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Metrology for THz Communications

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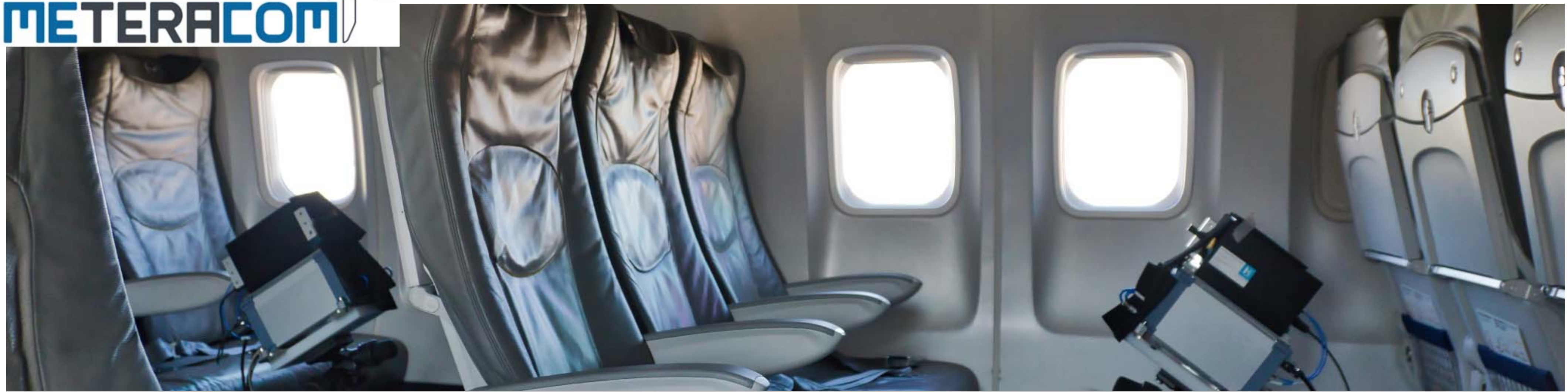


Characterization of RF Impairments in Analog Electronic THz Frontends

Dominik Wrana

2nd International Workshop on Metrology for THz Communications, Duisburg, 12 March 2024

Outline

1. Introduction and Motivation

2. Superheterodyne 300 GHz Tx / Rx Frontends

3. Harmonics from Frequency Multiplicative Carrier Generation

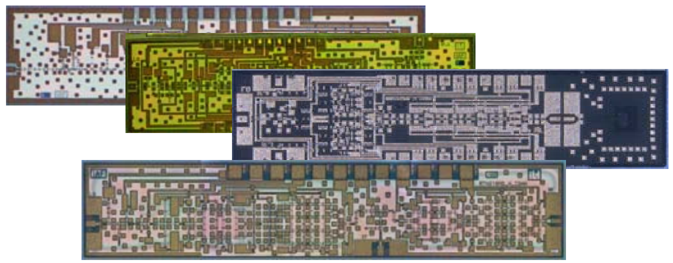
4. CrossLink Measurement Platform

5. Summary

1. Introduction and Motivation

- „Ultra-broadband“ **THz communication at 300 GHz**
- **Standardization** in progress for spectrum beyond 250 GHz c.p. IEEE802.15.3d[2], WRC2019 Final Act[3]

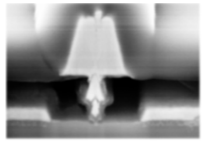
- Lots of **research activities and funding initiatives** addressing 300 GHz applications, e.g. mobile backhauling, data center, industrial environments, …
- Developement and optimization of **electronic analog frontends** is challenging and requires **thorough sensitivity analysis** with respect to its **impairments** on signal quality.
- **Carrier generation** at THz frequencies is one source of impairments, e.g. phase noise, **harmonics**, …
- Various approaches for LO generation, e.g. **electronic frequency multiplication**, photo mixing, …
- **Sophisticated measurement systems and setups** as enabler from MMIC characterization to system-level performance evaluation



