This project is co-funded by

Horizon 2020

National Institute of Information and Communications Technology

Short-Range Wireless Transmission Using a Superheterodyne THz Link

H2020 EU-Japan Project ThoR Final Workshop

Dominik Wrana, Braunschweig, 29-30 June 2022

Agenda

1. Introduction

2. Superheterodyne H-Band Transmit and Receive Modules

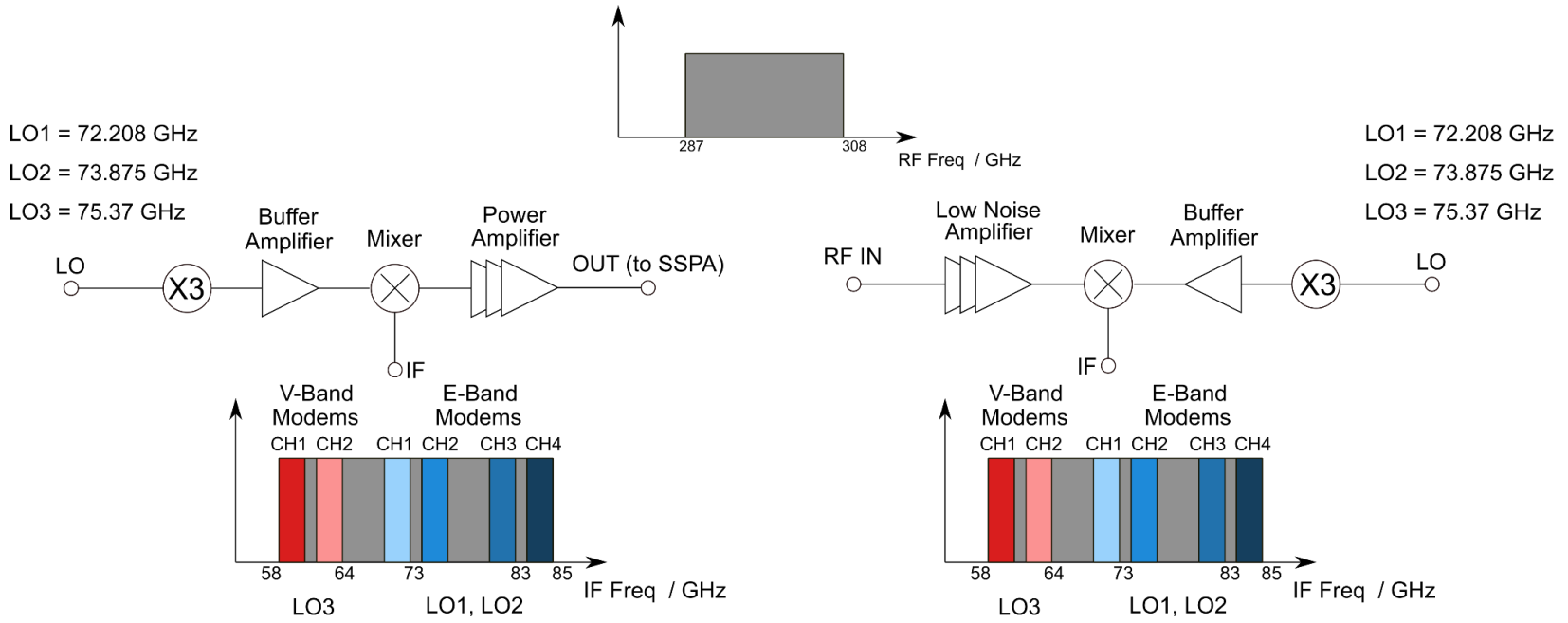
3. Short-Range Wireless Transmission Experiments
   - Simplex-Link
   - Full-Duplex Real-Time Link

4. Conclusion

1. Introduction

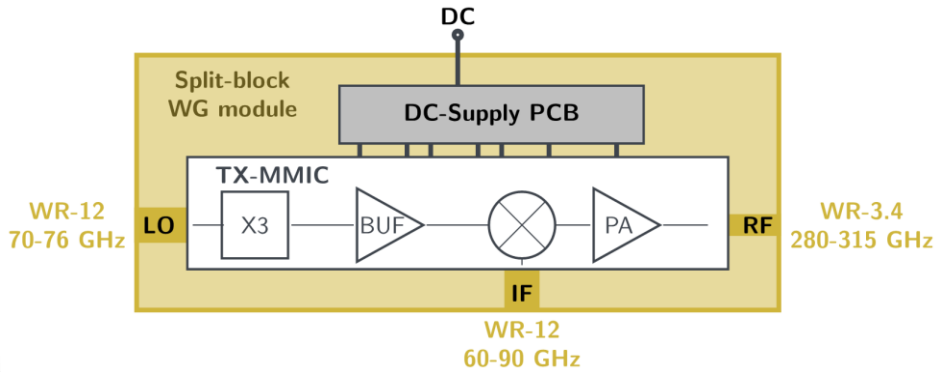
- ThoR frequency plan targets
  I. aggregation of multiple modem channels.
  II. compliance with IEEE802.15.3.d frequency standard.

