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

Submission Title: A first 300 GHz Phased Array Antenna
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Re: -

Abstract: Theory regarding the system functions according to Bello are presented. This theory is used to explain the operation of an M-Sequence based channel sounder in general. The technical parameters of a channel sounder, recently acquired by TU Braunschweig, are presented to explain its operation for future contributions of measurement results.

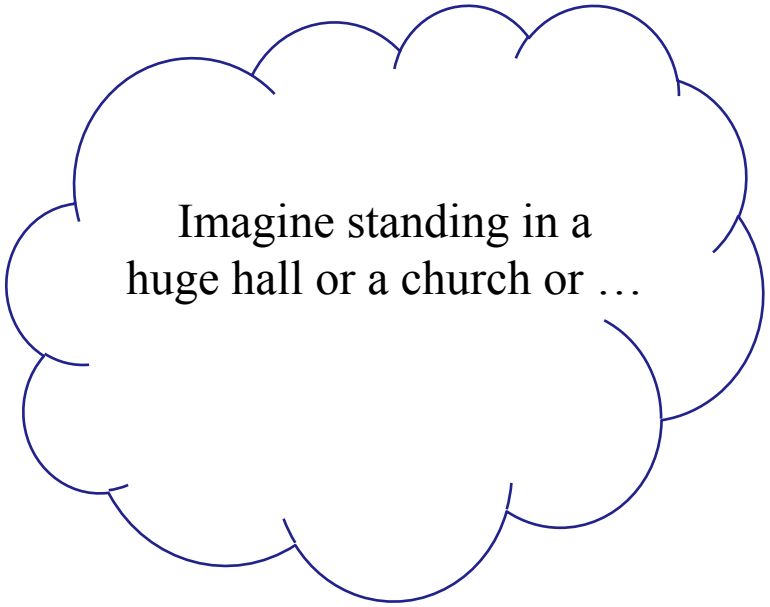
Purpose: Provide Information to the Interest Group

An Ultra Wide Band MIMO Channel Sounder 60 and 300 GHz

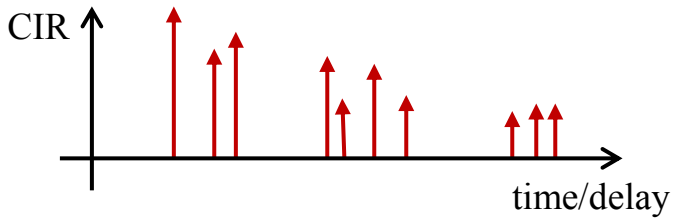
Outline

- **Theory**
  - **Channel Impulse Response**
  - **System functions according to Bello**
- Actual UWB MIMO Channel Sounder
  - Working Principle
  - Technical Parameters

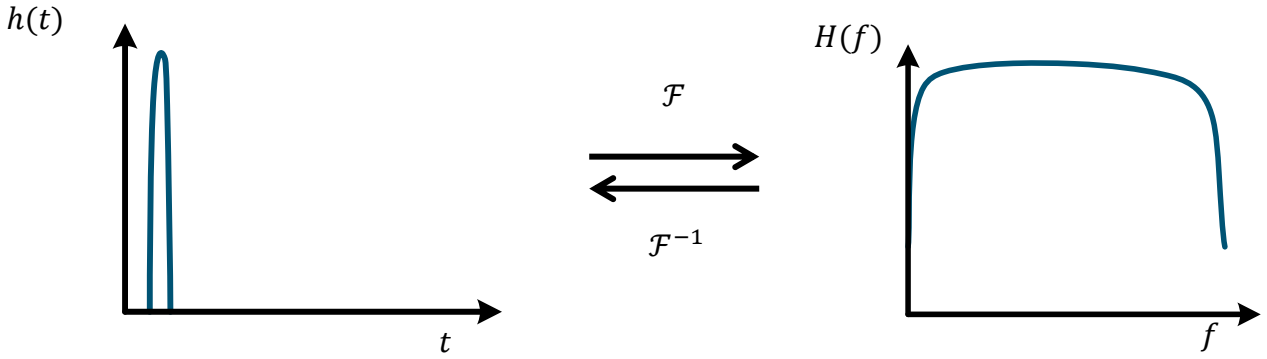
A plastic example of an channel impulse response



- Can anyone give a plastic example of a channel impulse response (does not need to be a radio channel)?
- What is the impulse response for the transmission channel from a person - speaking there - to one of your ears?
- How can this easily be „measured“?