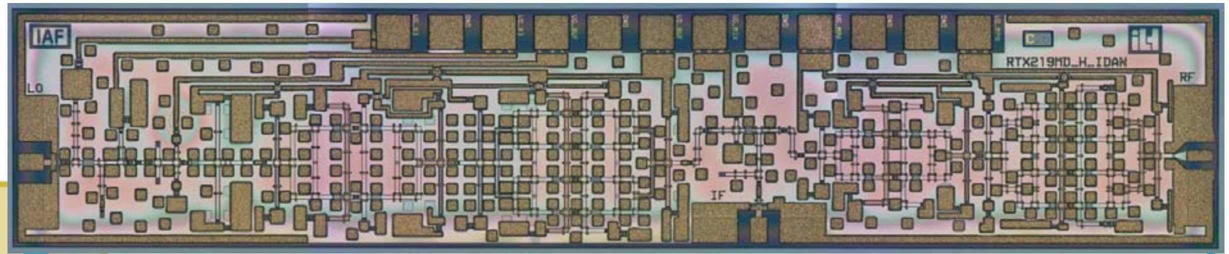
2. Superheterodyne 300 GHz Tx / Rx Frontends

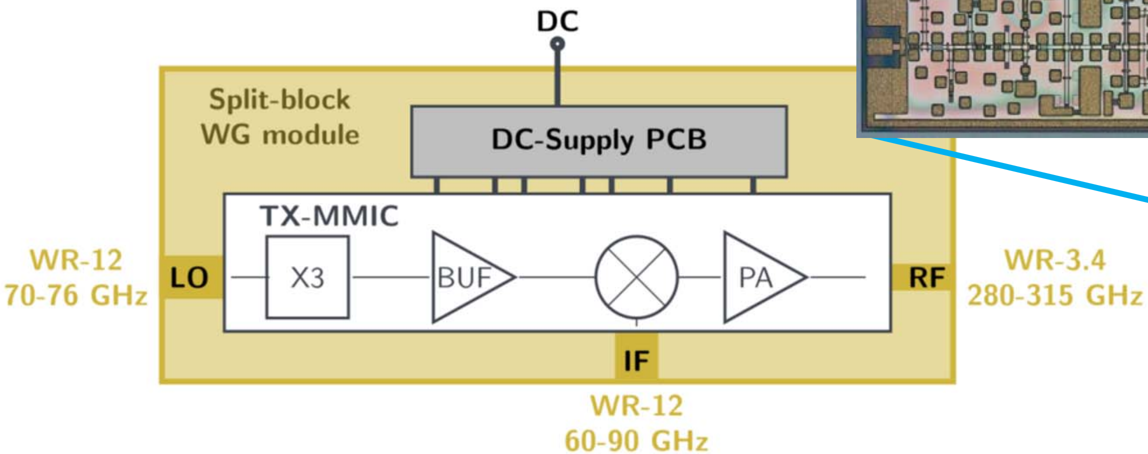
- LO chain with integrated X3 freq. multiplier and buffer amplifier
- fundamental resistive mixer
- RF power amplifier