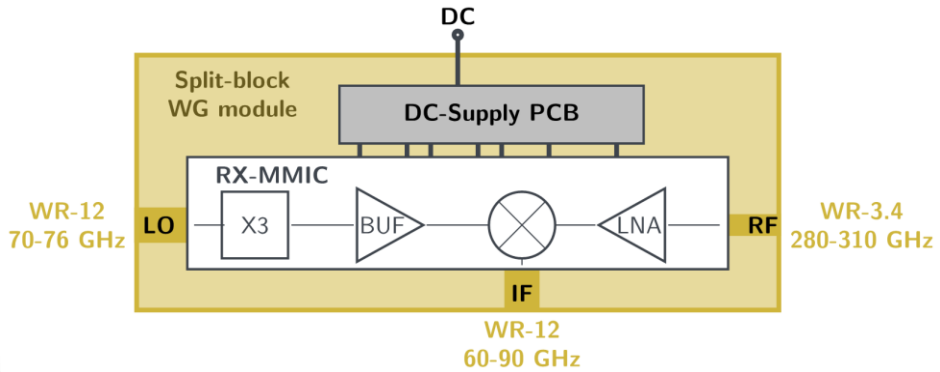
- Superheterodyne architecture offers possibility to embed already existing 70 / 80 GHz terrestrial links based on ETSI EN 302 217-2 standard which allocate the 71-76 GHz and 81-86 GHz frequency bands for up- and down-link.

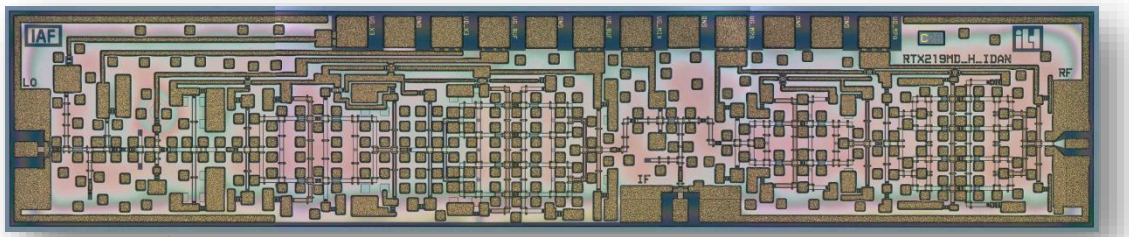


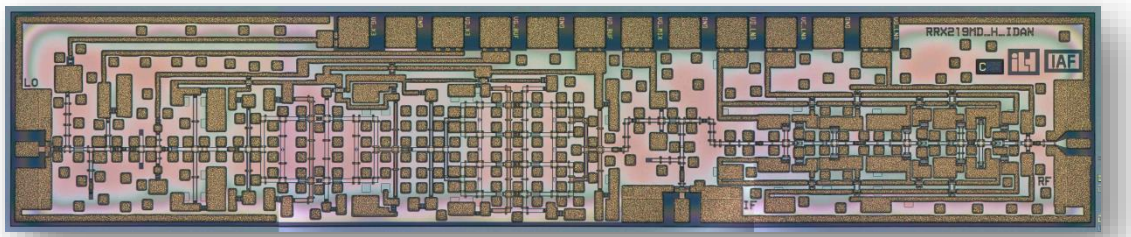
2. Superheterodyne H-Band Transmit and Receive Modules
MMIC Design

- Novel design, specifically developed to suit ThoR frequency plan.
- MMICs fabricated in 35 nm InGaAs mHEMT technology provided by Fraunhofer IAF (f_t > 500 GHz / f_{max} > 1 THz).
- Fully integrated Tx and Rx MMICs implement identical LO path driving a resistive mixer.
  - Tx contains additional RF MPA
  - Rx contains additional RF LNA
- Packaging in split-block waveguide modules with WR-12 (LO, IF) and WR-3.4 (RF) interfaces.





