MPI CORPORATION

10 incize YEARS
A DECADE OF TRUST & INNOVATION

Accelerating the Development of High-Speed, mmWave-Frequency Semiconductor Products and Applications

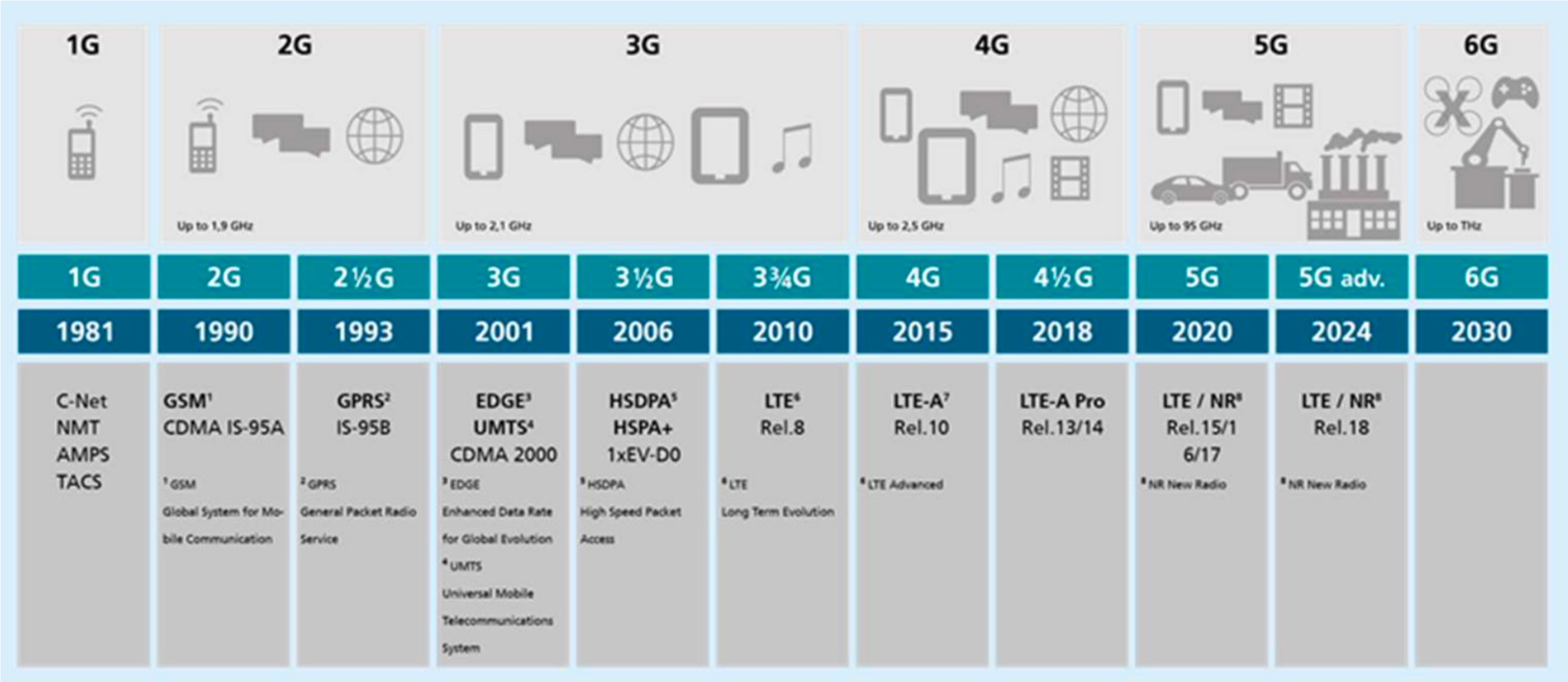
Dr. Andrej Rumiantsev

Director RF Technologies
Advanced Semiconductor Test Division

Outline

- Introduction: Instrumentation Evolution
- Modern Systems and Integration
- Automated Test over Multiple Temperatures
- Conclusion

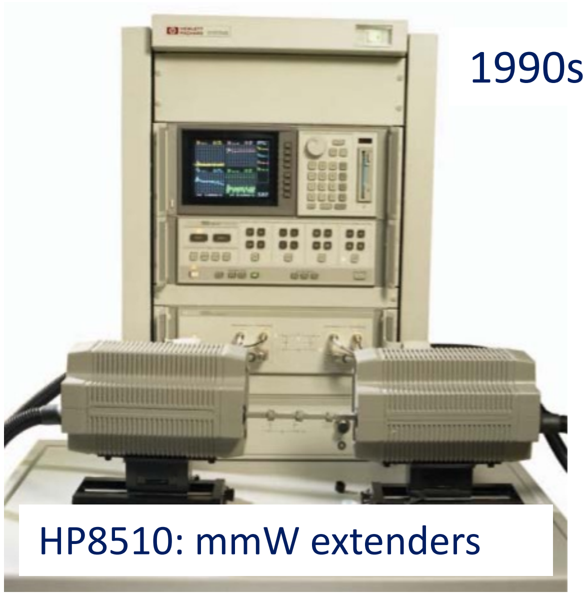
Instrumentation → Communication Enablers