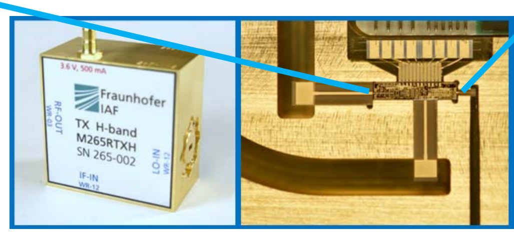
Fraunhofer IAF



35nm InGaAs mHEMT technology
f_T / f_{max}: > 500 GHz / > 1000 GHz



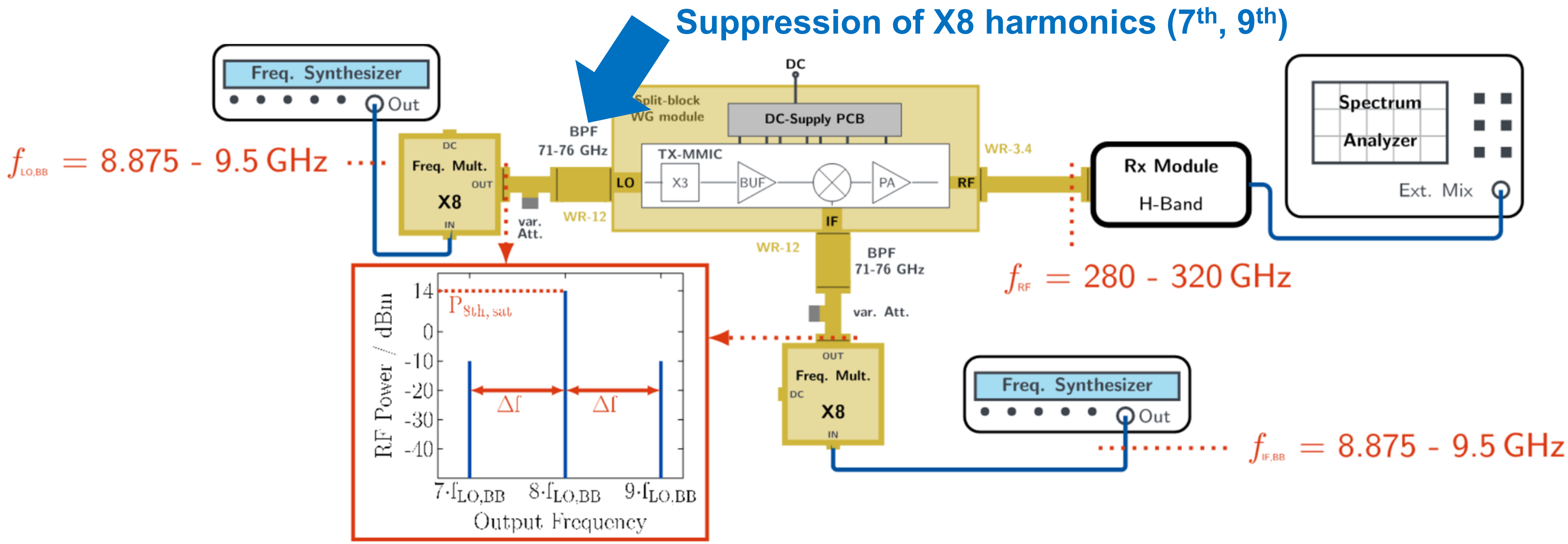




[3] Dan et al., “A Superheterodyne 300GHz Transmit Receive Chipset for Beyond 5G Network Integration”
[4] Wrana et al., “Sensitivity Analysis of a 280 – 312 GHz Superheterodyne Terahertz Link Targeting IEEE802.15.3d Applications“

3. Harmonics from Frequency Multiplicative Carrier Generation

Measurement Setup for TX characterization



- frequency synthesizer + external X8 freq. multiplier for generation of LO
- overall LO multiplication factor of 24

[5] D. Wrana et al., "Effects of Harmonics from Frequency-Multiplicative Carrier Generation in a Superheterodyne 300 GHz Transmit Frontend"

3. Harmonics from Frequency Multiplicative Carrier Generation

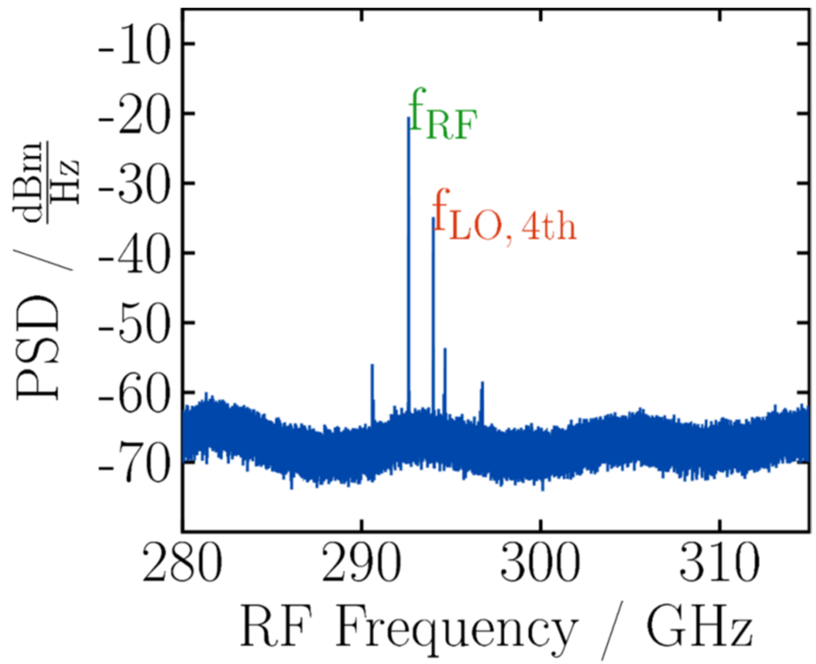
- 4th order mixing / intermodulation products cause spur in the RF domain
- Located in the RF frequency band of operation, $f_{LO,4th}$ poses risk of an in-band interferer, degrading the signal quality

