MPI CORPORATION

ARMMS
RF & Microwave Society

Evolution of the Wafer-level Characterization Solutions: Towards mmW 6G Applications

Vince Mallette, Dr Andrej Rumiantsev

Outline

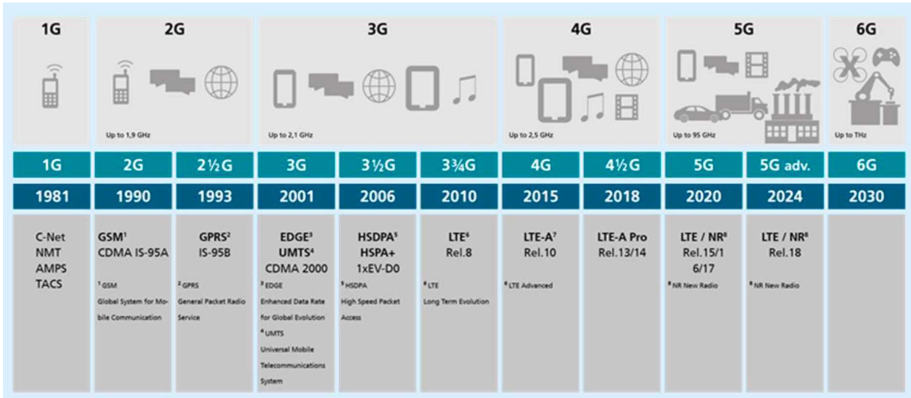
- Instrumentation Evolution
- Drivers and Challenges
- Next-Generation Characterization Systems and Components
- Differential and Multiport Characterization
- Conclusion

MPI CORPORATION

Outline

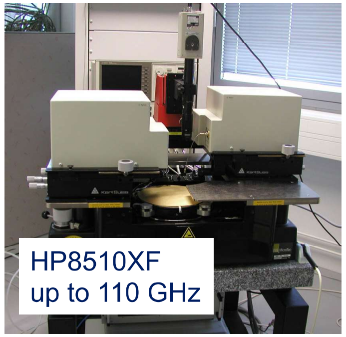
Introduction: Instrumentation Evolution

Instrumentation → Communication Enablers



On the Road to 6G: Drivers, Challenges, and Enabling Technologies, A Fraunhofer 6G white paper, Fraunhofer, Nov. 2021, 15pp.

Broadband Instrumentation Evolution

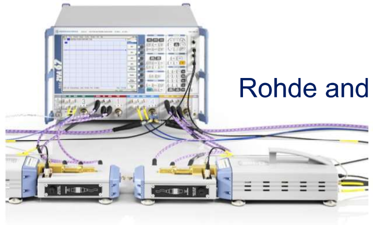


1999: Single Sweep
Development of accurate device models

Broadband Instrumentation Evolution

2000s: Size reduction

- Integration of other instrumentation (Load pull, ect.)
- Complex IC development
- Differential mmW



Rohde and Schwarz

Broadband Instrumentation Evolution

Anritsu VectorStar
110/145GHz

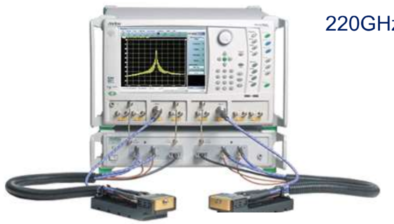
Keysight PNAx
120/130GHz

2010s: Further Size reduction and band expansion

- Characterization accuracy
- Differential mmW
- 145 GHz

Broadband Instrumentation Evolution

Anritsu VectorStar
220GHz



Keysight PNAx
220GHz

2020s: Further Size reduction and band expansion

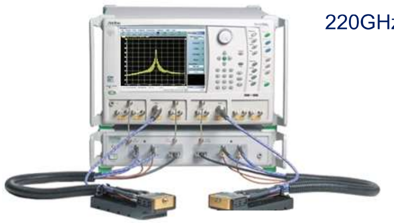
- 220 GHz
- 220 GHz differential
- D-band complex systems

https://www.keysight.com/ca/en/assets/3121-1515/technical-overviews/170GHz-220GHz-Broadband-Vector-Network-Analysis-Solution.pdf

