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Re: n/a

Abstract: The architecture, implementation and performance of an active MMIC-based 240 GHz frontend for multi-gigabit wireless communication is presented. Using this frontend, indoor transmission experiments show the feasibility of data rates up to 30 Gbit/s. In a long-range outdoor transmission, a distance of 1 km with data rates up to 24 Gbit/s is achieved.

Purpose: Information of IEEE 802.15 SG 100G

High Data Rate Wireless Communication using a 240 GHz carrier

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[3] Radiometer Physics GmbH, Meckenheim, Germany

Outline

- ❑ Motivation
- ❑ 240 GHz Frontend MMICs & Modules
- ❑ Transmission Experiments
  - ❑ Receiver sensitivity
  - ❑ Lab experiments
  - ❑ Long range outdoor transmission
- ❑ Comparison to State-of-the-Art

MOTIVATION

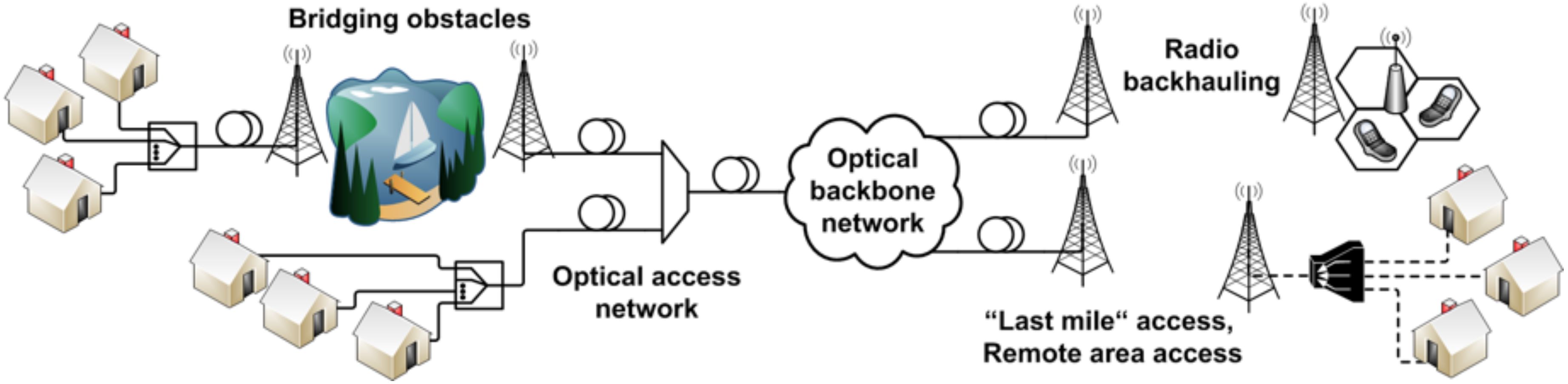
Motivation

Millimeter Wave Communication

- Available bandwidth
- Compactness of components
- High gain antennas combined with small aperture
- Large atmospheric transmission windows

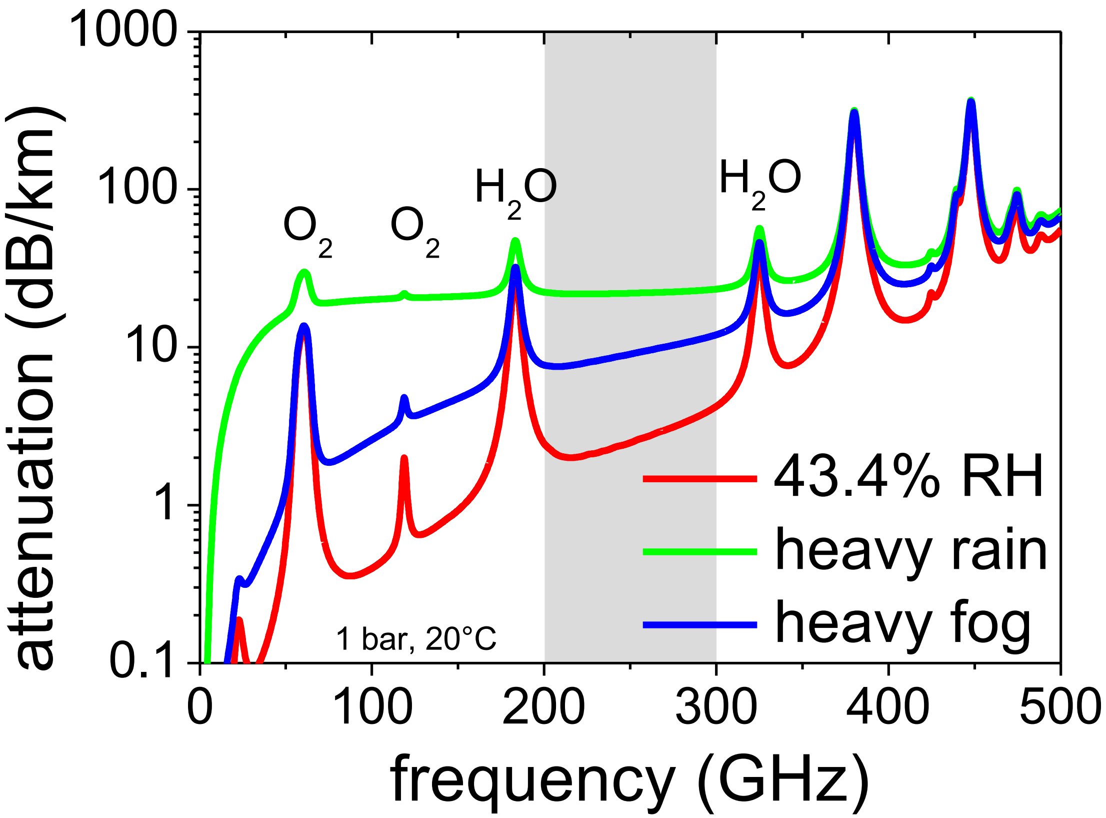
Application Scenarios

- Point-to-Point links
- Backhaul / “Last Mile” access
- Board-to-board
- Intra-machine communication



Atmospheric attenuation in the mmW range

- Large atmospheric transmission window between 183 and 325 GHz
- Atmospheric attenuation:
  - Clear atmosphere: 2.7 – 4.5 dB/km
  - Foggy atmosphere: 9.5 dB/km
  - Rain drops: 15.3 – 23 dB/km



I.T.U. Recommendation, "Attenuation by atmospheric gases," *ITU-R P.676-8*, 2009.

I.T.U. Recommendation, "Attenuation due to clouds and fog," *ITU-R P.840-4*, 2009.

1.1 km, 240 GHz Wireless Link

Long Range Demonstrator

Fraunhofer IAF

KIT Karlsruhe Institute of Technology

Radiometer Physics GmbH

SIEMENS

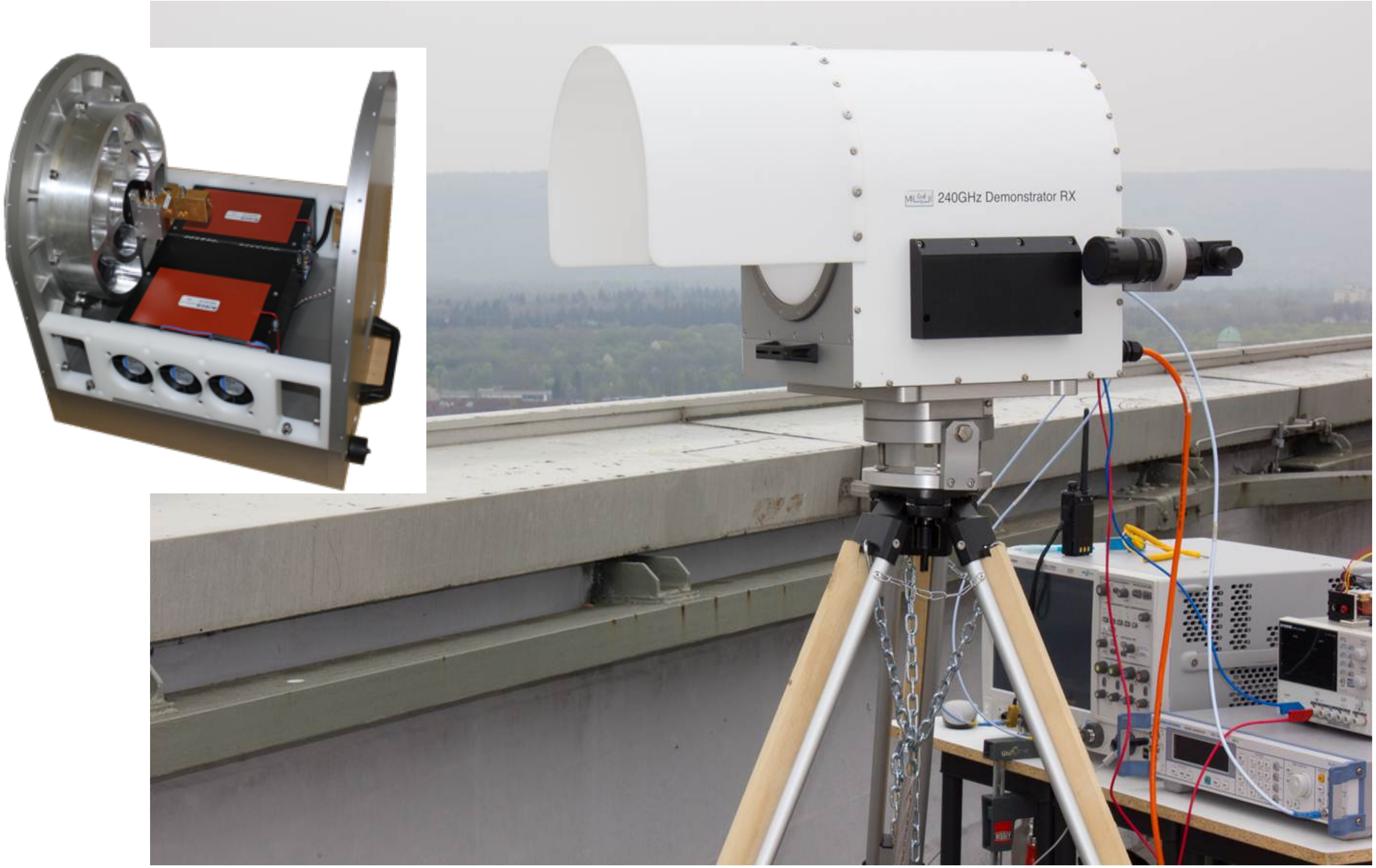
Long Range Demonstrator

Fraunhofer IAF

KIT Karlsruhe Institute of Technology

Radiometer Physics GmbH

SIEMENS



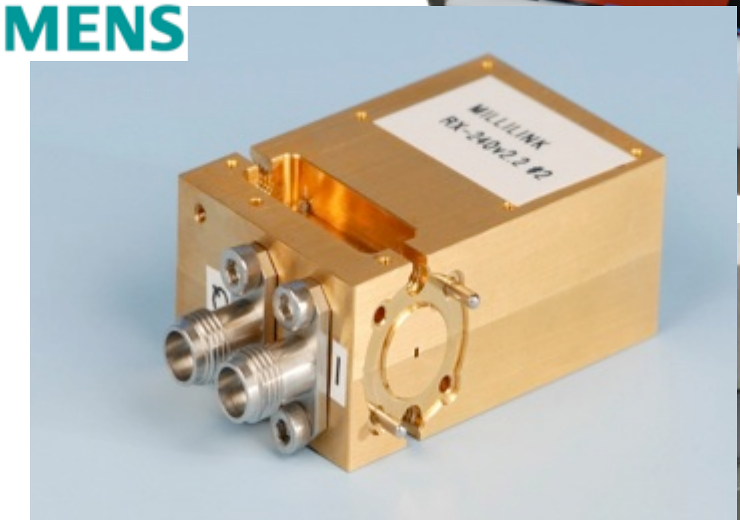
Long Range Demonstrator

Fraunhofer IAF

KIT Karlsruhe Institute of Technology

Radiometer Physics GmbH

SIEMENS



Long Range Demonstrator

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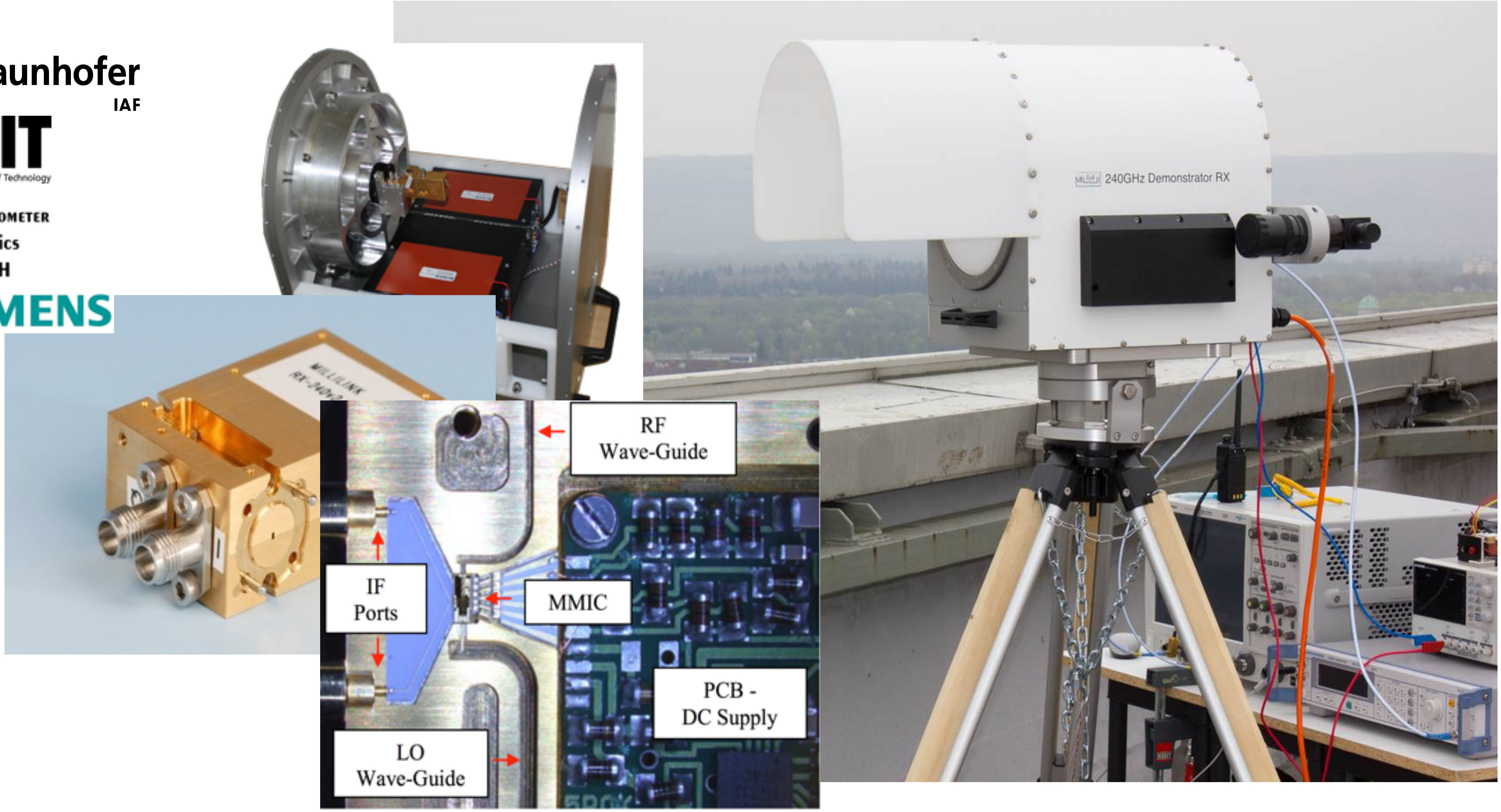