Operating conditions:
f_{LO} = 73.5 GHz
f_{IF} = 72.125 GHz
P_{IF} = -18 dBm

$$f_{RF} = 3 \cdot f_{LO} + f_{IF}$$

$$f_{LO,4th} = 4 \cdot f_{LO}$$

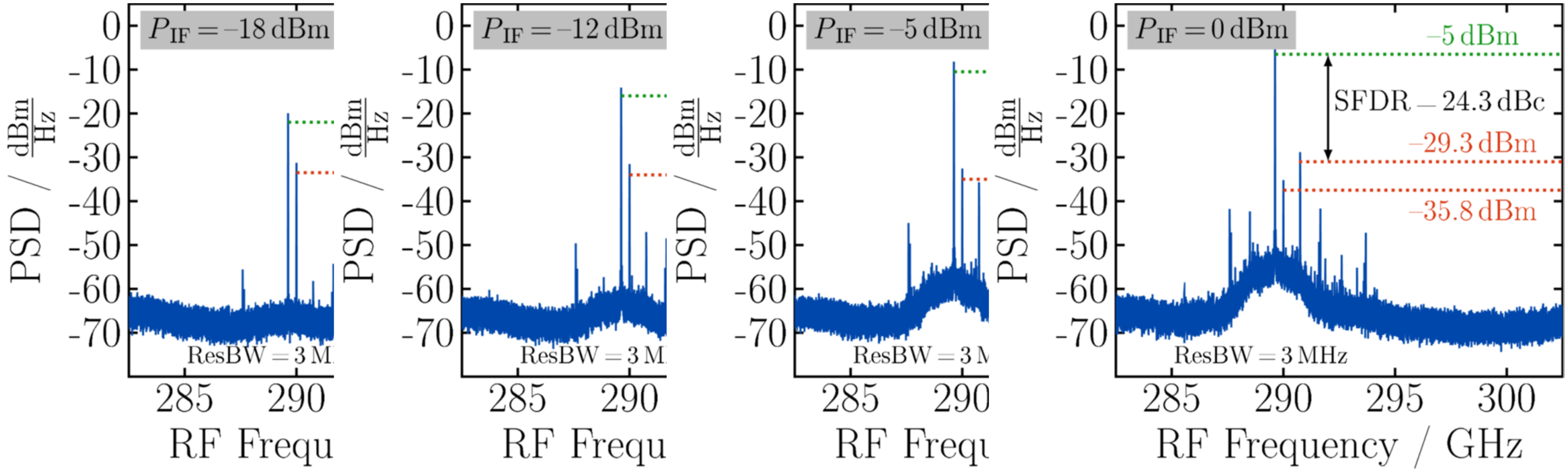
Frequency / GHz	7th	8th	9th	IF	Mixing Order
f_{RF} = 292.625	0	3	0	1	4
283.4375	2	0	1	1	4
301.8125	0	2	1	1	4
311	0	1	2	1	4
$f_{LO,4th}$ = 294	0	4	0	0	4
284.8125	1	3	0	0	4
303.1875	0	3	1	0	4



3. Harmonics from Frequency Multiplicative Carrier Generation

- absolute power of $f_{LO,4th}$ stays constant for P_{IF} levels < IP1dB
- carrier-to-interferer ratio (CIR) increases with IF input power
- IF linearity limits achievable CIR

