A 10-1000 GHz Wireless Measurement System with 50 GHz Bandwidth

Andreas Czylwik, Thomas Kaiser, and Andreas Stöhr

University Duisburg-Essen

czylwik@nts.uni-duisburg-essen.de

Contents

- Wave propagation in the mm-wave and THz frequency range
- Extreme wideband signal generation
- Wireless transmission towards 100 Gbit/s

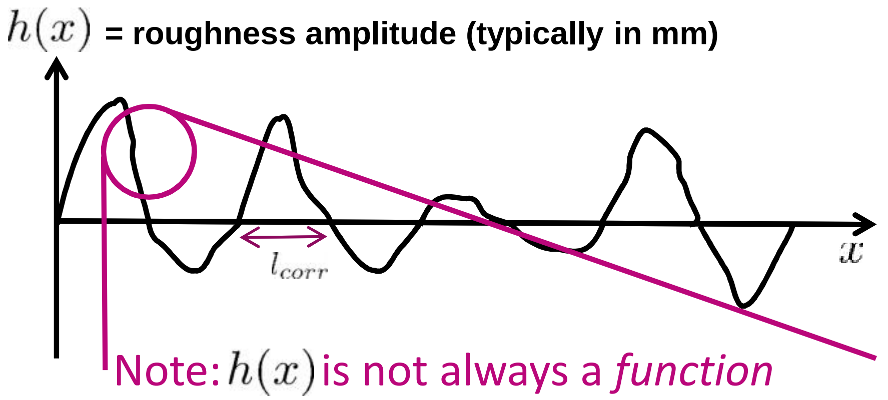
Wave propagation in the mm-wave and THz frequency range

- Analysis of indoor propagation at 300 GHz

- Propagation effects
  - Multipath propagation model
  - Line-of-sight (LOS)
  - Specular reflections
  - Scattering
  - Fresnel knife edge diffraction

Wave propagation in the mm-wave and THz frequency range

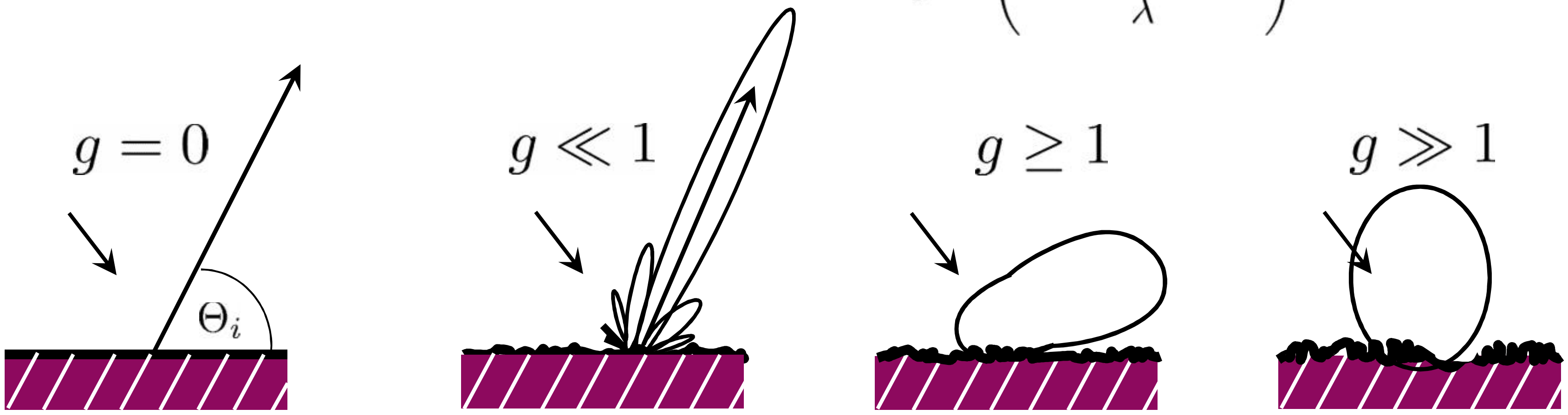
- Effect of rough surfaces: diffuse scattering



Two important statistical parameters:

1. **Standard deviation height =** σ_h **[mm]**
2. **Correlation length =** l_{corr} **[mm]**

$$g = \left(\frac{4\pi\, \sigma_h\, \cos\Theta_i}{\lambda} \right)^2$$



(a) Perfectly smooth surface **(b) Slightly rough surface** **(c) Moderately rough surface** **(d) Very rough surface**

Wave propagation in the mm-wave and THz frequency range

- Kirchhoff scattering theory: Rayleigh roughness factor r

$$\rho = e^{-\frac{g}{2}} = \exp\left(-\frac{8\pi^2 f^2 \sigma_h^2 \cos^2\Theta_i}{c^2}\right)$$

- *g* does not depend on the correlation length

- Modified reflection coefficients:

$$\widetilde{\Gamma}_{\mathrm{TE}} = \rho\,\Gamma_{\mathrm{TE}}$$

$$\widetilde{\Gamma}_{\mathrm{TM}} = \rho\,\Gamma_{\mathrm{TM}}$$

Pine wood is considered as *smooth*

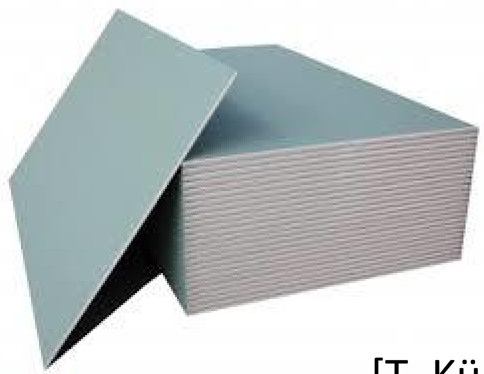
- **Standard deviation (height) = σ_h = 0 [mm]**
- **Real permittivity = $\epsilon_r^{'}$ = 1.734**
- **Imaginary permittivity = $\epsilon_r^{''}$ = 0.073**

Ingrain wallpaper is considered as *rough*

- **Standard deviation (height) = σ_h = 0.13 [mm]**
- **Real permittivity = $\epsilon_r^{'}$ = 2.25**
- **Imaginary permittivity = $\epsilon_r^{''} \approx$ 0.1**

Plaster is considered as *rough*

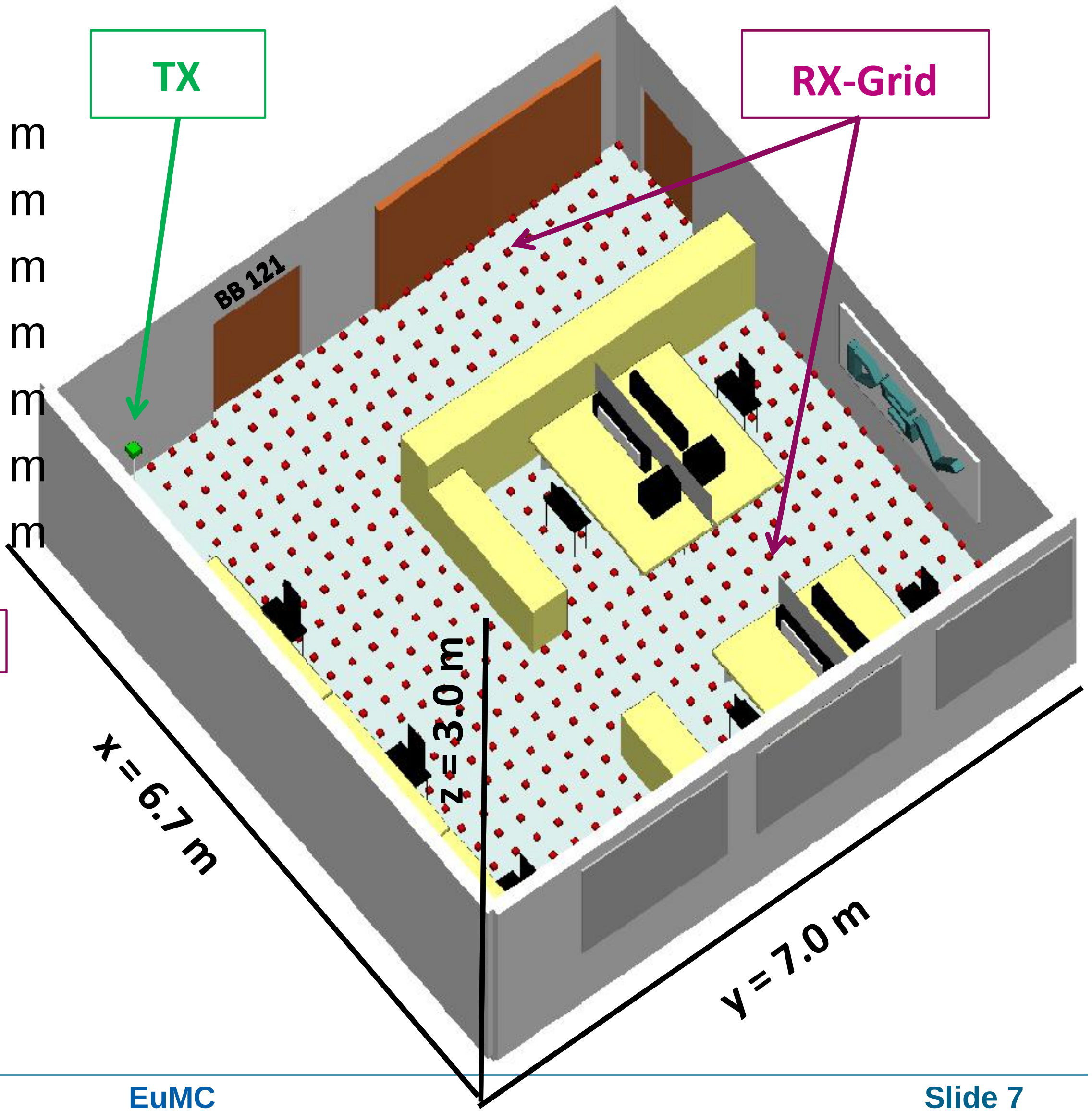
- **Standard deviation (height) = σ_h = 0.15 [mm]**
- **Real permittivity = $\epsilon_r^{'}$ = 3.691**
- **Imaginary permittivity = $\epsilon_r^{''}$ = 0.217**