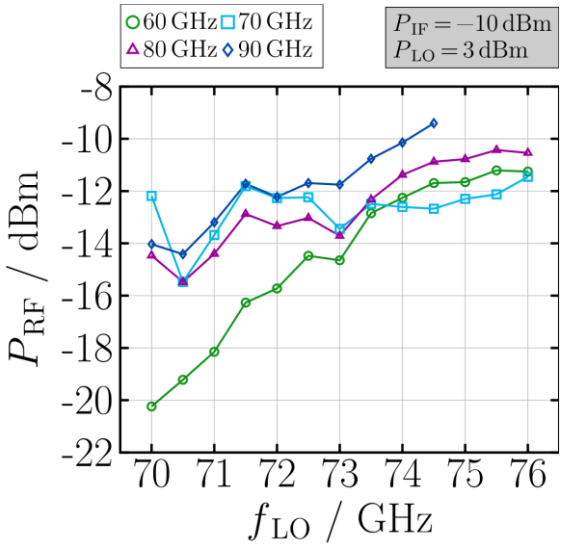




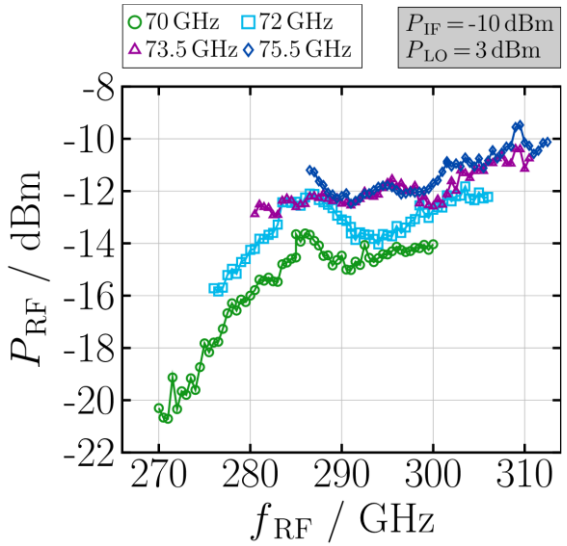
2. Superheterodyne H-Band Transmit and Receive Modules

Transmitter Performance

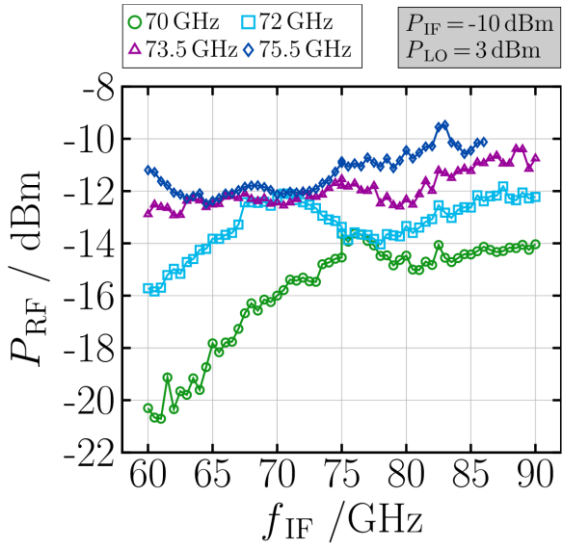
P_{RF} vs. f_{LO}



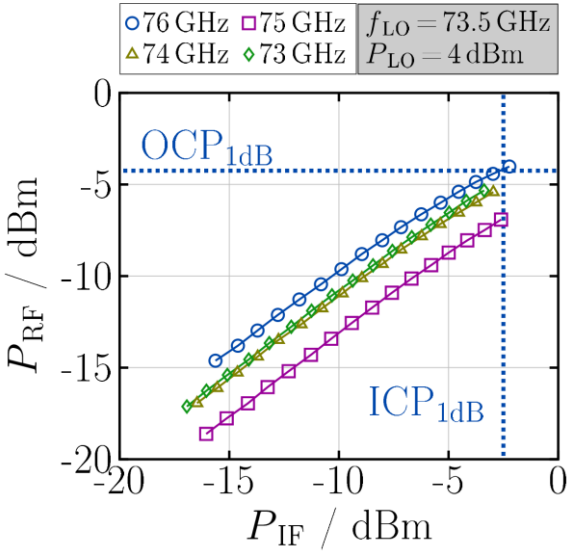
P_{RF} vs. f_{RF}



P_{RF} vs. f_{IF}



P_{RF} vs. P_{IF}

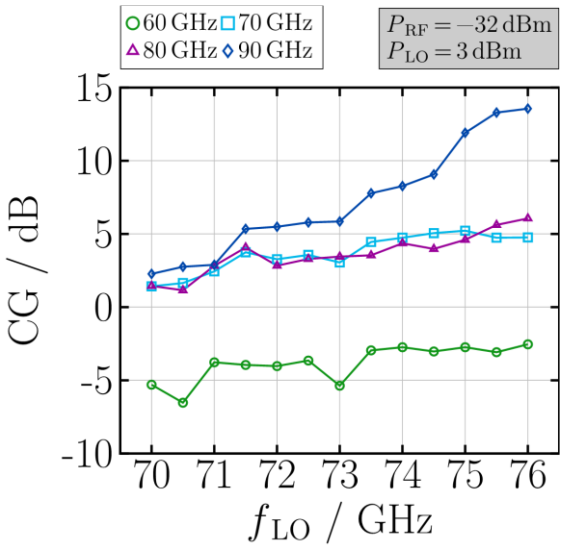


- LO frequency range: 70 – 76 GHz
- IF frequency range: 60 – 90 GHz
- RF frequency range: 280 – 312 GHz
- Conversion gain: -2 … 0 dB
- Input-related 1dB compression point: -4 … -2 dBm