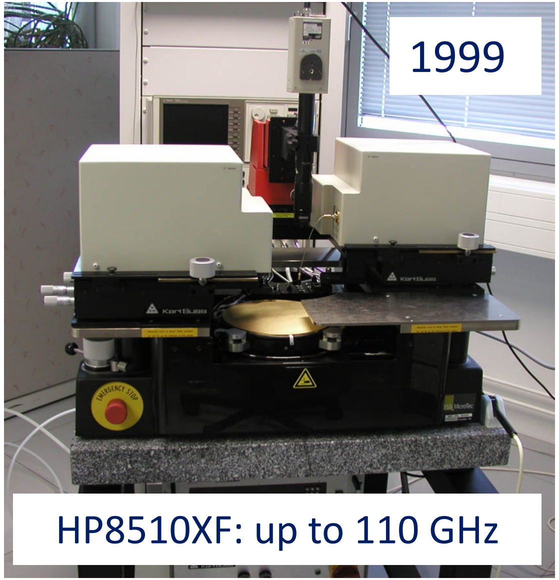


1G	2G	2½G	3G	3½G	3¾G	4G	4½G	5G	5G adv.	6G
1981	1990	1993	2001	2006	2010	2015	2018	2020	2024	2030
C-Net NMT AMPS TACS	GSM[1] CDMA IS-95A	GPRS[2] IS-95B	EDGE[3] UMTS[4] CDMA 2000	HSDPA[5] HSPA+ 1xEV-DO	LTE[6] Rel.8	LTE-A[7] Rel.10	LTE-A Pro Rel.13/14	LTE / NR[8] Rel.15/16/17	LTE / NR[8] Rel.18	
	[1] GSM Global System for Mobile Communication	[2] GPRS General Packet Radio Service	[3] EDGE Enhanced Data Rate for Global Evolution [4] UMTS Universal Mobile Telecommunications System	[5] HSDPA High Speed Packet Access	[6] LTE Long Term Evolution	[7] LTE Advanced		[8] NR New Radio	[8] NR New Radio	

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

1990s: Single-Sweep mmW System



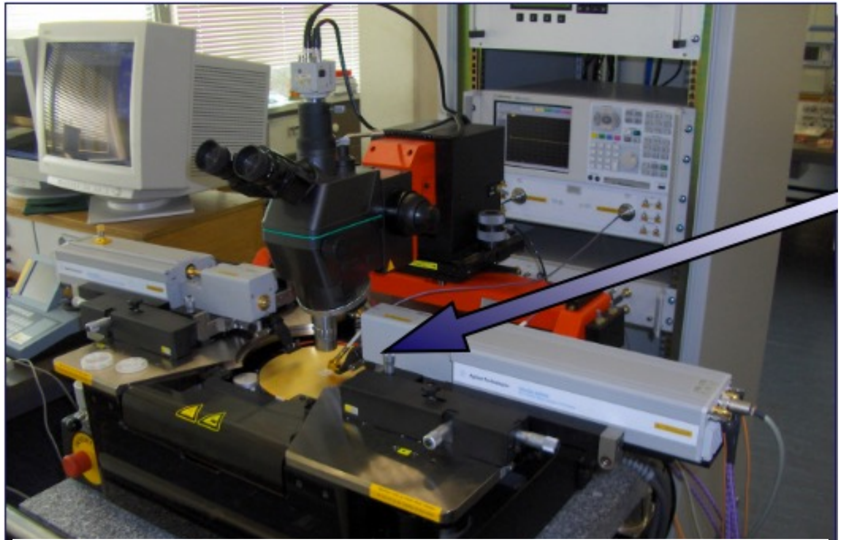


Enabled development of accurate device models for mmW applications

A. Rumiantsev and N. Ridler, "VNA calibration," *IEEE Microwave Mag.,* vol. 9, no. 3, pp. 86-99, 2008, doi: doi:10.1109/MMM.2008.919925.

R. F. Scholz, F. Korndorfer, B. Senapati, and A. Rumiantsev, "Advanced technique for broadband on-wafer RF device characterization," in *ARFTG Microwave Measurements Conference-Spring, 63rd*, 2004, pp. 83-90.

2000s: Broadband Compact System



Exp.: Agilent PNA N5227A 110 GHz

- Enabled Integration of other instrumentation
  - mmWave Load-Pull
  - RF Noise
- Differential wafer-level mmW measurements became possible
- Boosted development of the Large-signal device models
  - Complex IC development
  - Differential mmW circuits

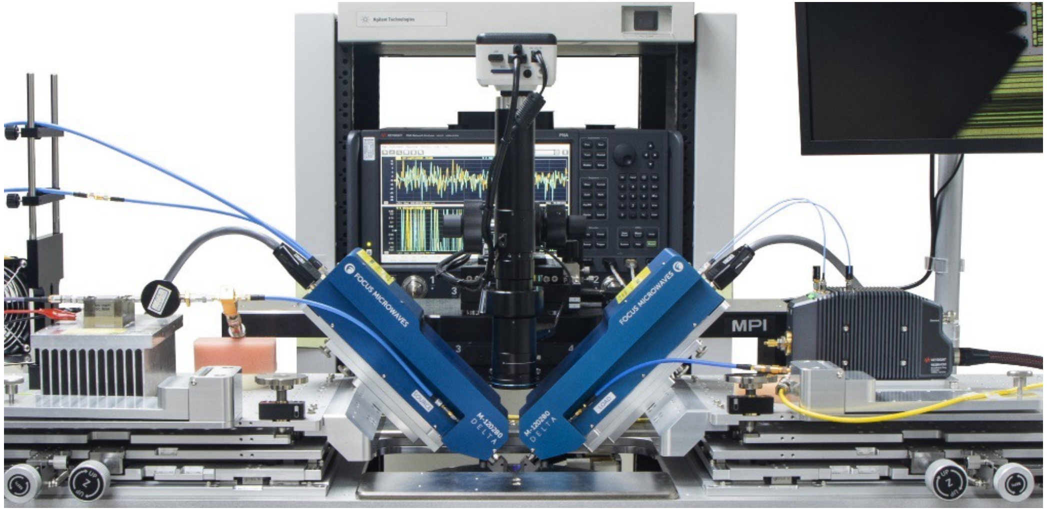
M. Camp, “RFID - Technologie: Funktion und Einsatz,” University of Hannover/Smarter Devices.