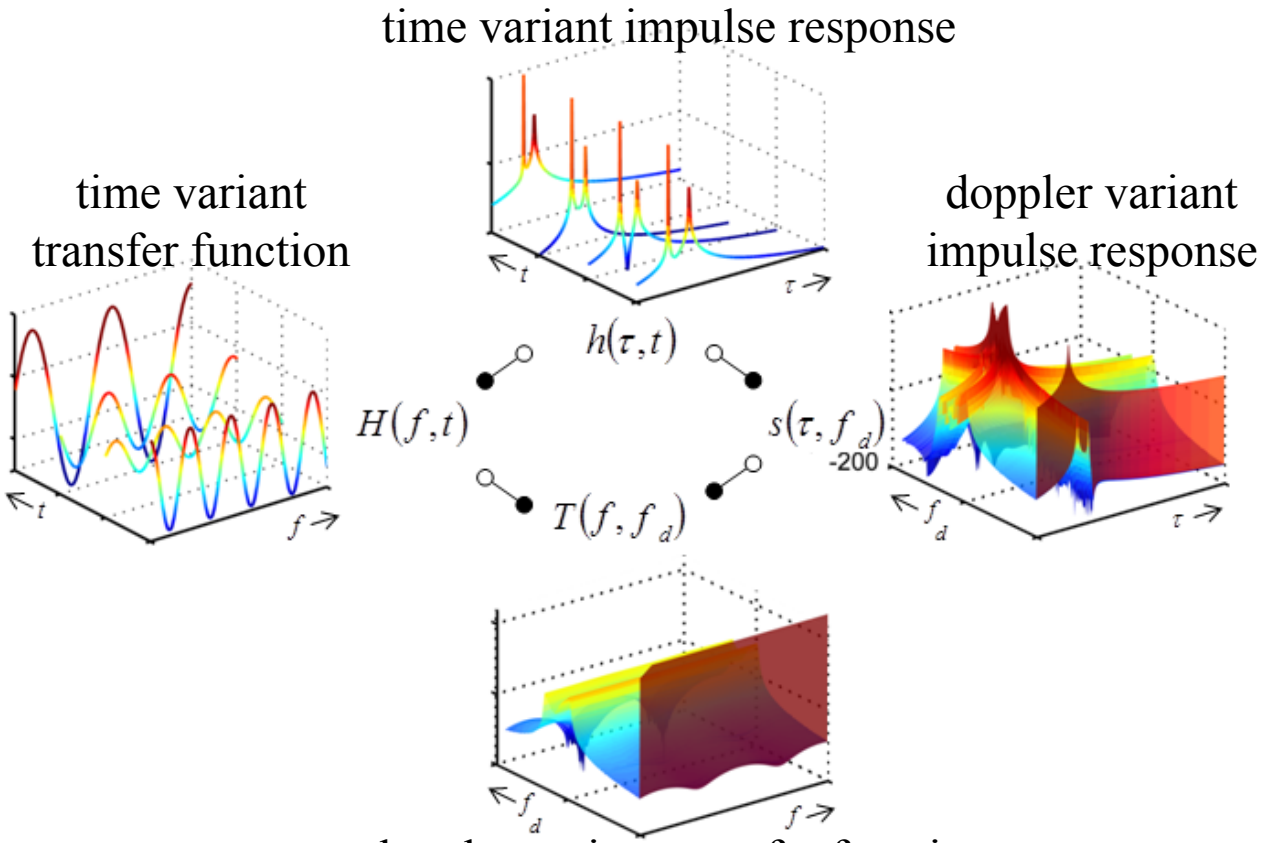
Channel Impulse Response and Channel Transfer Function



