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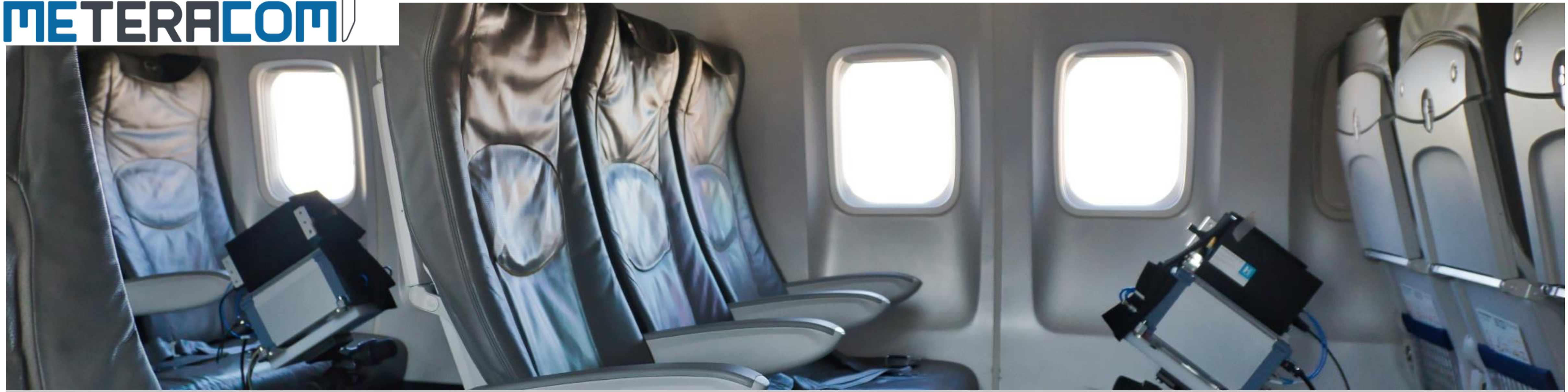
**FOR 2863 Meteracom**
**Metrology for THz Communications**

The 50th International Conference on Infrared, Millimeter, and Terahertz Waves
17-22 August, 2025



# Instrumentation for Traceable Distortion Characterization of Terahertz Transceivers

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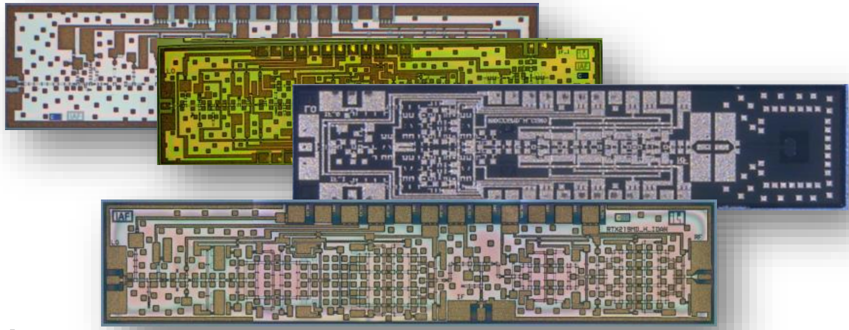
DFG FOR2863 Meteracom Final Workshop @ IRmmW-THz 2025, 20 August 2025

# Outline

1. Introduction and Motivation
2. CrossLink Measurement Platform
3. Superheterodyne 300 GHz Tx / Rx Frontends
4. Recap In-Band Interferer
5. Measurement Setup 300GHz Tx / Rx
6. EVM Degradation at Reference Planes
7. IMD Measurement in D-Band
8. Summary

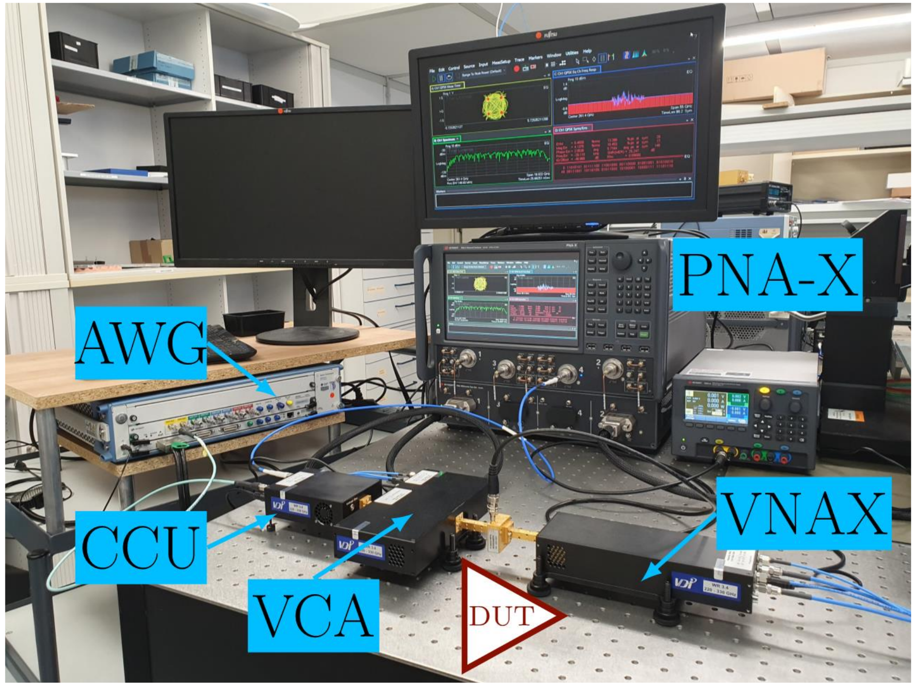
# Introduction and Motivation

- „Ultra-broadband“ **THz communication at 300 GHz**
- **Standardization** in progress for spectrum beyond 250 GHz
  c.p. IEEE802.15.3d[1], WRC2019 Final Act[2]
- Lots of **research activities and funding initiatives** addressing 300 GHz applications, e.g. mobile backhauling, data center, industrial environments, …
- Development 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