Long Range Demonstrator

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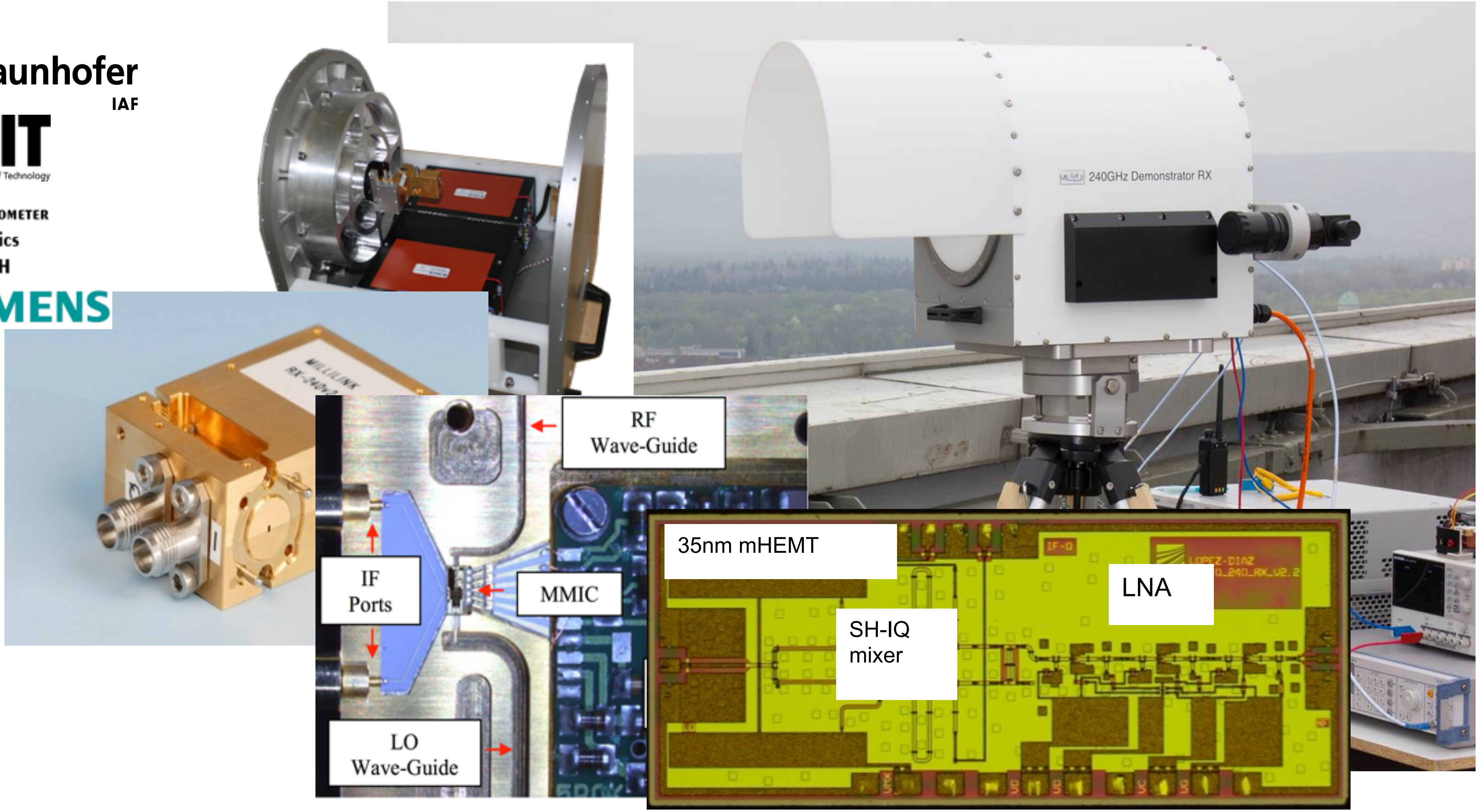

Long Range Demonstrator

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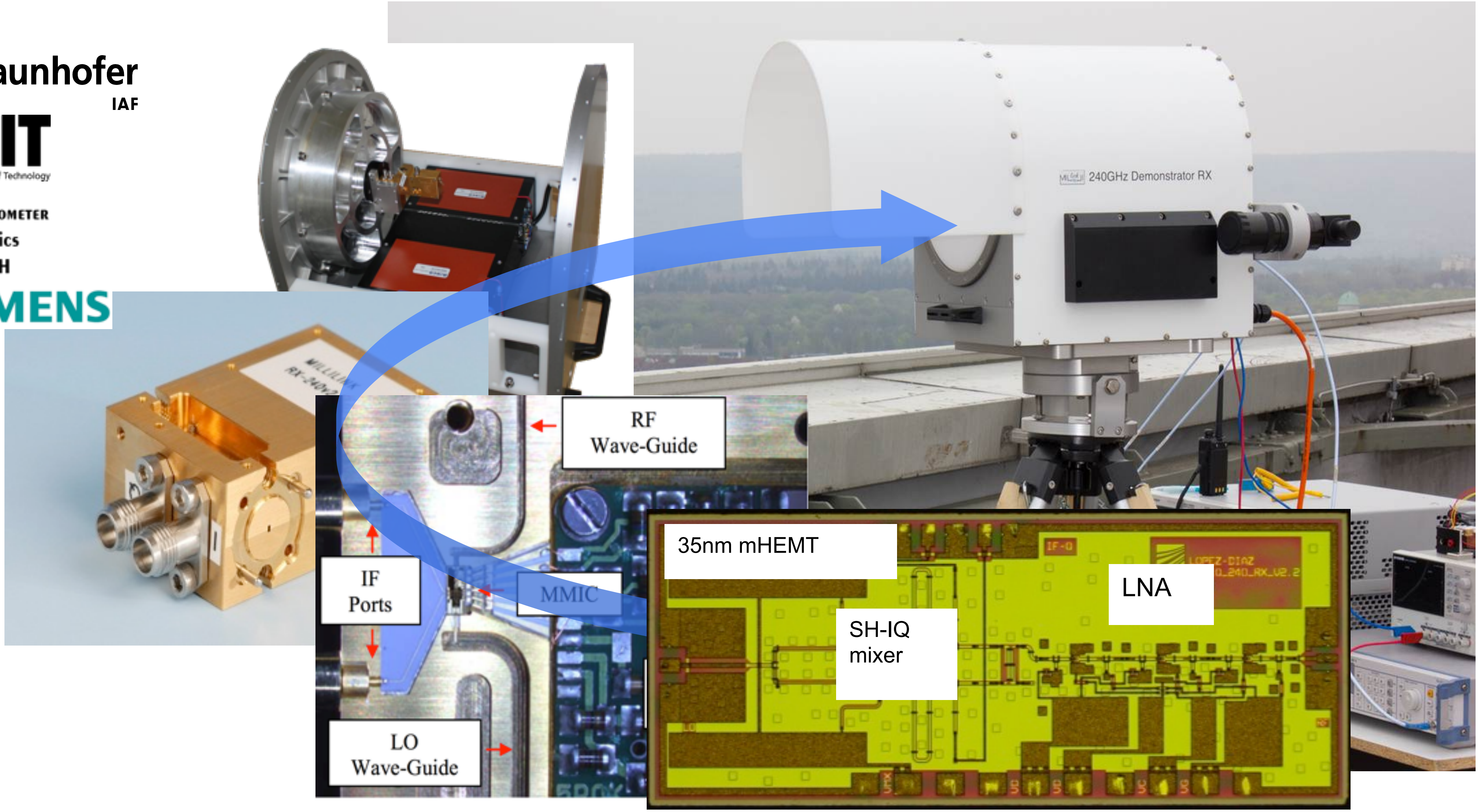
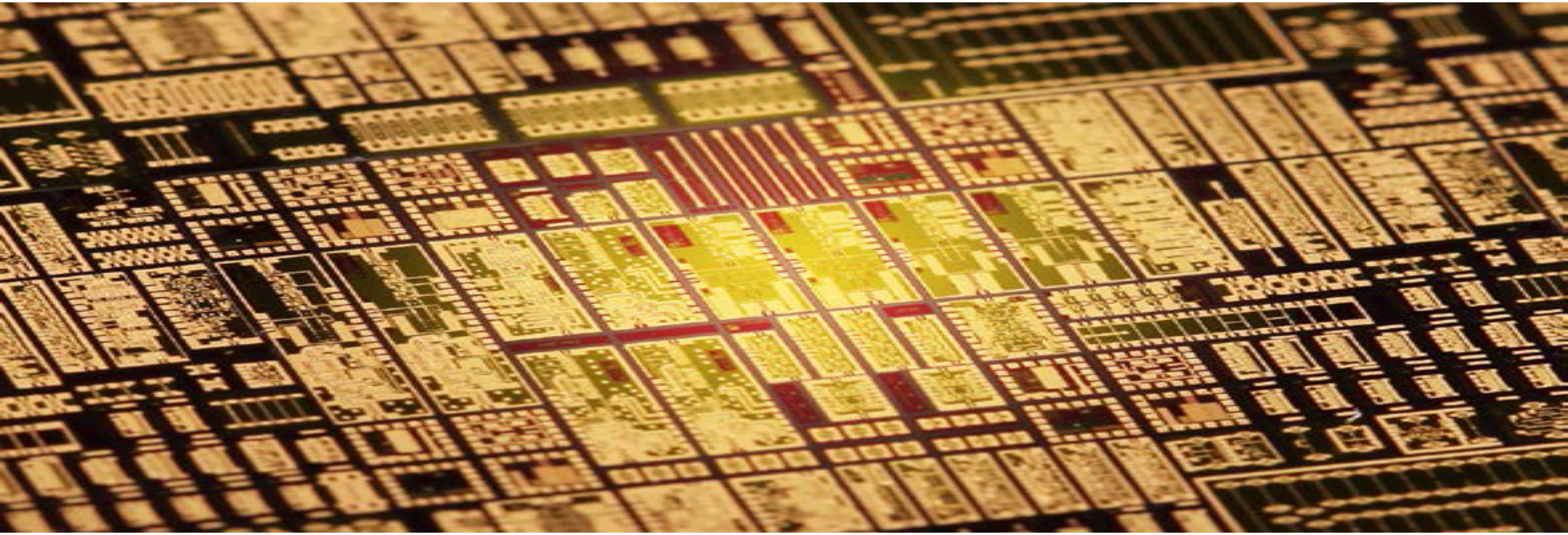
Radiometer Physics GmbH
SIEMENS





240 GHZ FRONTEND MMICS & MODULES

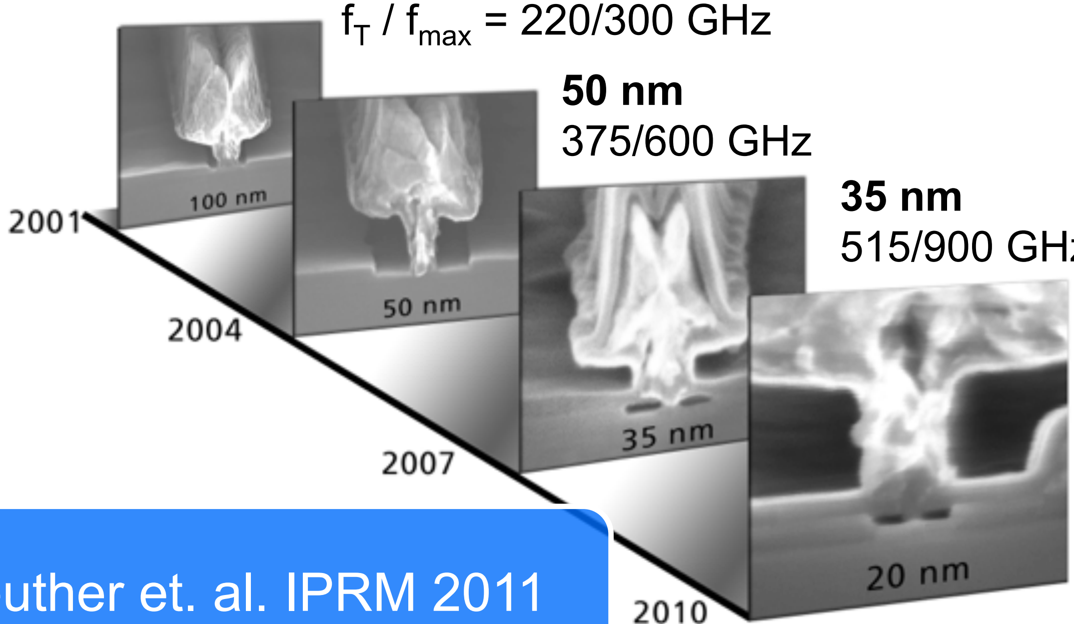
Metamorphic High Electron Mobility Transistor