Broadband Instrumentation Evolution

Anritsu VectorStar

220GHz



Keysight PNAx

220GHz

2020s: Further Size reduction and band expansion

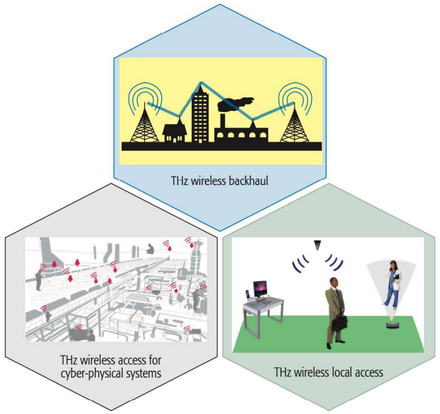
- 220 GHz
- 220 GHz differential
- D-band complex systems

MPICORPORATION

Drivers and Challenges

Example: 6G Drivers and Challenges

- THz wireless backhaul
- THz wireless access for cyber-physical systems
- THz wireless local access



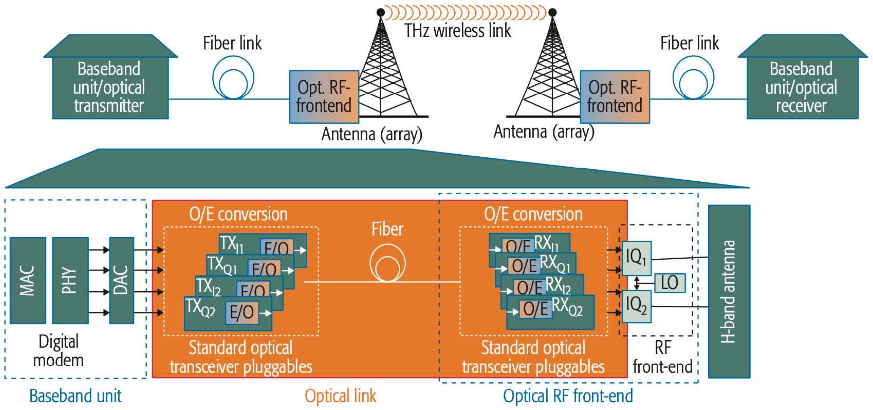
On the Road to 6G: Drivers, Challenges, and Enabling Technologies, A Fraunhofer 6G white paper, Fraunhofer, Nov. 2021, 15pp.

6G Drivers and Challenges

The key driver for 6G will remain ***the extended network capacity****. And this can be achieved only through* ***new, Terahertz (THz) spectrum-based technologies****. Be it capacities of 4 Tbit/s for AR/XR, the under 100 µs delay for industrial or holographic presence, a 7-nines reliability, or < 1 cm-precision localization.*

On the Road to 6G: Drivers, Challenges, and Enabling Technologies, A Fraunhofer 6G white paper, Fraunhofer, Nov. 2021, 15pp.

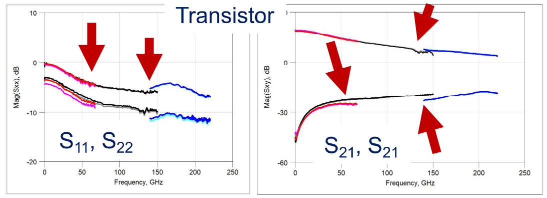
6G Challenges: Broadband Front-Ends

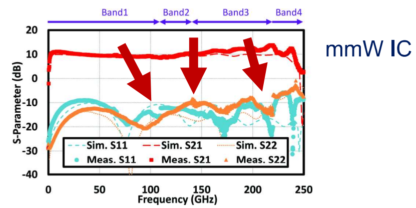


A. -A. A. Boulogeorgos et al., "Terahertz Technologies to Deliver Optical Network Quality of Experience in Wireless Systems Beyond 5G", in IEEE Communications Magazine, vol. 56, no. 6, pp. 144-151, June 2018

Challenge: Broadband Data Inconsistency

- Measurement data analysis and interpretation challenges increase with the number of frequency bands
- Sources of errors:
  - Frequency extenders
  - Wafer probe designs
  - Calibration methods
  - Measurement repeatability

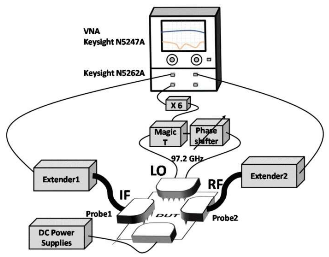




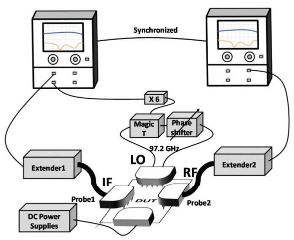
T. Jyo et al, "A 241-GHz-Bandwidth Distributed Amplifier with 10-dBm P1dB in 0.25-μm InP DHBT Technology," IMS, 2019.