Operating conditions:
f_{LO} = 72.5 GHz
f_{IF} = 72.125 GHz
P_{LO} = 3 dBm

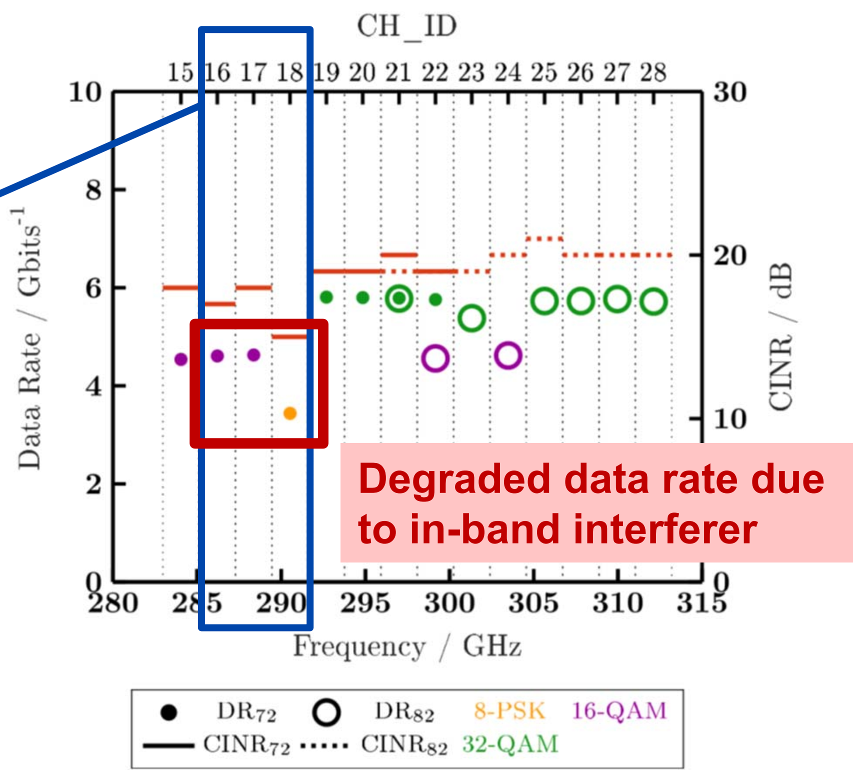


3. Harmonics from Frequency Multiplicative Carrier Generation

Real-Time Full-Duplex Transmission Experiment

- Full-duplex real-time link over 1 meter
- IF signals provided by E-band modems
- 2 GHz (1.6 GBd) channels similar to setup in [6]

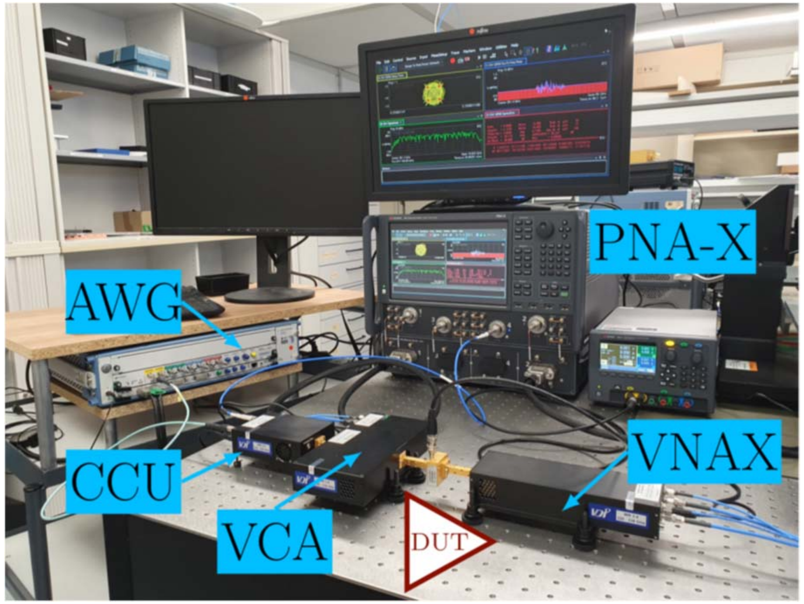
16: f_c = 286.2 GHz, $f_{LO,4th}$ = 285.4 GHz
17: f_c = 288.36 GHz, $f_{LO,4th}$ = 288.3 GHz
18: f_c = 290.52 GHz, $f_{LO,4th}$ = 291.2 GHz



[6] D. Wrana et al., "Short-Range Full-Duplex Real-Time Wireless Terahertz Link for IEEE802.15.3d Applications"

