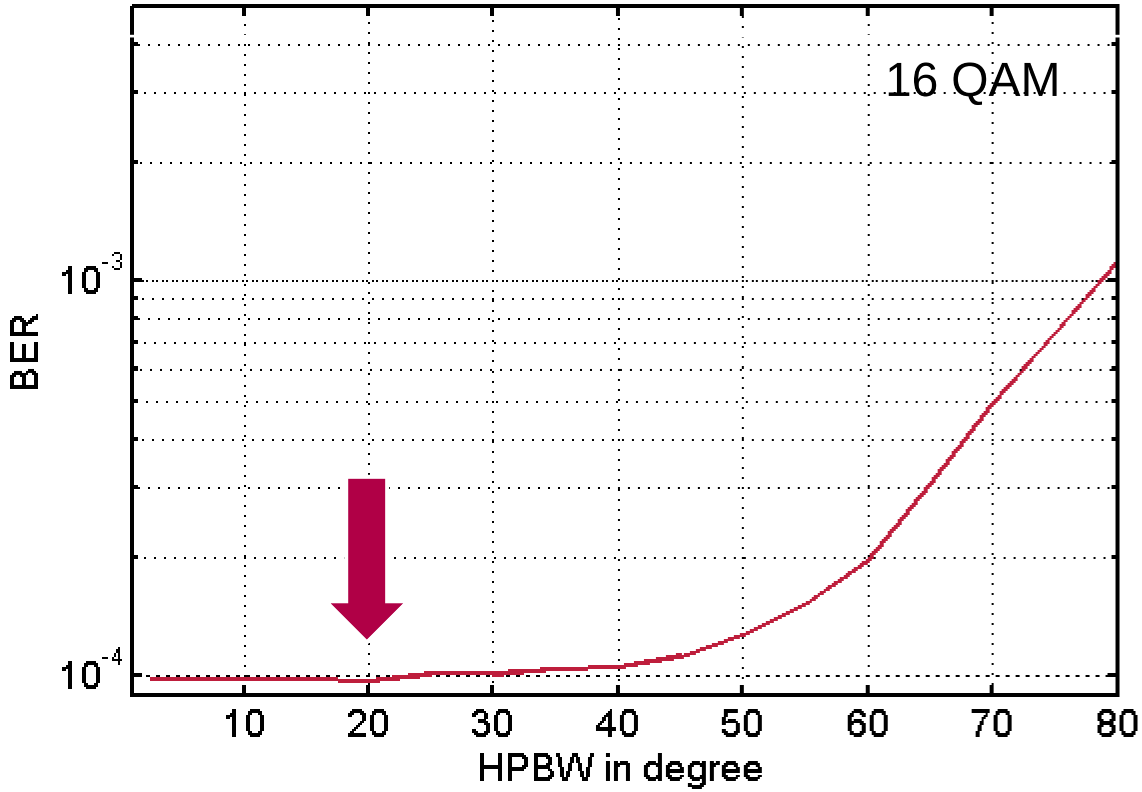


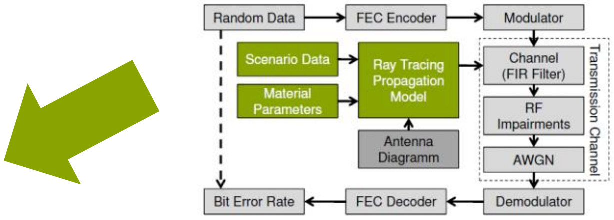



# Directive antennas – spatial filtering

**Problem**: Inter symbol interference (ISI) resulting from multipath components (MPC)

**Question**: Necessary HPBW to cancel out ISI?