# 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)**

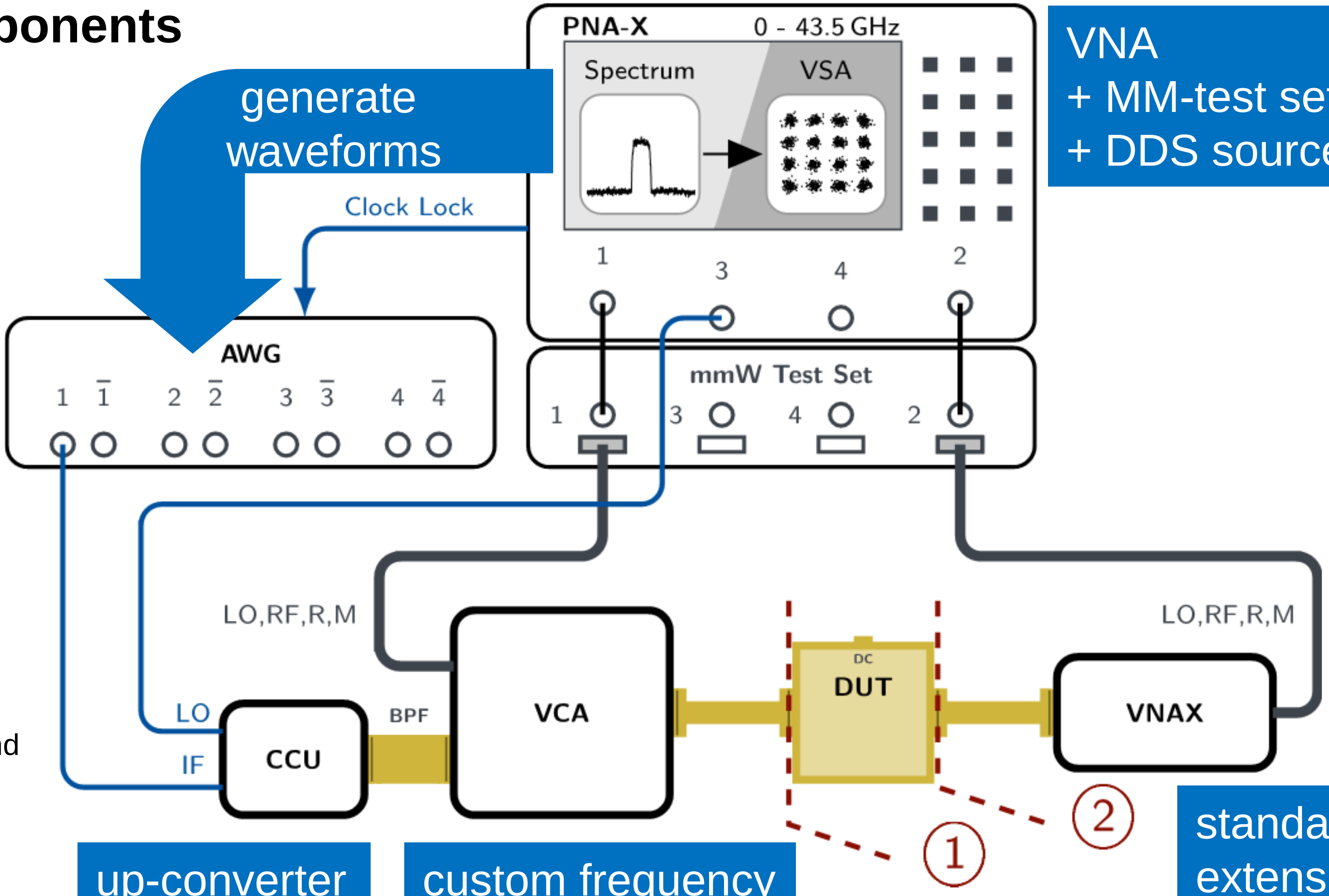



Major Instrumentation Initiatives

XLINK

# CrossLink Measurement Platform

## CrossLink Setup and Components




VNA
+ MM-test set,
+ DDS sources

wideband time-domain signal source

up-converter unit (CCU)

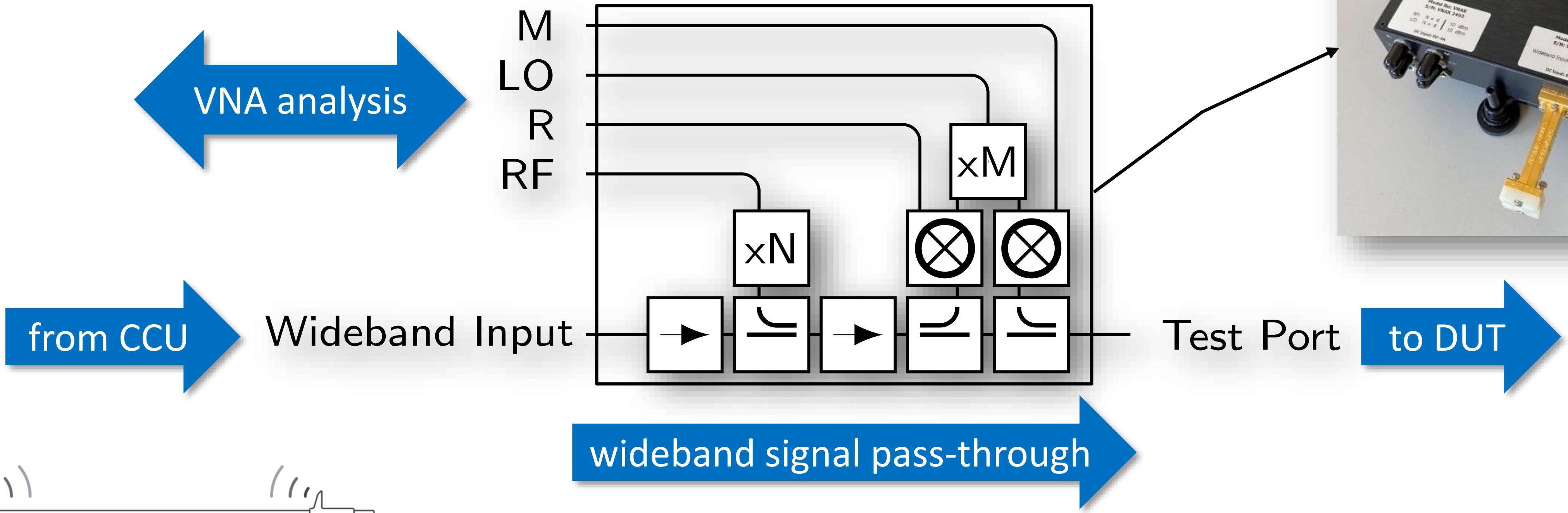
custom frequency extension (VCA)

standard frequency extension (VNAX)


[3] 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*

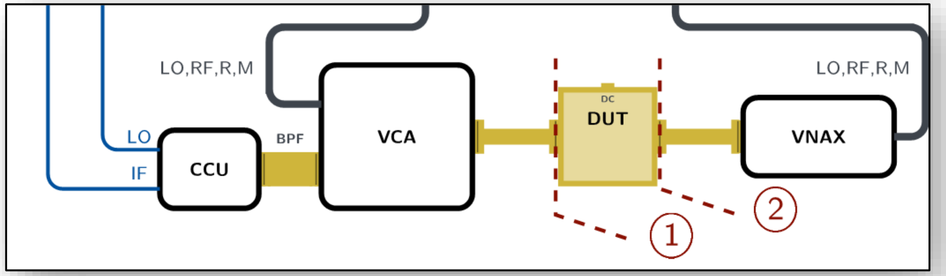
# CrossLink Measurement Platform

- **VCA module** enables
  - broadband multi-tone and complex-modulated signal injection
  - correction of waveforms at RF reference plan using vectorial network functionality and AWG pre-distortion