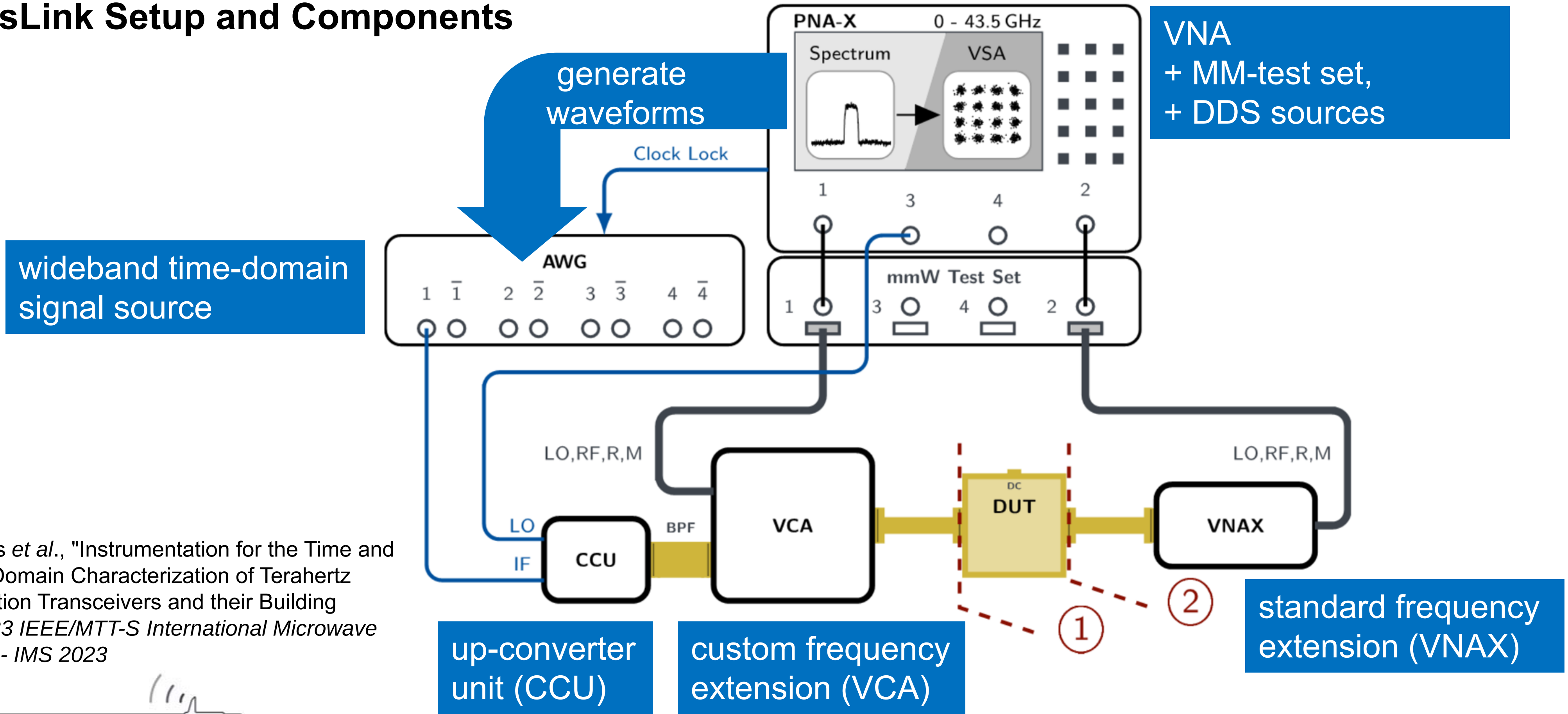
4. CrossLink Measurement Platform

- Versatile platform for the **characterization of transceivers and transceiver components** dedicated to **6G wireless communication**
- Combination of **synchronous signal analysis in the time and frequency domain**
- **Repetitive test signals** to enable vector averaging, wideband stitching, noise floor reduction
- Narrowband RF signal injection for **vectorial network analysis and calibration functionality**
- Hardware configuration available for
  - **W-band (67 – 115 GHz)**
  - **D-band (110 -170 GHz)**
  - **H-band (220 – 330 GHz)**