100 nm
f_T / f_{max} = 220/300 GHz

50 nm
375/600 GHz

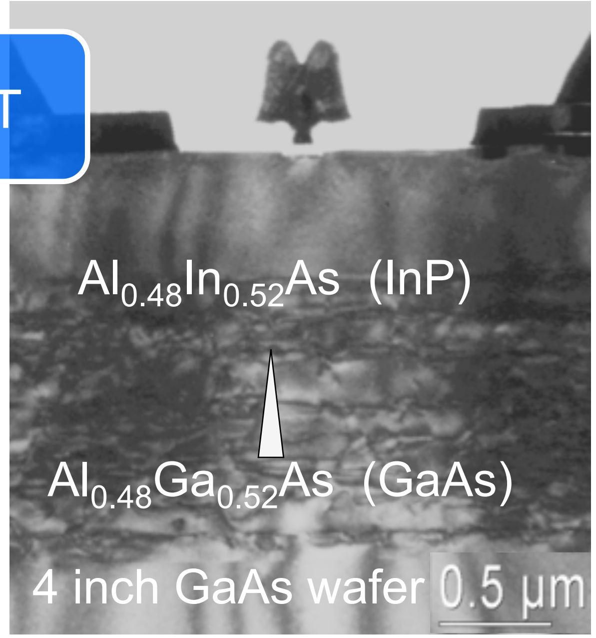
35 nm
515/900 GHz

20 nm
660/>1000 GHz

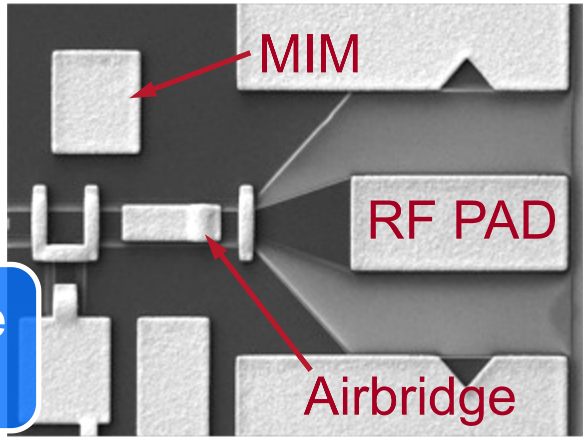


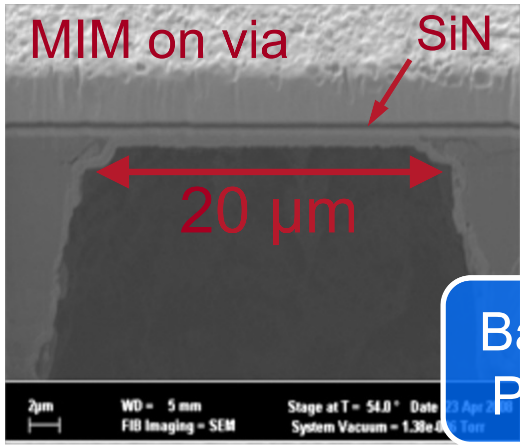
Leuther et. al. IPRM 2011

mHEMT



Frontside Process



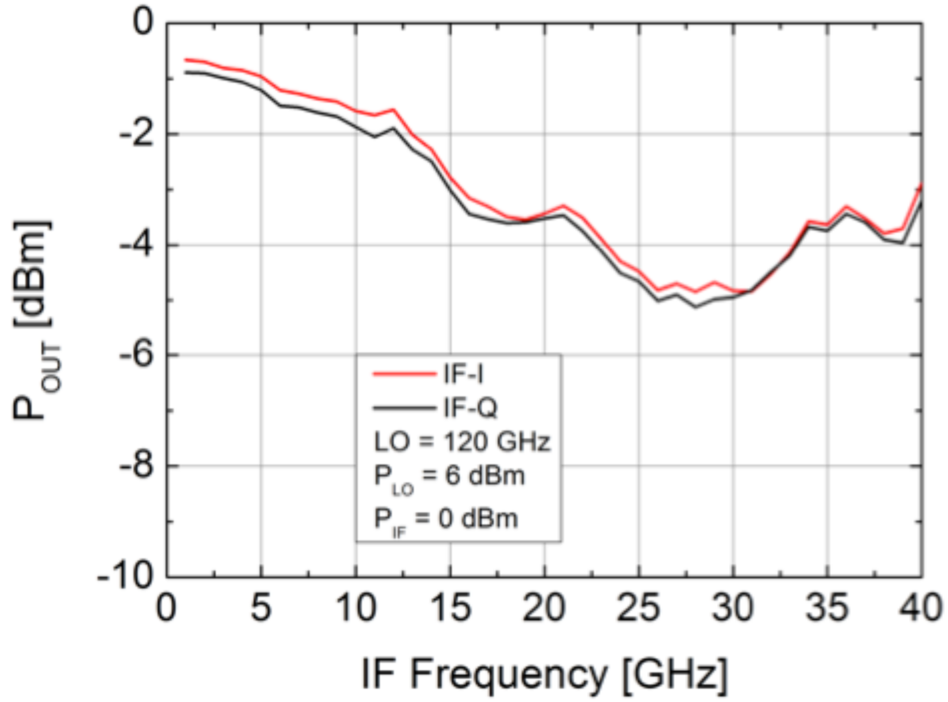


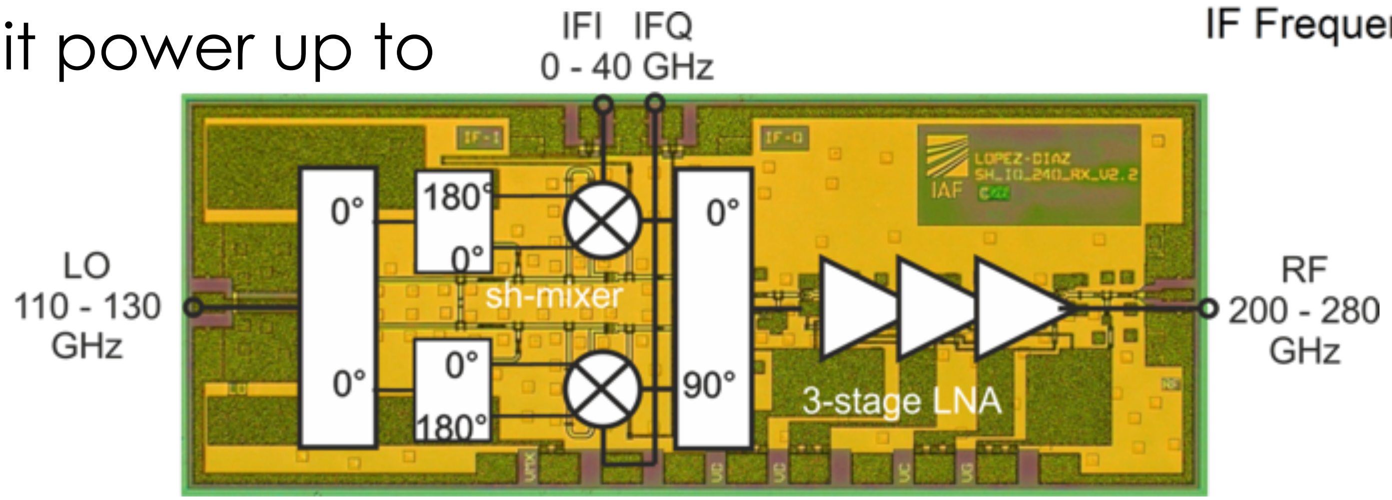
Backside Process

Fraunhofer IAF

240 GHz Subharmonic quadrature transmitter

- 35 nm mHEMT technology
- 2x subharmonic single balanced mixer cells
- 240 GHz Lange coupler for I/Q functionality
- 240 GHz LNA featuring > 35 dB gain
- RF transmit power up to -1 dBm

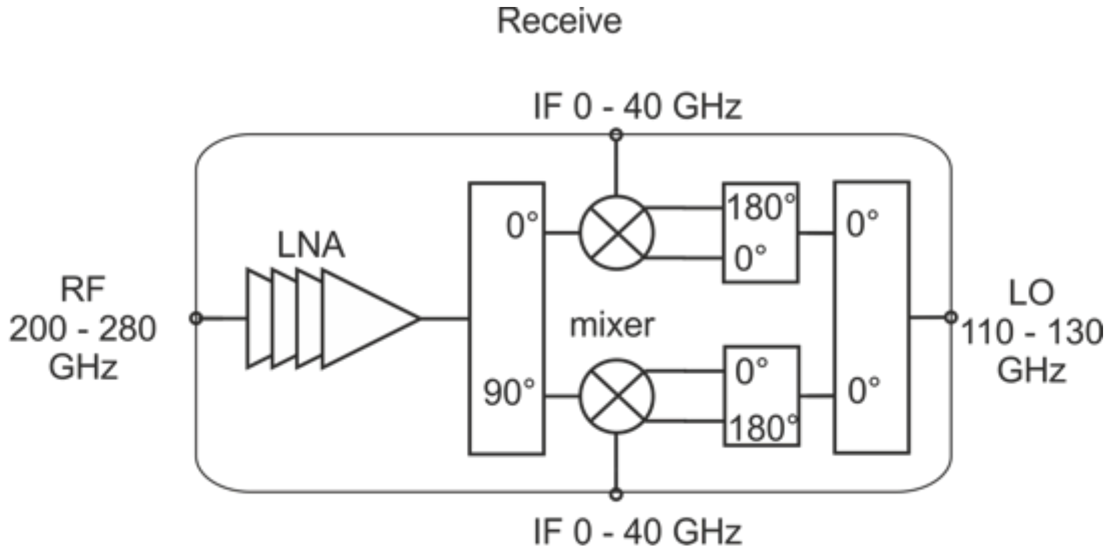


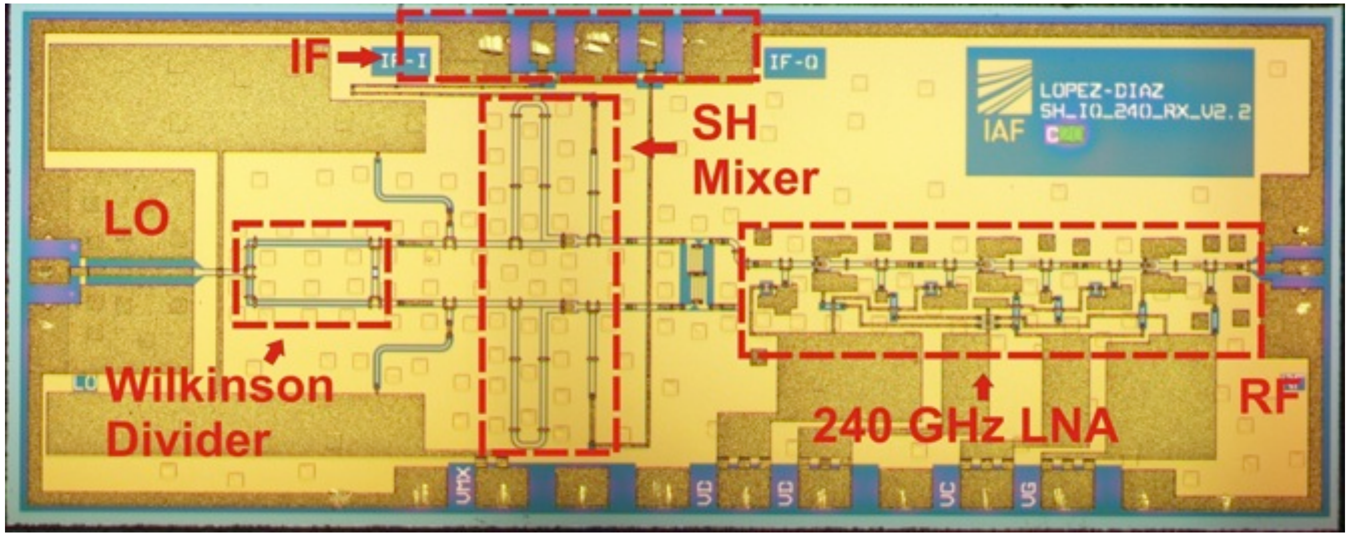


Fraunhofer IAF

240 GHz Subharmonic quadrature receiver

- Same stages as in Tx, but reversed LNA
- Same packaging interfaces as in Tx
- Conversion gain 10 dB