CIR and CTF are related by the Fourier transform (wide in one domain -> small in the other)

Impulse Response	Transfer Function
Time t	Frequency f
Duration T	Frequency Resolution $\Delta f = 1/T$
Time Resolution Δt	Bandwidth $B = 1/\Delta t$

Channel Impulse Responses and Doppler Frequency



- Repeated recording of channel impulse response
- Variation over time due to movement of transmitter/receiver or objects
- Doppler shift = Doppler frequency characterizes movement

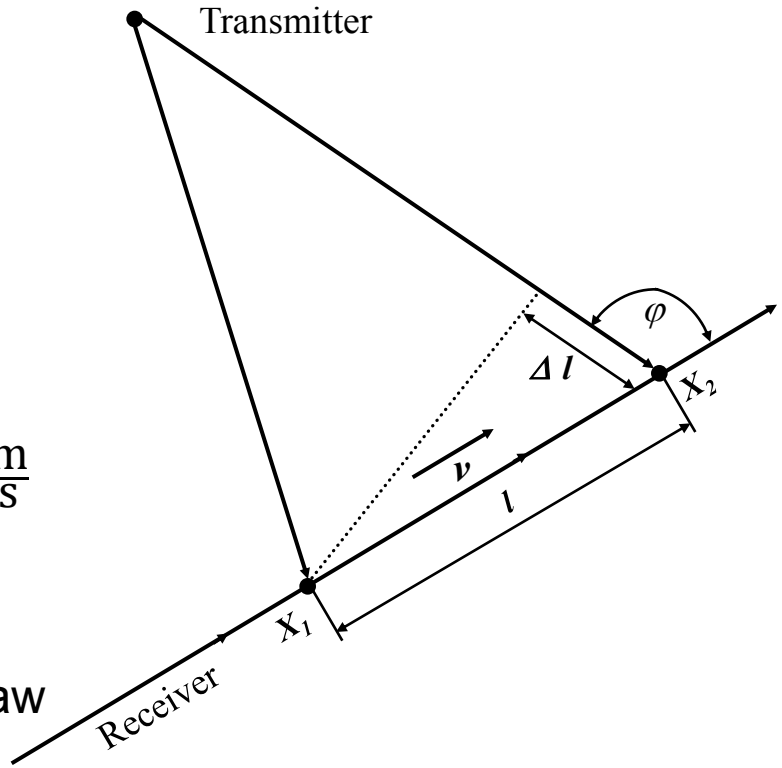
Summary of correspondences

- Channel Impulse Response (CIR) depends on
  - delay and time: time variant impulse response
  - delay and doppler frequency: doppler variant impulse response
- Channel Transfer Function (CTF) depends on
  - frequency and time: time variant transfer function
  - frequency and doppler frequency: doppler variant transfer function

Impulse response	Transfer Function
Time t	Doppler frequency f_d
Delay τ	Frequency f
Duration one CIR T	Frequency Resolution $\Delta f = 1/T$
Delay Resolution $\Delta\tau$	Bandwidth $B = 1/\Delta\tau$
Measurement Time T_M	Doppler resolution $\Delta f_d = 1/T_M$
Time resolution Δt	Max. doppler frequency $f_{d,\max} = 1/\Delta t$

Maximum Doppler Frequency

- Wave length $\lambda \approx 1\,\mathrm{mm}$ @ 300 GHz
- With $f_{d,max} \approx 8.5\,\mathrm{kHz}$
  - Max. speed $\mathrm{v} \approx 8.5\,\frac{\mathrm{m}}{\mathrm{s}} = 30.6\,\frac{\mathrm{km}}{h}$
- A pedestrian moves with $5\,\frac{\mathrm{km}}{h} \approx 1.4\,\frac{\mathrm{m}}{\mathrm{s}}$
  - Max. doppler $f_{d,max} \approx 1.4\,\mathrm{kHz}$
- Factor of 2 according to Shannon's law
- Higher Factor is better to prevent aliasing (e.g. pedestrian is moving arms with higher speed)