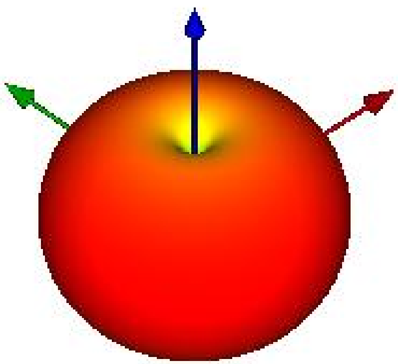
[T. Kürner 2007]

Simulation scenario 1

- Environment parameters
- PC desk height: 0.70 m
- PC desk length: 1.80 m
- PC desk width: 0.80 m
- Wardrobe height: 2.25 m
- Wardrobe length: 2.90 m
- Door height: 2.10 m
- Door width: 1.05 m

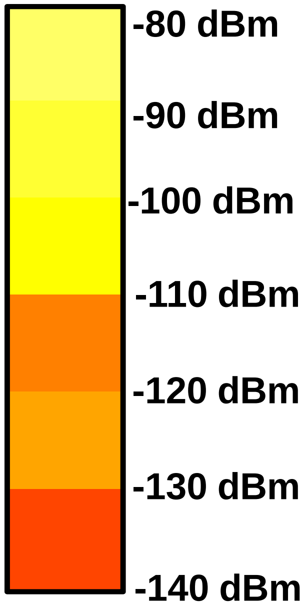


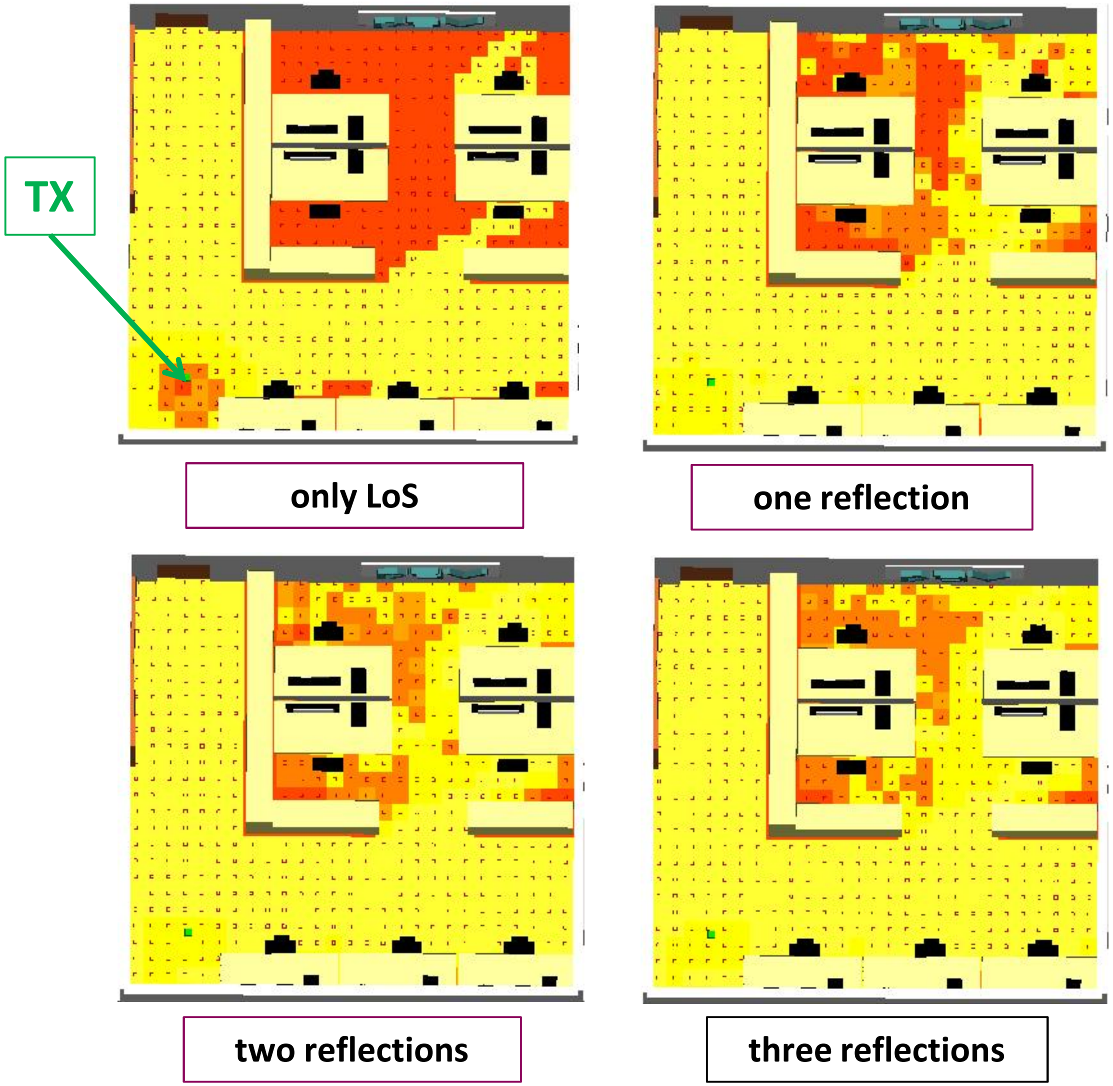
Omnidirectional antenna 3D pattern



Simulation results 1 (2D coverage map @ 300 GHz)

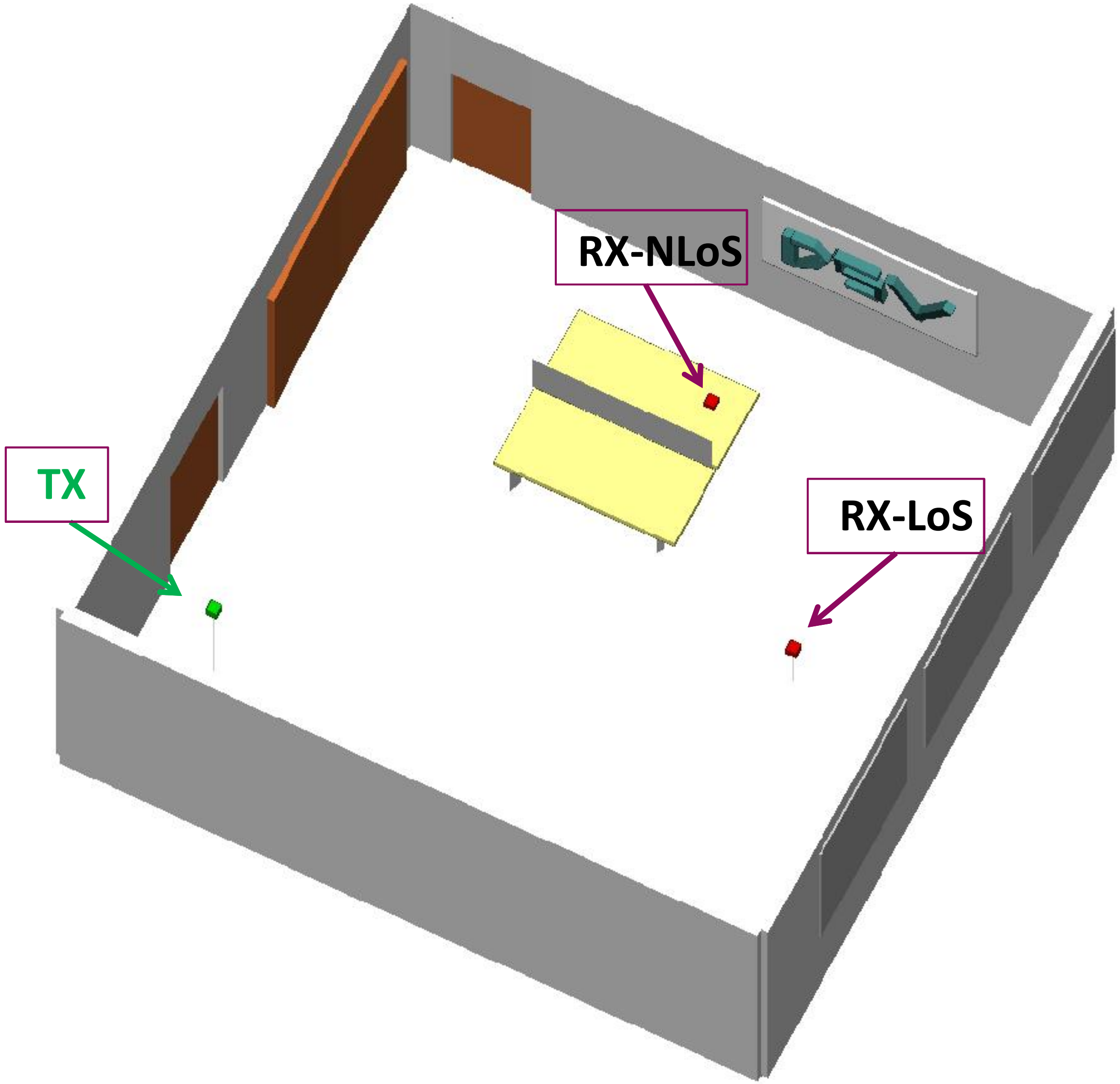
- TX power: 0 dBm
- TX height: 2.0 m
- RX-Grid height: 0.25 m
- RX-Grid points: 729
- TX-Antenna: omni
- RX-Antenna: omni
- Ray spacing: 0.25°