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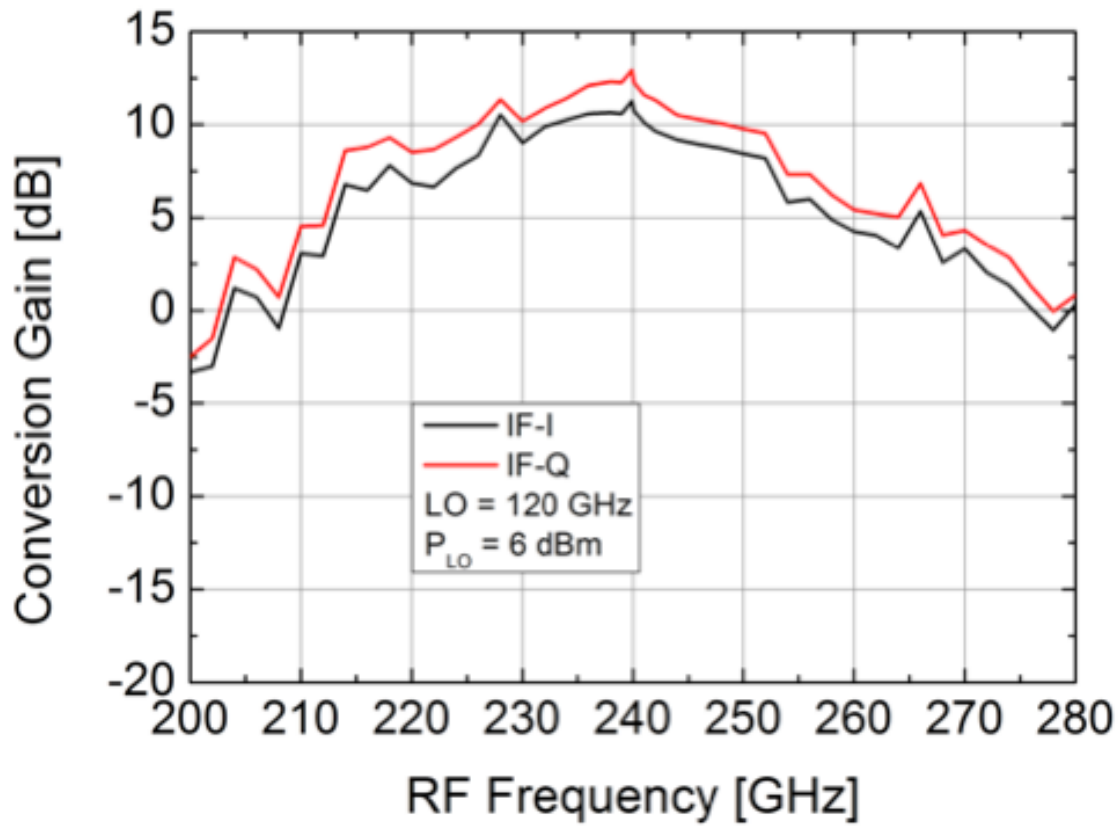
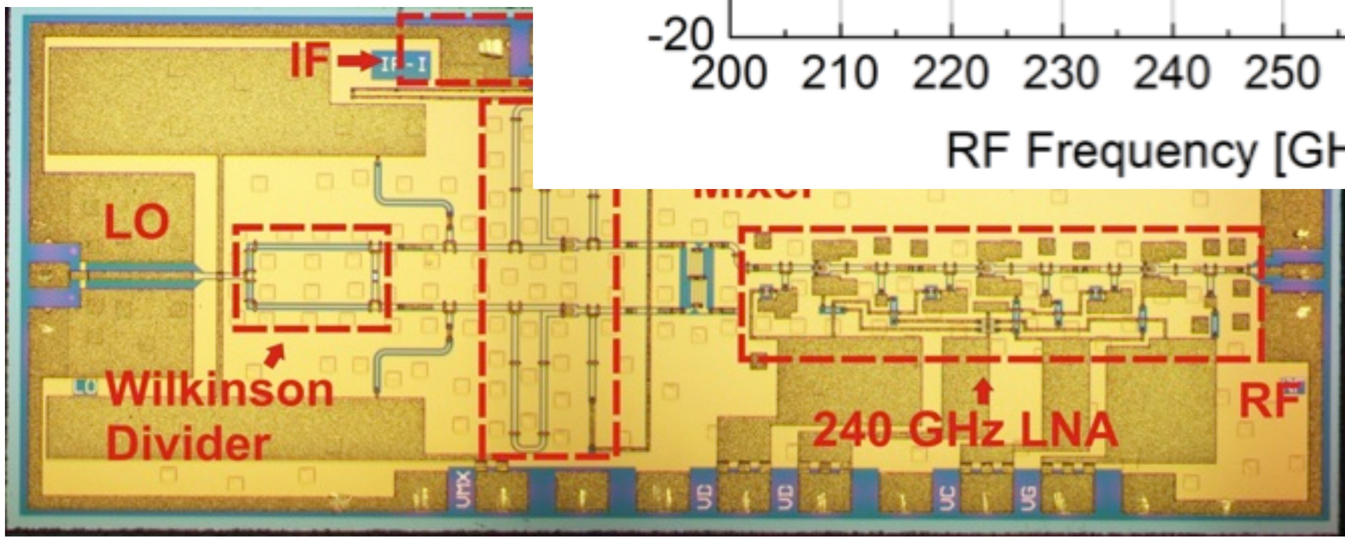
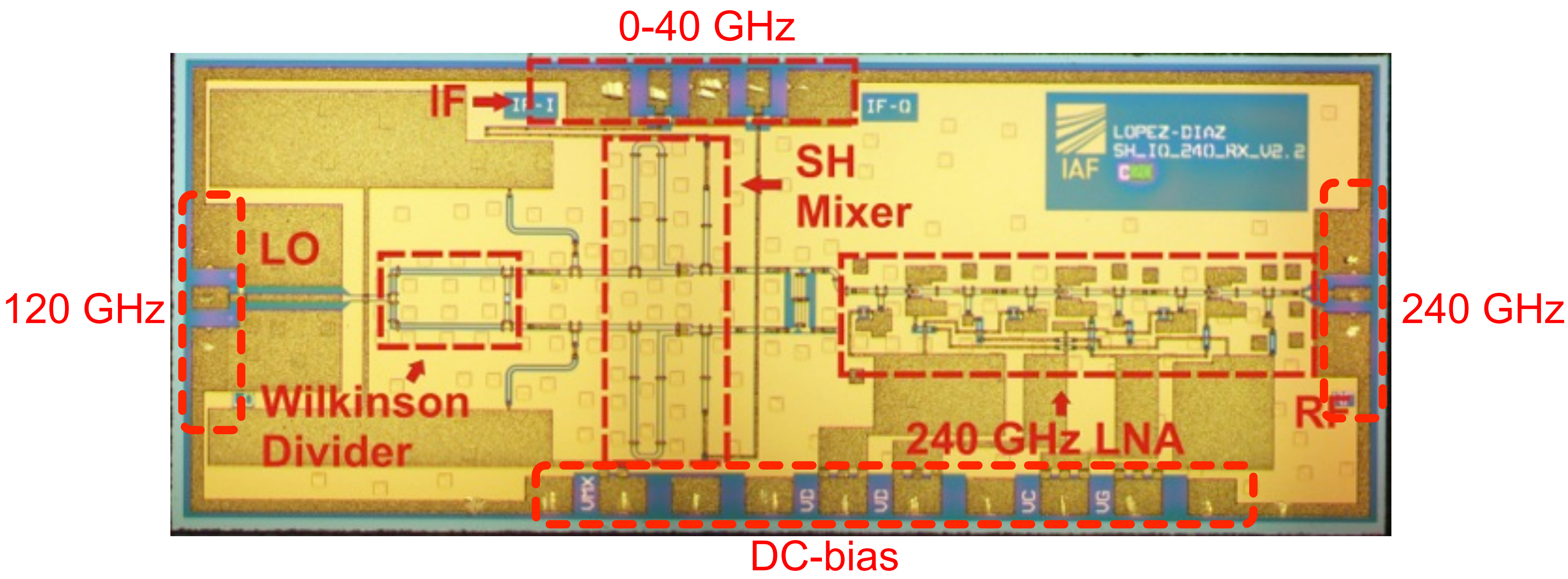