4. CrossLink Measurement Platform

CrossLink Setup and Components

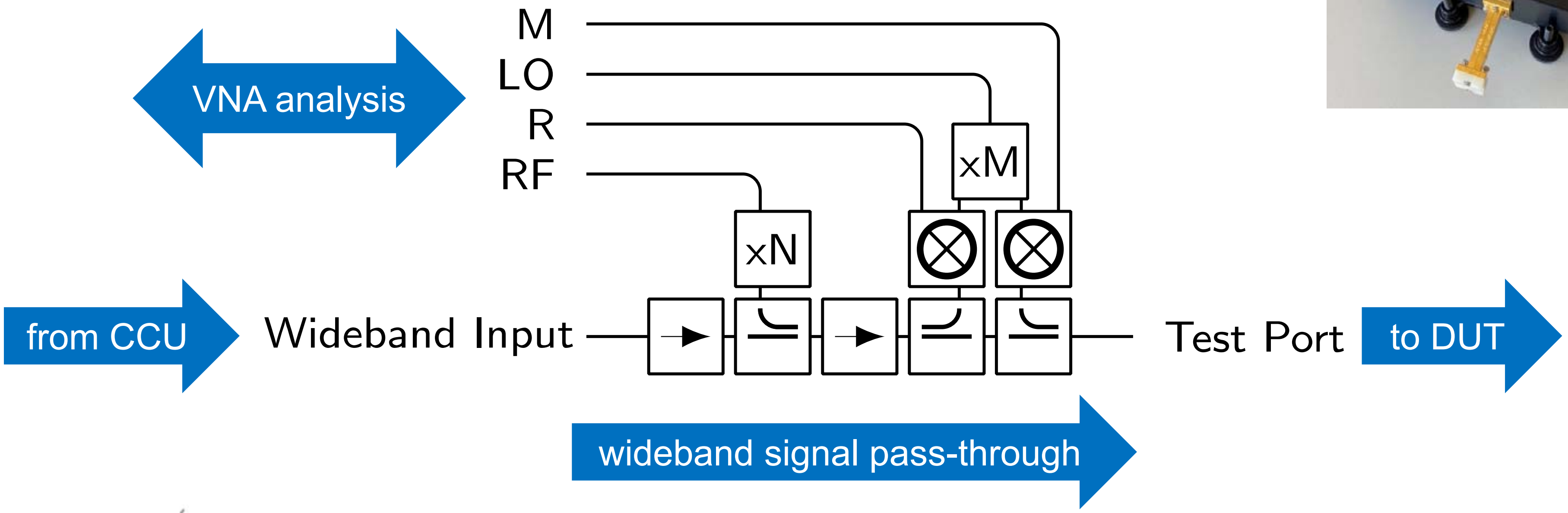


[7] I. Kallfass *et al*., "Instrumentation for the Time and Frequency Domain Characterization of Terahertz Communication Transceivers and their Building Blocks," *2023 IEEE/MTT-S International Microwave Symposium - IMS 2023*

4. CrossLink Measurement Platform

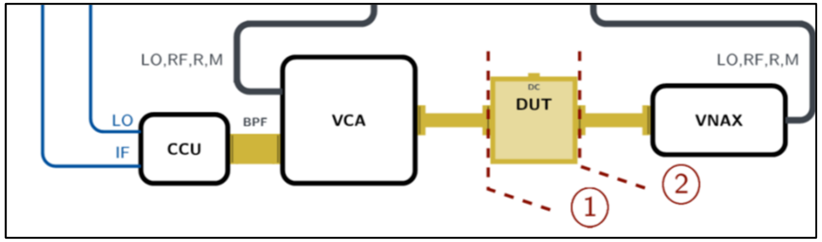
VCA module enables

- broadband multi-tone and complex-modulated signal injection
- calibration of waveforms at RF reference plan using vectorial network functionality.

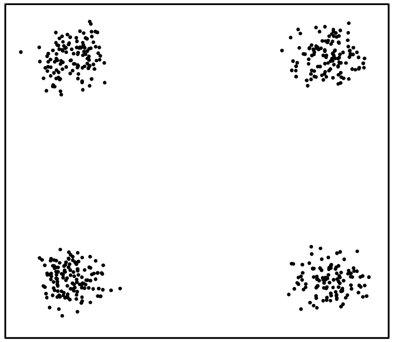


4. CrossLink Measurement Platform

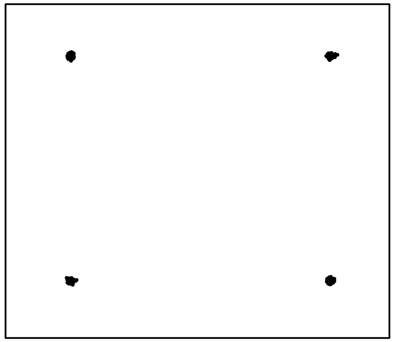
Exemplary source calibration (1 GBd QPSK signal in W-band, using a power amplifier as DUT)



