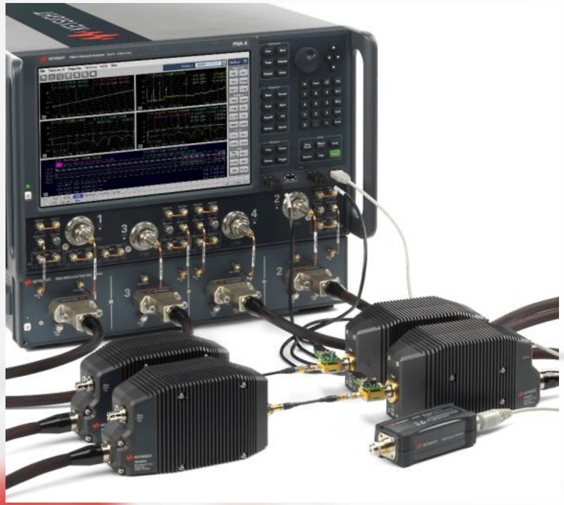
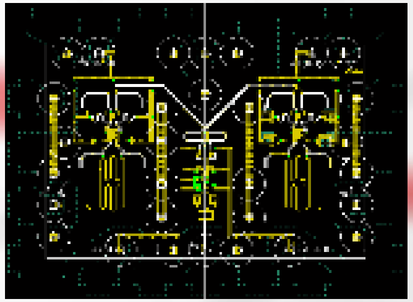
5G and Automotive Component Characterization at mmWave Frequencies
5G及汽車電子毫米波元件驗證方案



Kenny Liao **2019/1/15&16**

Senior Project Manager / Keysight Technologies

KEYSIGHT TECHNOLOGIES



Millimeter Component Characterization

DISCUSSION TOPICS

- Millimeter Wave Component Application Space
- Millimeter Vector Network Analyzer Architecture
- Calibration at Millimeter Wave Frequencies
- Amplifier Characterization
- Receiver Characterization
- PNA-TDR
- N5252A E-band VNA system
- Conclusions

Application Space

MILLIMETER WAVE FREQUENCIES

Commercial Industry

Wireless backhaul

WiGig 802.11 ad

57-71 GHz

Automotive radar

77 GHz & 120 GHz

Radar/EW

12 -18 GHz & 26-40 GHz

94 GHz to 650 GHz

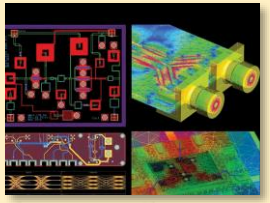
Next Gen wireless communications “5G”

38 – 40 GHz & 60-90 GHz

Courtesy www.NIST.gov

Secure communication system

44 GHz to 93 GHz



Millimeter Wave imaging

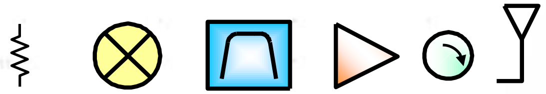
35 GHz to 325 GHz

Aerospace Defense Industry

Millimeter Wave Components

THE NEED FOR CHARACTERIZATION

- Millimeter wave components are underlying **building blocks** of systems in:
  - Imaging and sensing
  - Cyber security
  - EW Radar and communication systems
- **Device characterization and validation** of millimeter wave components
  - Millimeter wave couplers & filters – Front - end Tx/Rx
  - Mixers (Fundamental, Harmonic and differential) - Receivers and upconverters
  - Millimeter wave amplifiers - Transmitters
  - Millimeter wave sources - Transmitters



- Magnitude and phase information crucial for **simulation** during design stage
- Ensure devices meet **specifications** during manufacturing
- PNA-TDR