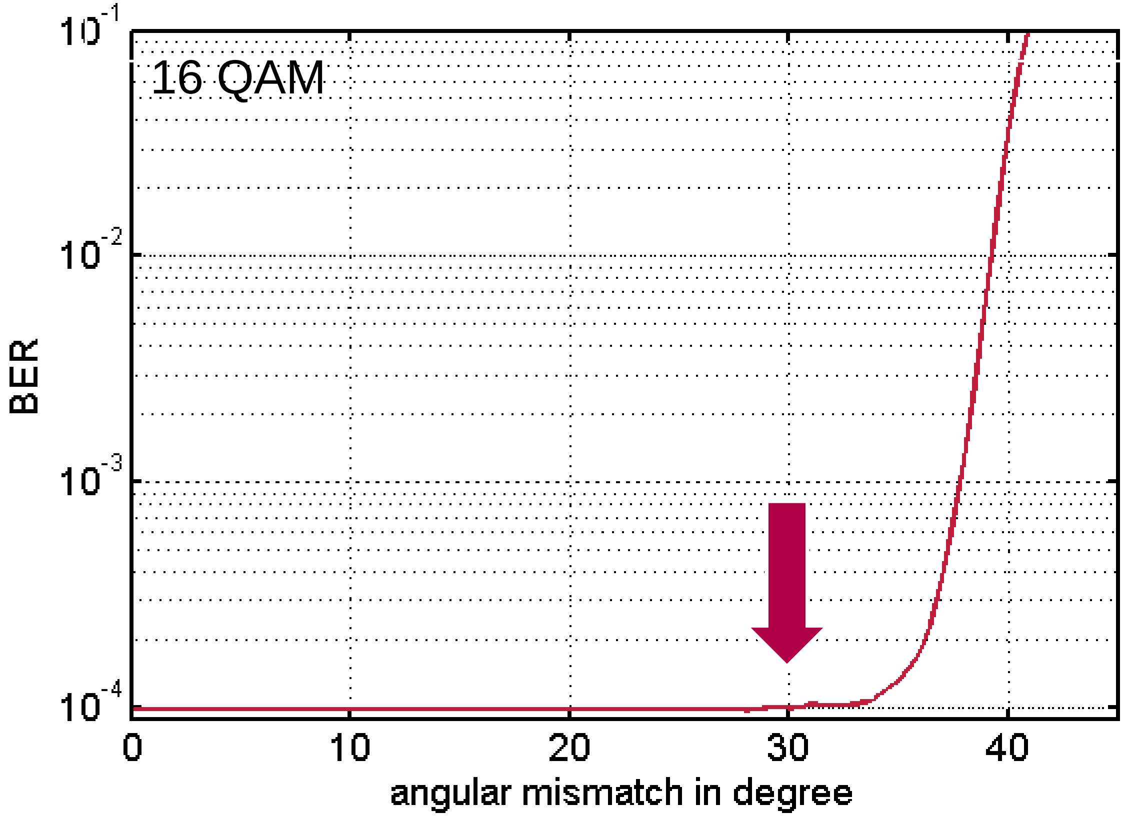



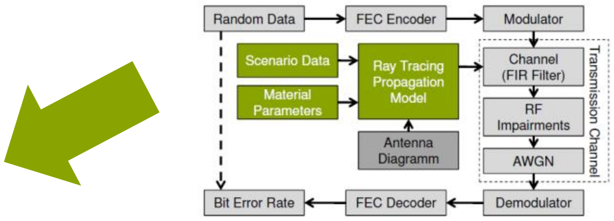

- a HPBW of 20° sufficiently suppresses ISI
- but the antenna gain is to low (only SNR not absolute power in the simulations)
- a **HPBW of 10°** is suitable (gain and ISI suppression)