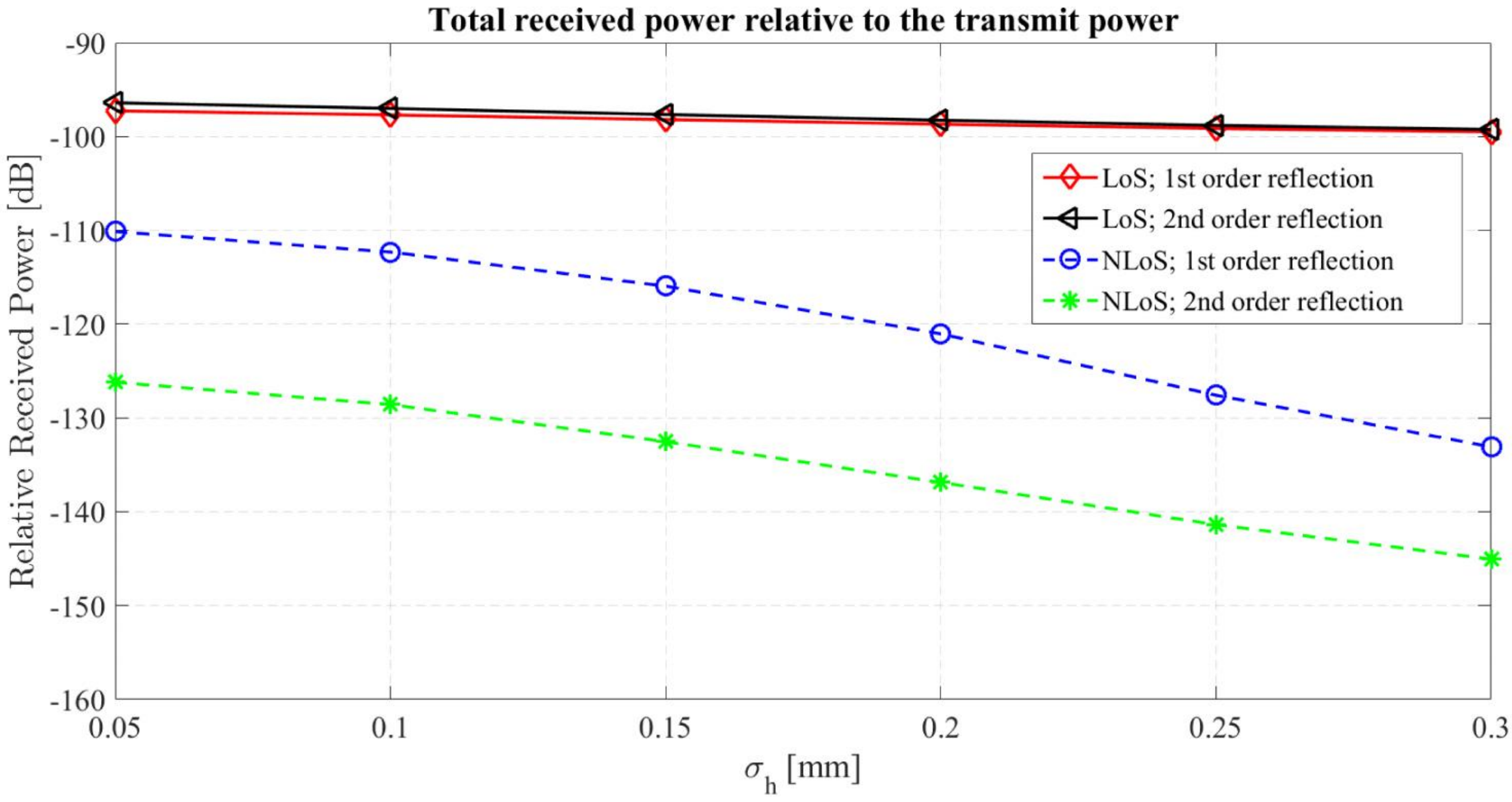


Simulation scenario 2

- TX power: 0 dBm
- TX height: 2.0 m
- RX-LoS height: 0.75 m
- RX-NLoS height: 0.75 m
- TX- RX-LoS distance: 5 m
- TX- RX-NLoS distance: 5 m
- TX-Antenna: omni
- RX-Antenna: omni
- No. of reflections: variable
- Roughness: variable
- Ray spacing: 0.25°