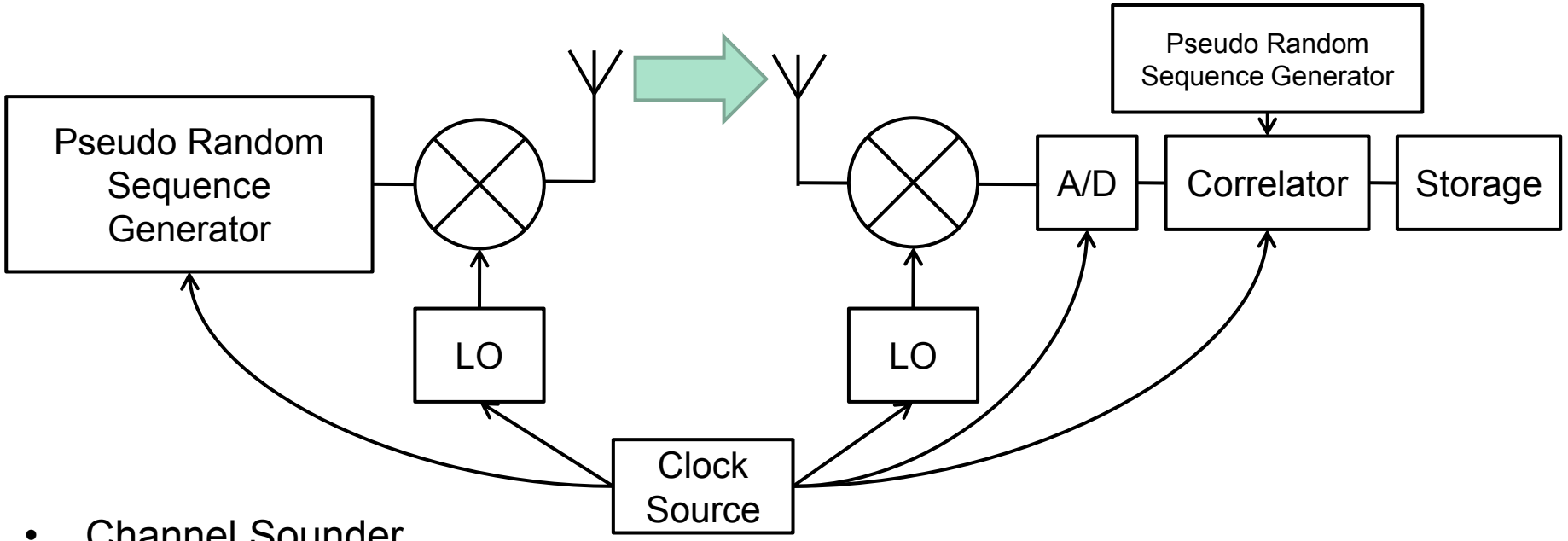
$$f_D = \frac{v}{\lambda}\cos\varphi$$

v: speed of the receiver
λ: wave length

Outline

- Theory
  - Channel Impulse Response
  - System functions according to Bello
- **Actual UWB MIMO Channel Sounder**
  - **Working Principle**
  - **Technical Parameters**

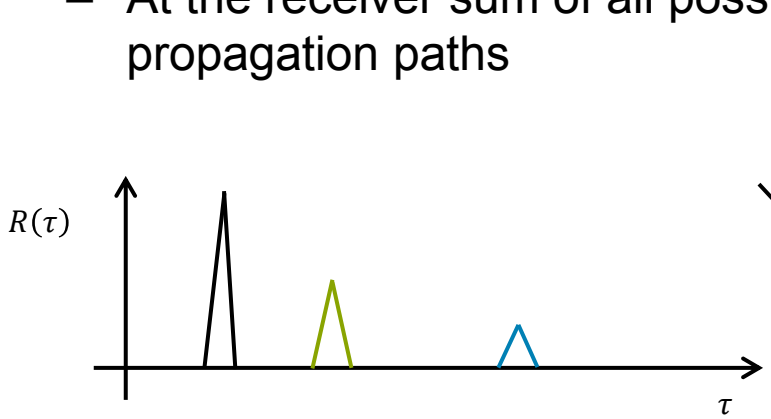
Simplified (Correlation) Channel Sounder principle