# Directive antennas – misalignment

**Problem**: Perfect alignment of the antennas to a (direct) propagation path is impractical.

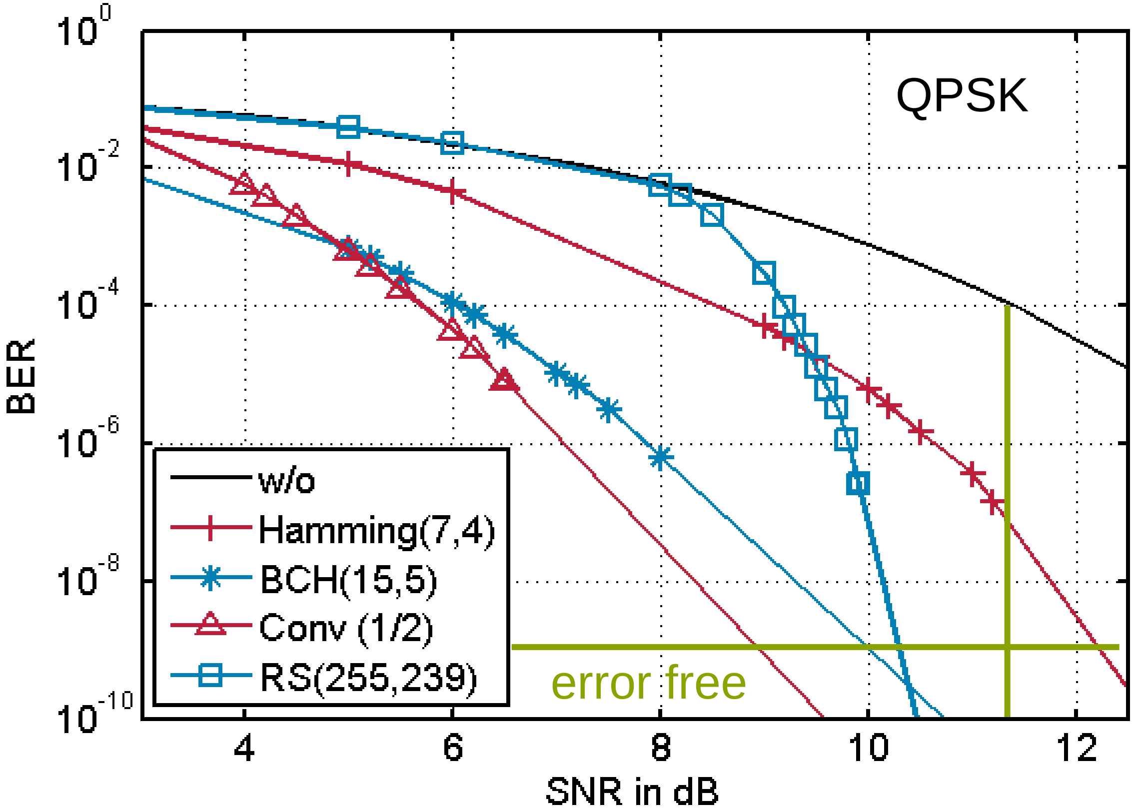
**Question**: How much misalignment can be tolerated (receiver, azimuth, HPBW=15°)?




- a misalignment of almost 30° can be tolerated in terms of suppressed ISI
- but the absolute antenna gain is to low (normalized CIR)
- a misalignment of **7.5°** means -3 dB in SNR