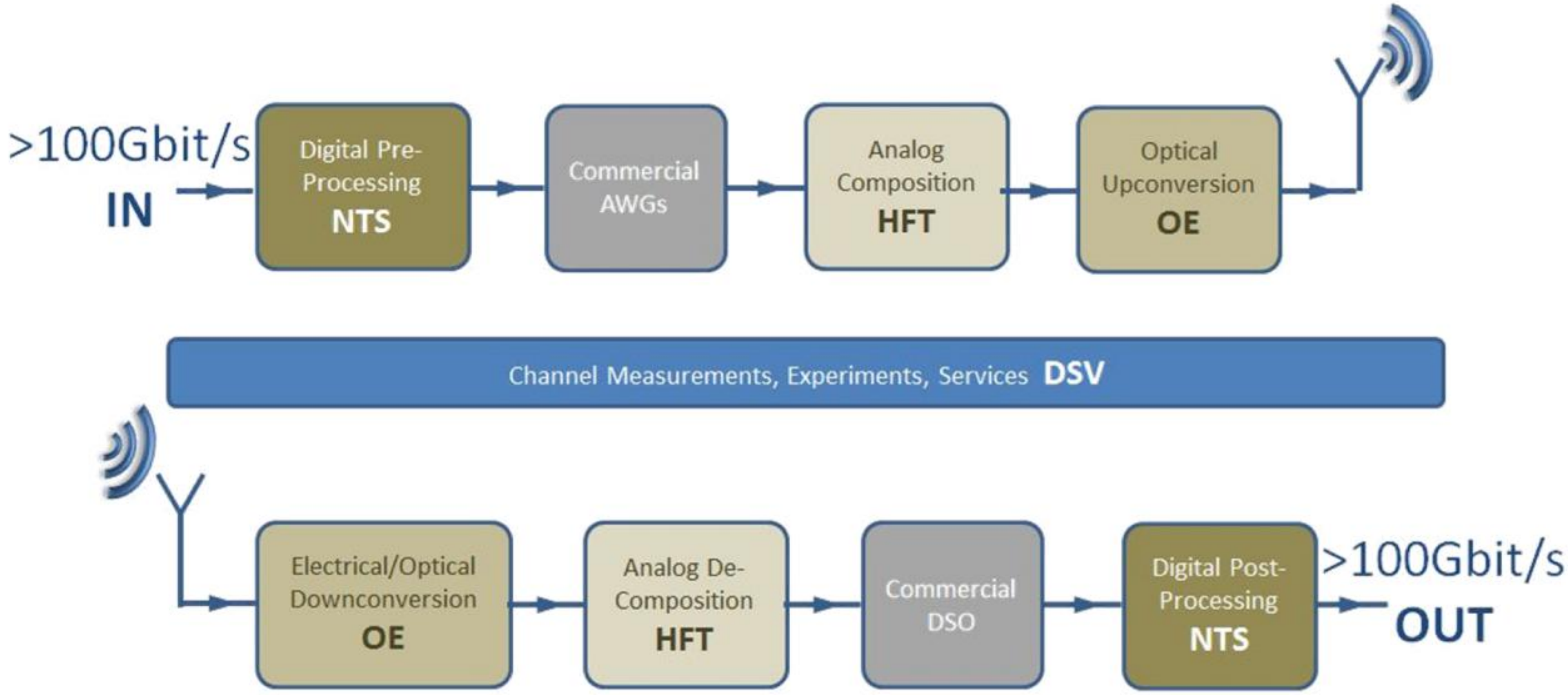


Simulation results 2 @ 300 GHz



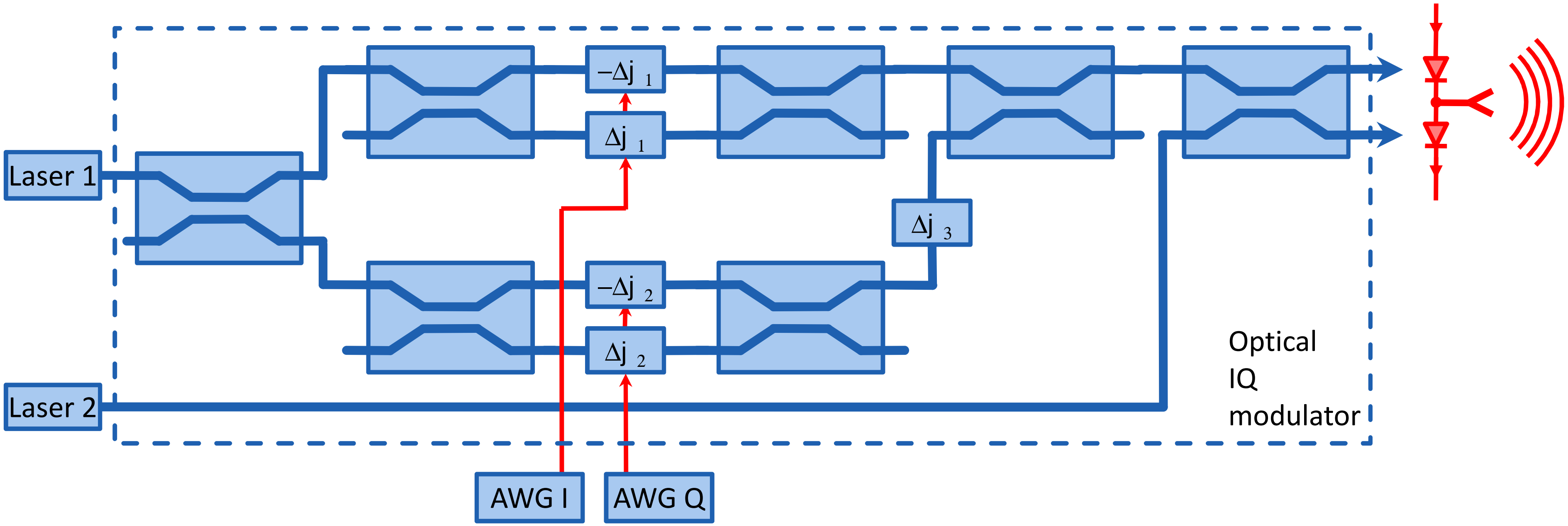
Extreme wideband signal generation

- ***Tera50***: A 10-1000 GHz wireless measurement system with 50 GHz bandwidth



Extreme wideband signal generation

- Optoelectronic IQ-modulator

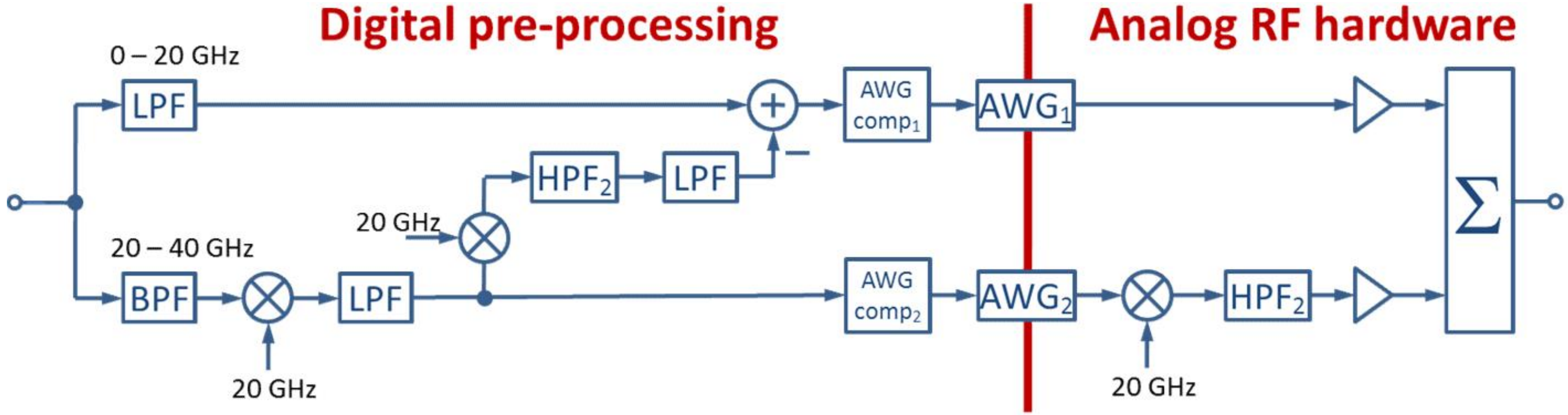


- Photodiode output current:

$$i(t) = -\frac{\eta e}{h f_{\mathrm{opt}}} \cdot \sqrt{P_1 P_2} \cdot \left(\sin\Delta\varphi_1 \cdot \cos\Delta\omega t - \sin\Delta\varphi_2 \cdot \sin\Delta\mu t\right)$$

Extreme wideband signal generation

- AWG by frequency multiplexing

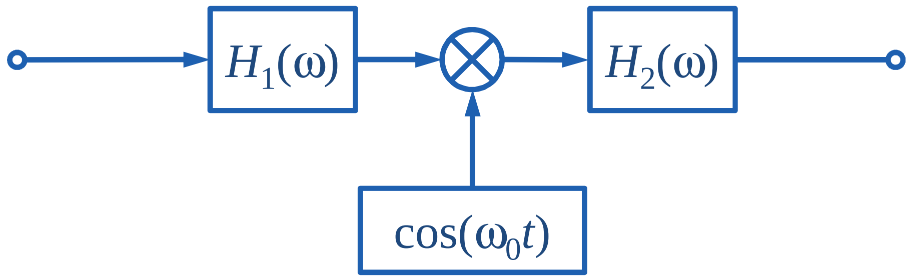


- Challenge: compensation of wideband signals
- AWG oscillators and synchronization are stable enough