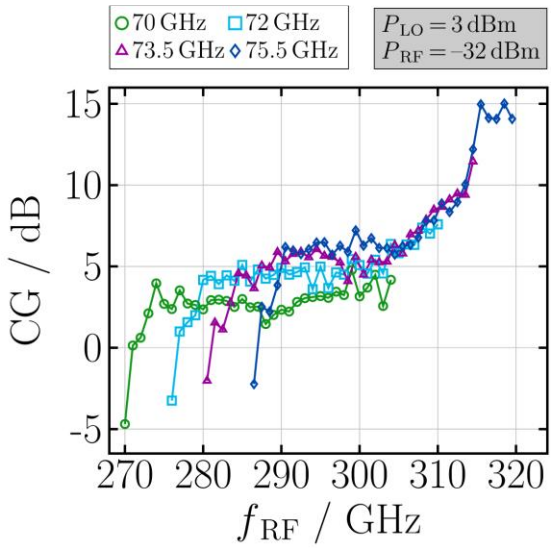
2. Superheterodyne H-Band Transmit and Receive Modules

Receiver Performance

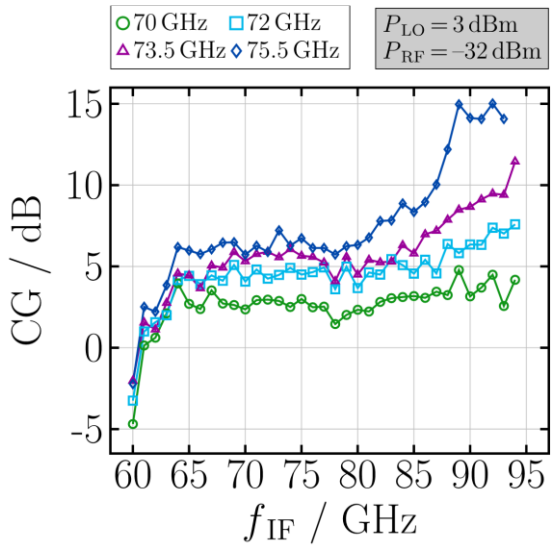
P_{RF} vs. f_{LO}



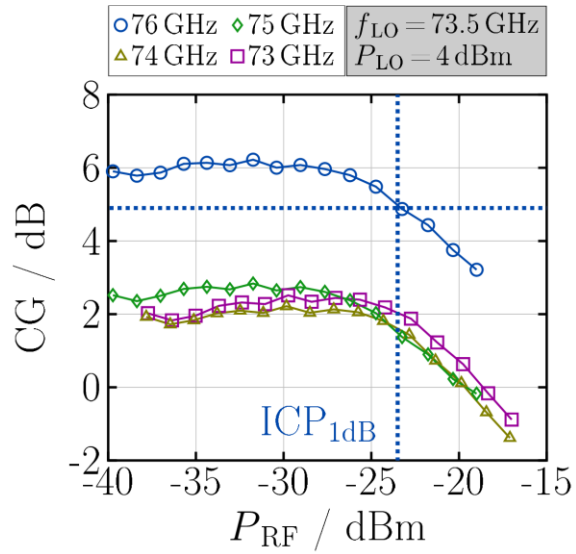
P_{RF} vs. f_{RF}



P_{RF} vs. f_{IF}



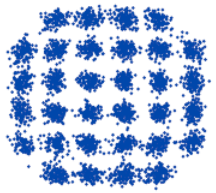
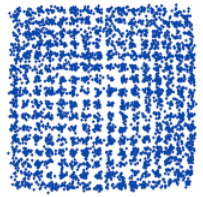
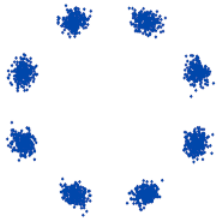
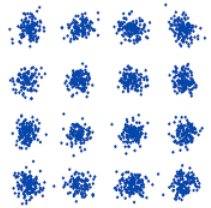
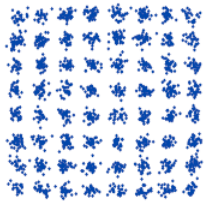
CG vs. P_{RF}



- LO frequency range: 70 – 76 GHz
- IF frequency range: 60 – 90 GHz
- RF frequency range: 270 – 312 GHz
- Conversion gain: 2 … 5 dB
- Input-related 1dB compression point: -24 … -20 dBm