Challenge: Setup Complexity & Reconfiguration

Conversion gain characterization



Band	RF freq. range	Extender1 (IF port)	Extender2 (RF port)	Probe1 (IF port)	Probe2 (RF port)	Pow. meter for IF pow. Cal.	Pow. meter for RF pow. Cal.
1	10 M – 110 GHz	Keysight N5260	Keysight N5260	Cascade I110-GSG	Cascade I110-GSG	Keysight U8489A	Keysight U8489A



Band	RF freq. range	Extender1 (IF port)	Extender2 (RF port)	Probe1 (IF port)	Probe2 (RF port)	Pow. meter for IF pow. Cal.	Pow. meter for RF pow. Cal.
2	110 G – 140 GHz	Keysight N5260	OML V08VNA2	Cascade I110-GSG	Cascade I140-GSG	Keysight U8489A	VDI PM5
3	140 G – 220 GHz	Keysight N5260	OML V05VNA2	Cascade I110-GSG	Cascade I220-GSG	Keysight U8489A	VDI PM5

T. Jyo *et al.*, "A DC to 194-GHz Distributed Mixer in 250-nm InP DHBT Technology," *2020 IEEE/MTT-S International Microwave Symposium (IMS)*, 2020, pp. 771-774

MPI CORPORATION

Next-Generation Characterization Systems

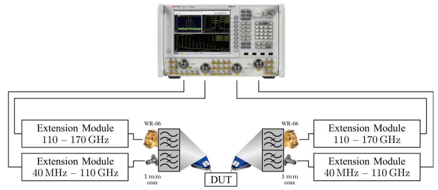
Broadband Measurement Systems: 110GHz +

- Instrumentation versatility
- Probe system integration complexity
- Probes
- Calibration standards
- Metrological solutions

- Single-ended for device characterization
- Differential for IC validation

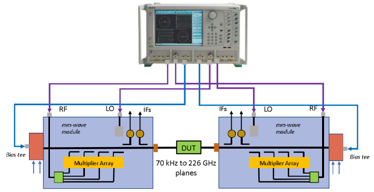
Instrumentation: Two Approaches

Conventional Instrumentation



- Two VNA Extenders
- DC to 170 GHz or to 220 GHz with WR5 and 120…140 GHz transition
- RF probe with 1mm, WR5 interfaces and an embedded combiner

Next-Generation Instrumentation



- One broadband frequency extender
- DC to 226 GHz
- RF probe with 0.6 mm broadband interface

F. Boes, G. Gramlich, M. Kretschmann, S. Marahrens, and T. Zwick, "Ultrabroadband Diplexers for Next-Generation High-Frequency Measurement Applications," IEEE Transactions on Microwave Theory and Techniques, vol. 68, no. 6, pp. 2161-2167, 2020
J. Martens and T. Roberts, "Broadband 220 GHz network analysis: structures and performance," 94th ARFTG Microwave Measurement Conference Digest, San Antonio, TX, 26-29, 2020.

Different Goals

Conventional Extenders

- Accumulate already existing PNA-X and WR6/WR5 extenders
- Purchase the probes, probe system adaptation

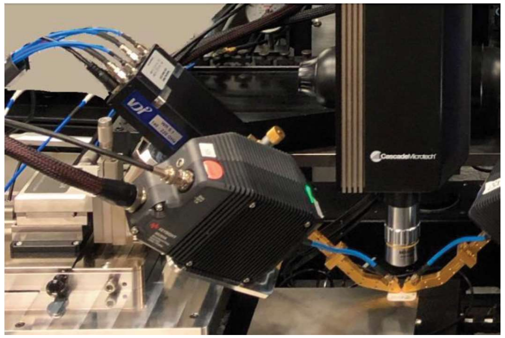
Next-Generation Extenders

- Upgrade path of the existing VectorStar 110/145 GHz systems
- New measurement systems with future upgrade path

F. Boes, G. Gramlich, M. Kretschmann, S. Marahrens, and T. Zwick, "Ultrabroadband Diplexers for Next-Generation High-Frequency Measurement Applications," IEEE Transactions on Microwave Theory and Techniques, vol. 68, no. 6, pp. 2161-2167, 2020
J. Martens and T. Roberts, "Broadband 220 GHz network analysis: structures and performance," 94th ARFTG Microwave Measurement Conference Digest, San Antonio, TX, 26-29, 2020.