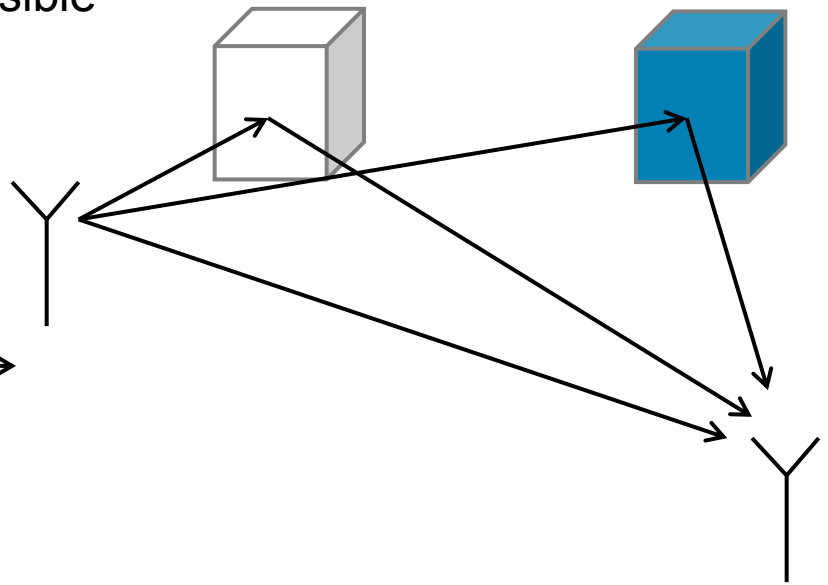


- Channel Sounder
  - Transmits a pseudo random binary sequence (PRBS)
  - Calculates the CIR by cross-correlation of the received signal and the PRBS
- Central Clock Source necessary for phase recovery

Impulse Response by Cross Correlation

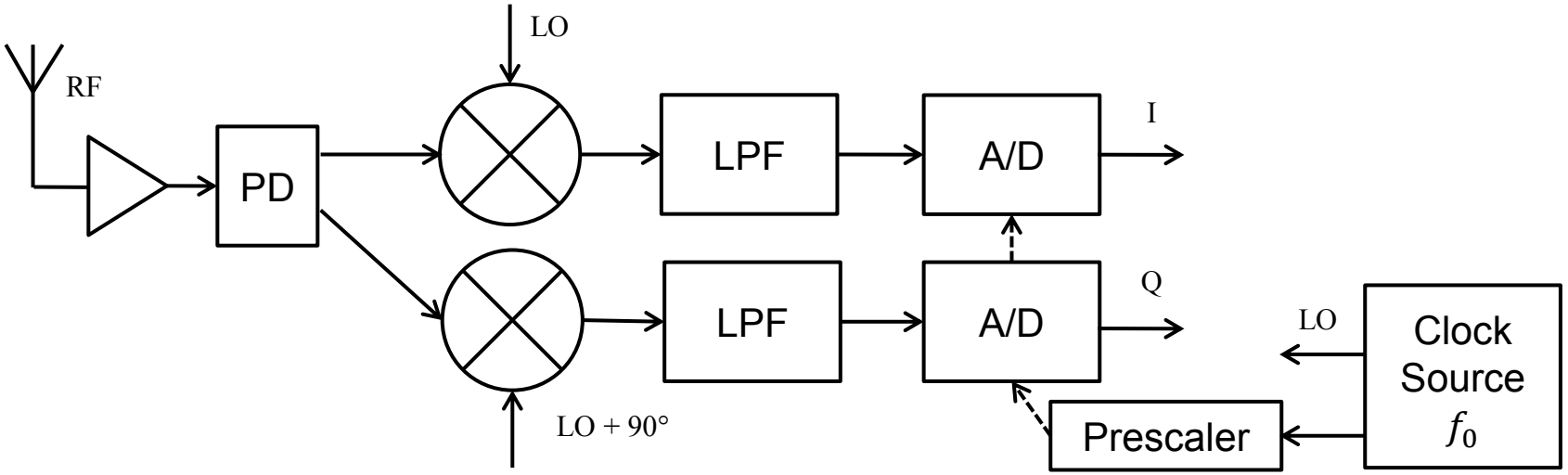
- M-sequence is transmitted in all directions
- At the receiver sum of all possible propagation paths