Outline

- Introduction: Instrumentation Evolution
- Modern Systems and Integration
- Automated Test over Multiple Temperatures
- Conclusion

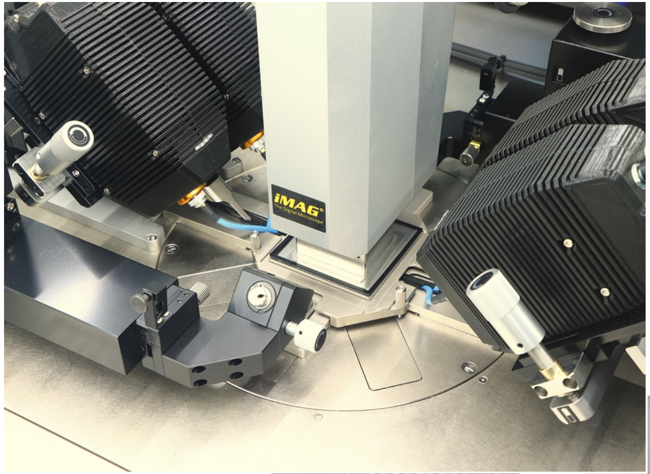
2017: Size, Performance, Complexity

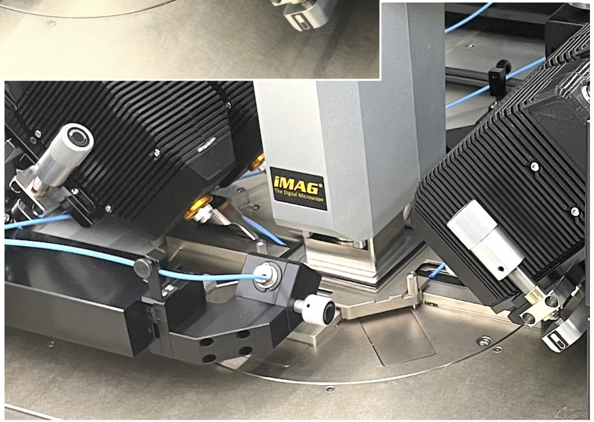
Keysight PNA-X N5291A



- 900 Hz…120 GHz band, accuracy, dynamic range, speed, calibrated power control, …
- A “software-defined instrument”: Integration of the elements of Spectrum Analyzers, Noise Figure Analyzers, Signal Generators, Pulse Generators
- Large-signal, Non-linear characterization, time-domain waveforms, modulated waveforms, mmW vectorial Load Pull, …

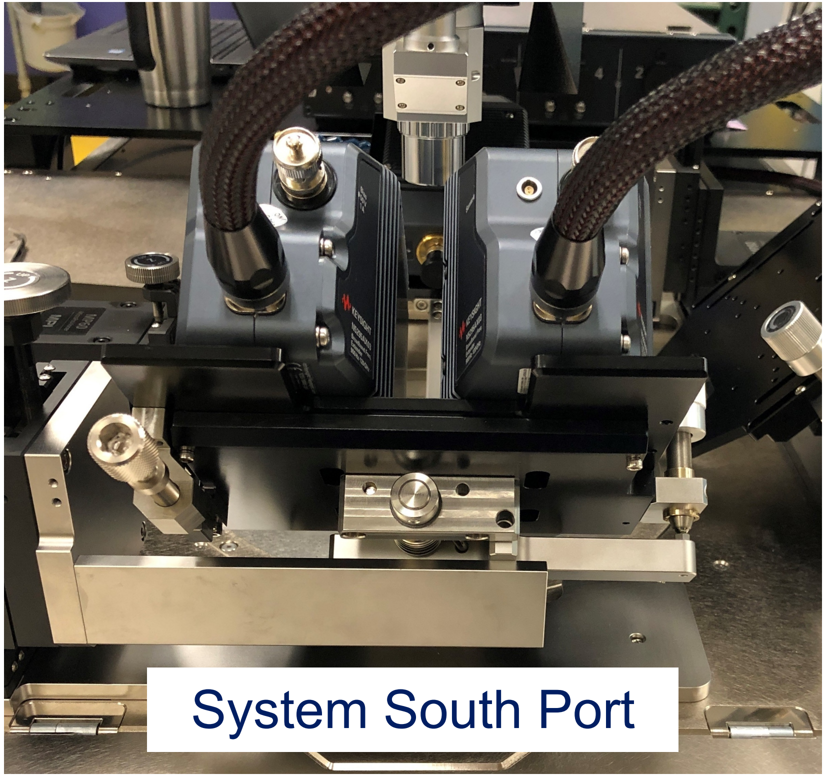
Differential PNA-X System Integration on MPI's TS3500-SE System



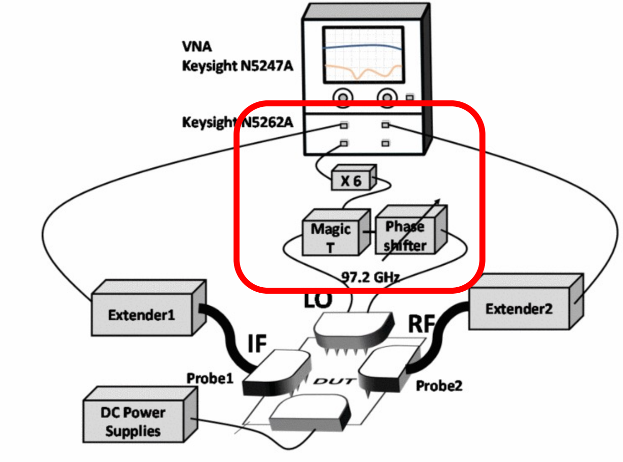


- DUT ShieldEnvironment™ (SE)
- Over-temperature differential mmW IC characterization
  - e.g. automotive IC in the range of -40°C to +175°C
- EMI, light-tight environment
- Easy re-configurable from 67 GHz to the full-sweep DC…120 GHz differential characterization