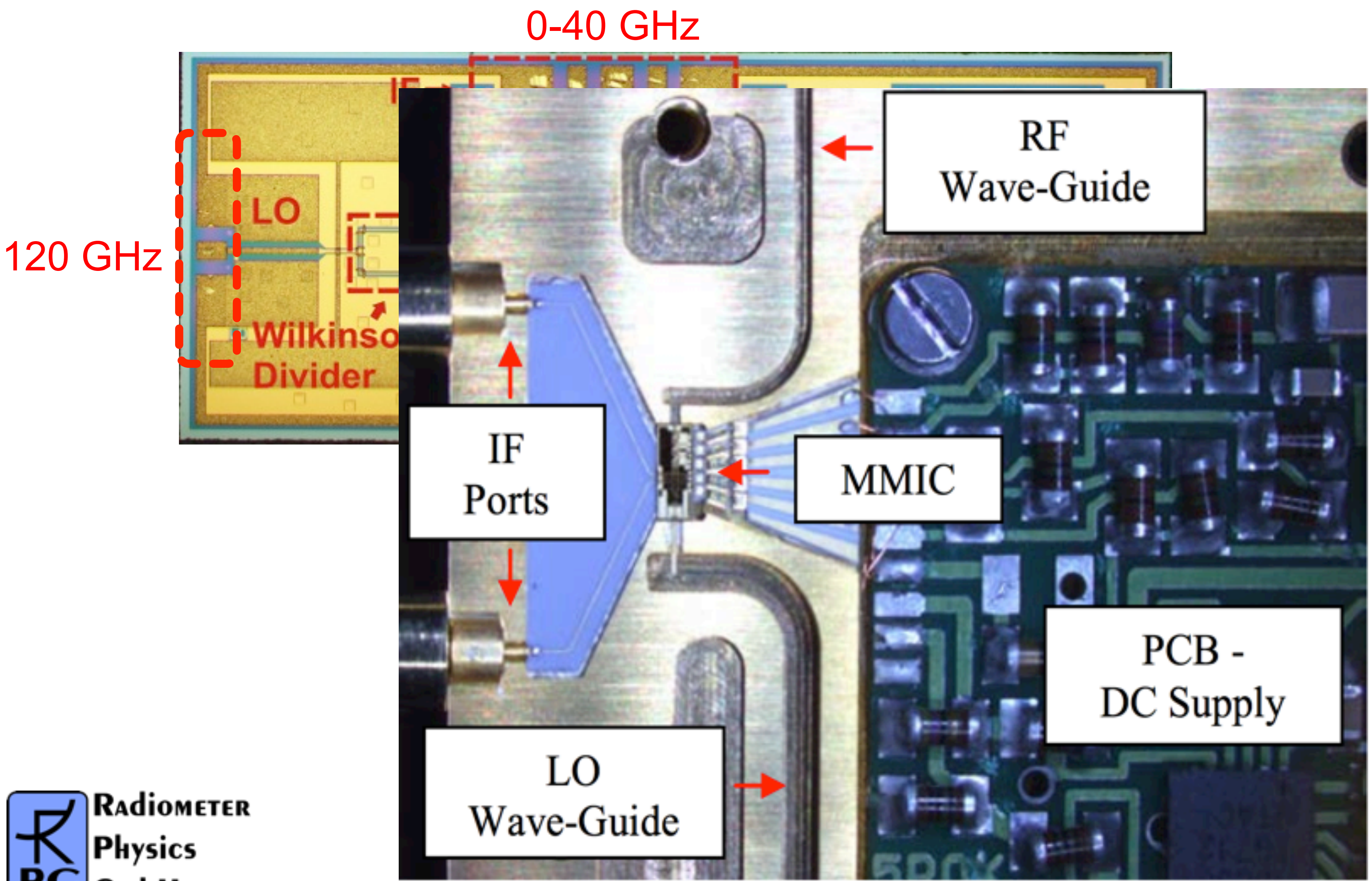
Fraunhofer
IAF

Splitblock Waveguide Packaging



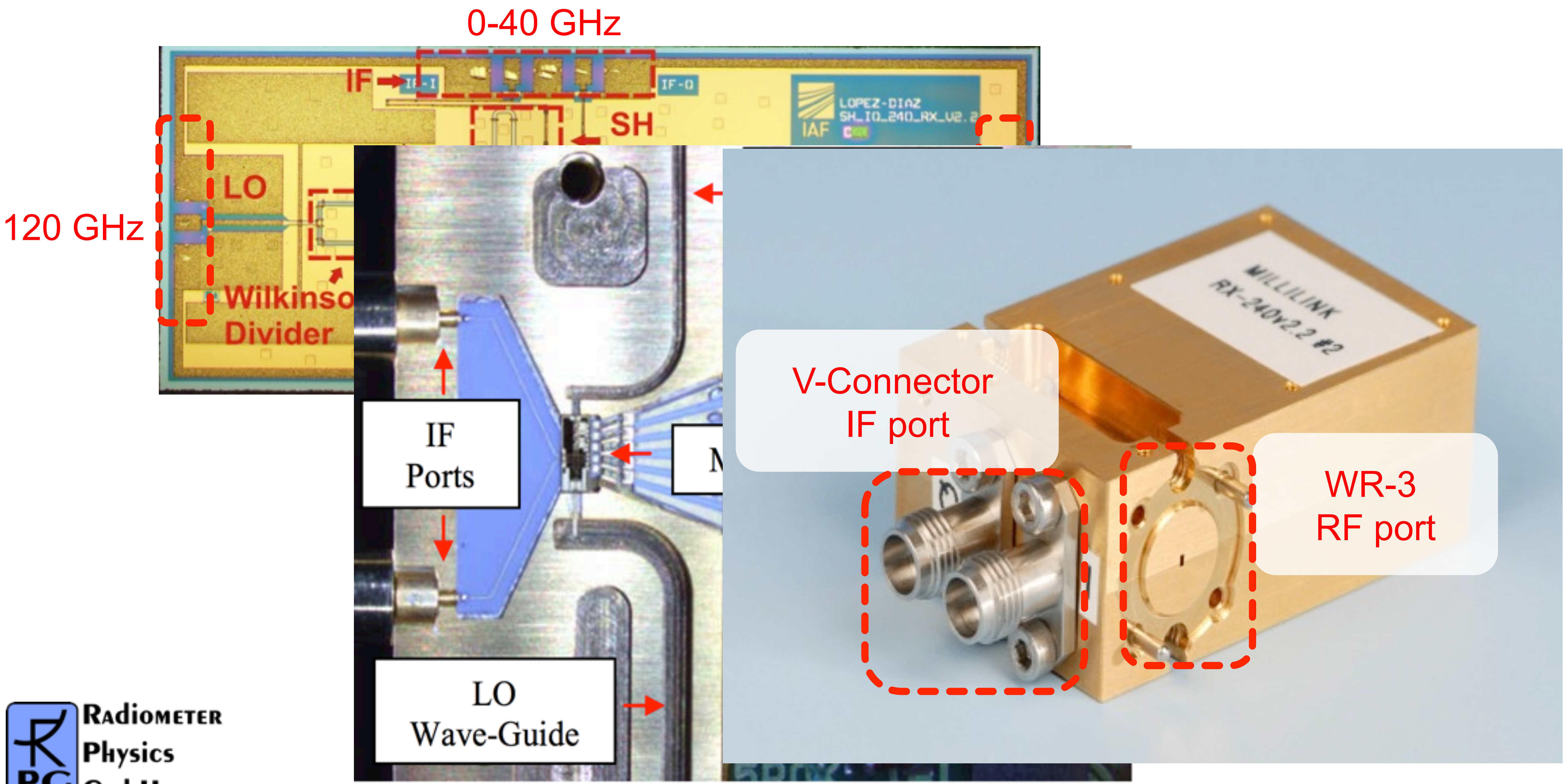
Radiometer Physics GmbH

Splitblock Waveguide Packaging



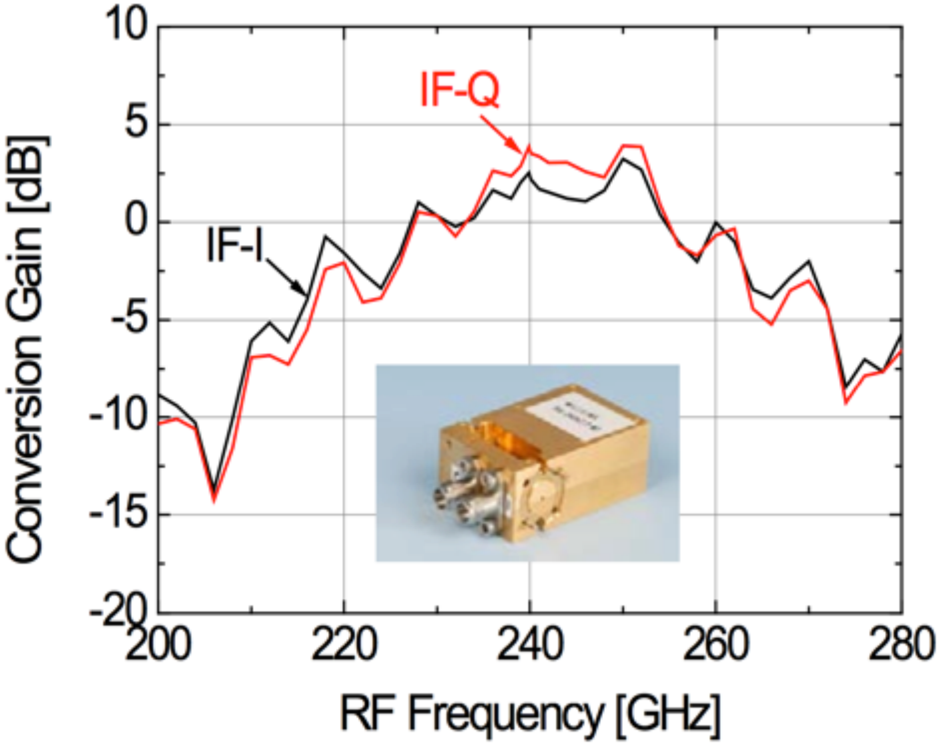
Radiometer Physics GmbH

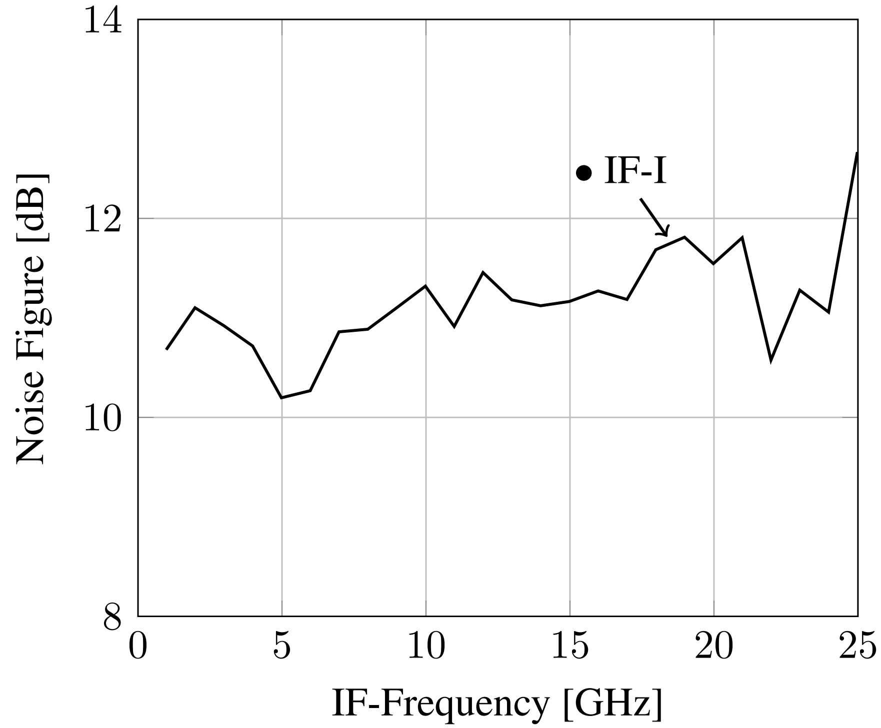
Splitblock Waveguide Packaging



Radiometer Physics GmbH

240 GHz Receiver





Conversion gain

- up to 3 dB
- I/Q imbalance below 2 dB

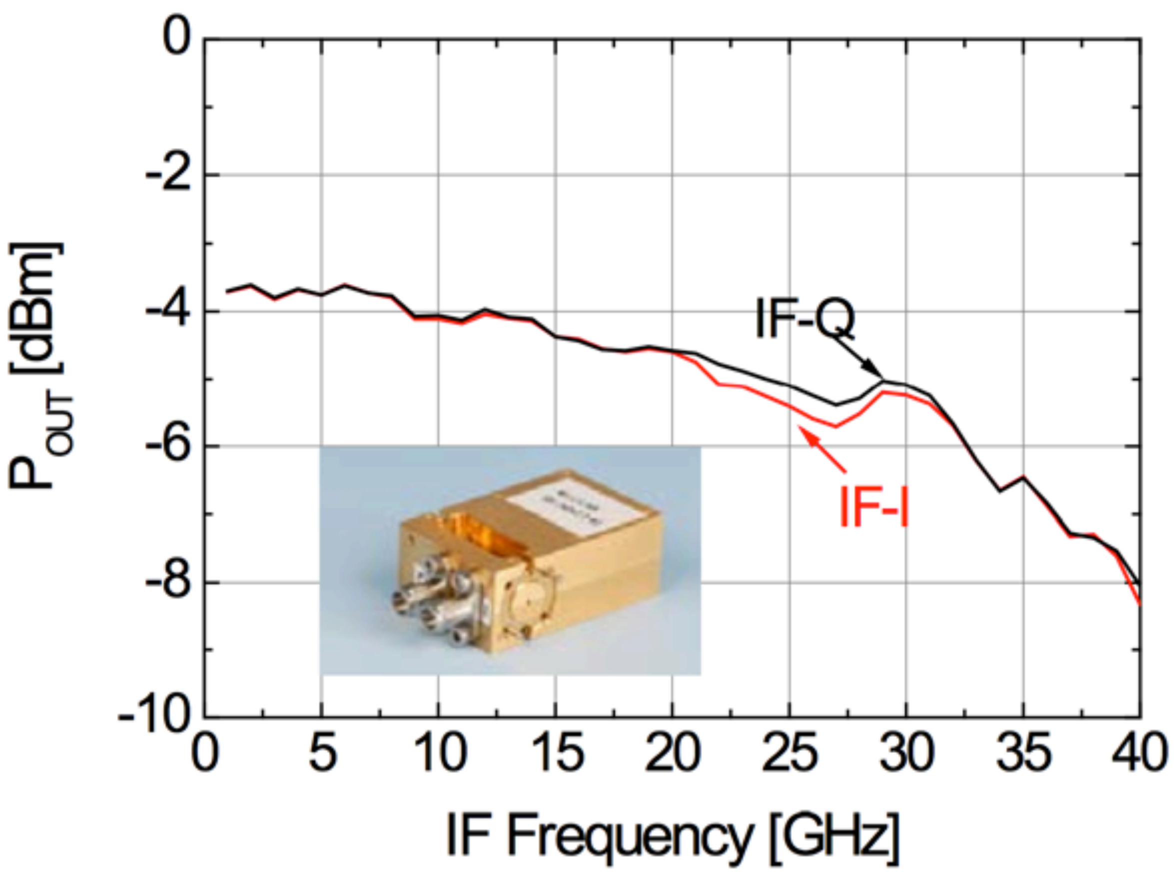
DSB noise figure

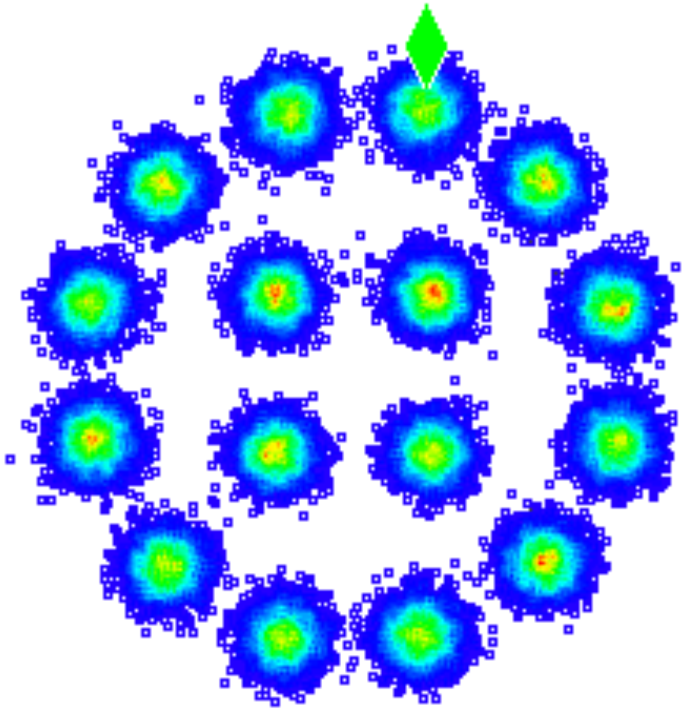
- NF approx. 11 dB over 20 GHz IF bandwidth @120 GHz LO

240 GHz Transmitter

- P_{LO} 7 dBm @ 120 GHz
- P_{out} -3.6 dBm
- IF-bandwidth approx. 35 GHz
- 2xLO-to-RF isolation >12 dBc
- I/Q imbalance below 1 dB

Lopez-Diaz et.al. EuMC2013

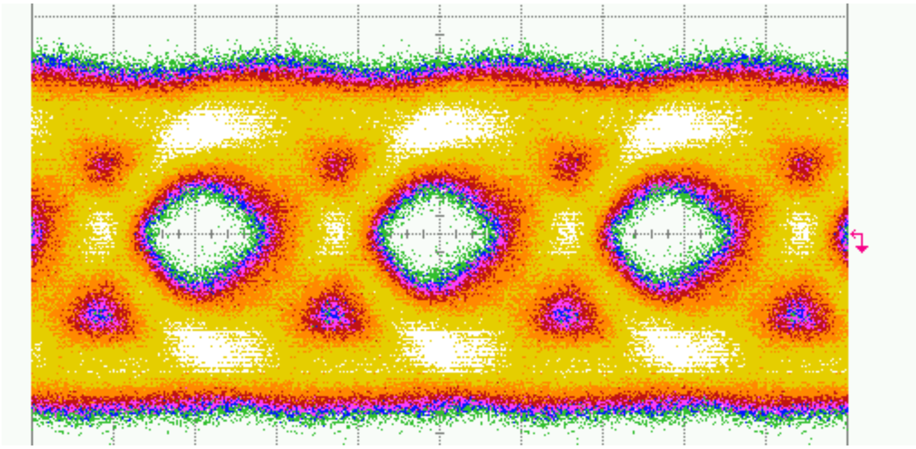




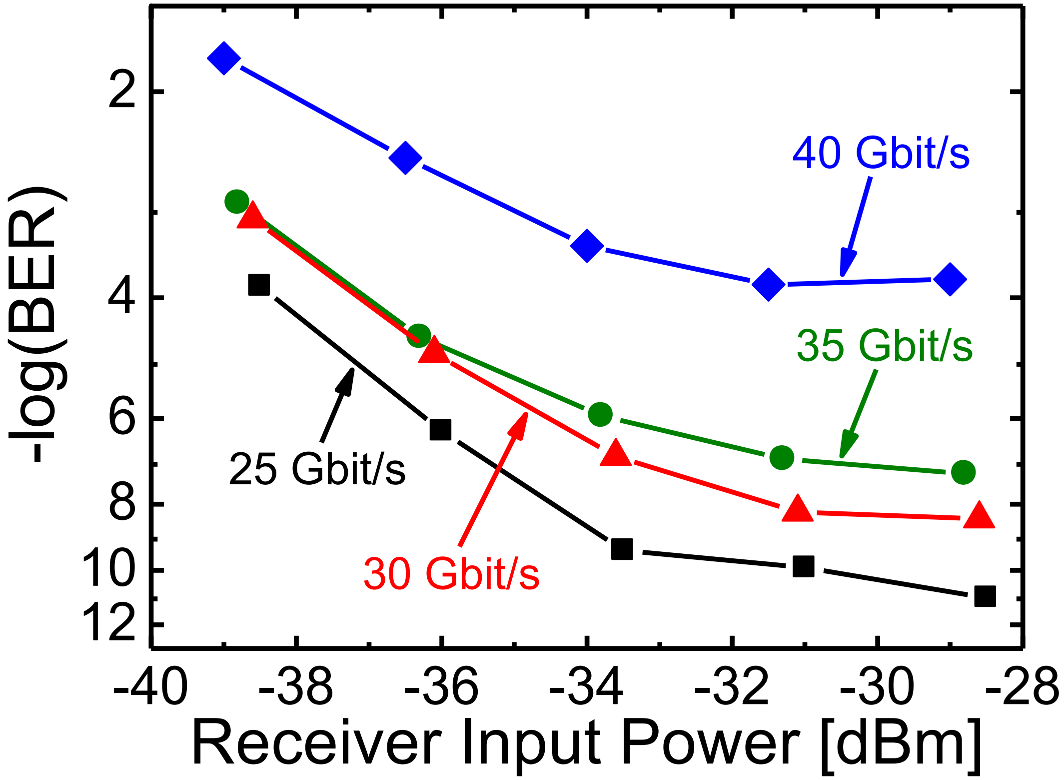
240 GHZ TRANSMISSION EXPERIMENTS

Receiver Sensitivity Measurement

- Back-to-back configuration with calibrated attenuator between Tx and Rx
- Measurement with BERT system
- BPSK modulation up to 40 Gbit/s
- Optimum Rx input power between -32 and -30 dBm