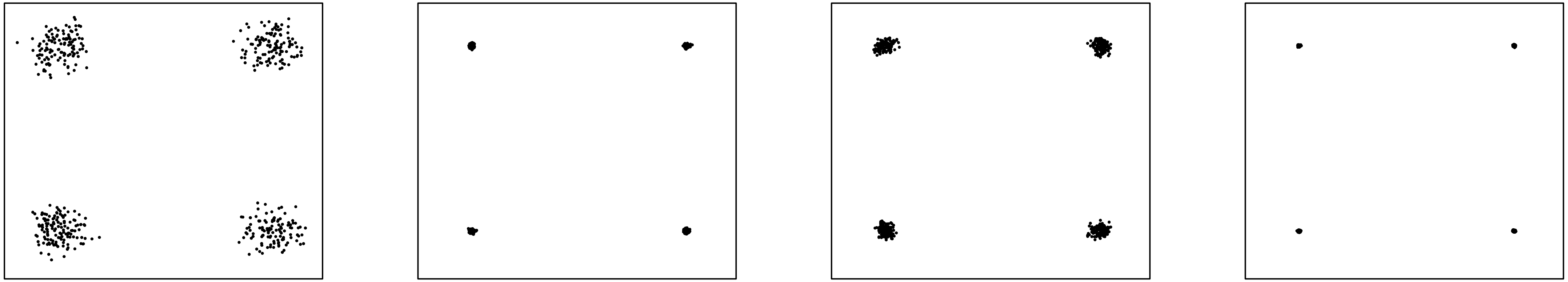



# CrossLink Measurement Platform

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



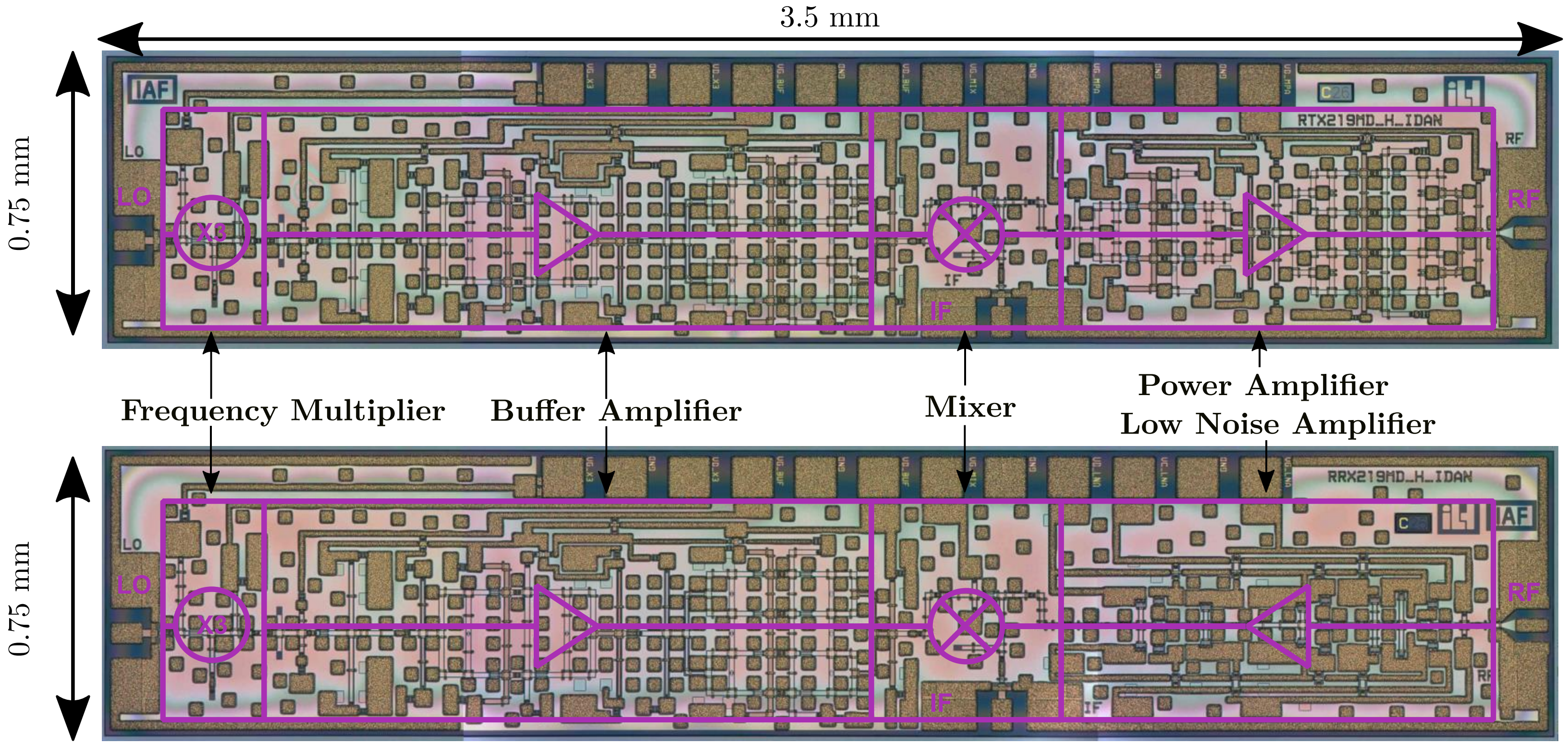

| view 1, uncalibrated | view 1, calibrated at 1 | view 2, calibrated at 1 | view 2, calibrated at 2 |
|---|---|---|---|
| EVM = 13% | EVM = 1.3% | EVM = 4.5% | EVM = 0.6% |
| $P_{RF}$ = -8 dBm | $P_{RF}$ = -8 dBm | $P_{RF}$ = 6 dBm | $P_{RF}$ = 6 dBm |



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

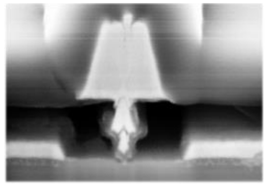
# 300 GHz Superheterodyne Tx / Rx

- IF range 75..95 GHz
- LO range 72..75.5 GHz
- RF range 288..320 GHz
- $P_{-1dB, Tx}$ = -3 dBm
- $NF_{Rx}$ = 7.3 dB (sim.)
- $P_{DC/MMIC}$ = 350 mW