Integration on the Probe System South Port

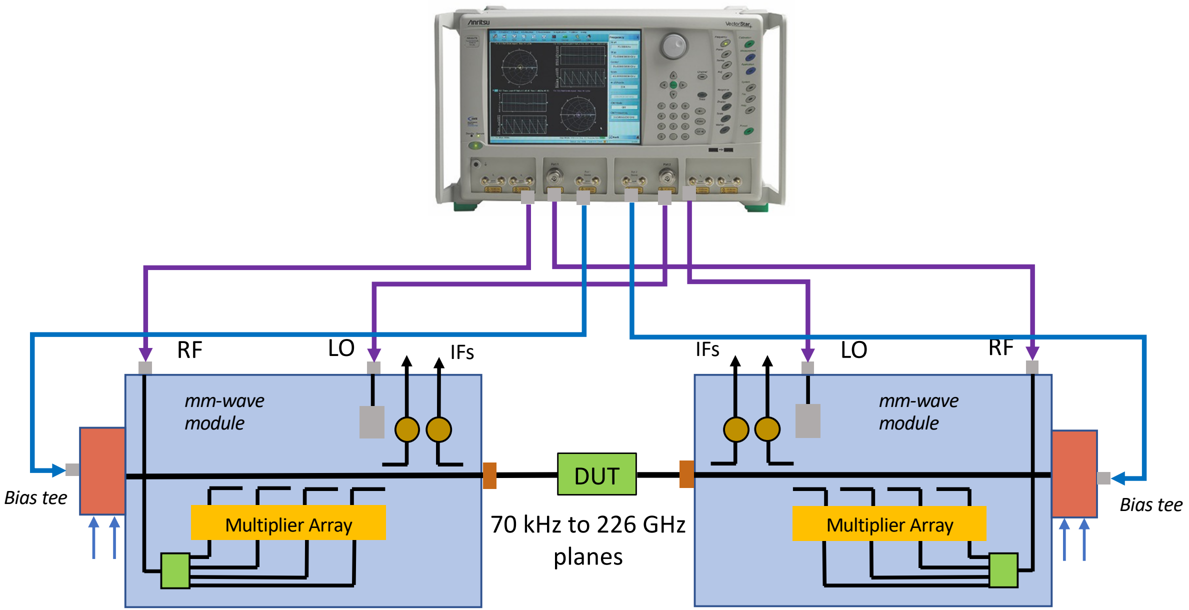


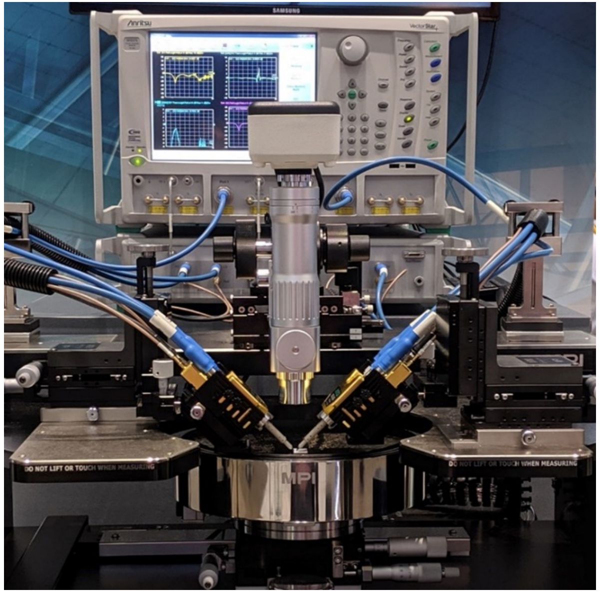
- Enables new-class of characterization
- Magic-T not longer required*



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.

Broadband 70 kHz-220 GHz Single-Sweep VNA

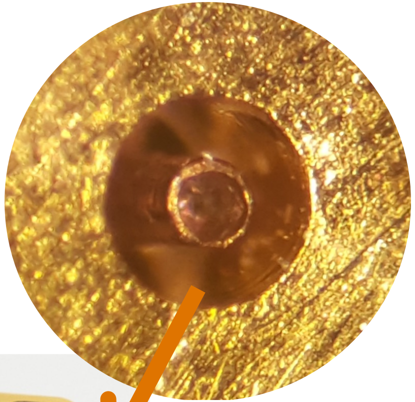


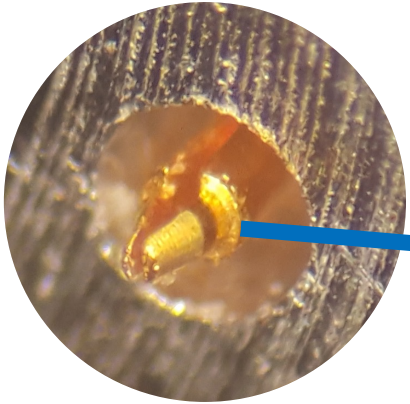


J. Martens and T. Roberts, "Broadband 220 GHz network analysis: structures and performance," 94th ARFTG Microwave Measurement Conference Digest, San Antonio, TX, 26-29 January, 2020.

Probe Interface with 220 GHz Module: MPI's TITAN™ T220A Probe

Slot-less 0.6mm female center conductor



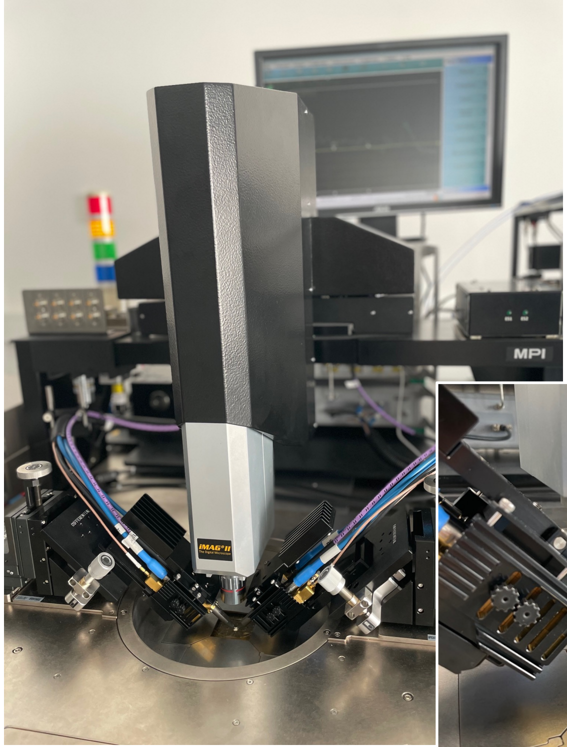


Slotted 0.6mm male pin center conductor

UG-387 Flange

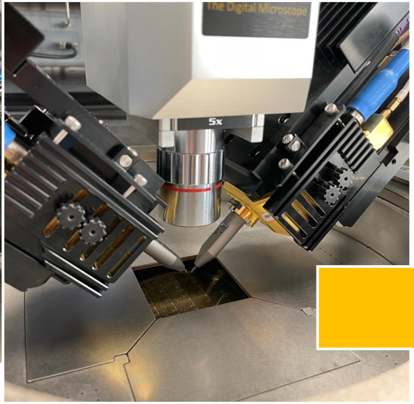
A. Rumiantsev, et al, Calibration, Repeatability and Related Characteristics of On-wafer, Broadband 70 kHz-220 GHz Single-Sweep Measurements, ARFTG-95th