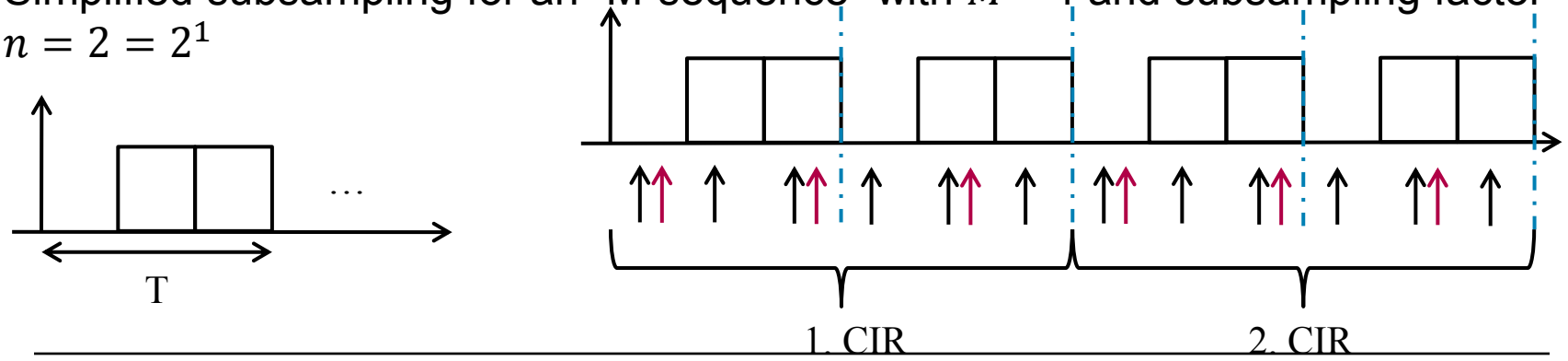


- Cross Correlation of received Signal and ideal M-sequence (width of peaks is usually smaller than resolution)