# Forward error correction (FEC)

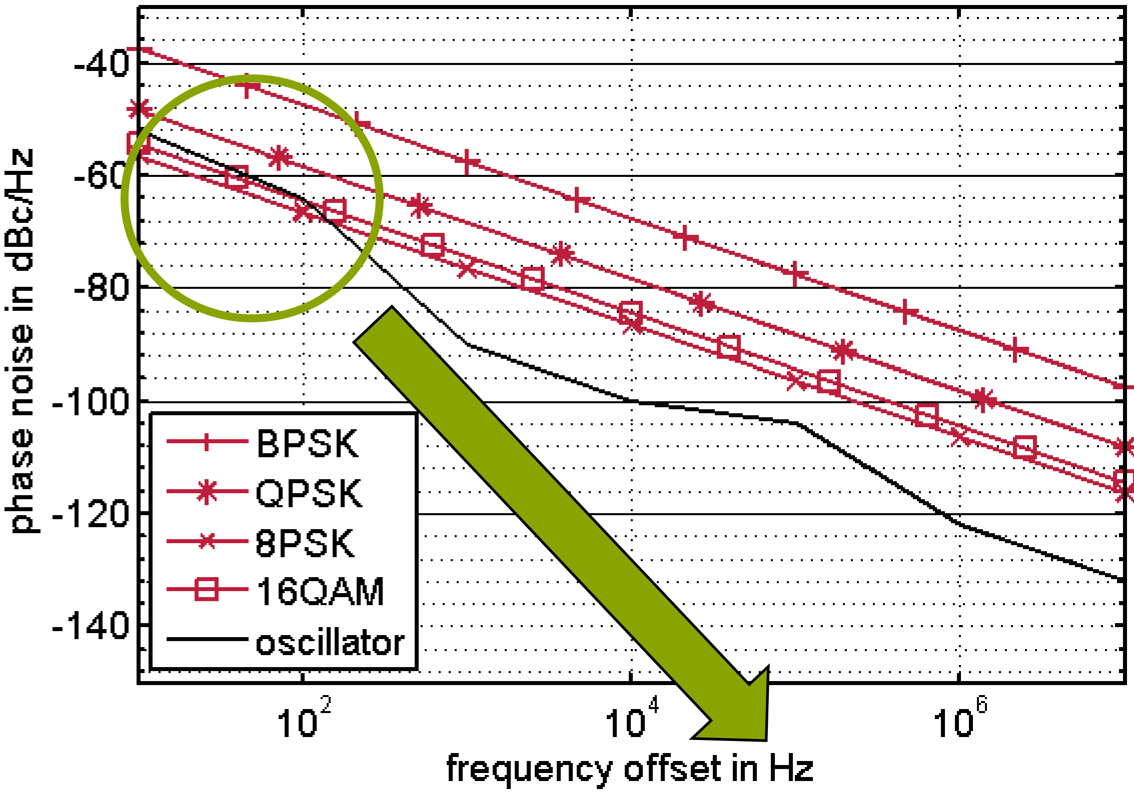


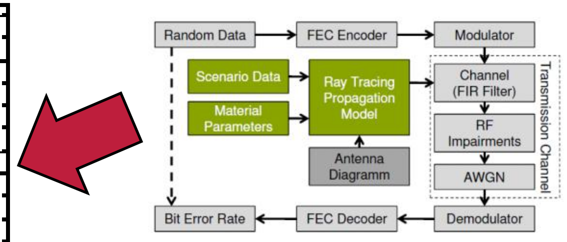

| Mod. | BPSK | QPSK | 8 PSK | 16 QAM |
|---|---|---|---|---|
| SNR (QEF) | 8.5 dB | 11.6 dB | 16.5 dB | 18.3 dB |

- **Error free** transmission requires approx. a BER<$10^{-9}$
- **Convolutional code**
  - very efficient (regarding code rate and SNR)
  - data rate (QPSK) 50 Gbit/s
  - decoder is (too?) complex
- **Hamming Code**
  - needs higher SNR
  - data rate (QPSK) 57 Gbit/s
  - very easy to decode (lookup table)
- **Quasi error free** definition for simulations without FEC: BER<$10^{-4}$

# Phase noise – current components

What is the maximum phase noise for a quasi error free transmission?