Millimeter Component Characterization

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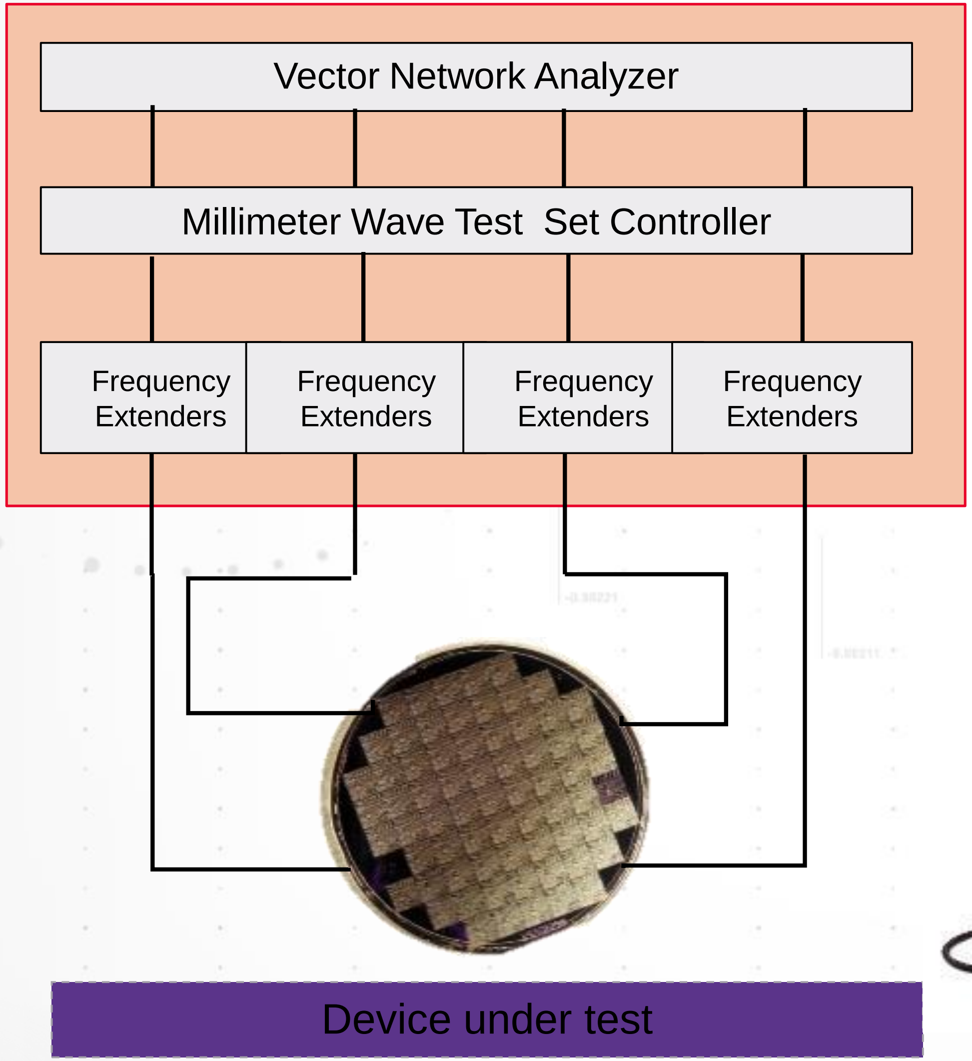
Typical System Implementation

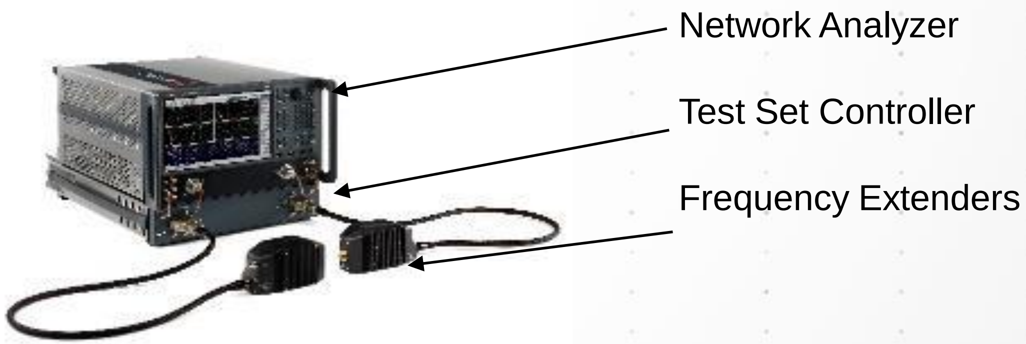
DISTRIBUTED ARCHITECTURE



Network Analyzer is the measurement engine

Required ***Test Set Controller*** interfaces to modules

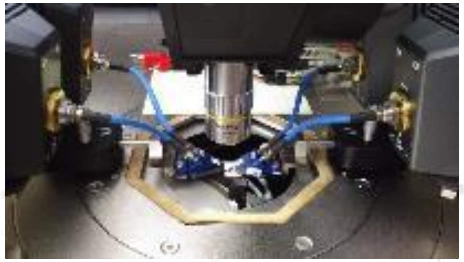
Frequency Extenders provide frequency conversion and signal coupling