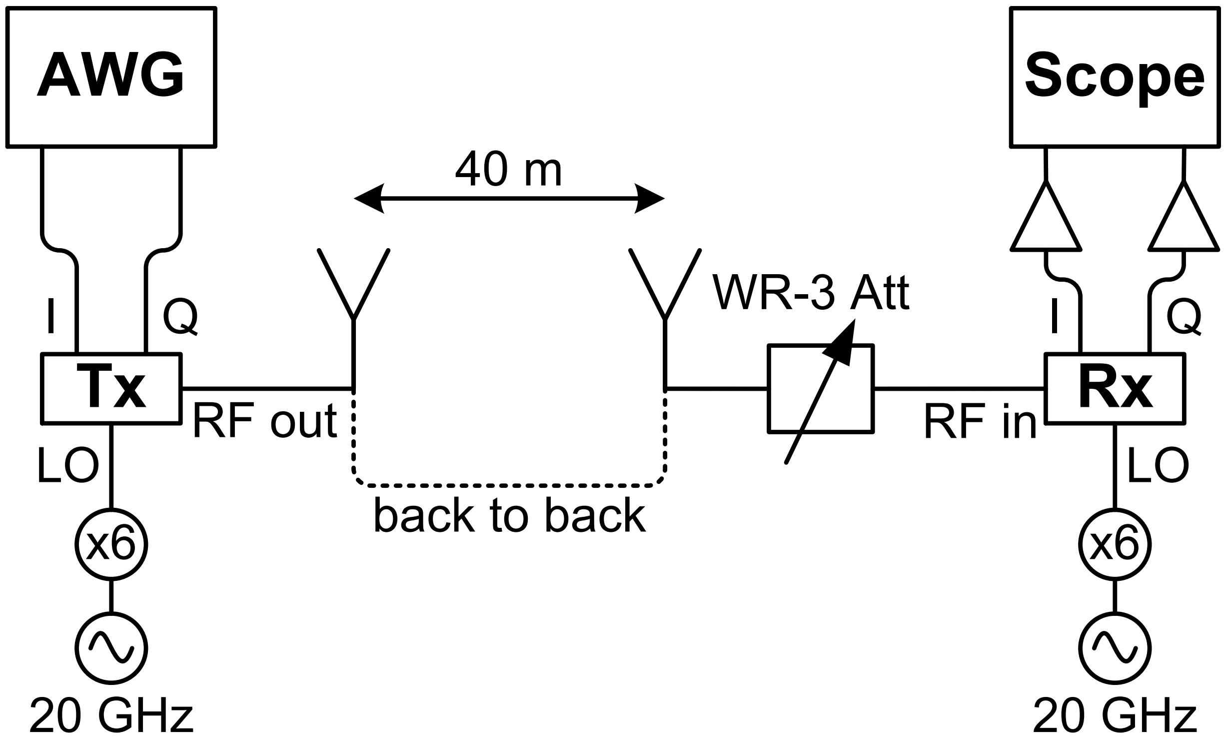


Measured eye diagram at 35 Gbit/s
BER < 6×10^{-8}

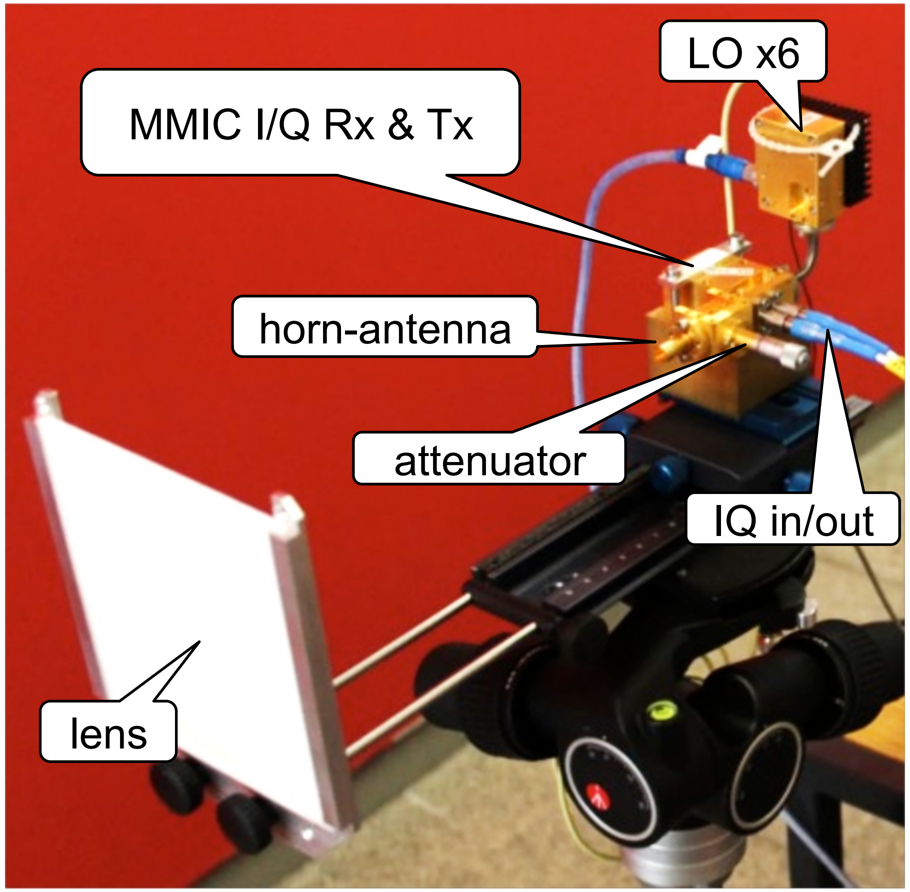


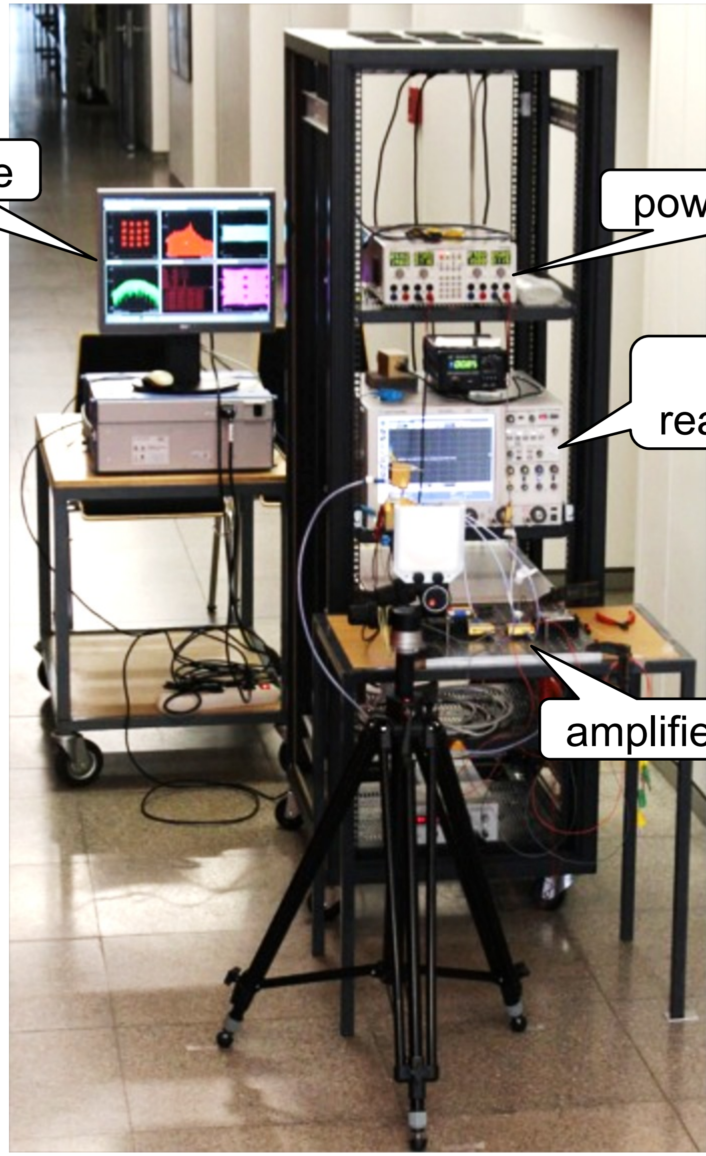
Indoor experiments I

- Back-to-back and wireless measurements
- 10 GS/s AWG as signal source
- 80 GS/s, real-time Scope for capturing received signal
- Demodulation with VSA software
- phase matched cables & IF amplification (22 dB) in receiver path
- Horn antennas + dielectric lenses (approx. 23dBi)
- Up to 40 m distance (WR-3 attenuator for linear Rx operation)