Details receiver



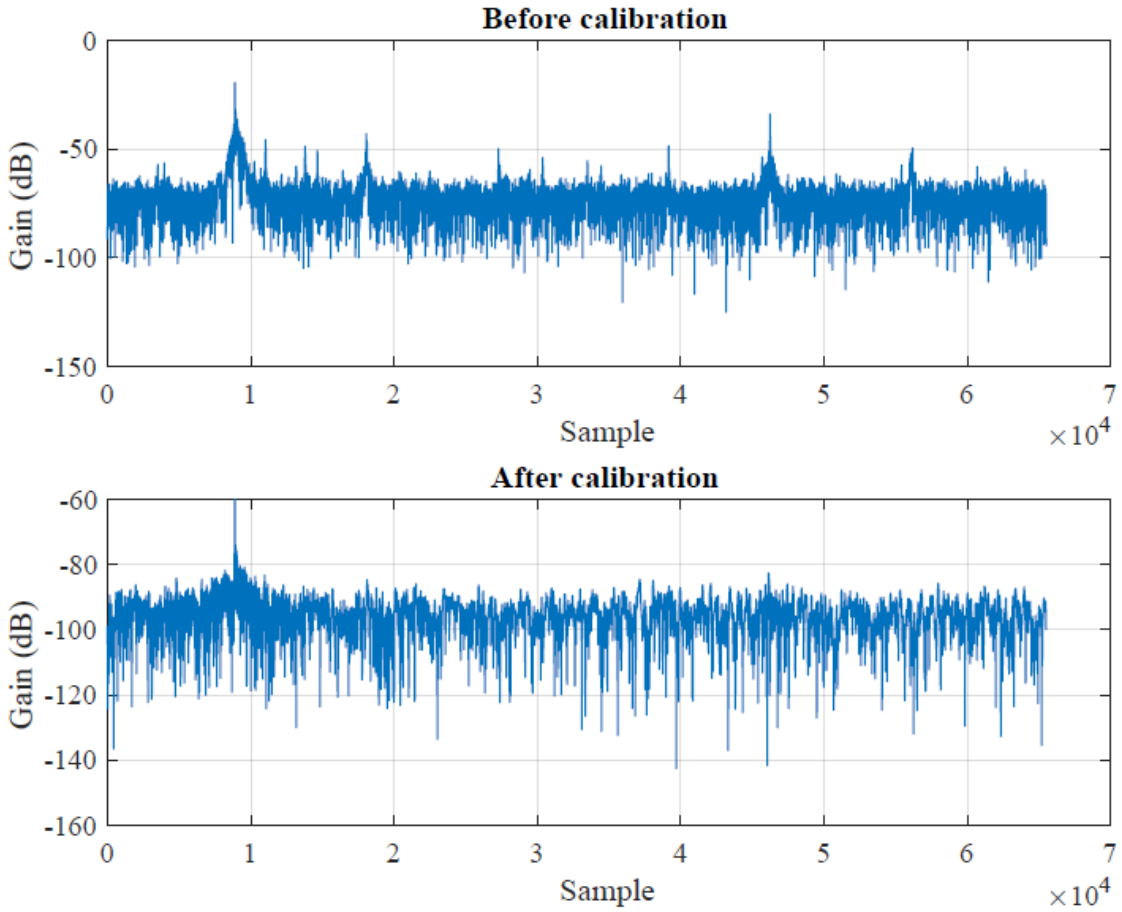
Simplified subsampling for an "M-sequence" with M =4 and subsampling factor $n = 2 = 2^1$