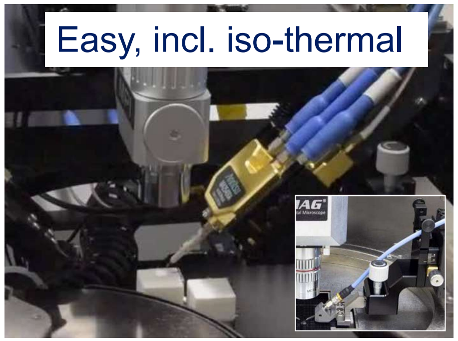
Integration with the Probe System

Conventional Extenders



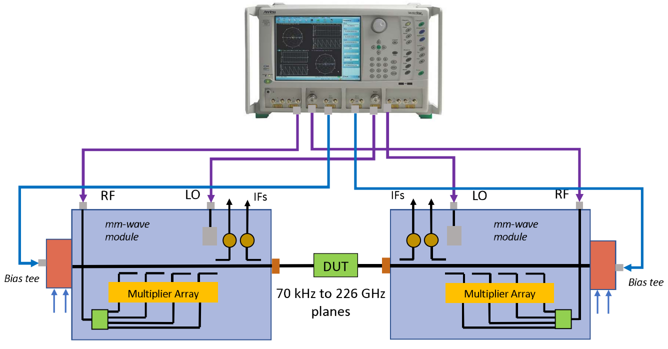
M. Bauers, A Dual-Band Probe for Ultra- Broadband Measurements, EuMW-2021

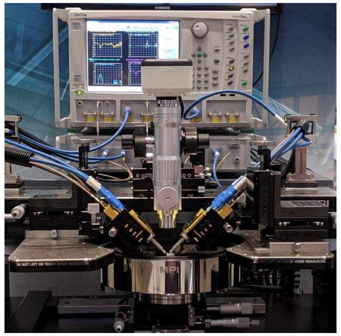
Next-Generation Extenders



Pictures: DMPI, Anritsu

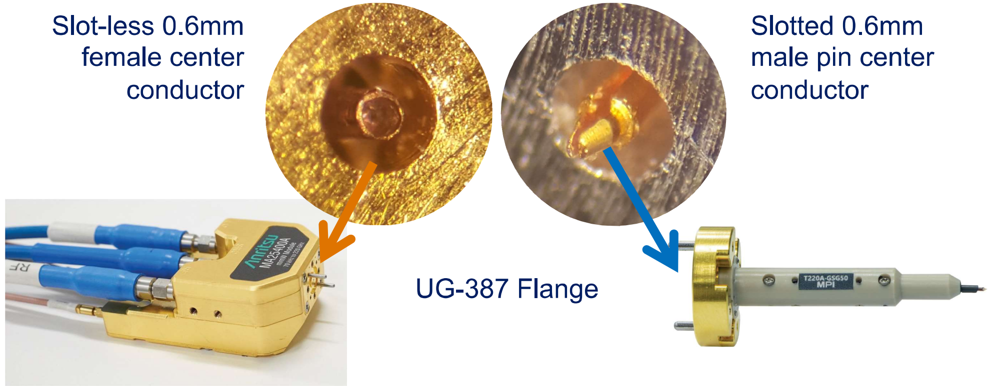
Broadband 70 kHz-220 GHz Single-Sweep VNA





J. Martens and T. Roberts, "Broadband 220 GHz network analysis: structures and performance," 94th ARFTG Microwave Measurement Conference Digest, San Antonio, TX, 26-29 January, 2020.