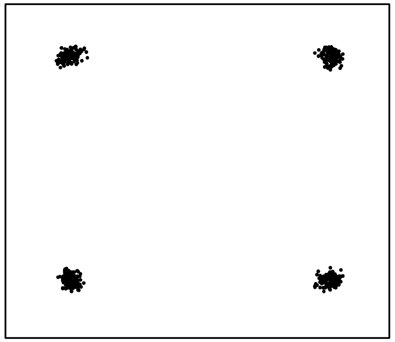
view 1, uncalibrated
EVM = 13%
P_{RF} = -8 dBm



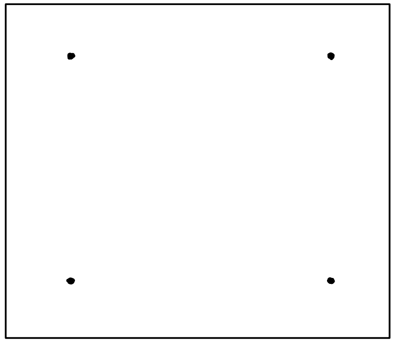
view 1, calibrated at 1
EVM = 1.3%
P_{RF} = -8 dBm



view 2, calibrated at 1
EVM = 4.5%
P_{RF} = 6 dBm



view 2, calibrated at 2
EVM = 0.6%
P_{RF} = 6 dBm



[8] B. Schoch et al., "Wideband Cross-Domain Characterization of a W-band Amplifier MMIC," *2023, 53rd European Microwave Conference (EuMC)*, Berlin

5. Summary

- Development and optimization of THz analog electronic frontends requires thorough sensitivity analysis w.r.t. frontend impairments
- Superheterodyne 300 GHz Tx/Rx chipset has been introduced
- Unwanted harmonics from frequency multiplication in the LO path pose risk of in-band interferers to modulated signals, degrading the CIR.
- Superheterodyne Tx module was characterized w.r.t. the on-chip generated 4th LO harmonic located in the RF spectrum.
- CrossLink measurement platform was introduced offering innovative capabilities for the characterization of transceivers and transceiver components dedicated to 6G

Interested in a live demo of the CrossLink system?

Visit us at the Keysight booth on the exhibition floor!

References

[1] IEEE Standard for High Data Rate Wireless Multi-Media Networks–Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer, Std.

[2] World Radiocommunication Conference 2019 - Final Acts, 2019.

[3] Dan et al., “A Superheterodyne 300GHz Transmit Receive Chipset for Beyond 5G Network Integration,” in 2021 16th European Microwave Integrated Circuits Conference (EuMIC), 2022, pp. 117–120.

[4] Wrana et al., “Sensitivity Analysis of a 280 – 312 GHz Superheterodyne Terahertz Link Targeting IEEE802.15.3d Applications“, IEEE Transactions on Terahertz Science and Technology, vol. 12, no. 4, pp. 325–333, 2022.

[5] D. Wrana, S. Haussmann, B. Schoch, L. John, A. Tessmann and I. Kallfass, "Effects of Harmonics from Frequency-Multiplicative Carrier Generation in a Superheterodyne 300 GHz Transmit Frontend," *2023 53rd European Microwave Conference (EuMC)*, Berlin, Germany, 2023, pp. 138-141, doi: 10.23919/EuMC58039.2023.10290717

[6] D. Wrana, Y. Leiba, L. John, B. Schoch, A. Tessmann, and I. Kallfass, “Short-Range Full-Duplex Real-Time Wireless Terahertz Link for IEEE802.15.3d Applications,” in 2022 IEEE Radio and Wireless Symposium (RWS), 2022, pp. 94–97.

[7] I. Kallfass *et al*., "Instrumentation for the Time and Frequency Domain Characterization of Terahertz Communication Transceivers and their Building Blocks," *2023 IEEE/MTT-S International Microwave Symposium - IMS 2023*, San Diego, CA, USA, 2023, pp. 1030-1033, doi: 10.1109/IMS37964.2023.10188006.

[8] B. Schoch, D. Wrana, A. Tessmann and I. Kallfass, "Wideband Cross-Domain Characterization of a W-band Amplifier MMIC," *2023 53rd European Microwave Conference (EuMC)*, Berlin, Germany, 2023, pp. 770-773, doi: 10.23919/EuMC58039.2023.10290485.

Thank you very much for your Attention

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