Fraunhofer IAF



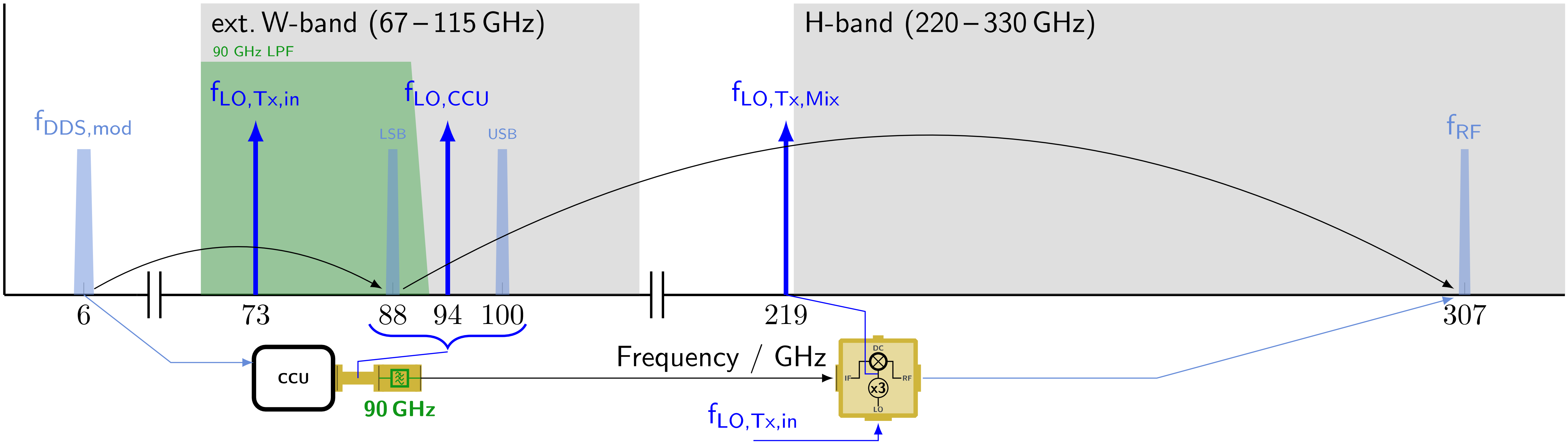
35nm InGaAs mHEMT technology
$f_T$ / $f_{max}$: > 500 GHz / > 1000 GHz

METERACOM



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

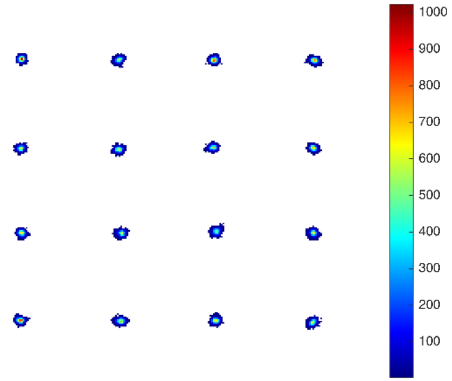
# Superheterodyne Frequency Scheme



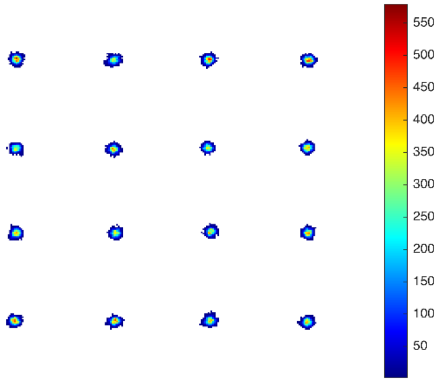
# Recap In-Band Interferer

- Harmonics pose risk of in-band interferer for modulated signal in the RF domain
- Sever degradation of quantities like EVM and SNR
- exemplary 1.6 GBd 16-QAM signal

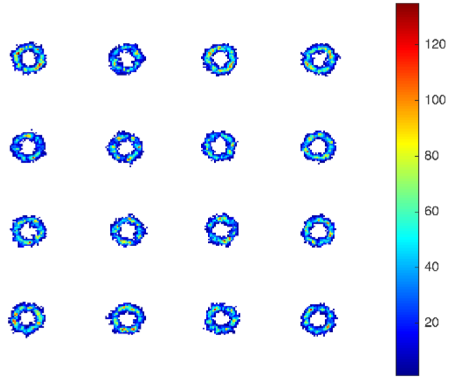
$P_{signal}$ = -6 dBm
w/o Interf.
$EVM_{rms}$ = 1.6%