2. Superheterodyne H-Band Transmit and Receive Modules

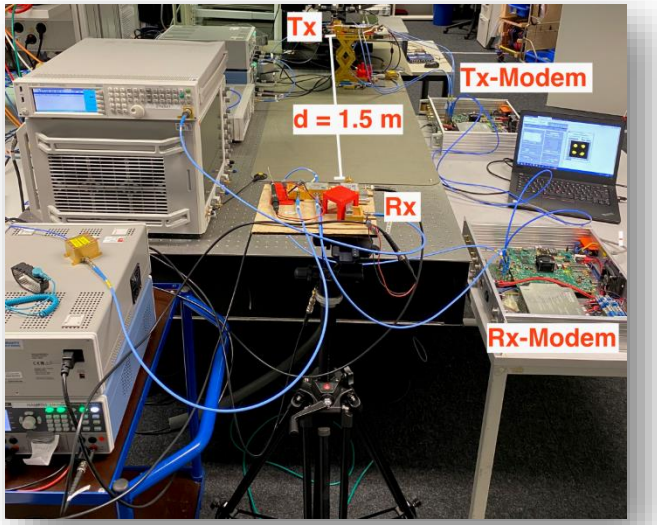
Back-to-Back Results

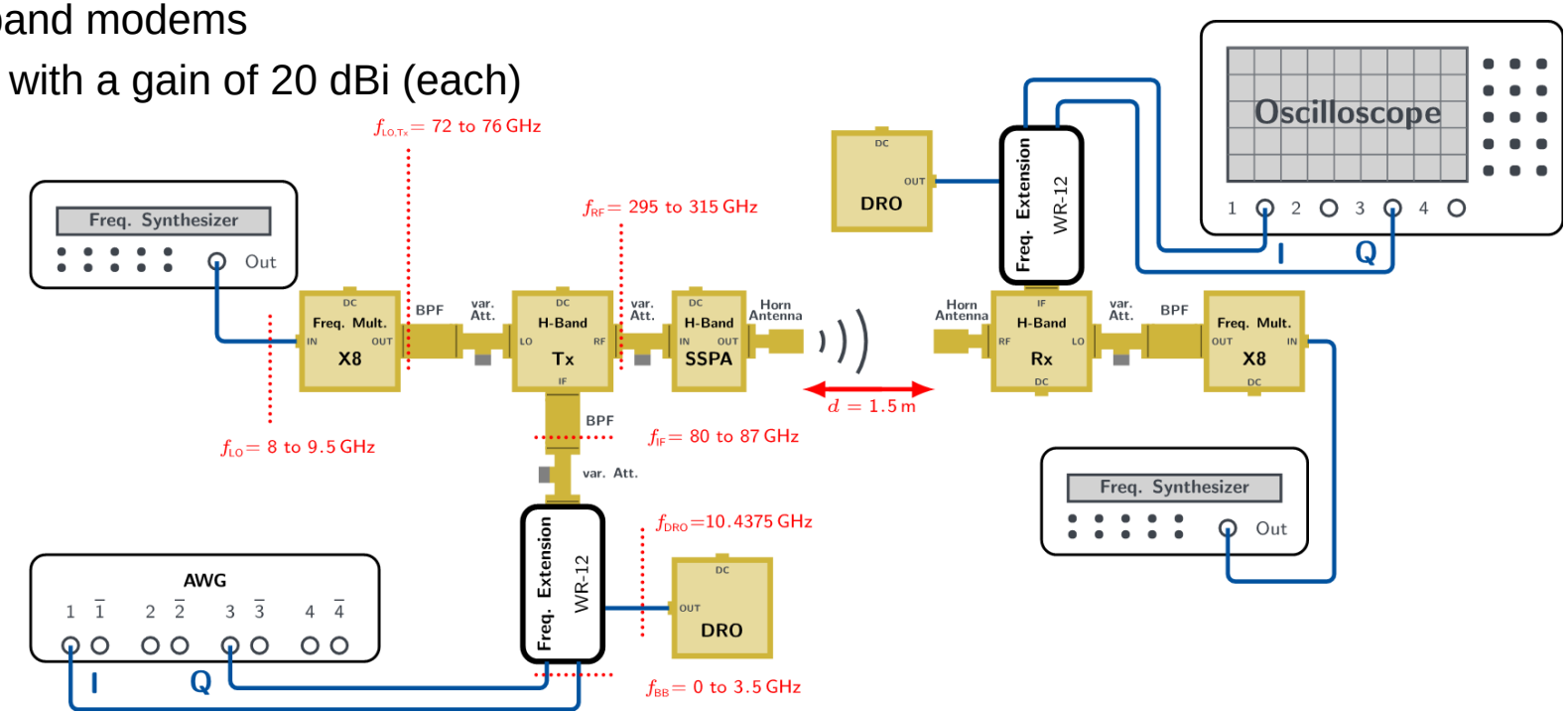
	Maximum performance		IEEE802.15.3d			
Channel ID	-	-	44	54	25	26
$f_{IF,center}$ / GHz	79.1	79.25	85.7	79.1	84.6	84.6
$f_{RF,center}$ / GHz	301.2	304.25	302.4	300.2	305.6	307.8
Bandwidth / GHz	8.64	1.35	4.32	8.64	2.16	2.16
Data Rate / Gbit/s	32	8	9.6	25.6	9.6	11.2
Modulation Scheme	32-QAM	256-QAM	8-PSK	16-QAM	64-QAM	128-QAM
Constellation						
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