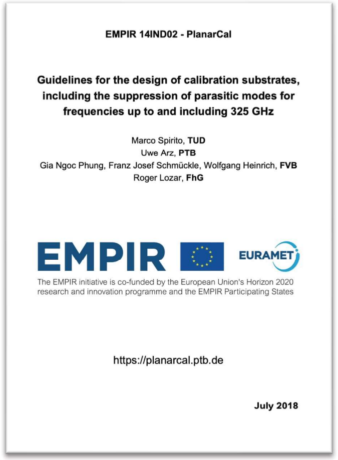
Probe Interface with 220 GHz Module



A. Rumiantsev, et al, Calibration, Repeatability and Related Characteristics of On-wafer, Broadband 70 kHz-220 GHz Single-Sweep Measurements, ARFTG-95th

Calibration Standards

Guidelines for the design of calibration substrates, including the suppression of parasitic modes for frequencies up to and including 325 GHz


EMPIR 14IND02 - PlanarCal

Guidelines for the design of calibration substrates, including the suppression of parasitic modes for frequencies up to and including 325 GHz

Marco Spirito, **TUD**
Uwe Arz, **PTB**
Gia Ngoc Phung, Franz Josef Schmückle, Wolfgang Heinrich, **FVB**
Roger Lozar, **FhG**

EMPIR EURAMET

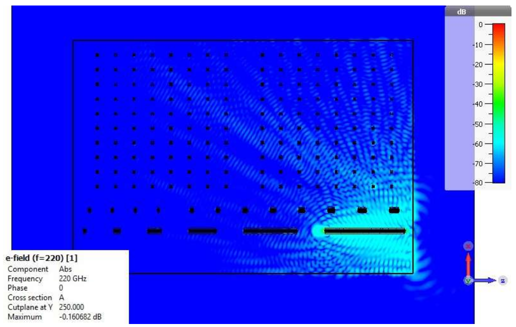
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

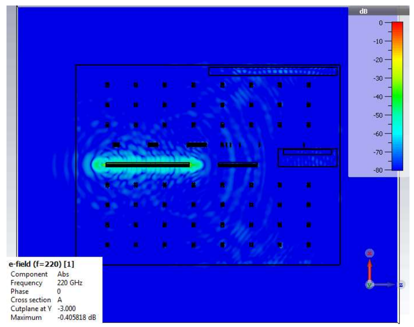
https://planarcal.ptb.de

July 2018

Minimized Coupling and Higher Order Modes: 220 GHz

- Conventional vs optimized cal substrate

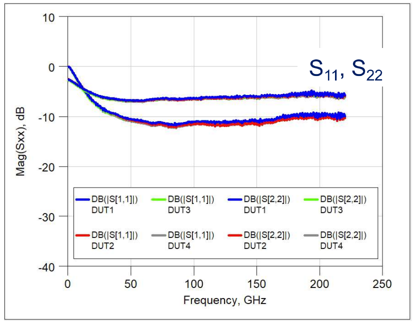


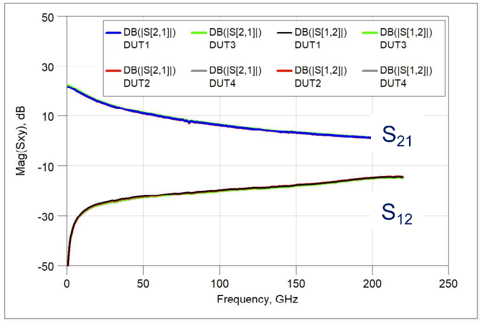


Rumiantsev, Andrej, Ralf Doerner, and Gia Ngoc Phung, "Calibration Substrate Design for Accurate Mm-Wave Probe-Tip Calibration." 94th ARFTG Microwave Measurement Conference, San Antonio, TX, 26-29 January, 2020.