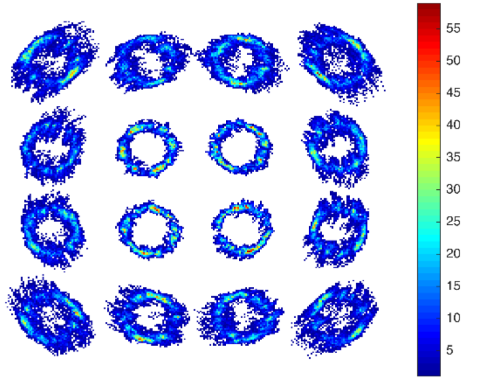

$P_{signal}$ = -6 dBm
$P_{interf} << P_{signal}$
$EVM_{rms}$ = 1.8%




$P_{signal}$ = -6 dBm
$P_{interf} \approx P_{signal}$
$EVM_{rms}$ = 6.3%



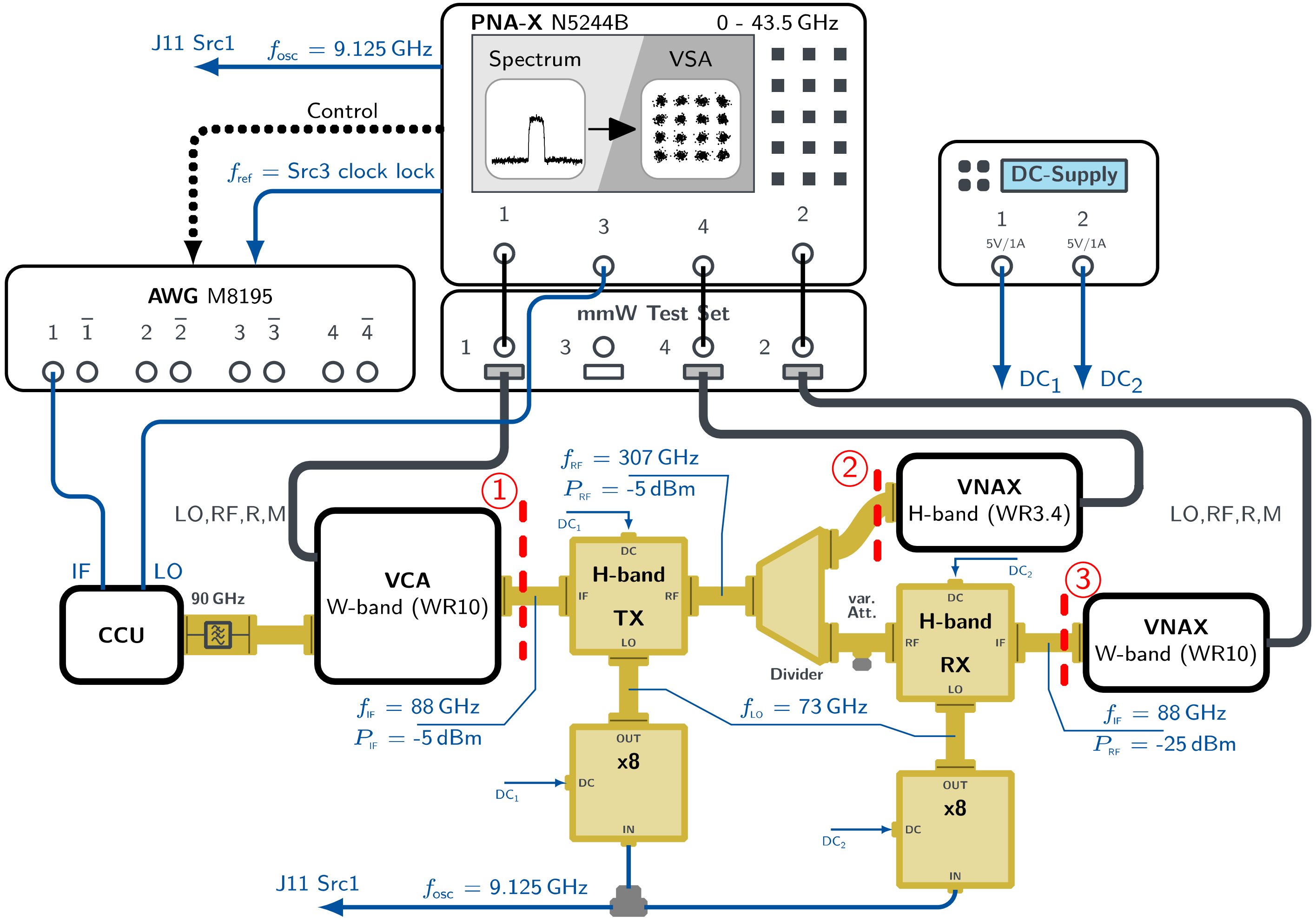

$P_{signal}$ = -6 dBm
$P_{interf} >> P_{signal}$
$EVM_{rms}$ = 12.6%

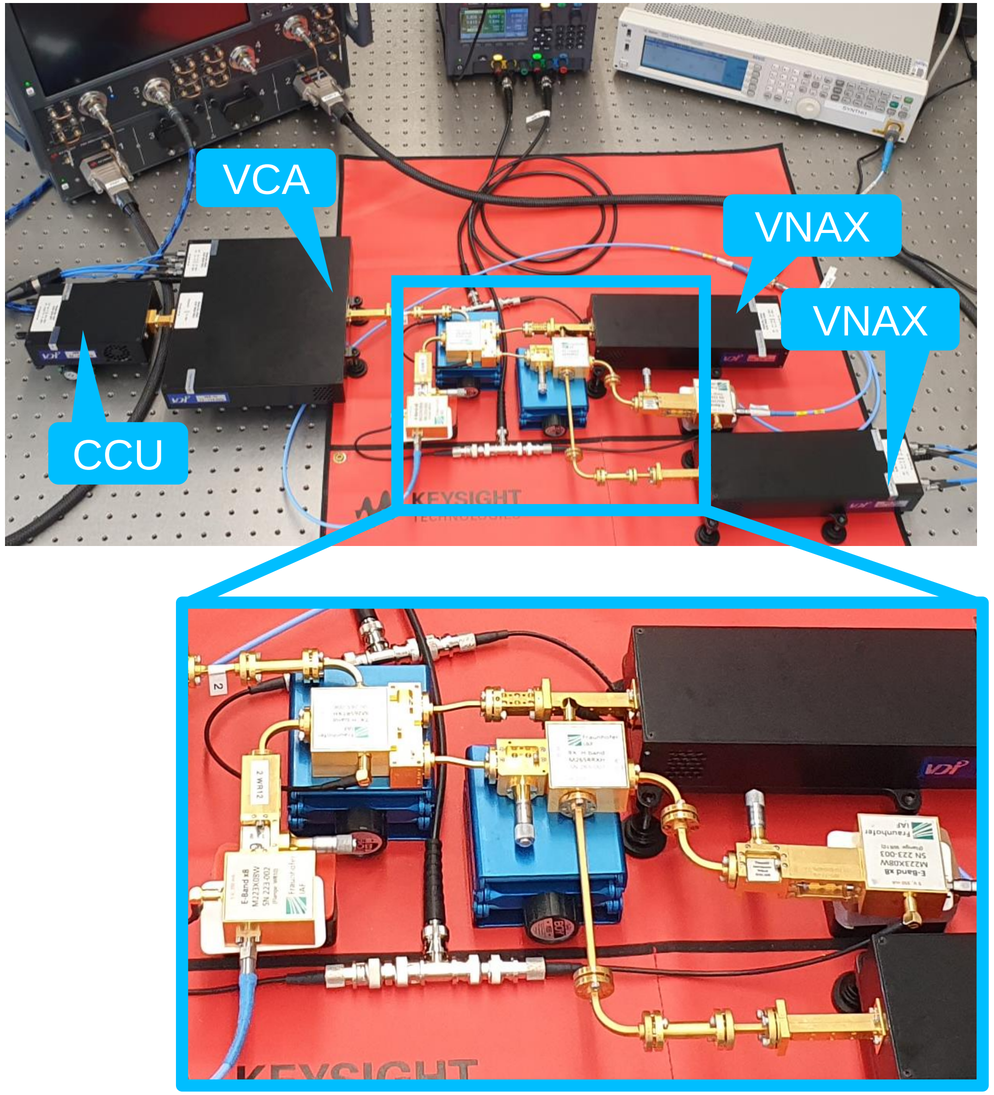





[7] D. Wrana et al., "Effects of Harmonics from Frequency-Multiplicative Carrier Generation in a Superheterodyne 300 GHz Transmit Frontend"