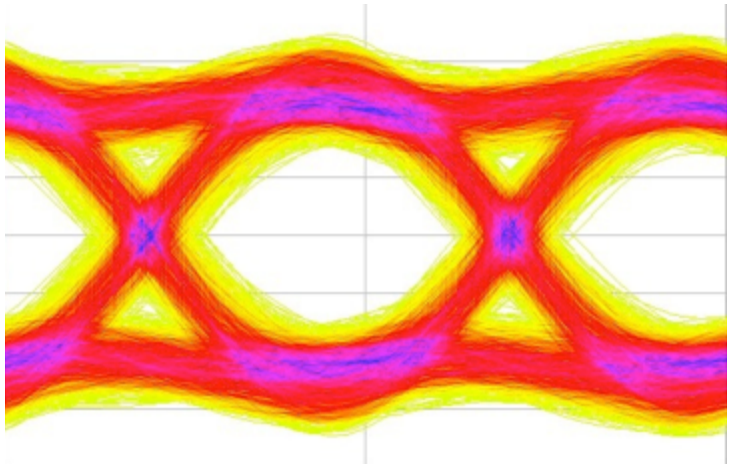
Indoor experiments II

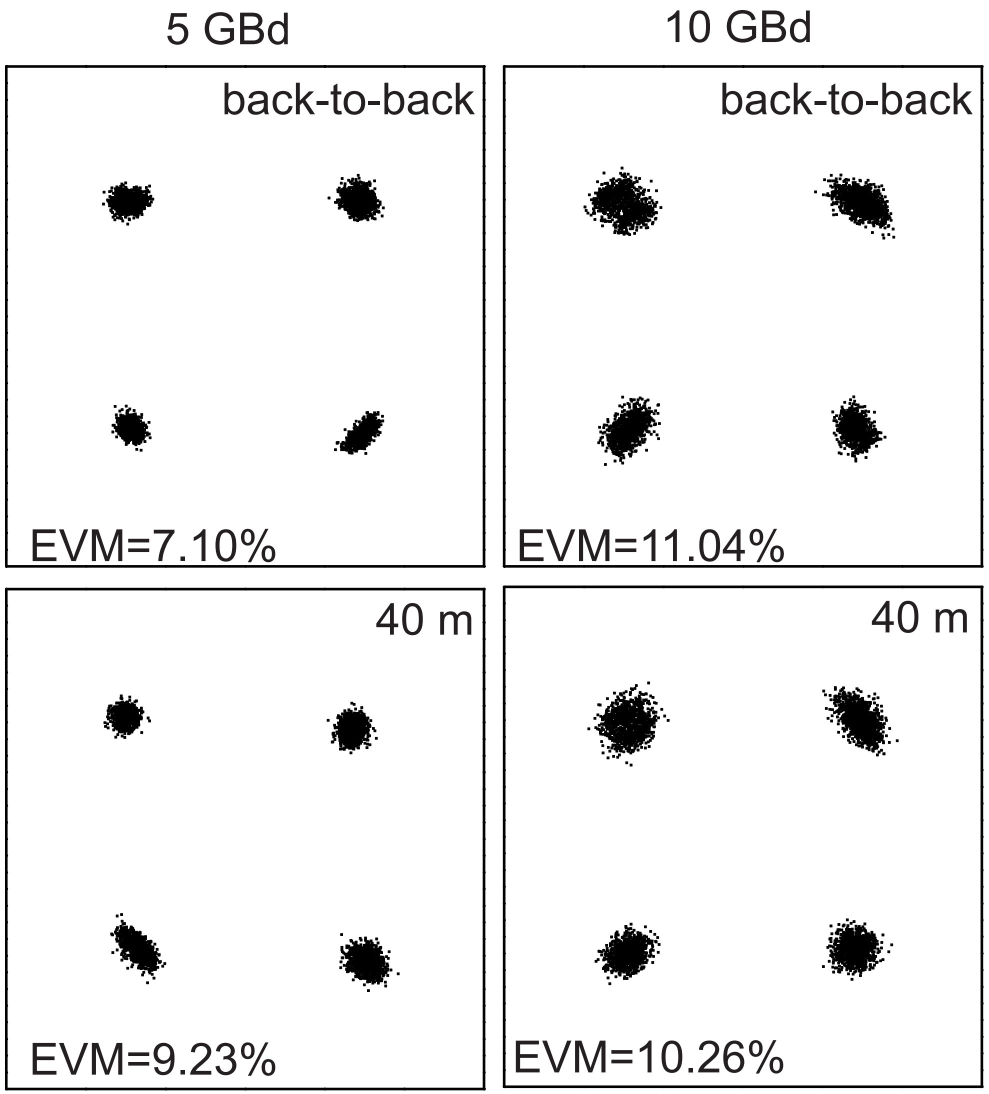




Indoor experiments III

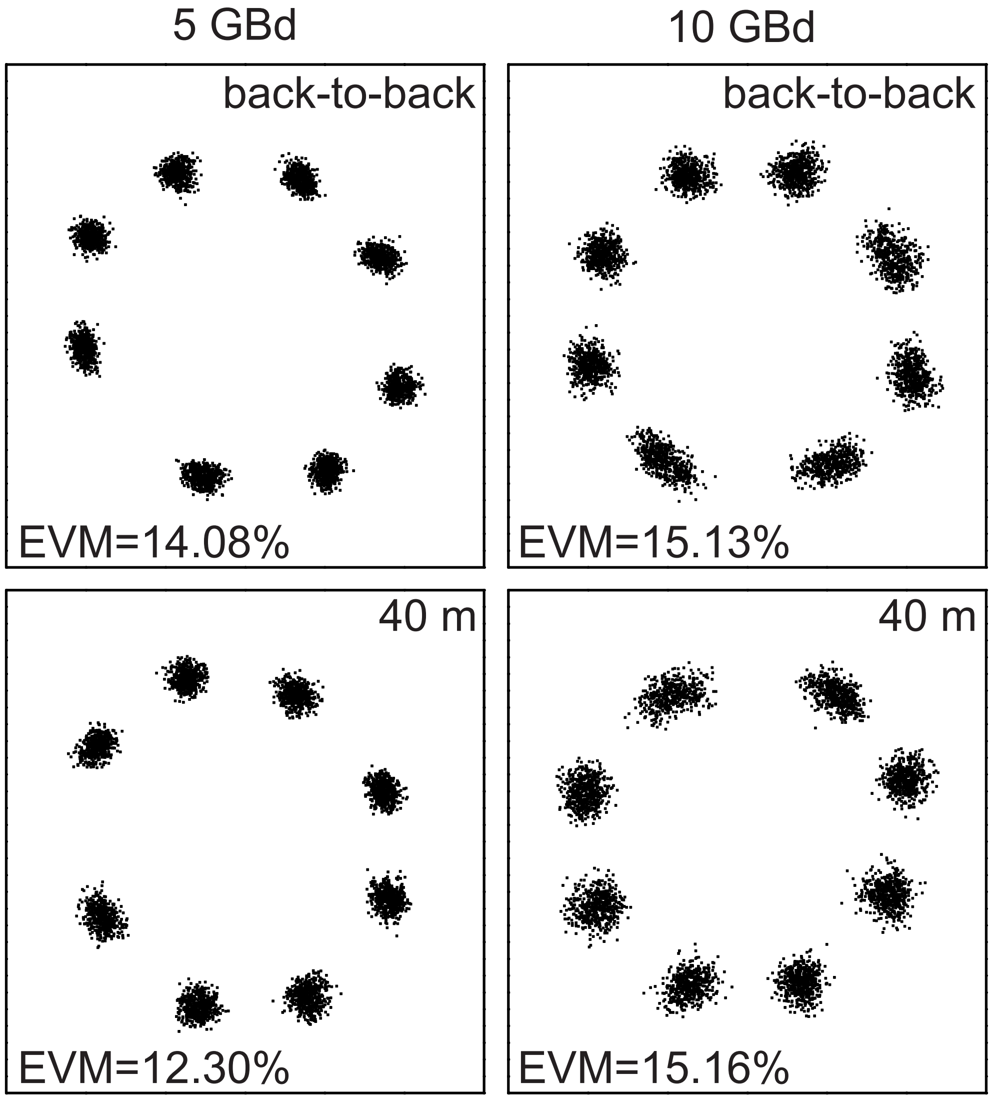
- Constellation diagram for a QPSK modulated signal with 5 and 10 GBd
- Demodulated Eye-diagram for the 10 GBd signal



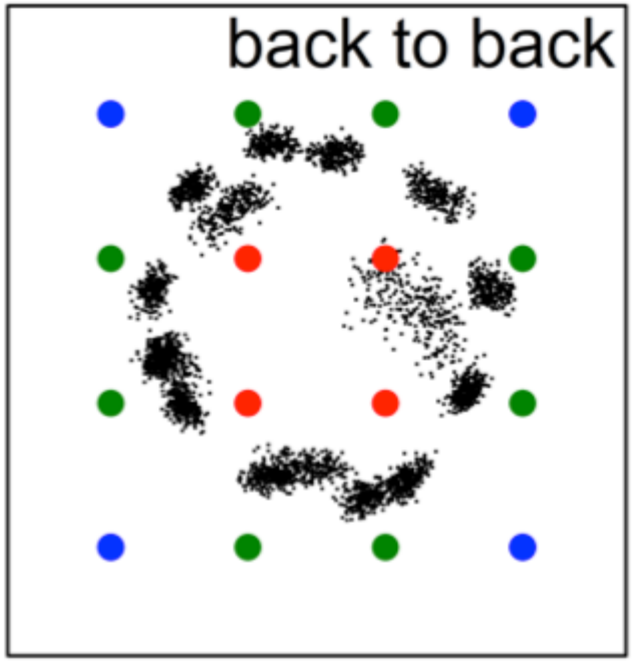


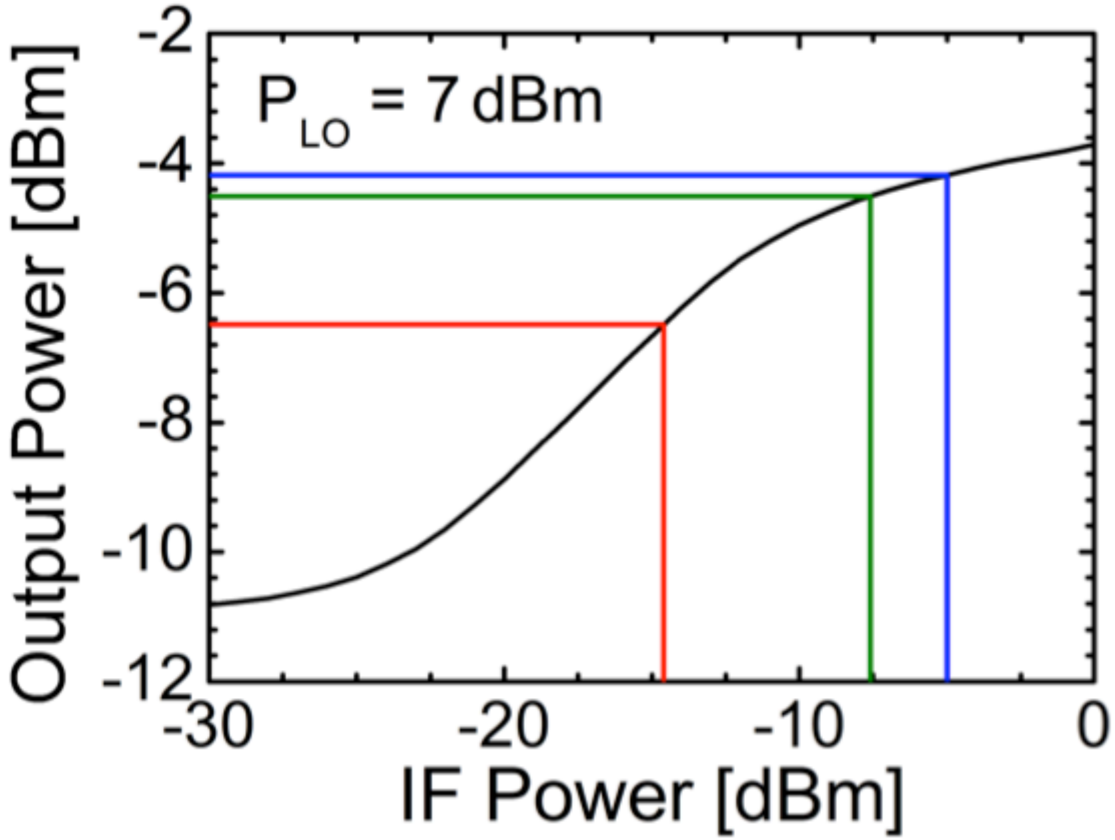
Indoor experiments IV

- Constellation diagram for an 8-PSK modulated signal with 5 and 10 GBd
- Slight decrease in signal quality between b2b and wireless transmission
- Data rate limited by sampling rate of AWG



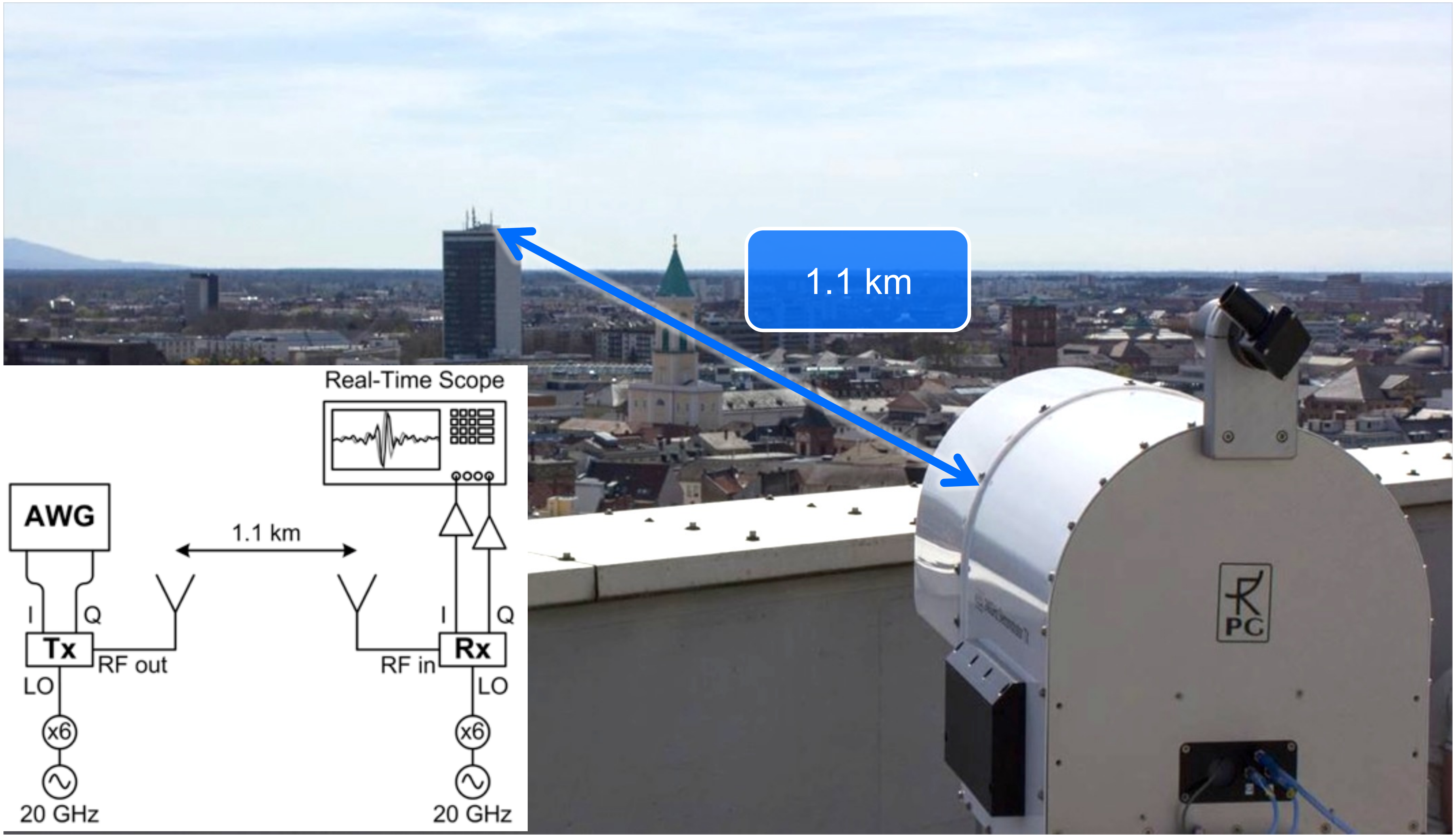
Indoor experiments V



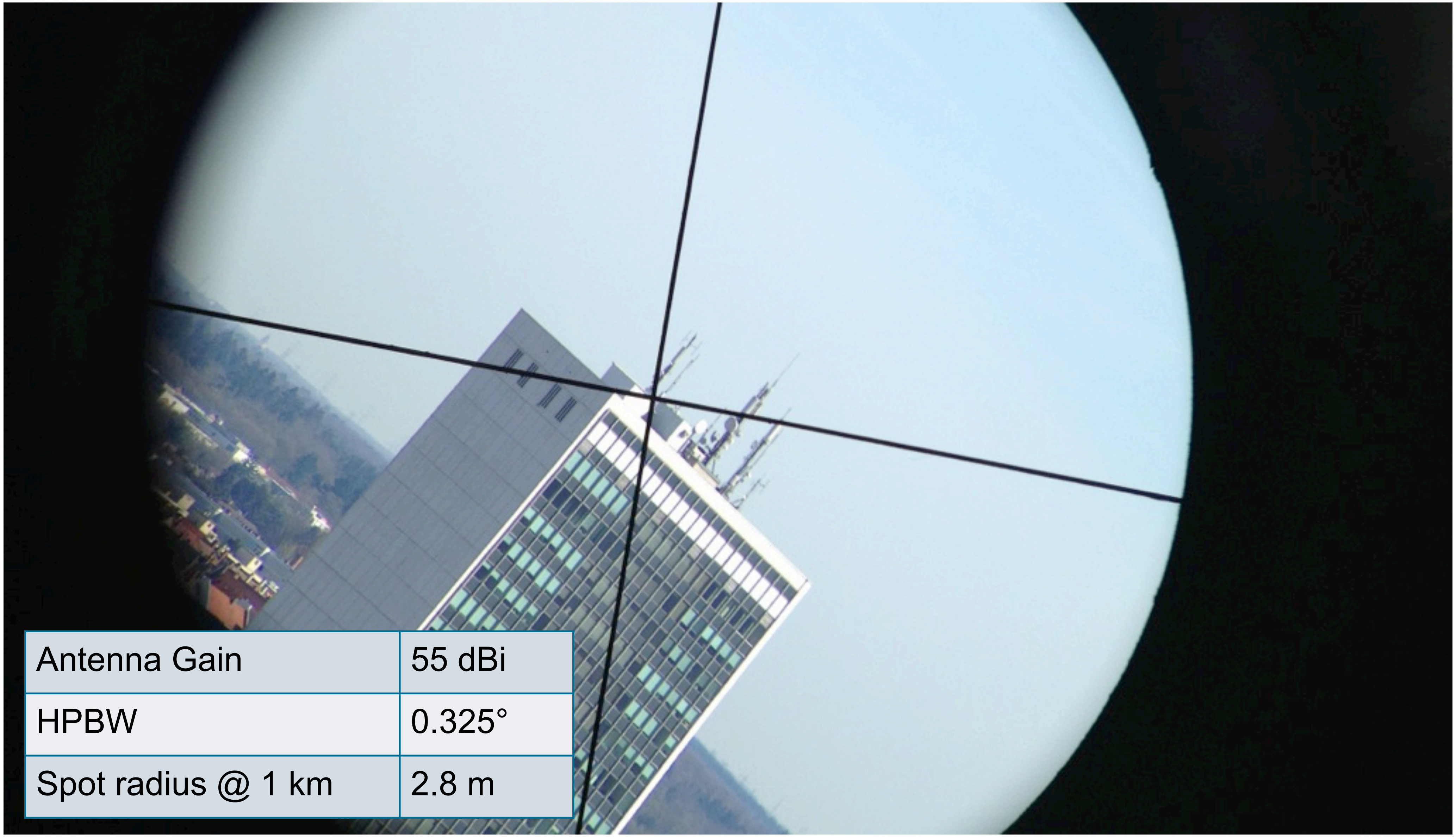


- Transmission of 16QAM not possible
  - LNA in transmitter operates in compression