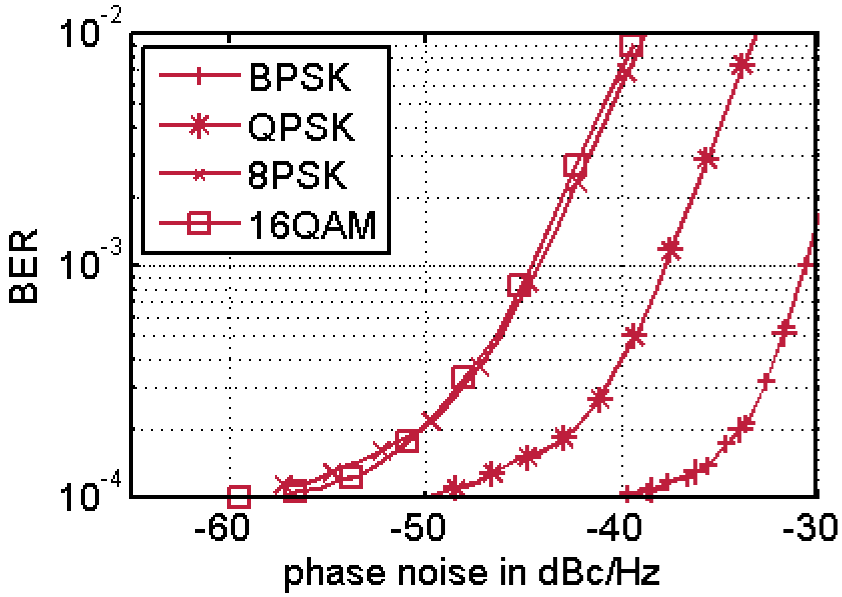


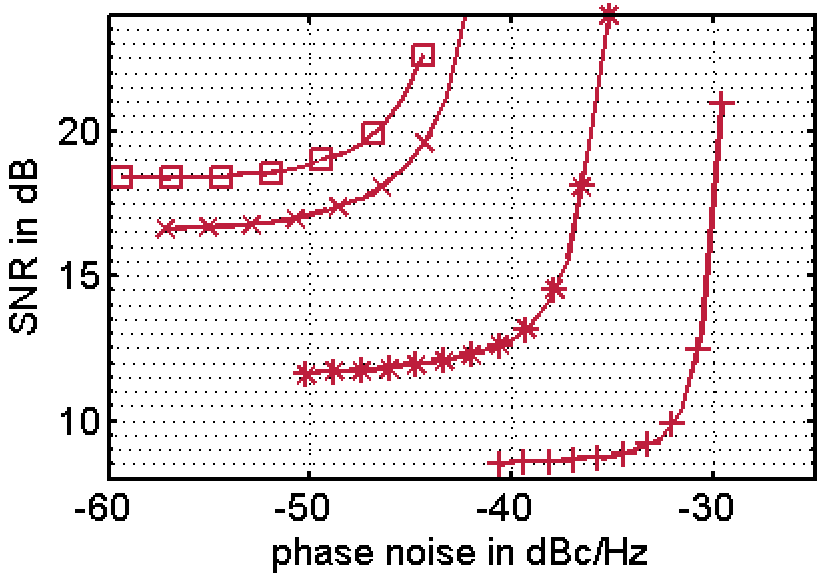




1. SNR as determined for QEF without phase noise for each modulation
2. Max. phase noise for QEF for each mod.
3. Comparison with a commercialy available oscillator with a multiplier

Only BPSK and QPSK work with this oscillator

# Phase noise – BER and SNR



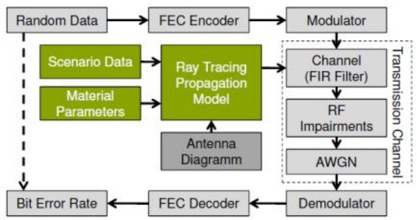

A small increase of the phase noise (@10Hz)…

- … increases the bit error rate if the SNR is kept constant.
- … can be „compensated“ by increasing the SNR slightly ($BER<10^{-4}$).

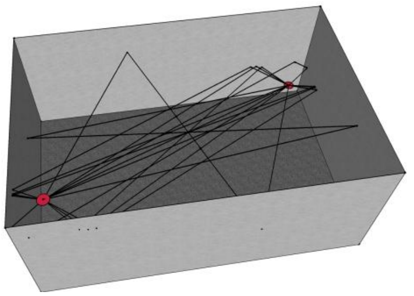
# Outline

1. Introduction
2. Broadband ray tracing and link level simulation
    - Simulation environment
    - Scenario
3. System aspects and simulation results
    - Directive Antennas
    - Forward Error Correction
    - Phase Noise
4. **Summary**

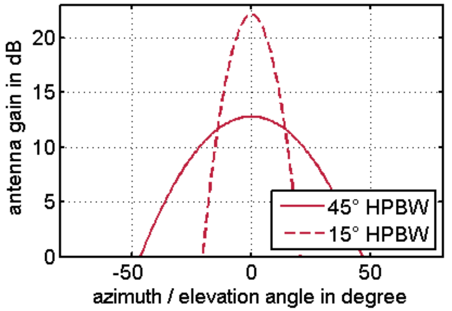
# Summary



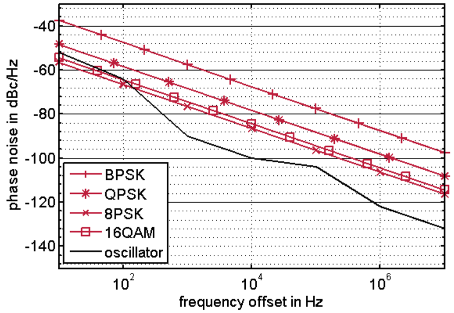

– Physical layer simulation environment
  - incorporating realistic THz channels
  - obtained by broadband ray tracing



– Exemplary results
  - highly directive antennas (10° HPBW) needed (ISI suppression and antenna gain)
  - fec
  - phase noise is a limiting factor for modulations schemes (only simple ones)




– Future steps:
  - other scenarios
  - more RF impairments



# *Thank you for paying attention.*

*Dipl.-Ing. Sebastian Rey*

*rey@ifn.ing.tu-bs.de*