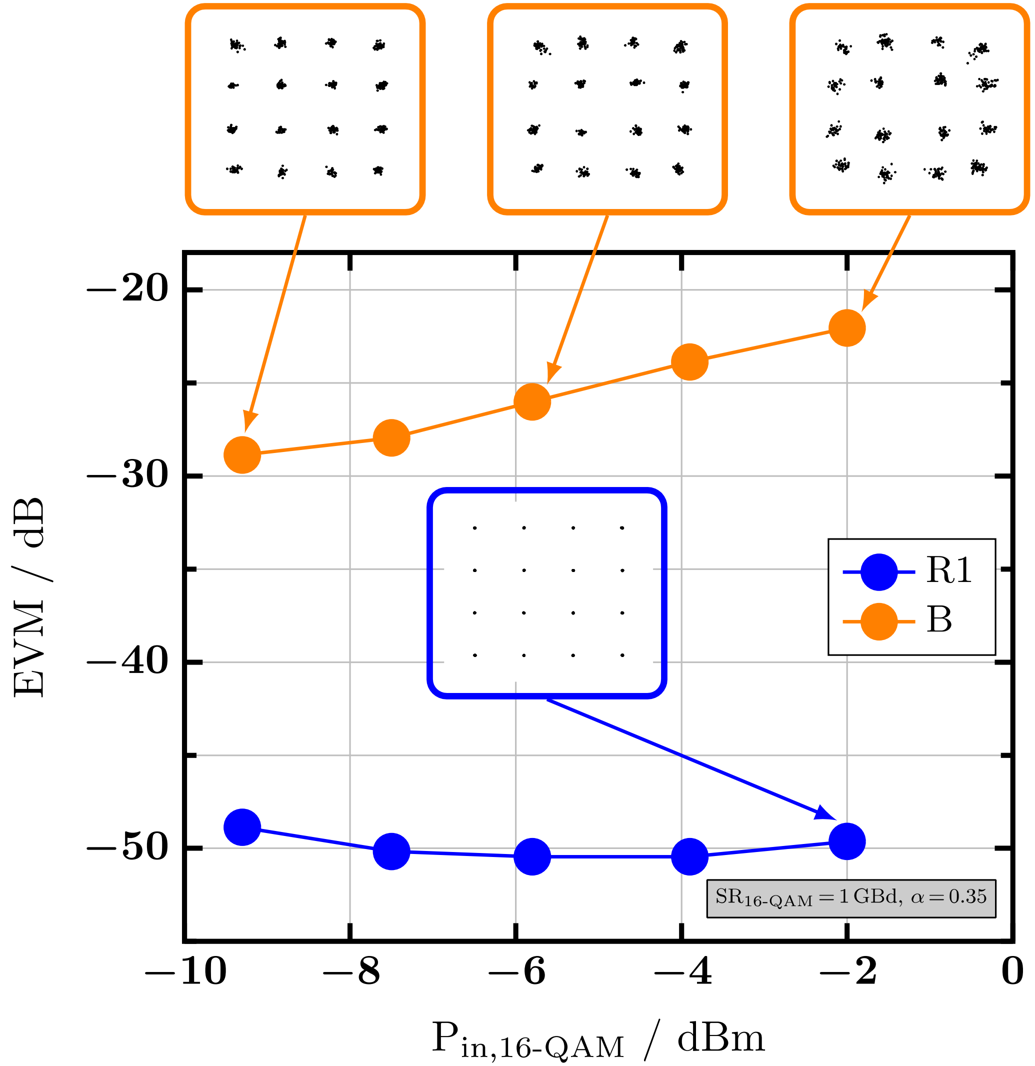
# Measurement Setup 300GHz Tx / Rx



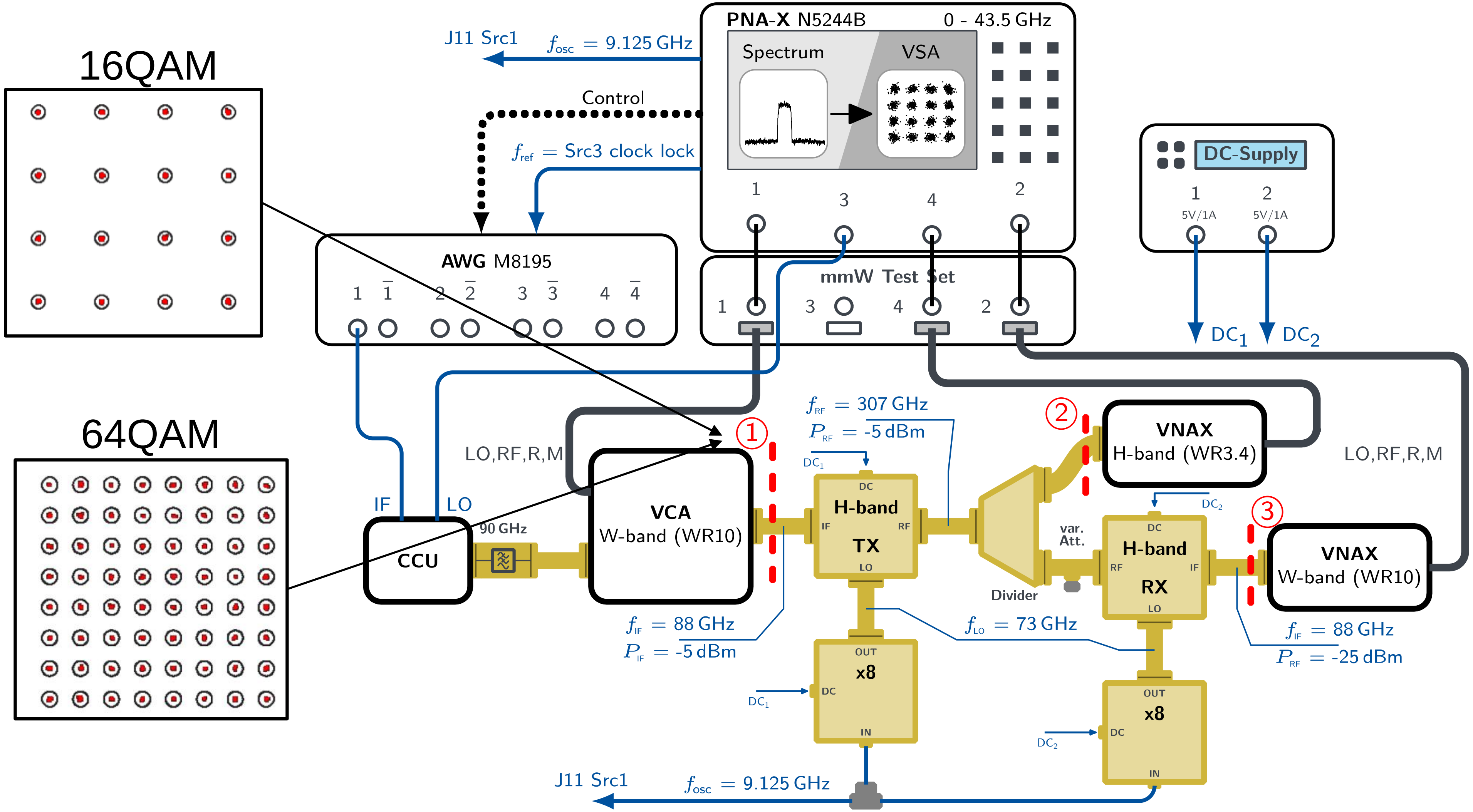
# EVM Degradation Tx - Rx

- W-band to W-band
- Source correction capability at DUT input (R1) allows for nearly ideal input signal quality (<1% $EVM_{RMS}$)
- Capture and demodulate at DUT output (B)
- Observation of non-linear behavior of the DUT over power



# Reference Plane 1

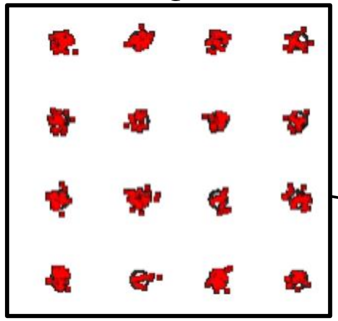
- W-band
- EVM 0.8%
- 5 GBd
- α=0.35
- -5 dBm
- Fc = 88 GHz