- Maximum datarate 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

3. Short-Range Wireless Transmission Experiments
Simplex Link - Setup

- H-band Tx + SSPA[1] / Rx modules
- Custom E-band frequency extension to provide IF signals
- Two data generation and reception scenarios
  - I. PRBS Setup: Arbitrary Waveform Generator (AWG) + oscilloscope
  - II. Real-Time Setup: Pair of baseband modems
- Air interface realized with horn antennas with a gain of 20 dBi (each)

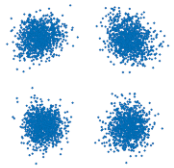
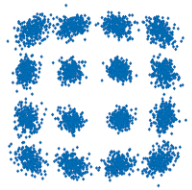
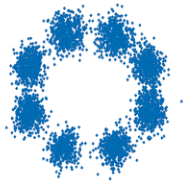
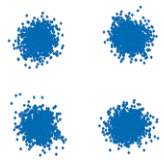




[1] L. John, A. Tessmann, A. Leuther, P. Neininger, T. Merkle, and T. Zwick, “Broadband 300-GHz Power Amplifier MMICs in InGaAs mHEMT Technology,” IEEE Transactions on Terahertz Science and Technology, vol. 10, no. 3, pp. 309–320, 2020.

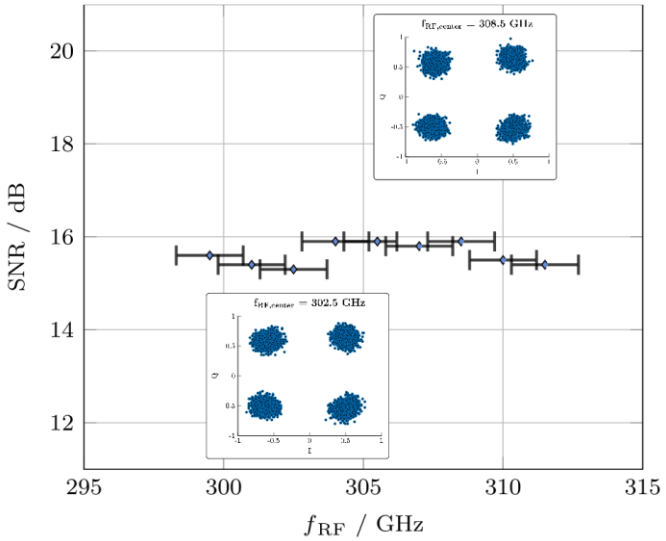
3. Short-Range Wireless Transmission Experiments
Simplex Link - Results

PRBS Setup

	Maximum performance		IEEE802.15.3d		
Channel ID	-	-	27	46	46
$f_{RF,center}$ / GHz	308.5	309.5	309.96	311.04	311.04
$f_{IF,center}$ / GHz	83.5	84.5	84.6	83.5	83.5
Bandwidth / GHz	6.75	1.35	2.16	4.32	4.32
Data Rate / Gbps	10	5	6.4	9.6	6.4
Modulation Scheme	QPSK	32-QAM	16-QAM	8-PSK	QPSK
Constellation					
EVM_{rms} / %	23.7	6.5	10	19.9	19.7
SNR / dB	12.5	19.7	17.4	14	14.1

- Max. data rate of 10 Gbit/s
- Max. spectral efficiency using 32-QAM
- Successful addressing of various IEEE802.15.3d channels with bandwidth of 2.16 and 4.32 GHz