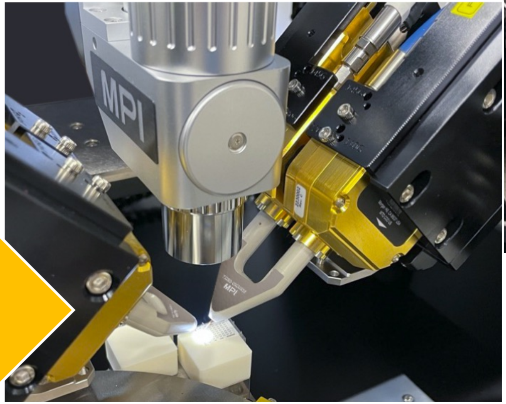
Enabling Differential Broadband Characterization: DC … 220 GHz

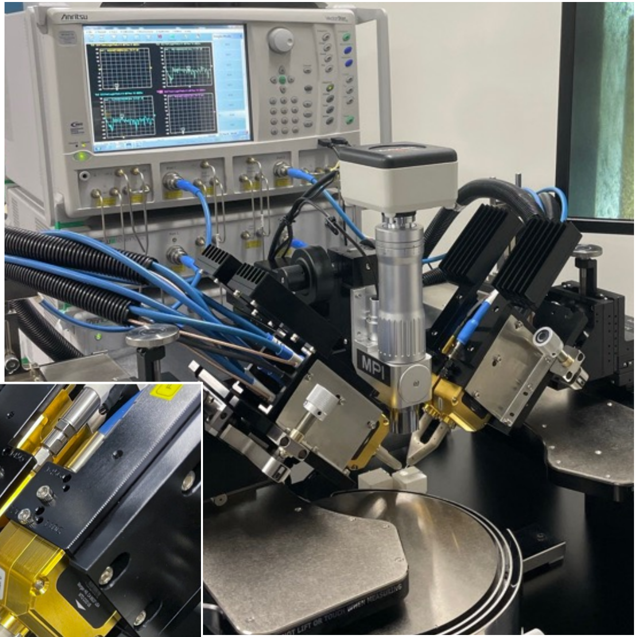


Anritsu ME7838G4
Single Sweep
70 kHz – 220 GHz

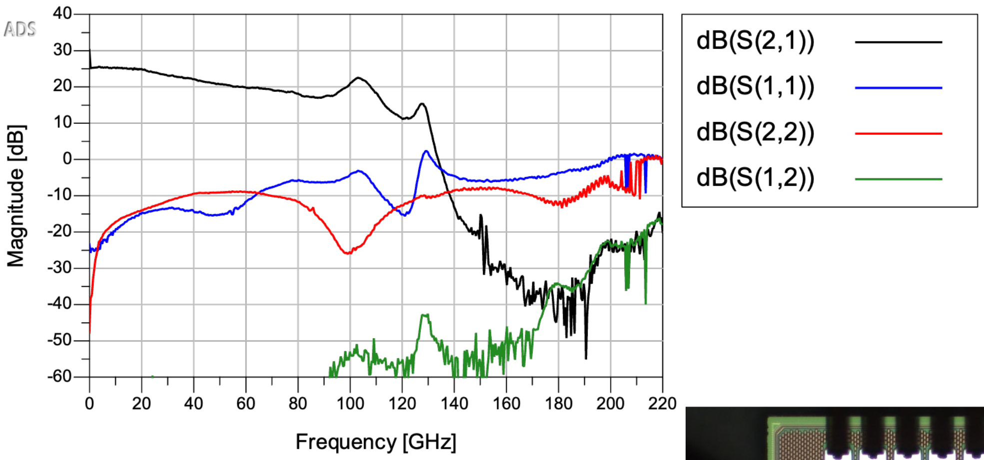
MPI's TITAN™ Differential
Probes T220D-GSGSG

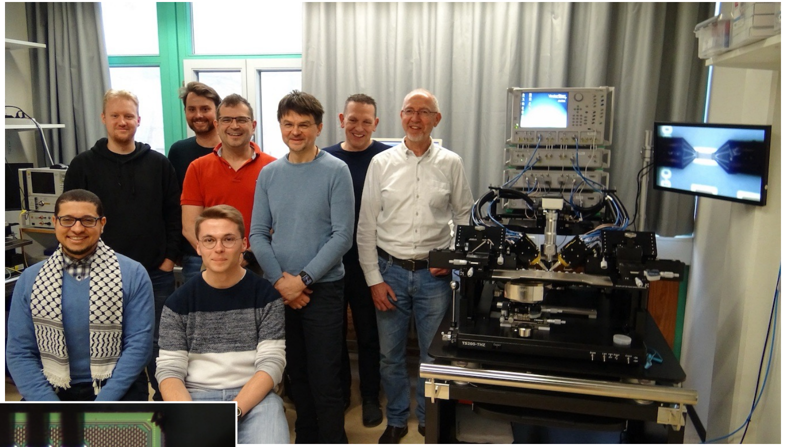


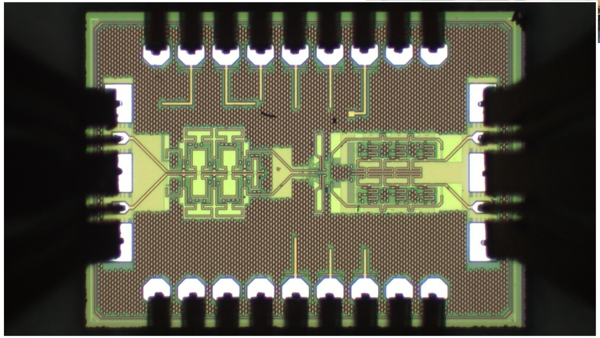




Industry-Record Measurements of a Broadband mmWave Driver Circuit







Courtesy: Ulm University, Germany

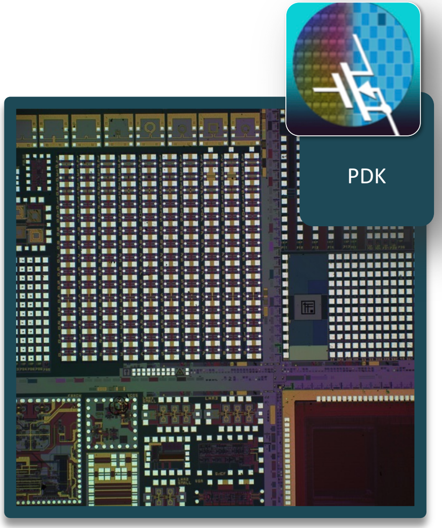
A. Rumiantsev, et al, A Differential Broadband Single-Sweep 70 kHz-220 GHz Wafer-Level System: First Calibration and Measurement Characteristics, ARFTG-100