1.1 km, 240 GHz Wireless Link

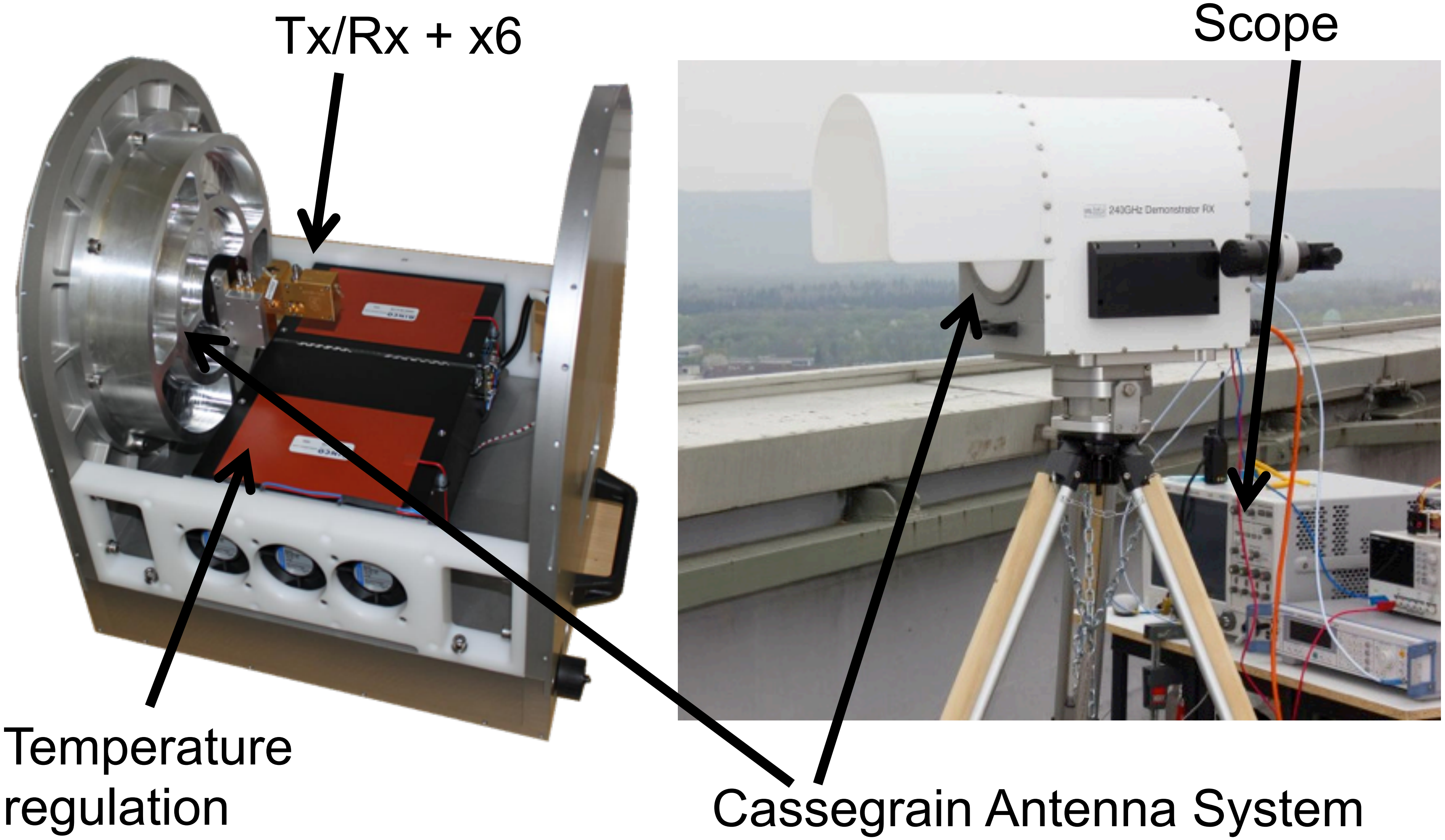


Beam Alignment

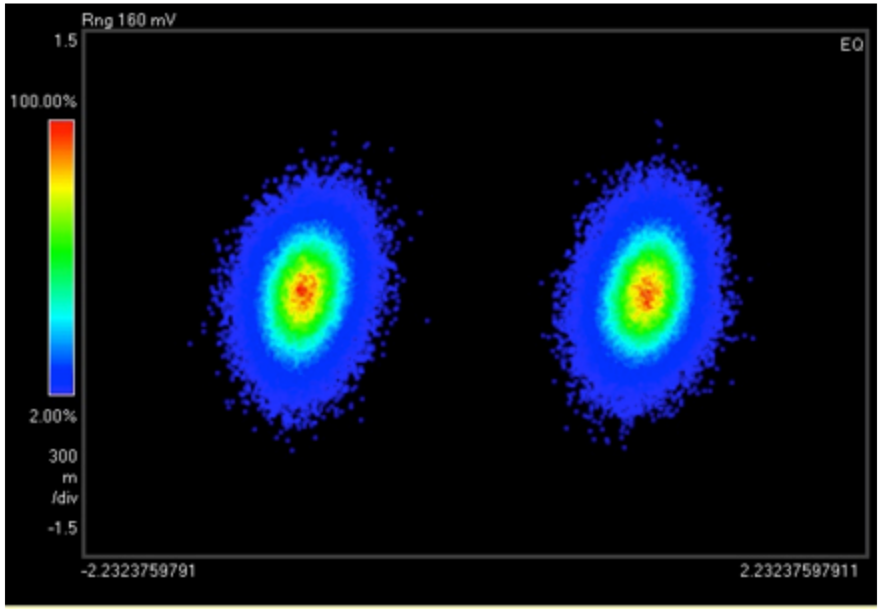


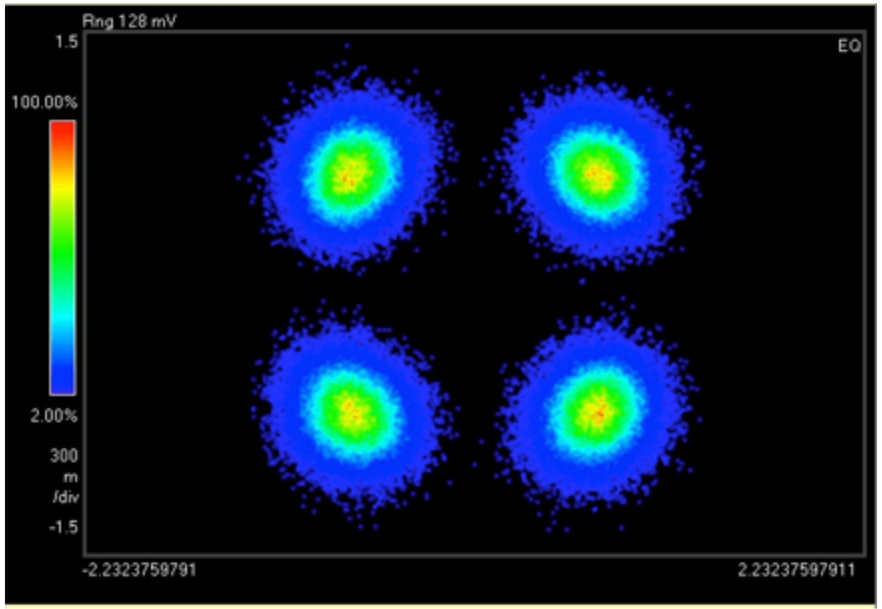
Antenna Gain	55 dBi
HPBW	0.325°
Spot radius @ 1 km	2.8 m

Transmit & Receive Housing with integrated Antenna



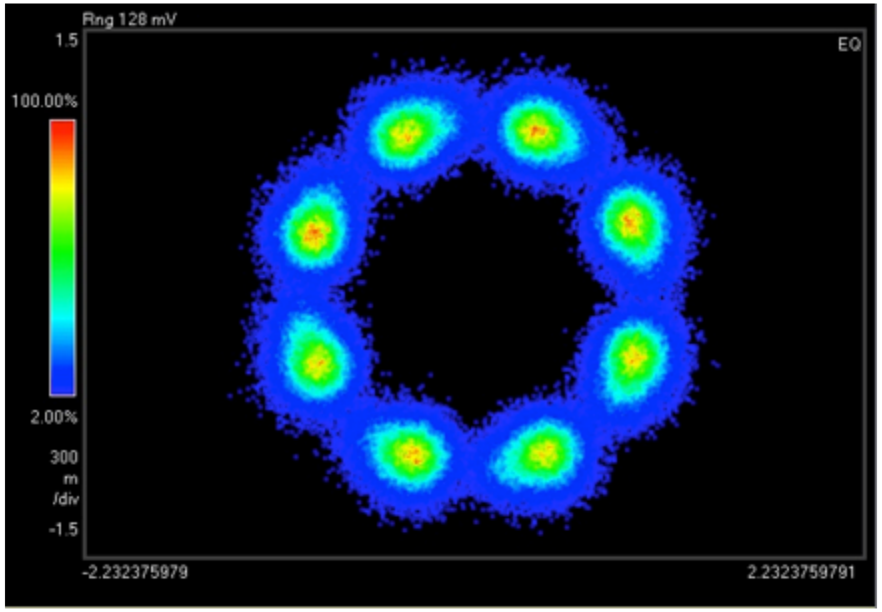
1.1 km PSK transmission at 12 GBd

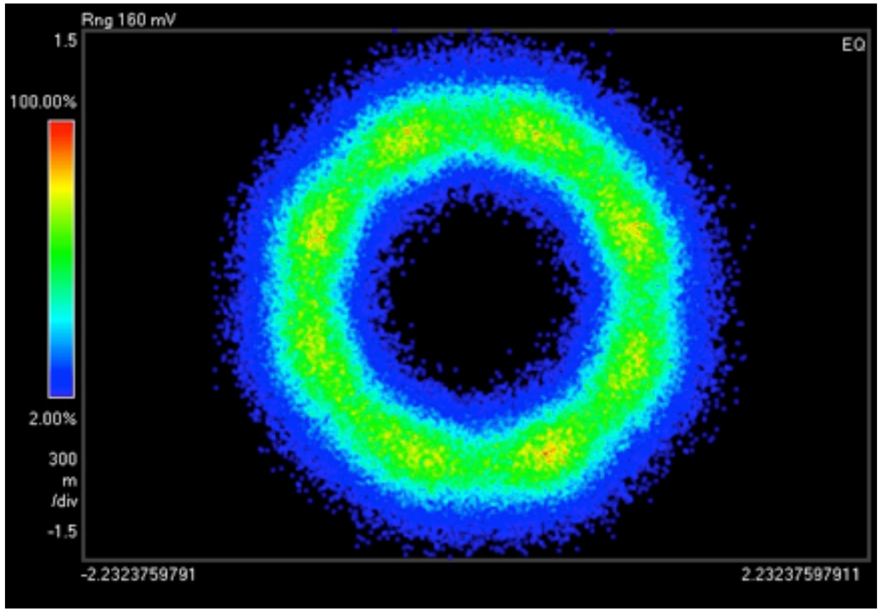




- EVM for
  - BPSK 24.9%
  - QPSK 22.7%
- Both equals a BER better than $1x10^{-5}$

1.1 km 8-PSK transmission





- 6 GBd
  - EVM 18.5%
  - Results in BER around $1x10^{-3}$
- 12 GBd
  - Mapping of symbols not possible

State-of-the-Art Wireless Communication above 100 GHz

Frequency	Transmitter	Receiver	Bit rate	Group	Ref.
120 GHz	MMIC	MMIC (direct detection)	20 Gbps	NTT	[1]
200 GHz	Photonic	direct detection	1 Gbps	IEMN	[2]
240 GHz	MMIC	MMIC	Up to 30 Gbps	ILH, Fraunhofer IAF, KIT, RPG	this work
300-400 GHz	Photonic	direct detection	> 20 Gbps	NTT	[3]
300 GHz	Frequency multiplexer	heterodyne detection	~100 Mbps	TU Braunschweig	[4]
300 GHz	Resonant-tunneling Diode	Resonant-tunneling Diode	1.5 Gbps	Rohm	[5]
625 GHz	Frequency multiplexer	Direct detection	2.5 Gbps	Bell Labs	[6]

Conclusion

- 240 GHz Tx and Rx Frontend Modules
  - Quadrature up- and down-conversion
  - Subharmonic LO drive
  - RF pre- and post-amplification
  - Approx. 20 GHz IF bandwidth on module level
- Receiver sensitivity characterized up to 40 Gbit/s
  - Reasonable BER of better than 6×10^{-8} for data rates up to 35 Gbit/s
- Indoor transmission experiments up to 40 m and 30 Gbit/s
  - PSK modulation up to 8-PSK
  - No amplitude modulation possible due to LNA linearity in Tx
- Outdoor transmission at 1.1 km and 24 Gbit/s QPSK

Future Work

- Evaluation of the critical system components
- Redesign on MMIC level with replacement of the LNA in the transmitter with a power amplifier
- Improvements on module level to overcome losses and bandwidth limitations
- Replacement of data source to overcome bandwidth limitations

Acknowledgements

- The MILLILINK project partners Fraunhofer IAF, Kathrein, KIT Radiometer Physics, Siemens CT
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Thank you for your attention

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Iai, S. Okabe, S. Kimura, H. Ikegawa, H. Nishikawa, T. Nakayama, and T. Inada, “10-Gbit/s wireless link using InP HEMT MMICs for generating 120-GHz-band millimeter-wave signal,” IEEE Trans. Microwave Theory Tech., Vol. 57, No. 5, pp.1102-1109, 2009.

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