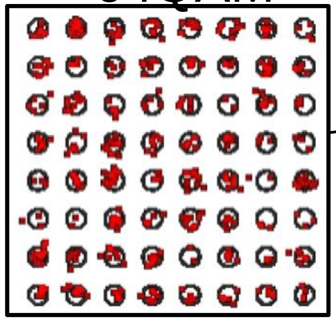
# Reference Plane 2

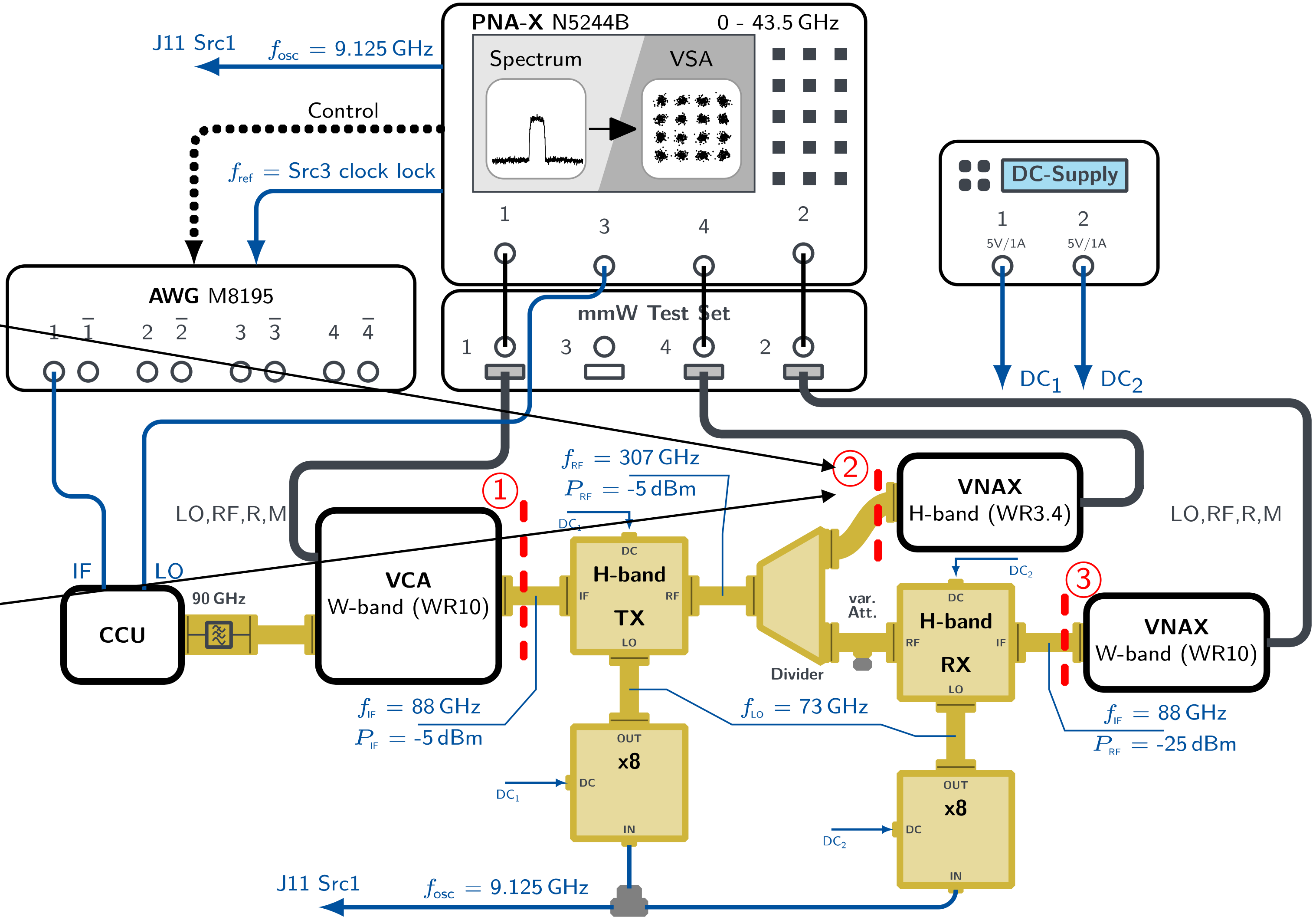
- W-band to H-band
- EVM 4%
- 5 GBd
- α=0.35
- -10 dBm
- Fc = 307 GHz

16QAM



64QAM

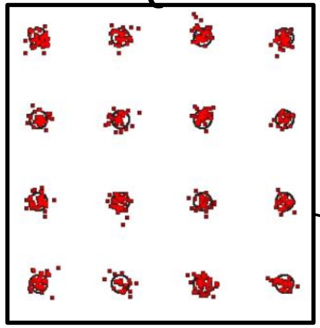




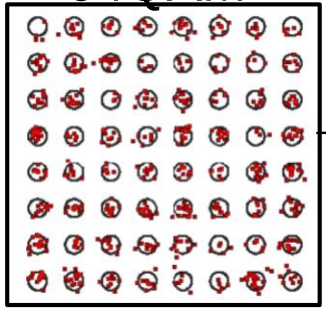
# Reference Plane 3

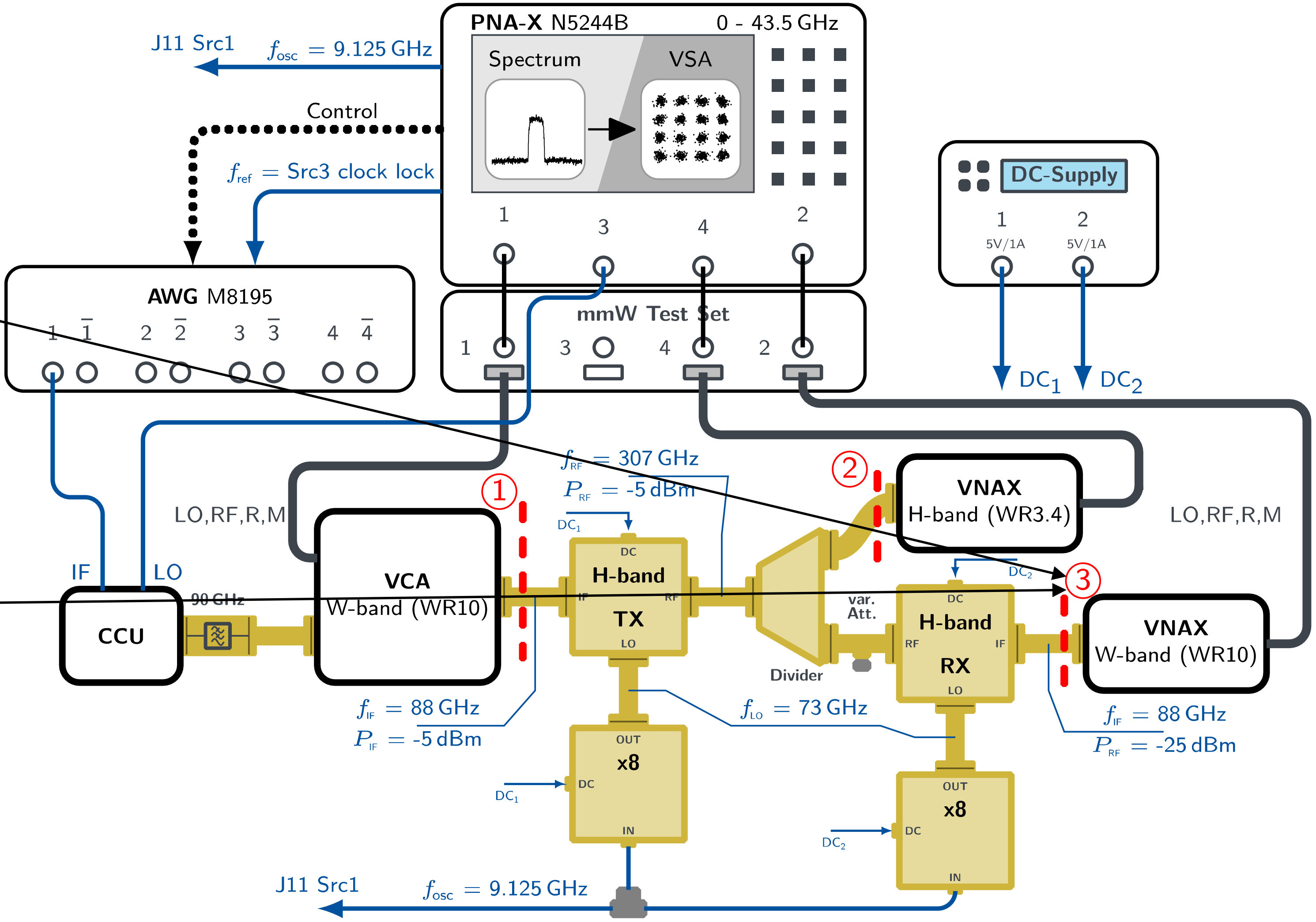
- W-band to W-band
- EVM 4%
- 5 GBd
- α=0.35
- -25 dBm
- Fc = 88 GHz