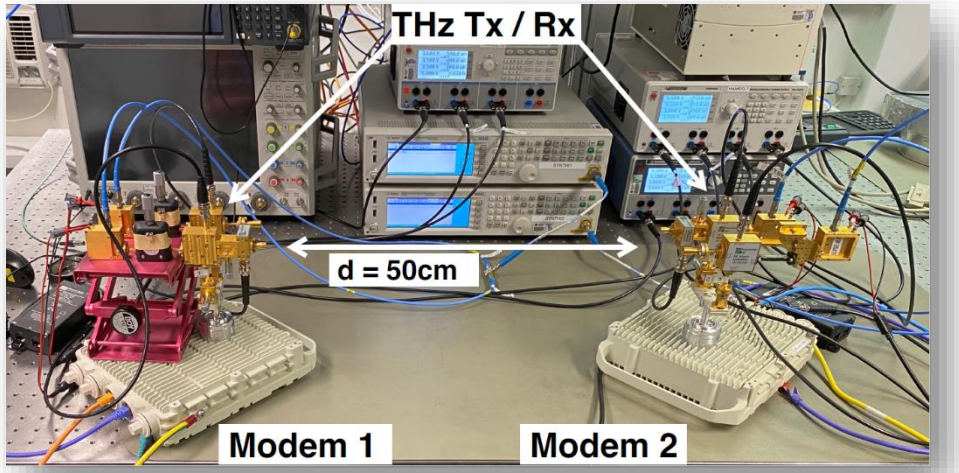
Real-Time Setup



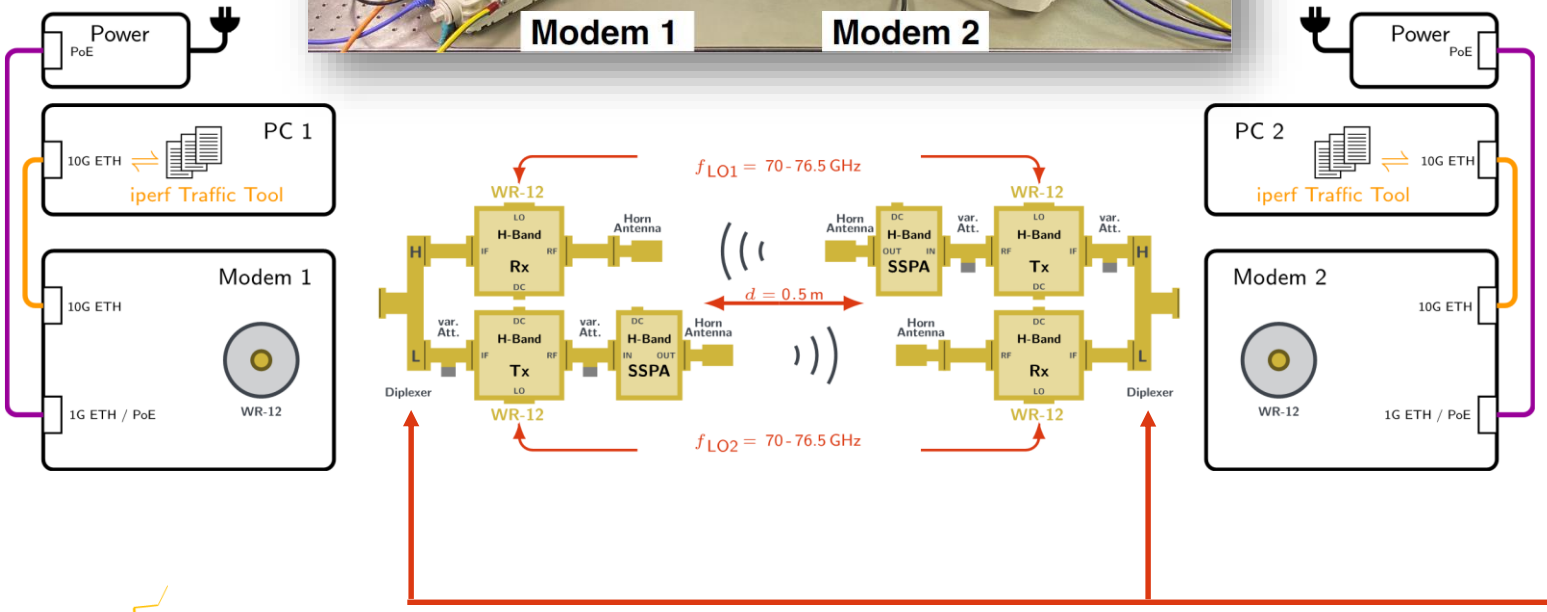
- Successfull transmission in channels 22 – 28 of the IEEE802.15.3d scheme
- Data rate of 2.85 Gbit/s
- Constant SNR of 15 to 16 dB
  → prevents use of higher modulation order than QPSK modulation by the modems

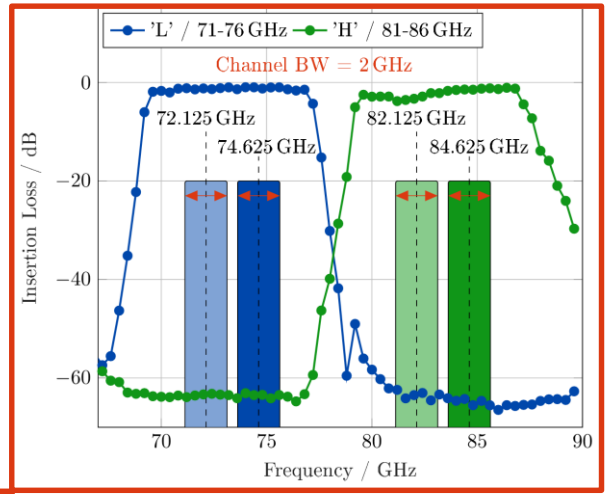
3. Short-Range Wireless Transmission Experiments