Outline

- Introduction: Instrumentation Evolution
- Modern Systems and Integration
- Automated Test over Multiple Temperatures
- Conclusion

Device Characterization for PDK Challenges Increase

- Wide temperature range:
  - -40, -10, +27, +75, +125, (trend: +175°C)
- “Long-Term Measurements” **LTM**
  - S-parameters sweep for multiple V bias points
  - Different devices and geometries
- Chuck (temperature source) stays in the same location for long time
  - Uneven temperature distribution across the probe platen and the probe arms
  - Thermal stress causes mechanical drift
  - Probes drift and measurement results fail

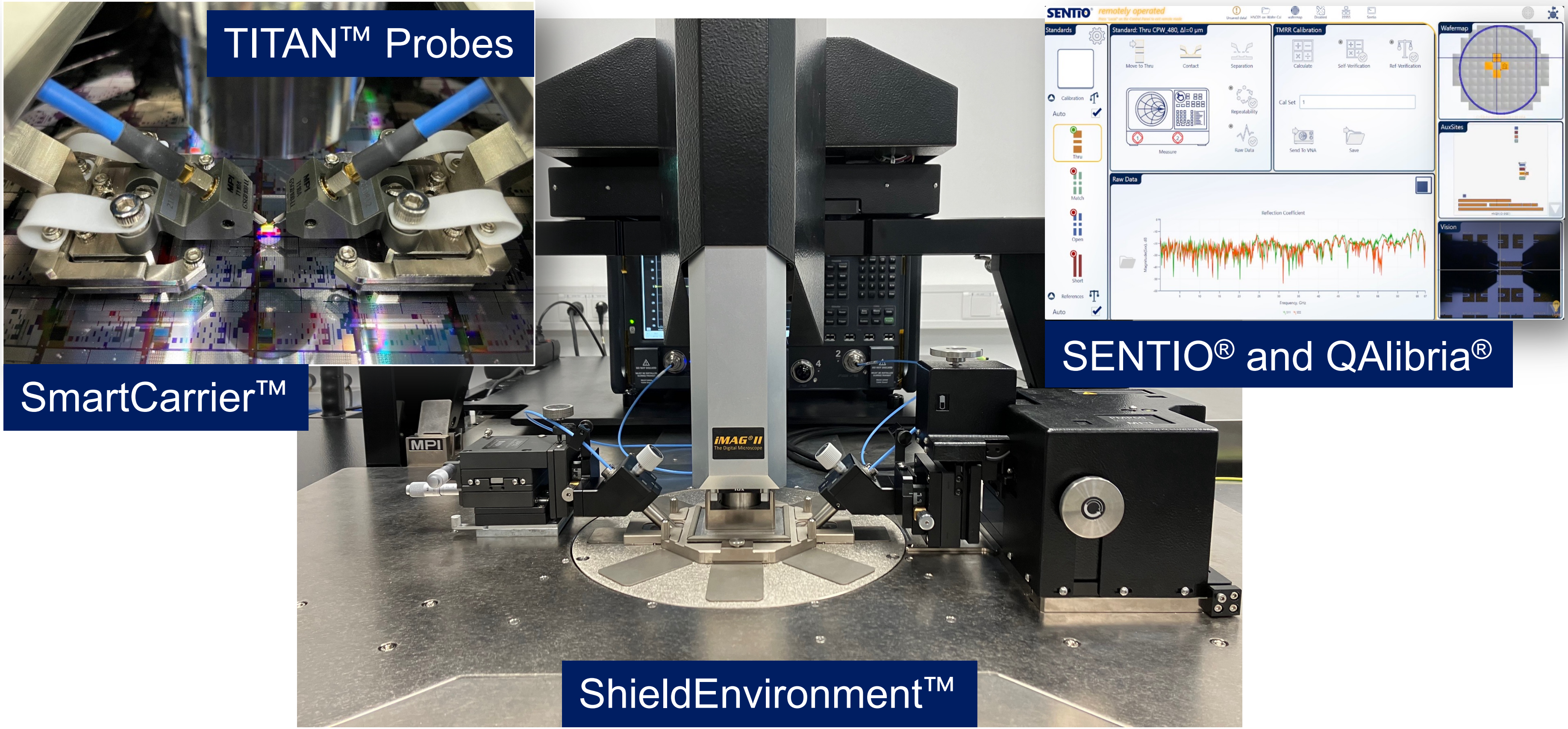


Two Main Problems and MPI’s Solution

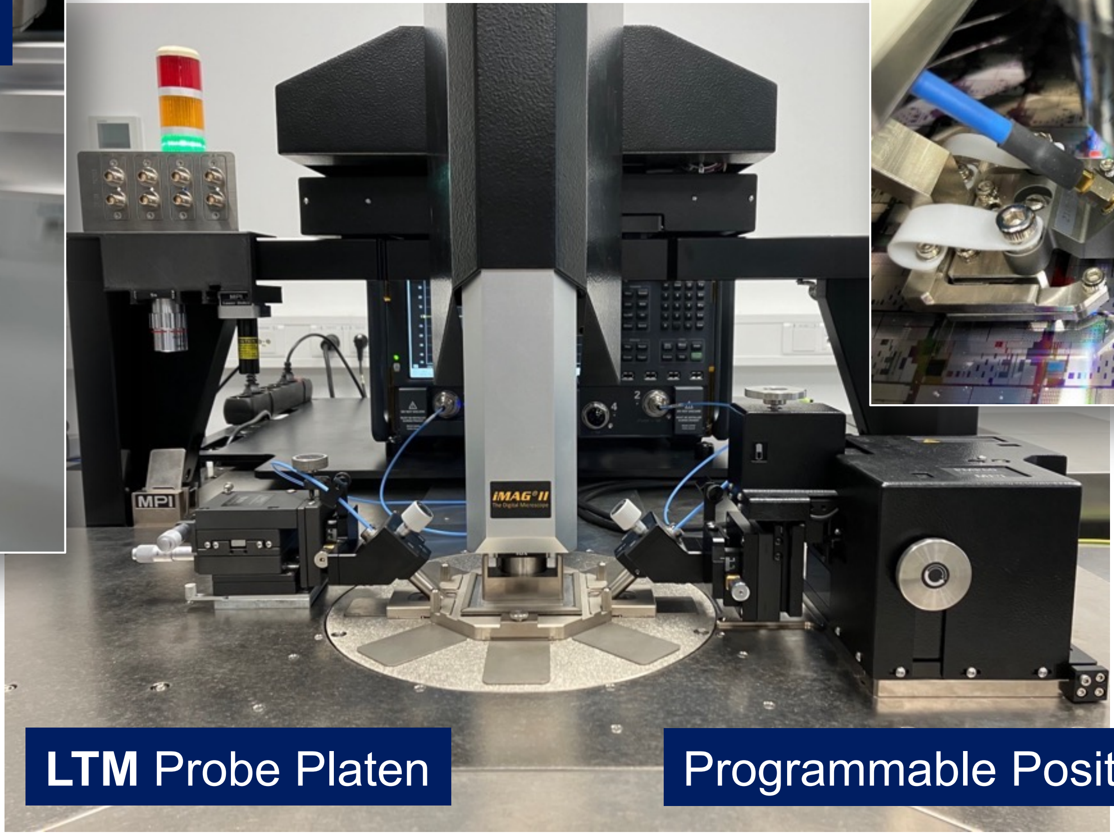
- How to minimize the mechanical drift?
  - Less to compensate
  - Faster time to data
  - More accurate data
- How to minimize the electrical drift?
  - Reduce time outside of the temperature source

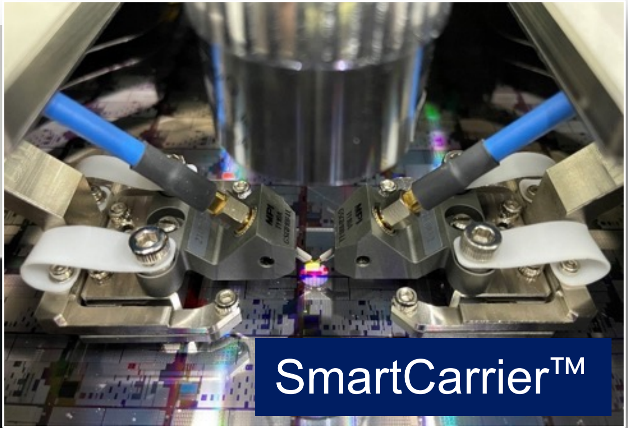
- MPI solutions and vision: ATMT™ Automated Test over Multiple Temperatures
  - Innovative temperature stable hardware
  - Innovative probe adjustment methods with SENTIO® prober software
  - On-wafer calibration with QAlibria® calibration software