16QAM

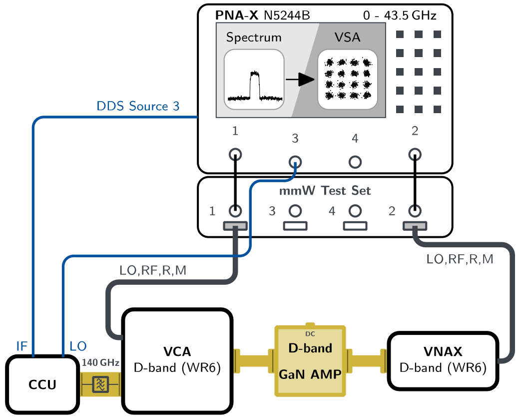


64QAM





# IMD Measurement in D-band



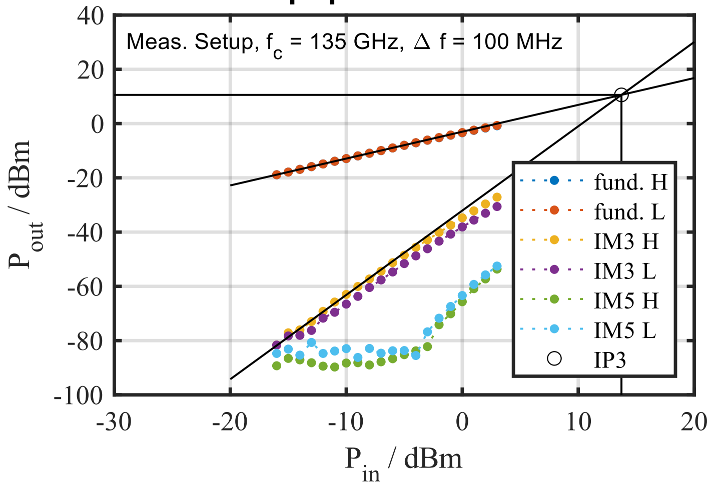

$$\mathrm{OIP3} = \left(\frac{1}{OIP3' \cdot g_2} + \frac{1}{OIP3''}\right)^{-1}$$

**Table 1.** Measured OIP3 points of the measurement setup and different DUT.

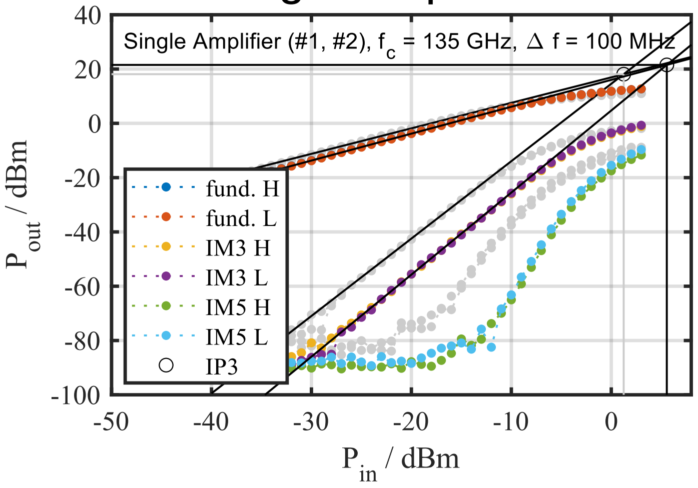
| | $OIP3_{meas}$ | $OIP3_{corr}$* |
|---|---|---|
| measurement setup | 13.06 dBm | - |
| amplifier #1 | 21.22 dBm | 23.39 dBm |
| amplifier #2 | 17.62 dBm | 18.95 dBm |
| cascaded amplifier | 20.32 dBm | 21.22 dBm |
| cascaded amplifier calculated from #1 and #2 | - | 21.85 dBm |

*Measurement setup has been deducted.

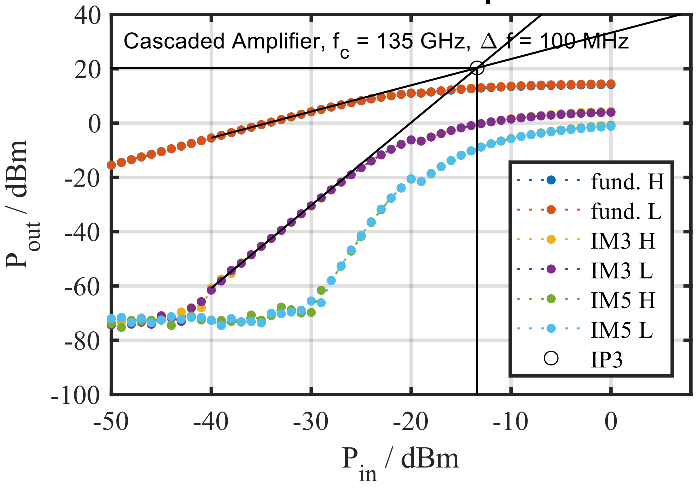
## Setup performance




## Single Amplifier




## Cascaded Amplifier




## More information?

Visit talk “Intermodulation Distortion Analysis In Cascaded D-Band GaN Amplifiers” on Thursday 14:00 Hall D

# 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.
- CrossLink measurement platform was introduced offering innovative capabilities for the characterization of transceivers and transceiver components dedicated to 6G
- In-situ combined time and frequency domain measurement
- Custom VCA unit for inline time and frequency domain characterization
  - EVM
  - IMD
  - Transfer function
- Inline correction of wideband complex modulated communication signals at DUT input and DUT output

# 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] 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.

[4] 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.

[5] 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.

[6] 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.

[7] 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

# Thank you very much for your Attention

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