Full-Duplex Real-Time Link - Setup



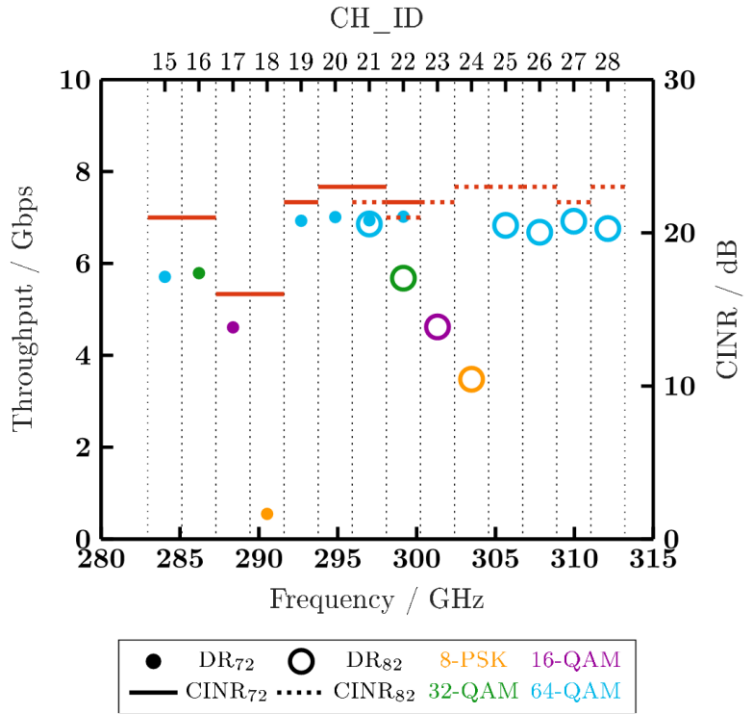
- Two pairs of superheterodyne Tx and Rx modules.
- Solid-state power amplifiers (SSPA) provide transmit power up to 0 dBm.
- E-band modems using frequency division duplex.
- Traffic generation performed by one PC per link terminal running open-source traffic tools.





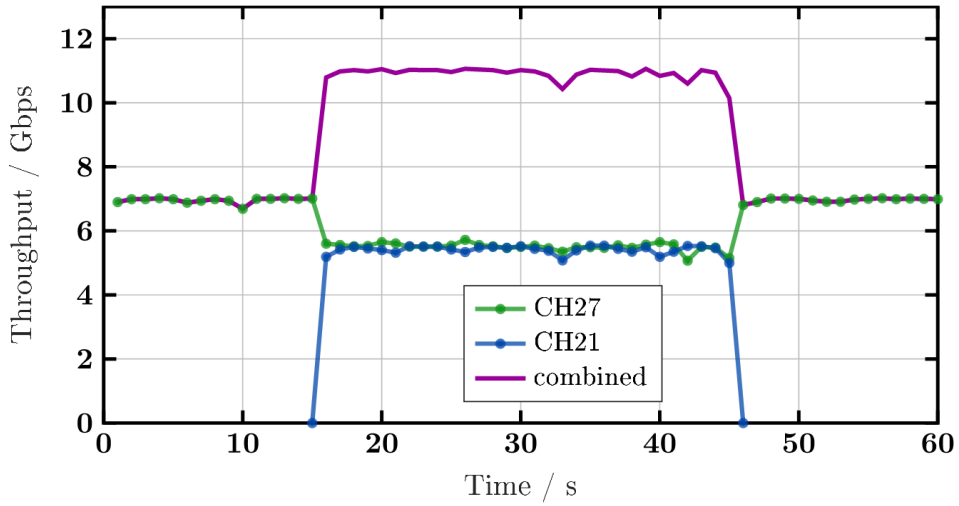
3. Short-Range Wireless Transmission Experiments
Full-Duplex Real-Time Link - Results

IEEE802.15.3d compliance (CH15 - 28)



- Maximum throughput per channel of 7 Gbps is achieved using 64-QAM.
- Channels 16, 17 and 18 impaired by in-band interferer arising from LO harmonic.

Full-Duplex Transmission



- Sequential initiation and termination of traffic generation in channel 21 and 27.
- Maximum throughput of 11.09 Gbps

4. Conclusion

- Newly developed superheterodyne Tx and Rx chipset suiting the ThoR frequency plan was shown.

- Successful operation of the superheterodyne link has been demonstrated in short range wireless transmission experiments.

- H-band hardware shows sufficient transparency to support higher order modulation schemes
  - 10 Gbit/s (QPSK) and 5 Gbit/s (32-QAM) in PRBS setup using custom E-band freq. extensions.
  - 11.09 Gbit/s net data rate using 64-QAM for a duplex transmission using E-band modems.

- Compliance with the IEEE802.15.3d frequency standard is demonstrated for channels 15 - 28.

Thank you for your attention!

ご清聴ありがとうございました

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