Broadband Transistor Characterization

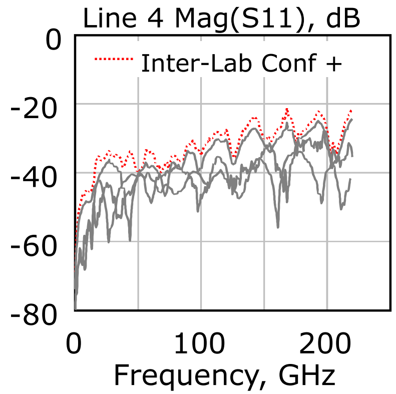
- Four devices, consistent results

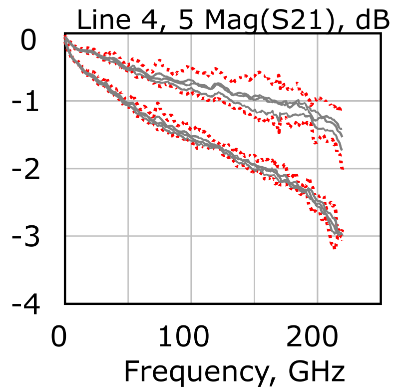




Data courtesy: FBH

Metrology: Inter-Laboratory Comparison



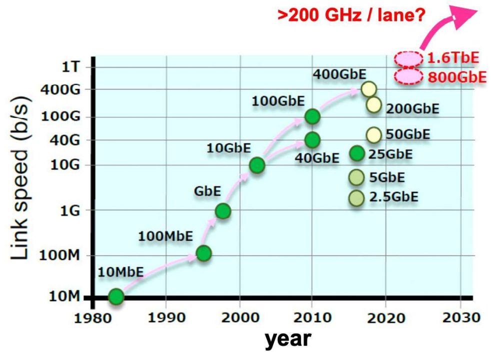


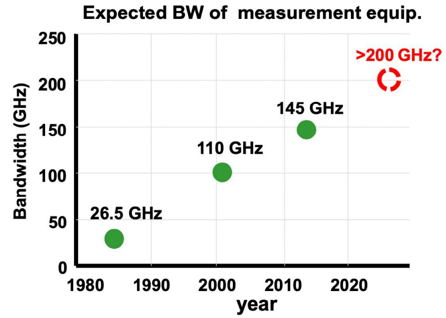
A. Rumiantsev, R. Doerner, J. Martens, and S. Reyes, "Inter-Laboratory Comparison of On-Wafer Broadband 70kHz-220GHz Single-Sweep Measurements," presented at the 2021 51st European Microwave Conference (EuMC)

MPI CORPORATION

Differential and Multiport Characterization

Required BW for DAC/ADC is Expected to Reach 200 GHz





- Differential design, characterization

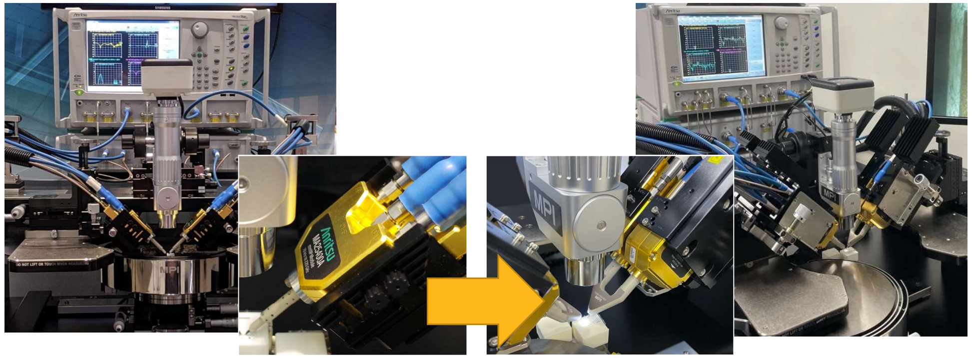
Teruo Jyo, Munehiko Nagatani, Minoru Ida, Miwa Mutoh, Hitoshi Wakita, Naoki Terao, Hideyuki Nosaka A DC to 194-GHz Distributed Mixer in 250-nm InP DHBT Technology. IMS-2020, We3C-2

Why Differential Broadband System?

One of the differential RF signals is terminated inside the chip for convenience of measurement ***because a differential probe (GSGSG) above 110 GHz is unavailable****.*

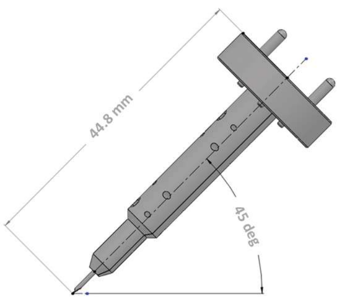
*T. Jyo *et al.*, "A DC to 194-GHz Distributed Mixer in 250-nm InP DHBT Technology," *2020 IEEE/MTT-S International Microwave Symposium (IMS)*, 2020, pp. 771-774