Extreme wideband signal generation

- Wideband characterization of double-balanced mixers

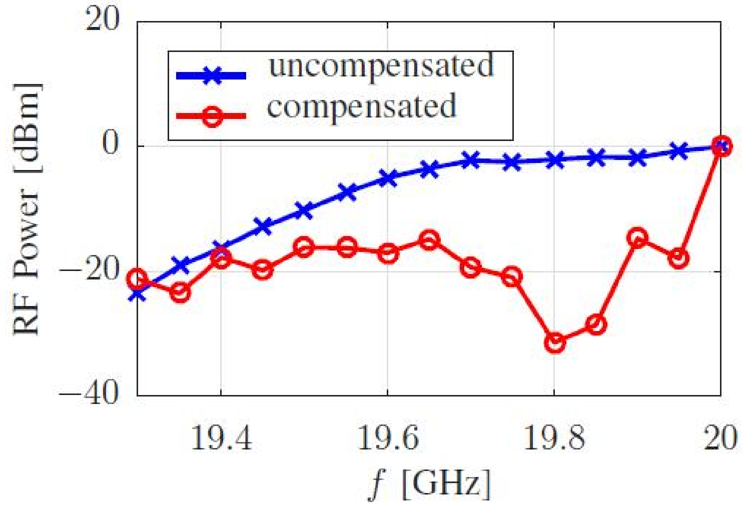
- Frequency-selective model



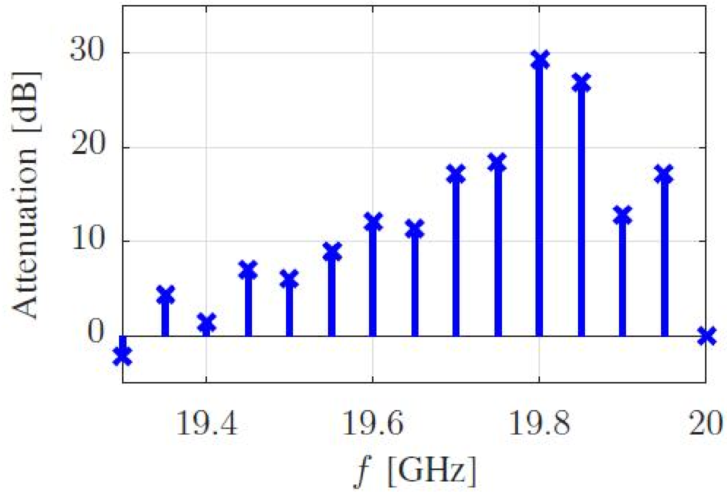
Extreme wideband signal generation

- Lower sideband compensation

- Measured distortion power created from the non-ideal highpass filter HPF_2

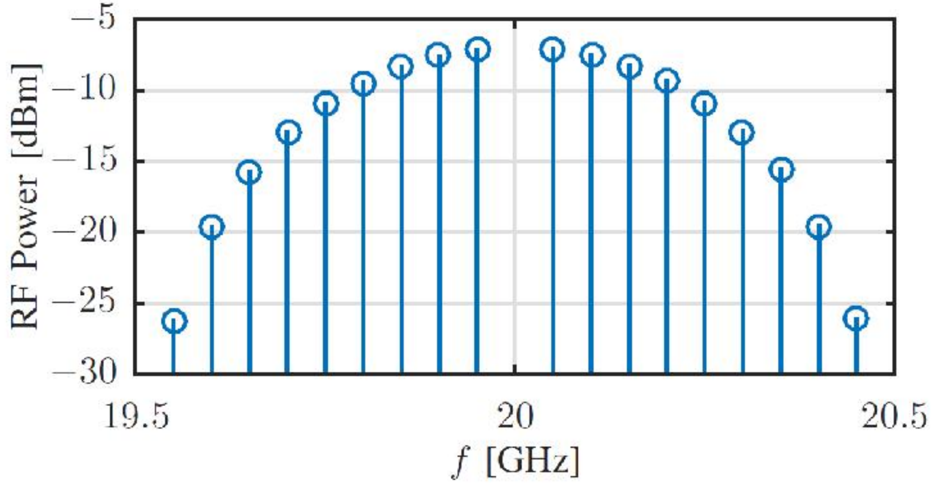


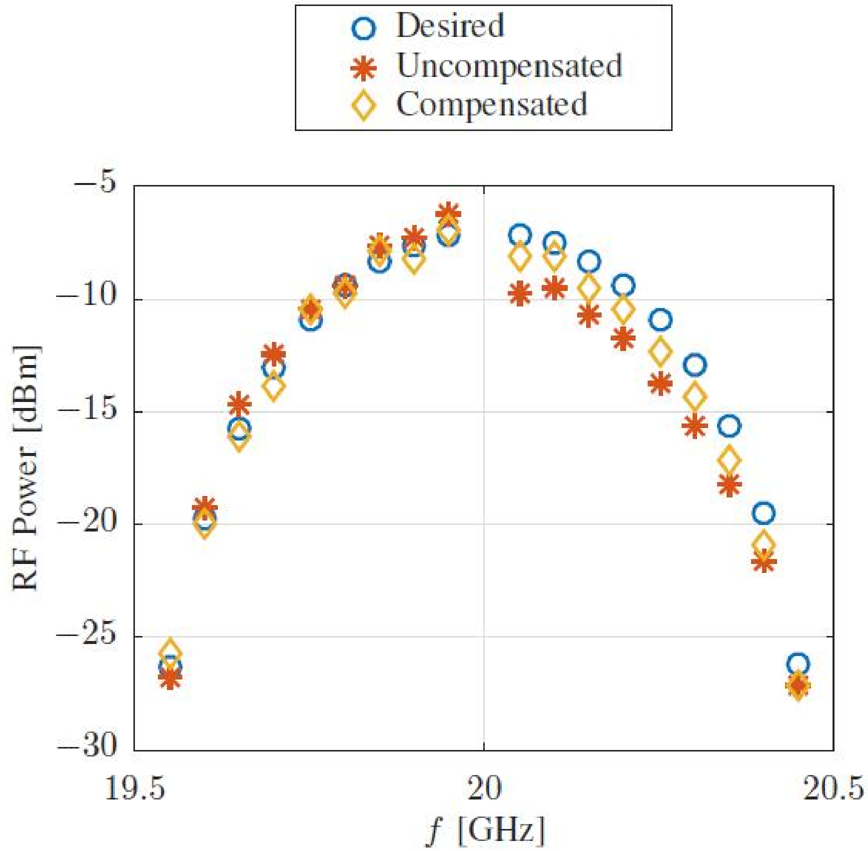
- Compensation gain (attenuation) of the lower sideband components



Extreme wideband signal generation

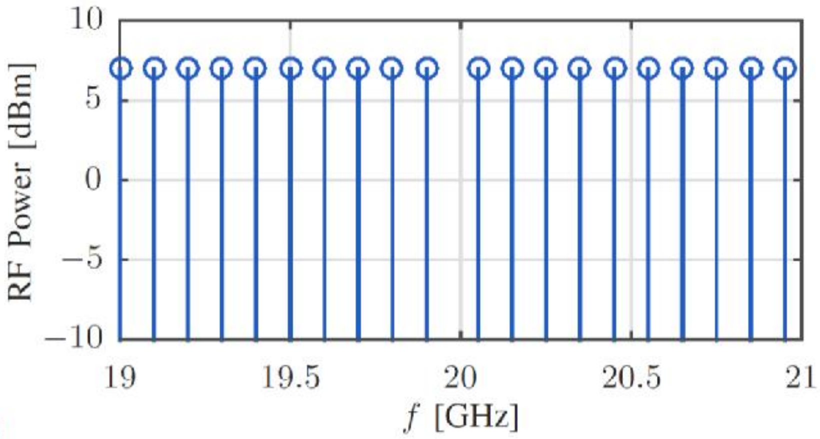
- Narrow-band test signal 1
  - Desired test signal
  - Measurements

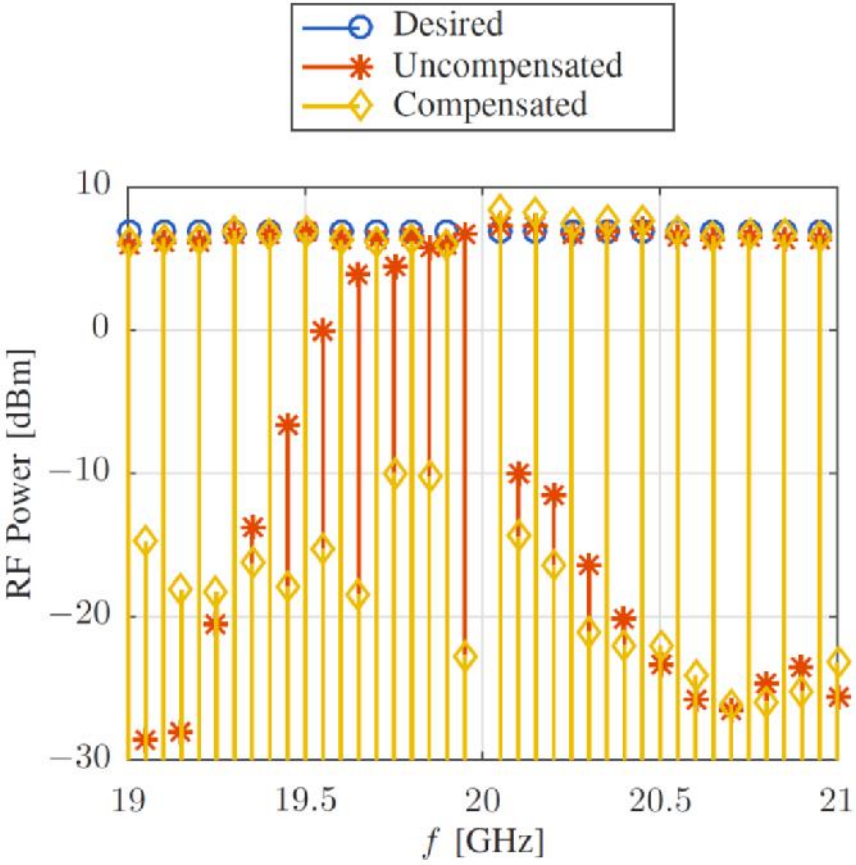




Extreme wideband signal generation

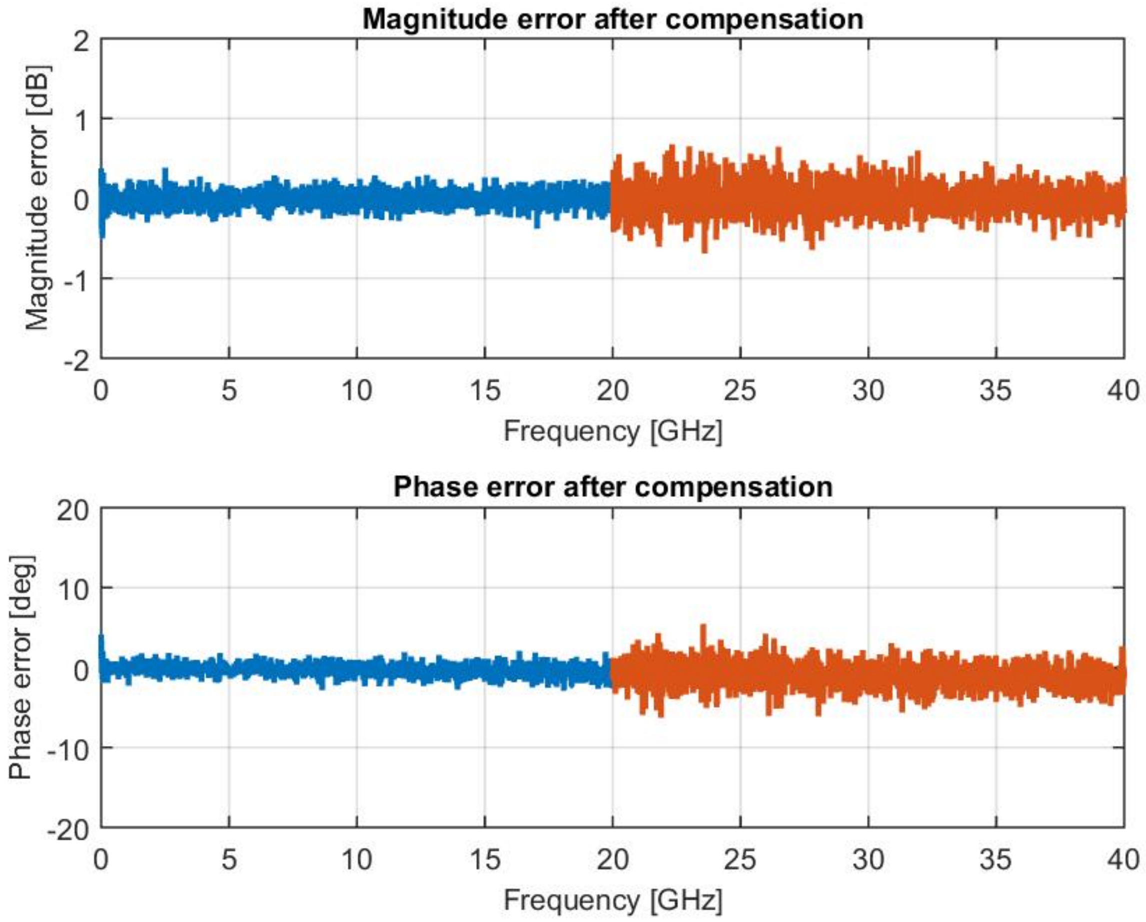
- Narrow-band test signal 1
  - Desired test signal
  - Measurements