MPI's ATMT™ Automated Test over Multiple Temperatures

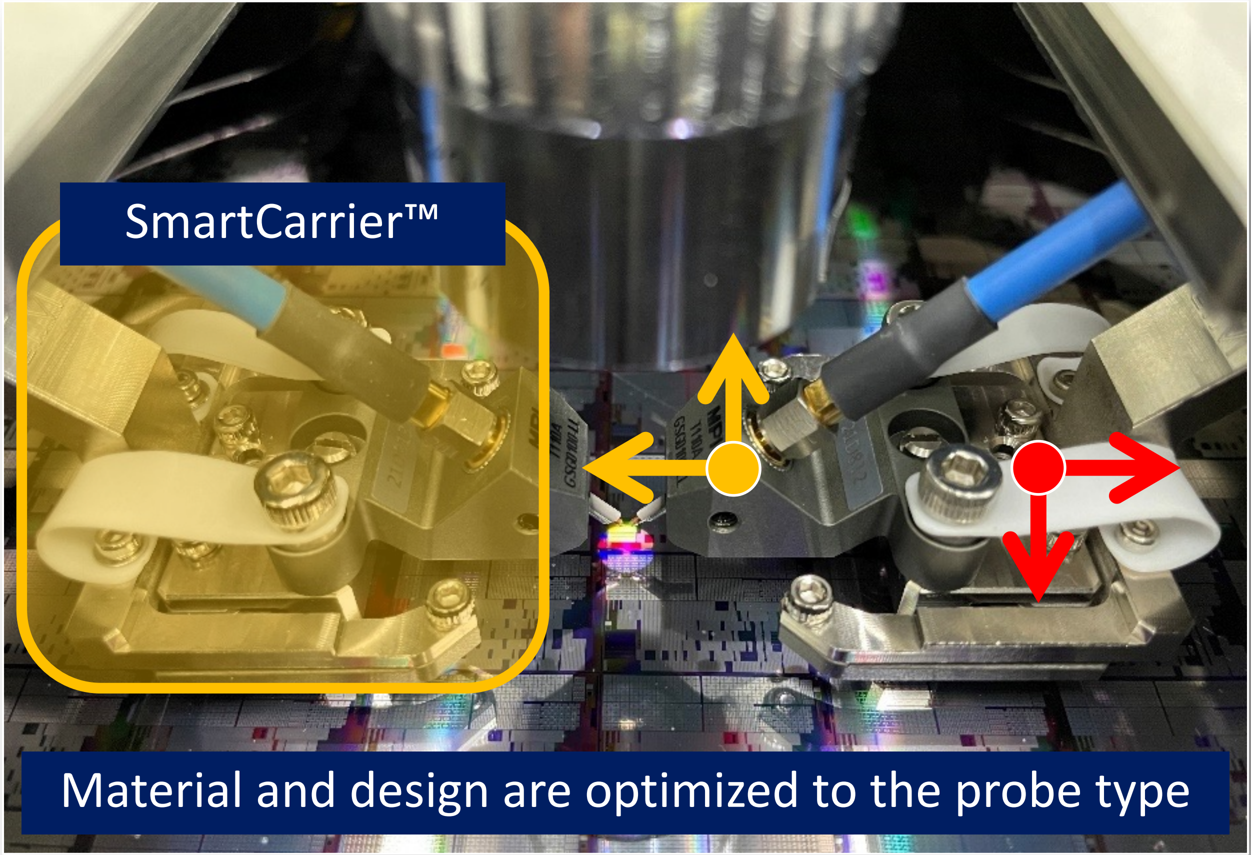


Hardware System Configuration: Example for Two-Port RF

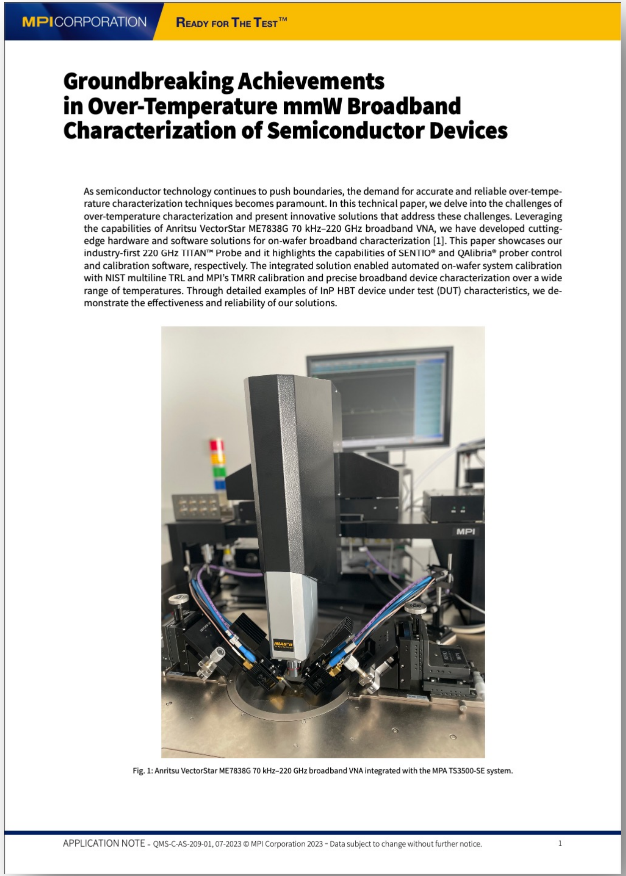




SmartCarrier™ Compensates Probe Drift in X, Y, and Z



Broadband Single-Sweep over Temperature Characterization

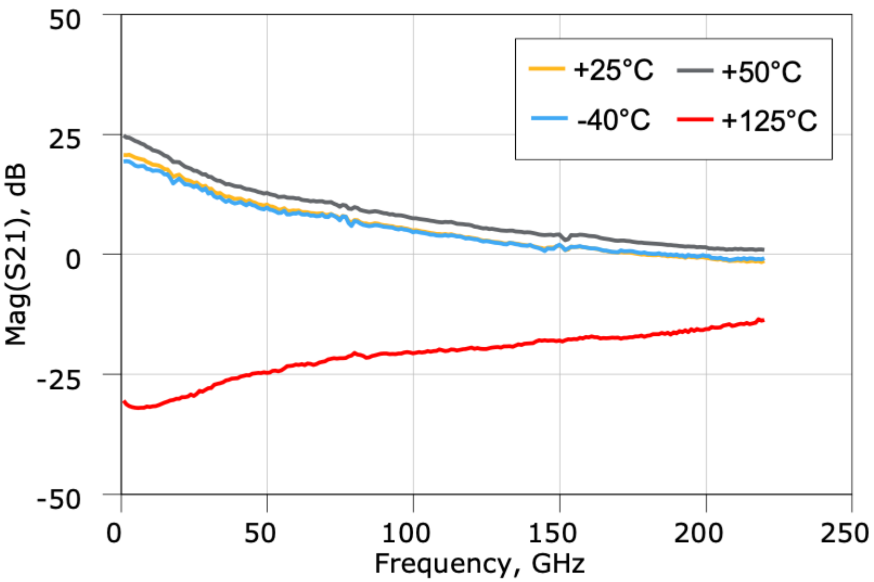

MPICORPORATION READY FOR THE TEST™

Groundbreaking Achievements in Over-Temperature mmW Broadband Characterization of Semiconductor Devices

As semiconductor technology continues to push boundaries, the demand for accurate and reliable over-temperature characterization techniques becomes paramount. In this technical paper, we delve into the challenges of over-temperature characterization and present innovative solutions that address these challenges. Leveraging the capabilities of Anritsu VectorStar ME7838G 70 kHz–220 GHz broadband VNA, we have developed cutting-edge hardware and software solutions for on-wafer broadband characterization [1]. This paper showcases our industry-first 220 GHz TITAN™ Probe and it highlights the capabilities of SENTIO® and QAlibria® prober control and calibration software, respectively. The integrated solution enabled automated on-wafer system calibration with NIST multiline TRL and MPI's TMRR calibration and precise broadband device characterization over a wide range of temperatures. Through detailed examples of InP HBT device under test (DUT) characteristics, we demonstrate the effectiveness and reliability of our solutions.

Fig. 1: Anritsu VectorStar ME7838G 70 kHz–220 GHz broadband VNA integrated with the MPA TS3500-SE system.

APPLICATION NOTE - QMS-C-AS-209-01, 07-2023 © MPI Corporation 2023 - Data subject to change without further notice. 1



DUT characteristics at -40C, +25C, +50C and +125C corrected by on-wafer mTRL

Refer to: https://www.mpi-corporation.com/ast/technical-library/

Conclusion

- Progress in instrumentation enabled the development of the next-generation highly-integrated circuits and system
- Innovative integration solutions for wafer-level characterization without compromising the instrument performance
- Software and system automation solutions for the over-temperature characterization accelerated time-to-data for the next-generation products for 5G and 6G Application Research

Thank You.

MPI CORPORATION