Extension for Differential Measurements

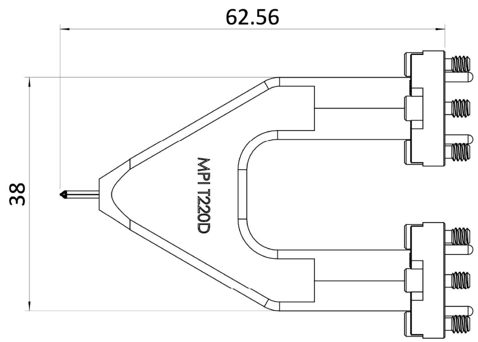


Only < 40% Longer than the Single-Ended Probe

T220A: ~45 mm

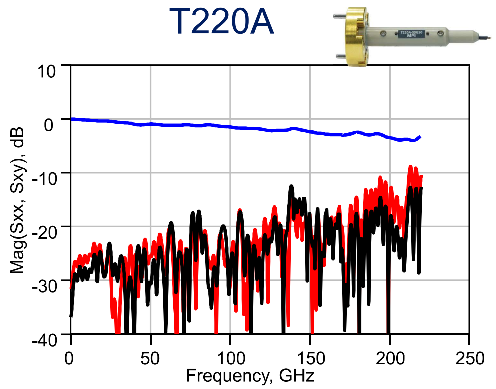


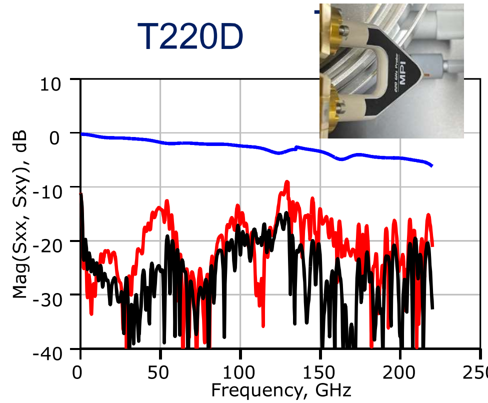
T220D: ~63mm



A. Rumiantsev, J. Martens, S. Reyes, A Differential Broadband Single-Sweep 70 kHz-220 GHz Wafer-Level System: First Calibration and Measurement Characteristics, ARFTG-110th, 2023

Insignificant Increase of the Probe Loss: < 1.7 dB@220 GHz

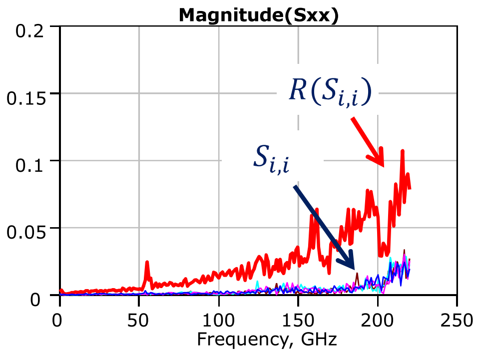


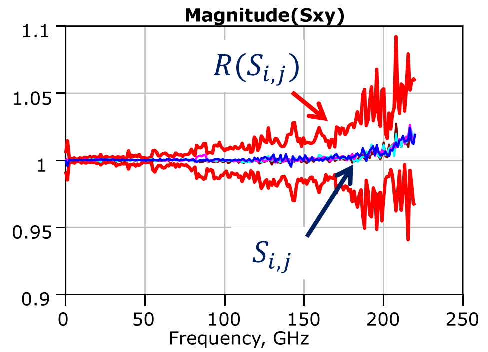


A. Rumiantsev, J. Martens, S. Reyes, A Differential Broadband Single-Sweep 70 kHz-220 GHz Wafer-Level System: First Calibration and Measurement Characteristics, ARFTG-110th, 2023

First Step Towards Metrological Solution

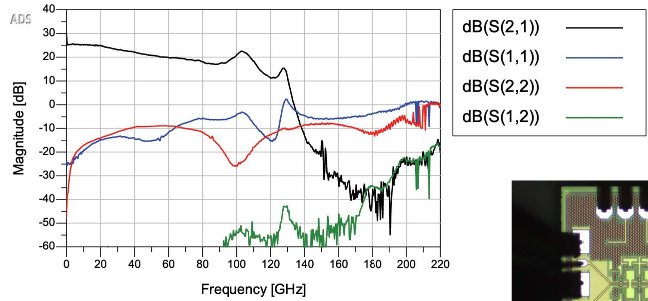
Measurement Reproducibility Limit R: Thru