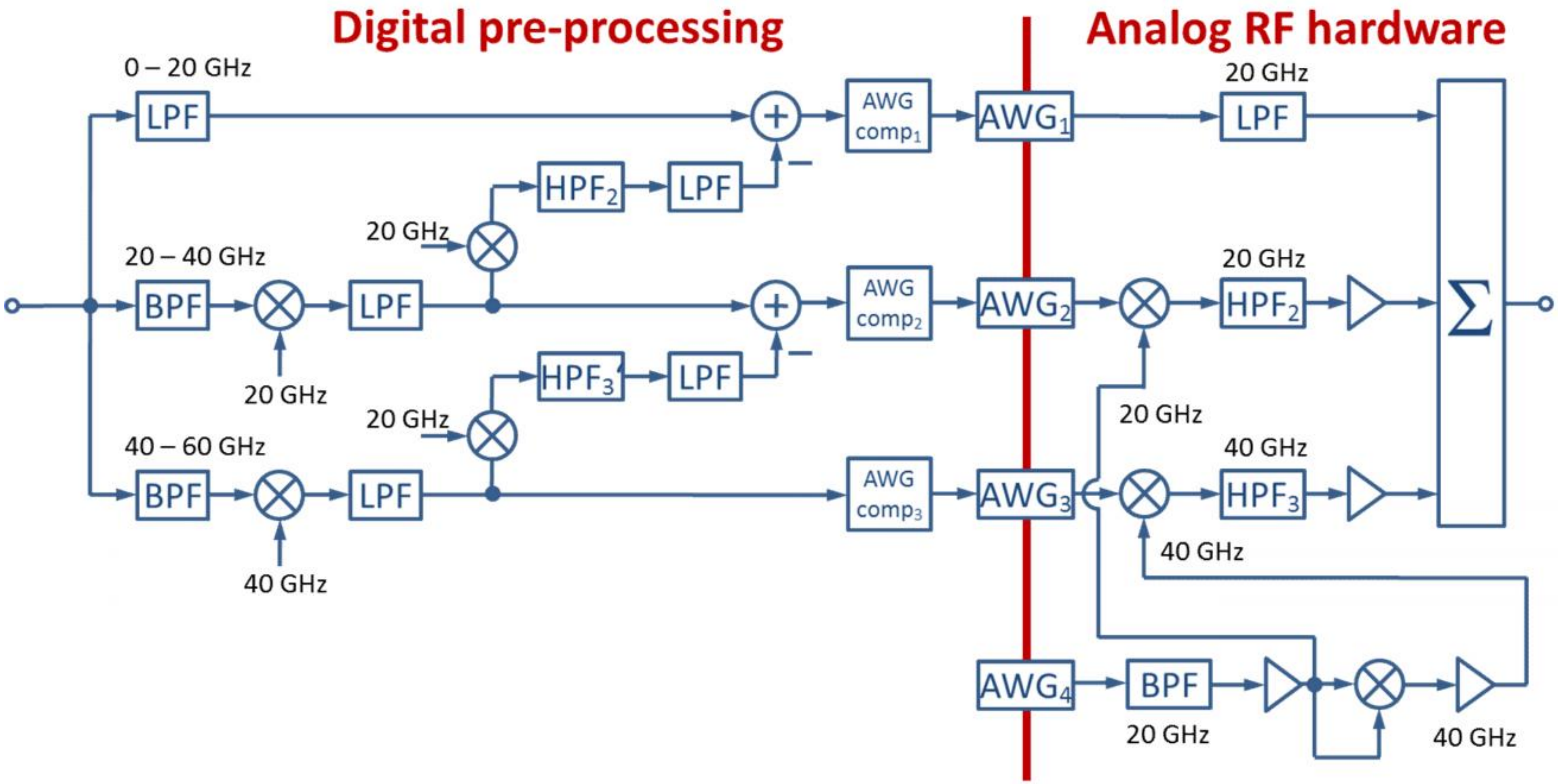
Extreme wideband signal generation

- Frequency response



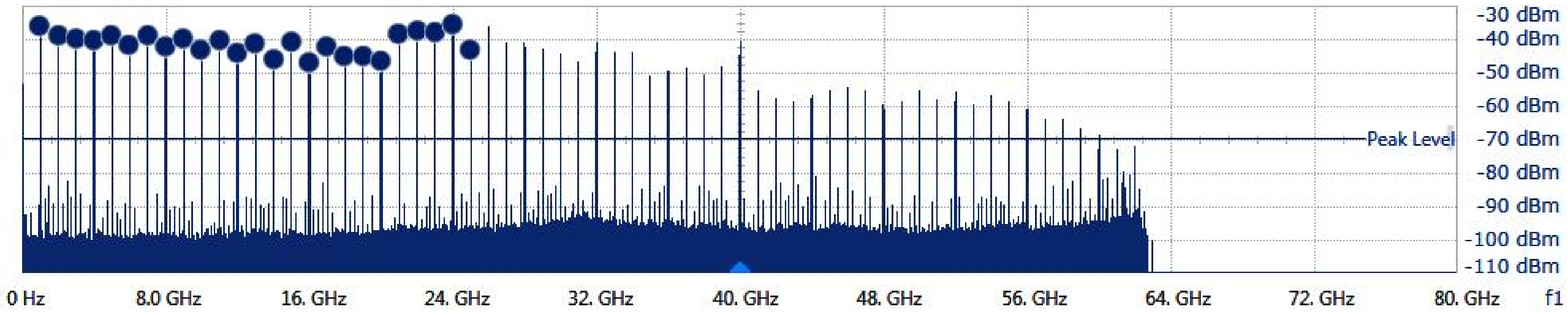
Extreme wideband signal generation

- Practical realization of a 60 GHz AWG



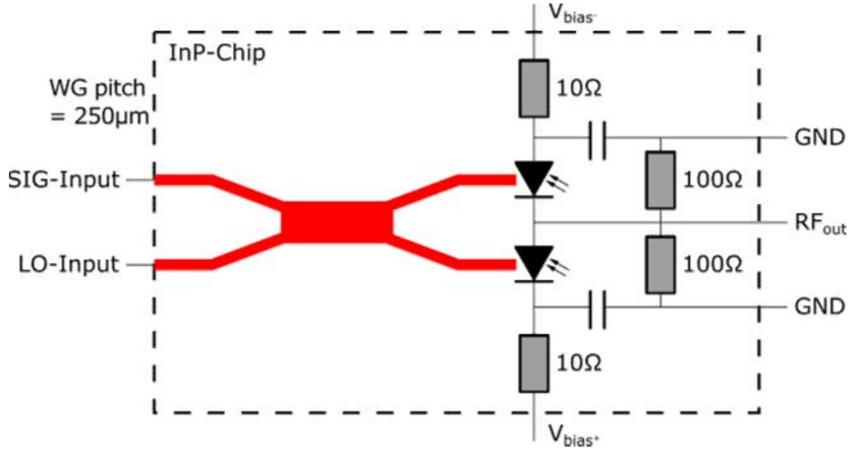
Extreme wideband signal generation

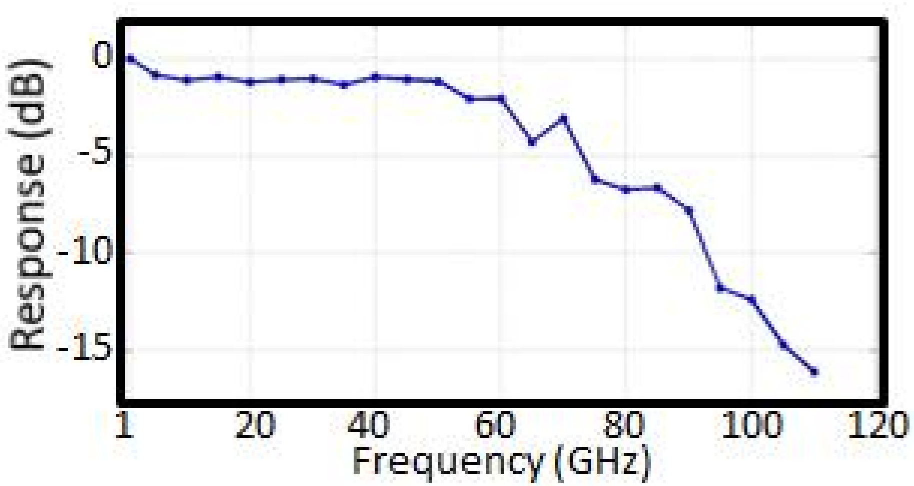
- Combining three subbands

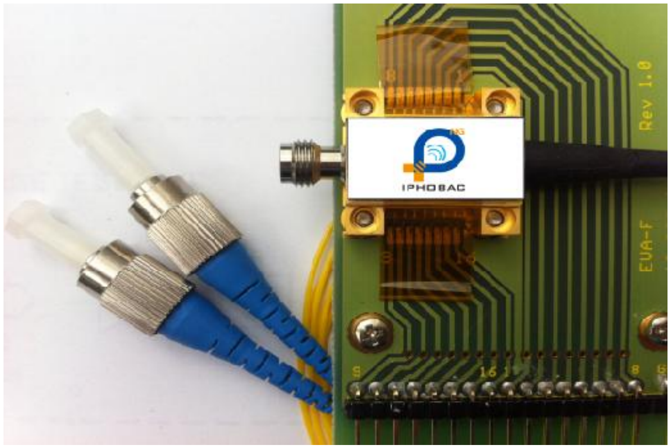


Wireless transmission towards 100 Gbit/s

- Coherent photonic mixer (CPX)
  - Balanced photodiodes
  - Optic-to-RF photomixer at 1550 nm
  - 3 dB cut-off frequency: 65 GHz
  - Output power +7dBm @ 76 GHz
  - LO laser power 4.85 dBm