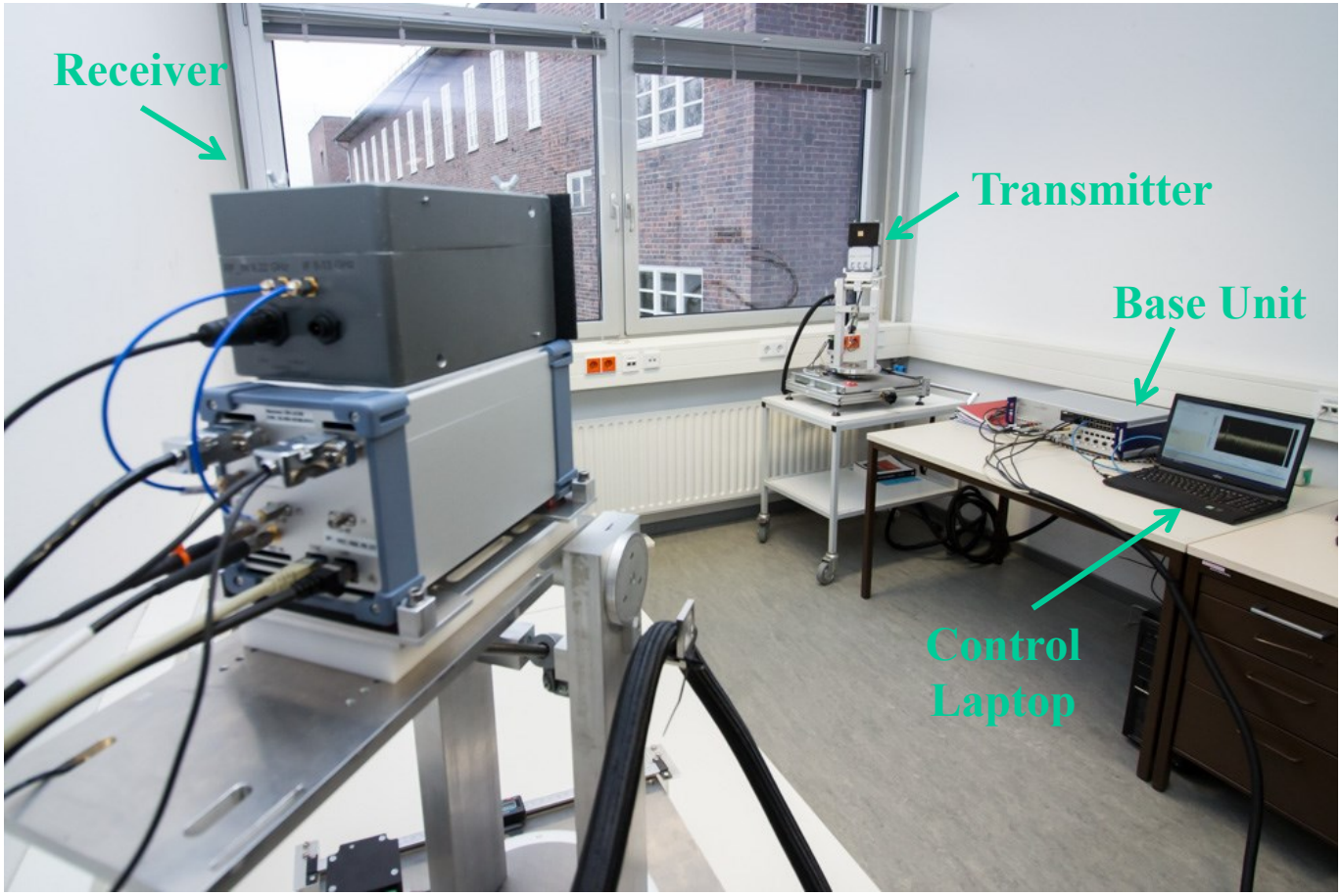
Parameters of the Channel Sounder

- This Channel Sounder has been acquired by TU Braunschweig from Ilmsense GmbH
- Clock frequency $f_0 \approx 9.22\ \mathrm{GHz}$
  - Bandwidth $f_0 \geq B \approx 8\ \mathrm{GHz}$
  - Chip duration $T_c = 1/f_0 \approx 108.5\ \mathrm{ps}$
- M-Sequence $M = 12$
  - Sequence Length $L = 2^{12} - 1 = 4095$
  - Sequence Duration $T_p = L \cdot T_c \approx 444.14\ \mathrm{ns}$
- Subsampling factor $n = 128 = 2^7$
  - Measurement time for one sequence $T_{p,sub} = n \cdot T_p = n \cdot L \cdot T_c \approx 56.85\ \mathrm{us}$
  - Measurement rate $r = 1/T_{p,sub} \approx 17590\ \mathrm{Hz}$
- Frequency Ranges 5.2-13.2 GHz 60.32-68.32 GHz 300.2-308.2 GHz (extension)
- MIMO (4x4 UWB, 2x2 60 GHz, 2x2 300 GHz, or combination)
- Channel Measurements
  - With CIR duration T_p a maximum path length of $\approx 133.15\ \mathrm{m}$
  - Maximum doppler frequency (c.f. to Shannon's law): $f_d = \frac{1}{2} r \approx 8.795\ \mathrm{kHz}$

An Example of a CIR



Channel Sounder in a Small Office



Summary

- Review of some theory
- Working Principle of a Channel Sounder
- Technical parameters of a real channel sounder

Vielen Dank für
Ihre Aufmerksamkeit.

Thank you for paying attention!