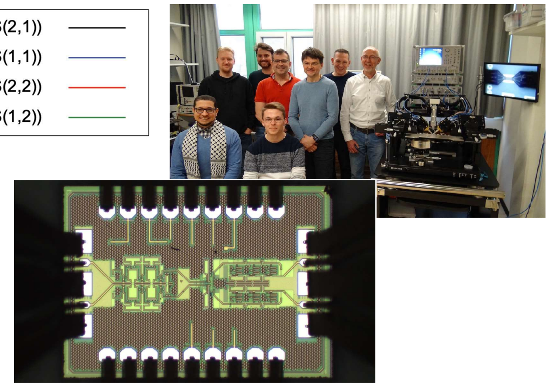




A. Rumiantsev, J. Martens, S. Reyes, A Differential Broadband Single-Sweep 70 kHz-220 GHz Wafer-Level System: First Calibration and Measurement Characteristics, ARFTG-110th, 2023

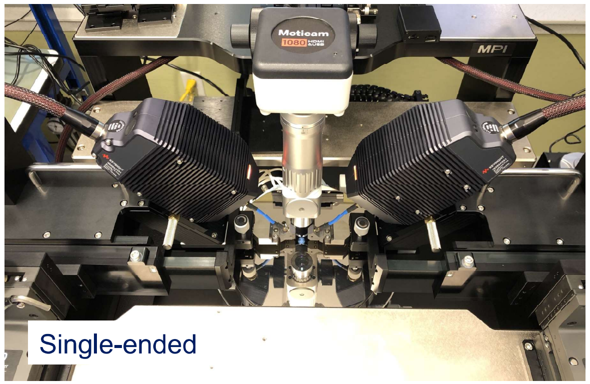
Broadband mmWave Driver Circuit

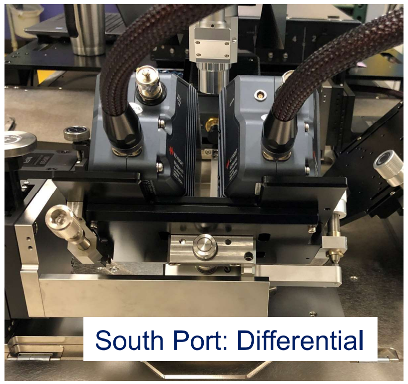




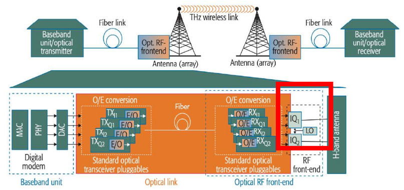
Courtesy: Ulm University, Germany

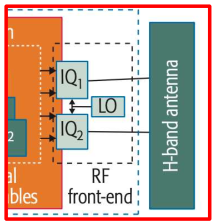
Broadband Single-Ended and Differential Characterization





Broadband Sub-Harmonic Mixer Characterization



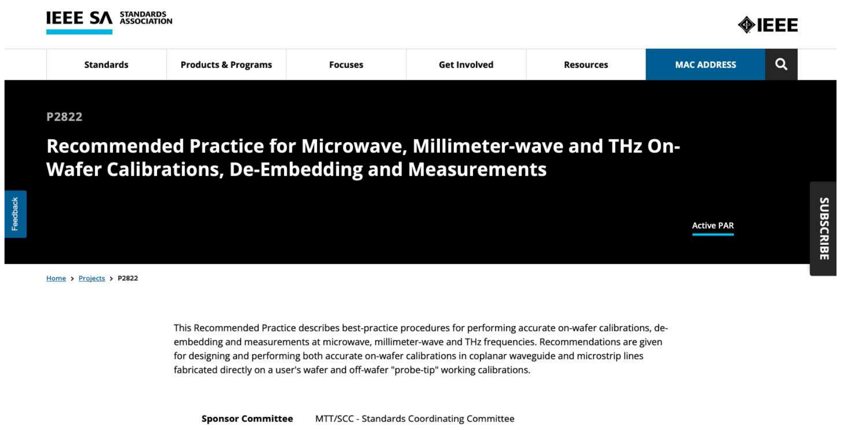


Testing of the two-sided coupling energy of mmW and LO signals

Conclusion

- New instrumentation for the broadband DC through 220 GHz device and differential IC characterization, including probes, standards, and probe systems
- System integrated solutions developed, including mixer characterization at mmW band
- First results of the broadband measurement metrology solutions, including for the differential DUT

MTT-S/SCC P2822 Working Group: Join us!



Thank you!

MPI CORPORATION