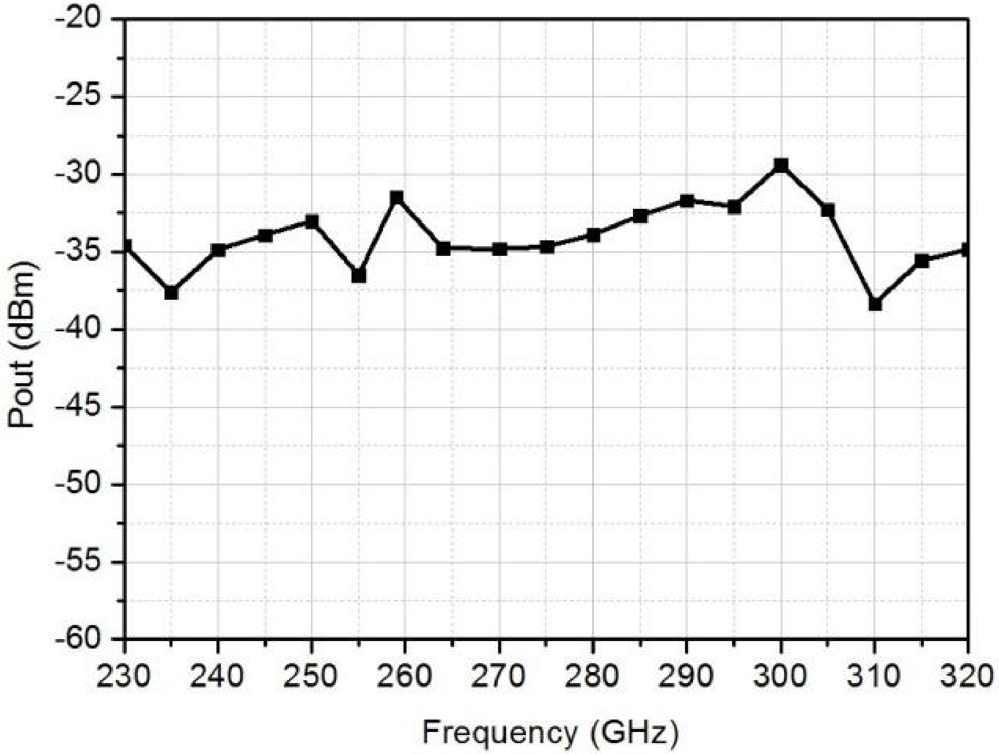






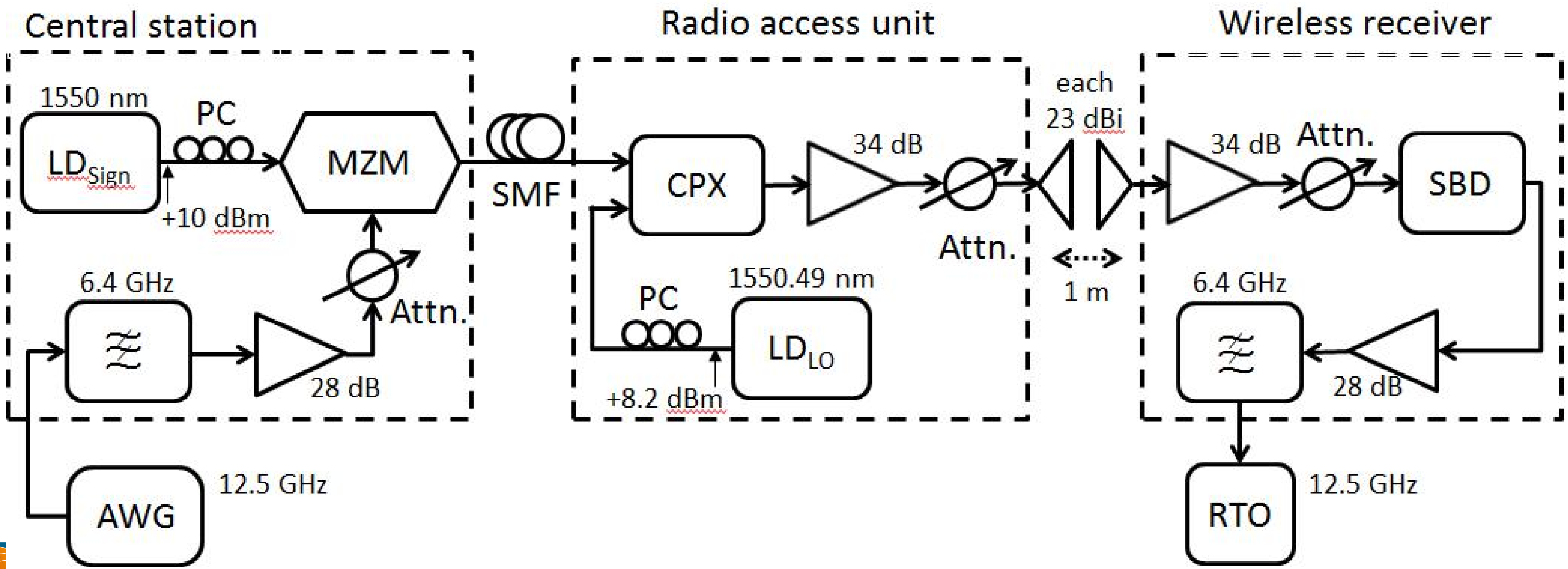
Wireless transmission towards 100 Gbit/s

- J-band uni-traveling-carrier photodiode (UTC-PD)
  - Photocurrent: 0.6 mA
  - DC-voltage: 1V
  - Bandwidth up to 100 GHz



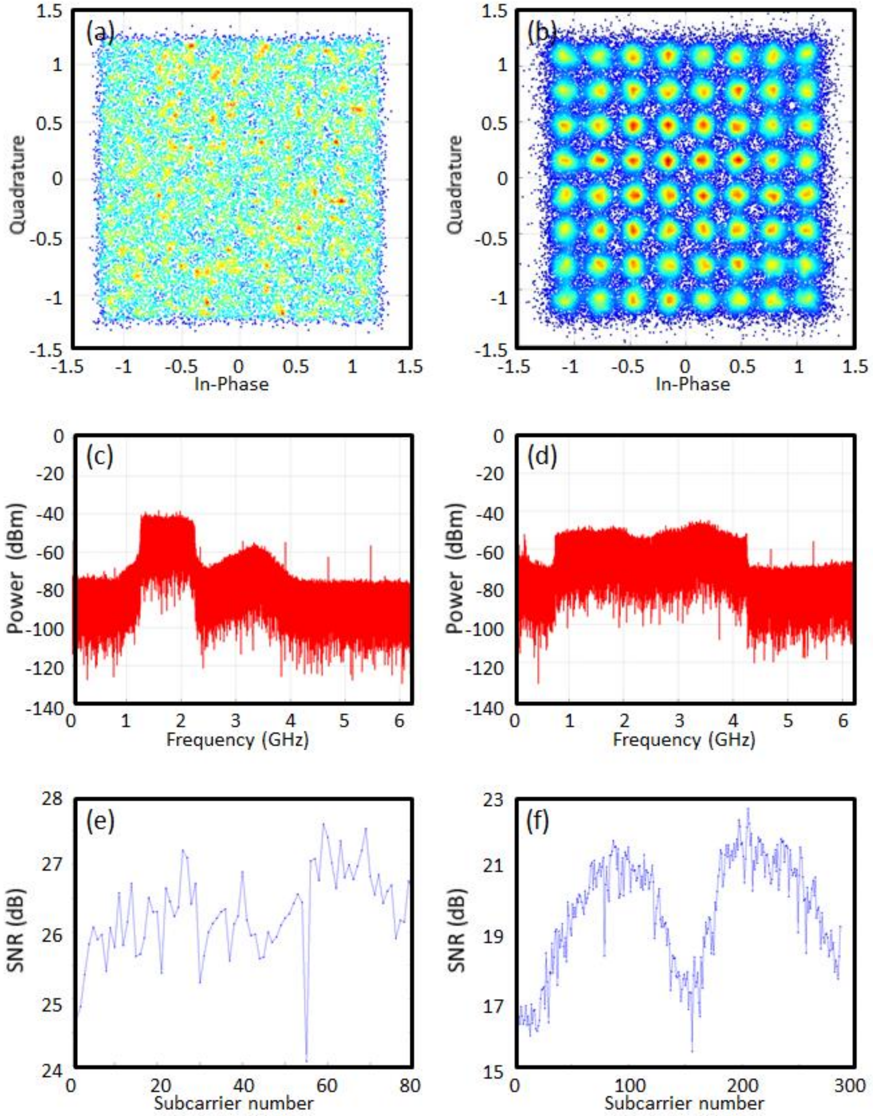
Wireless transmission towards 100 Gbit/s

- OFDM wireless transmission at 60 GHz
  - Photomixer with banced photodiodes
  - Pair of horn antennas over a 1 m reference air link
  - Transmission of data signal and auxiliary carrier signal
  - Zero-bias envelope detector



Constellations, spectra, and SNR per subcarrier

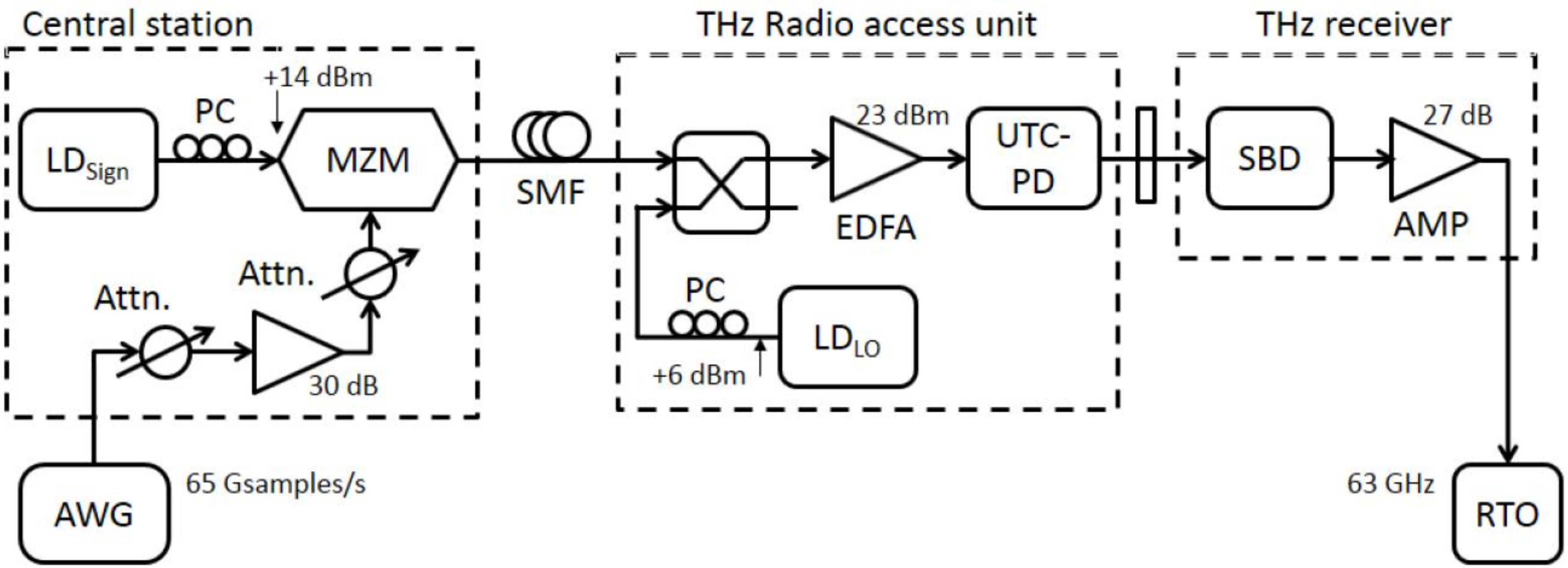
- Left column:
- 1024-QAM OFDM
- (10 bit/s/Hz)
- Bandwidth: 1 GHz
- 80 subcarriers
- Data rate: 9.7 Gbit/s
- SNR: 25.8 dB
- EVM: 5.13 %
- BER < $2 \cdot 10^{-4}$



- Right column:
- 64-QAM OFDM
- (6 bit/s/Hz)
- Bandwidth: 3.5 GHz
- 286 subcarriers
- Data rate: 20.95 Gbit/s
- SNR: 18.74 dB
- EVM: 11.57 %
- BER < $2 \cdot 10^{-6}$.

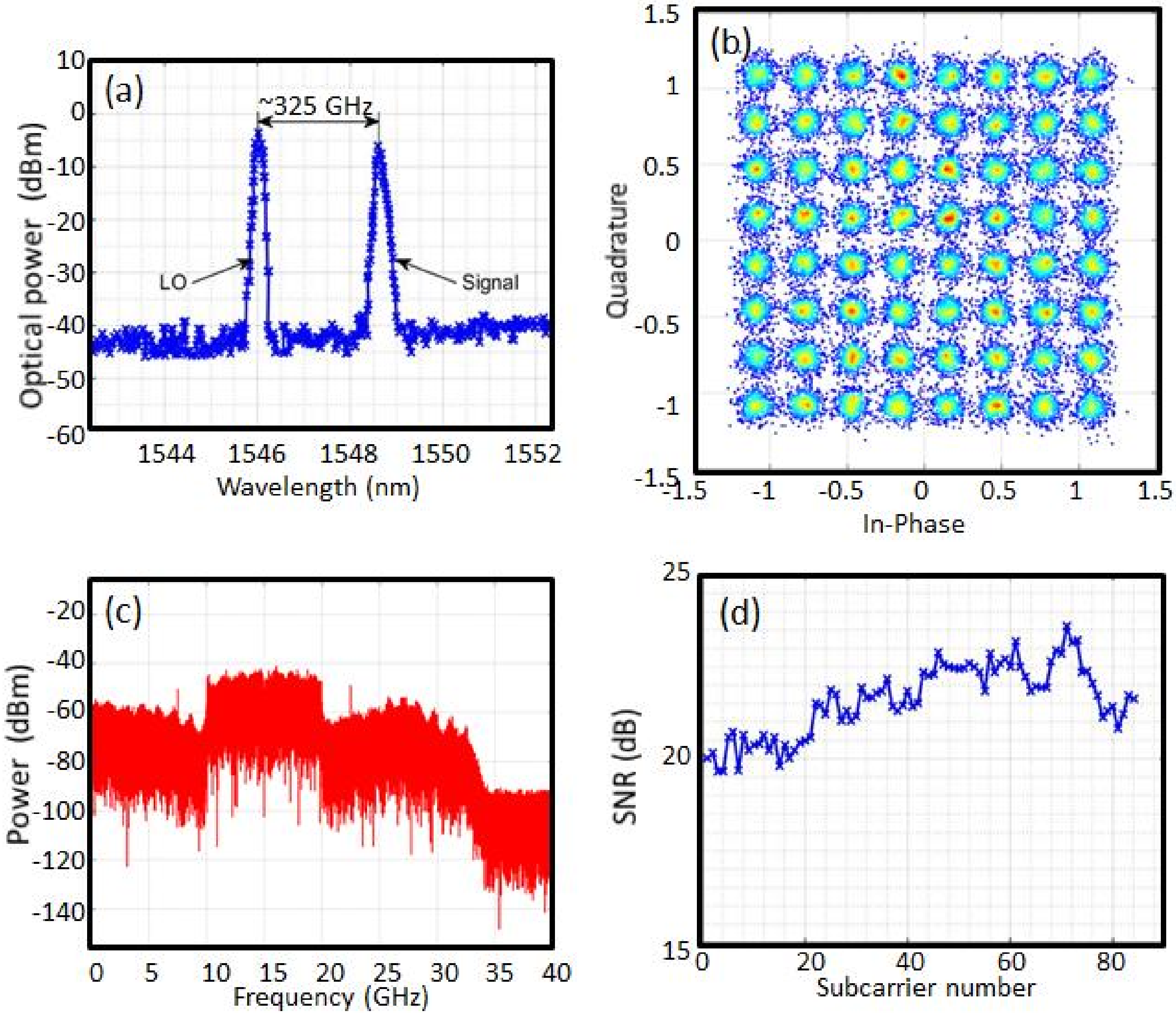
Wireless transmission towards 100 Gbit/s

- OFDM wireless transmission at 325 GHz
  - UTC photodiode
  - Transmission over a 2 cm long WR3.4 waveguide
  - Transmission of data signal and auxiliary carrier signal
  - Zero-bias envelope detector



Optical spectrum, constellation, IF spectrum, and SNR per subcarrier

- 64-QAM OFDM
- (6 bit/s/Hz)
- Bandwidth: 10 GHz
- 82 subcarriers
- Data rate: 59 Gbit/s
- SNR: 21.4 dB
- EVM: 8.51 %
- BER < $3 \cdot 10^{-3}$



Conclusion

- Simulations of a 300 GHz indoor radio channel
  - Roughness of surfaces plays an important role
  - Influence of atmospheric attenuation small for indoor communications
- Generation of an extreme wideband signal by frequency multiplexing
  - Arbitrary waveforms can be generated
  - Unwanted sidebands can be compensated by filtering and pre-processing
- Wireless transmission towards 100 Gbit/s
  - Integrated coherent photonic mixer (CPX), 5 dB higher conversion gain than commercial photodiodes
  - Coherent radio over fiber approach for seamless hybrid fiber wireless networks (HFW)
  - Record spectral efficiencies of 10 bit/s/Hz and 6 bit/s/Hz in the 60 GHz and 325 GHz band
  - Data rate: 59 Gbit/s

Acknowledgements

- This work was supported by Deutsche Forschungsgemeinschaft (DFG) within the DFG-SPP 1655 program “Wireless 100 Gbit/s and beyond”.
- The technological development of the CPX by ZHO/OE and FINISAR Germany, was supported by the European Commission within the IPHOBAC-NG (www.iphobac-ng.eu) projects.
- Furthermore, the support by CORNING Inc., USA in OFDM-QAM digital signal processing is acknowledged.

Thank you for your attention!