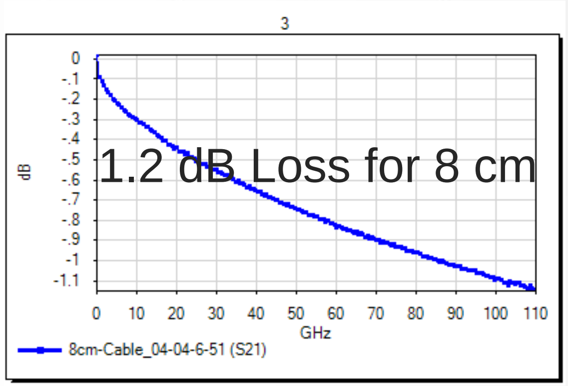


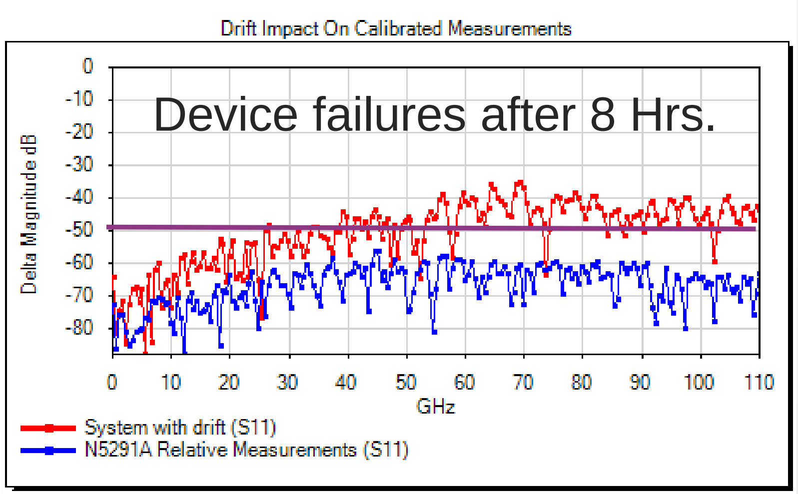
Millimeter VNA Architecture

MEASUREMENT REQUIREMENTS

- Bring the measurement to the device
- Stable system architecture
- Sufficient power to get desired compression behavior
- Accurately control the phase of the stimulus
- Fully corrected and traceable measurements with uncertainty

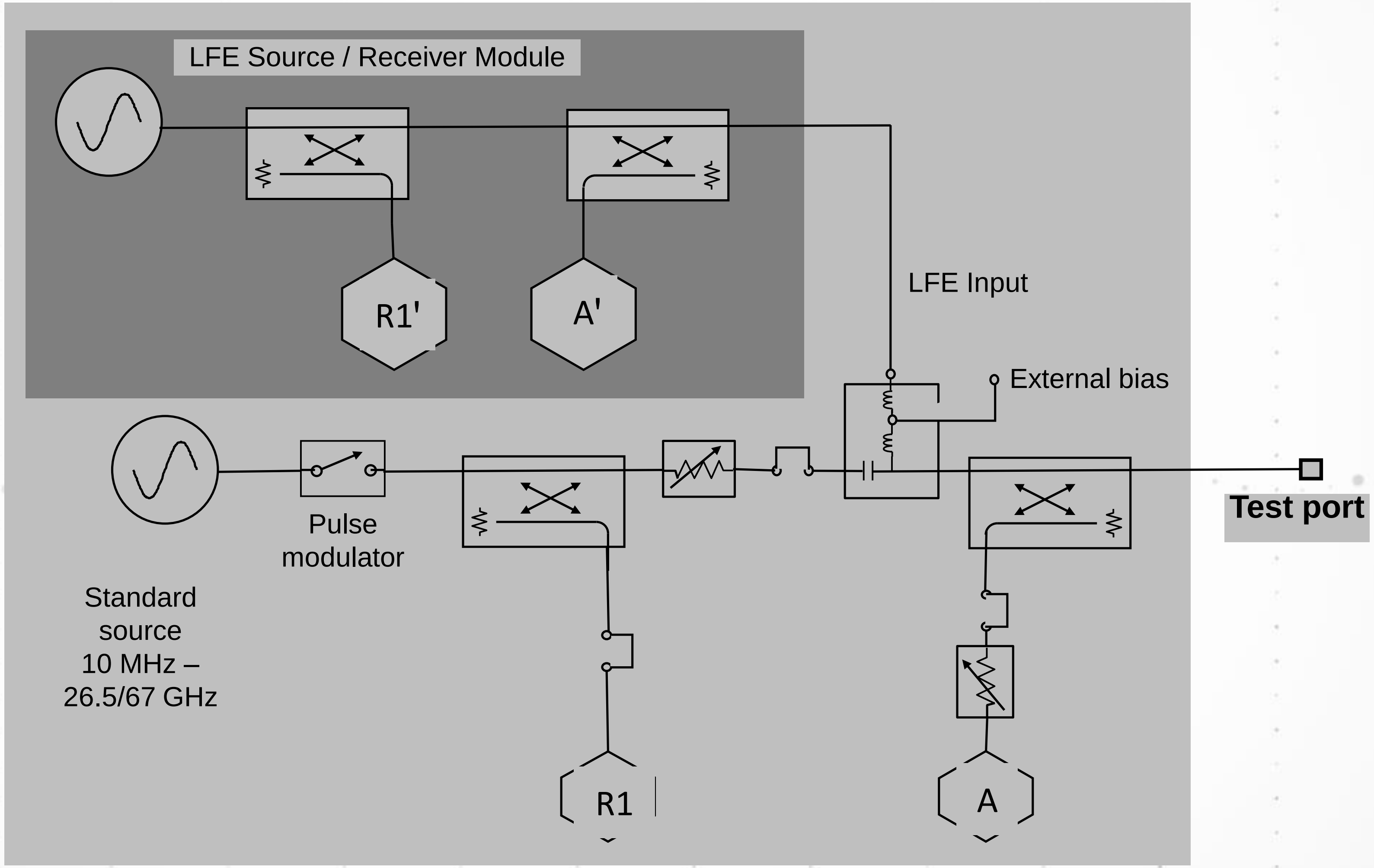






Distributed Architectures Challenges

ADDING LOW FREQUENCY

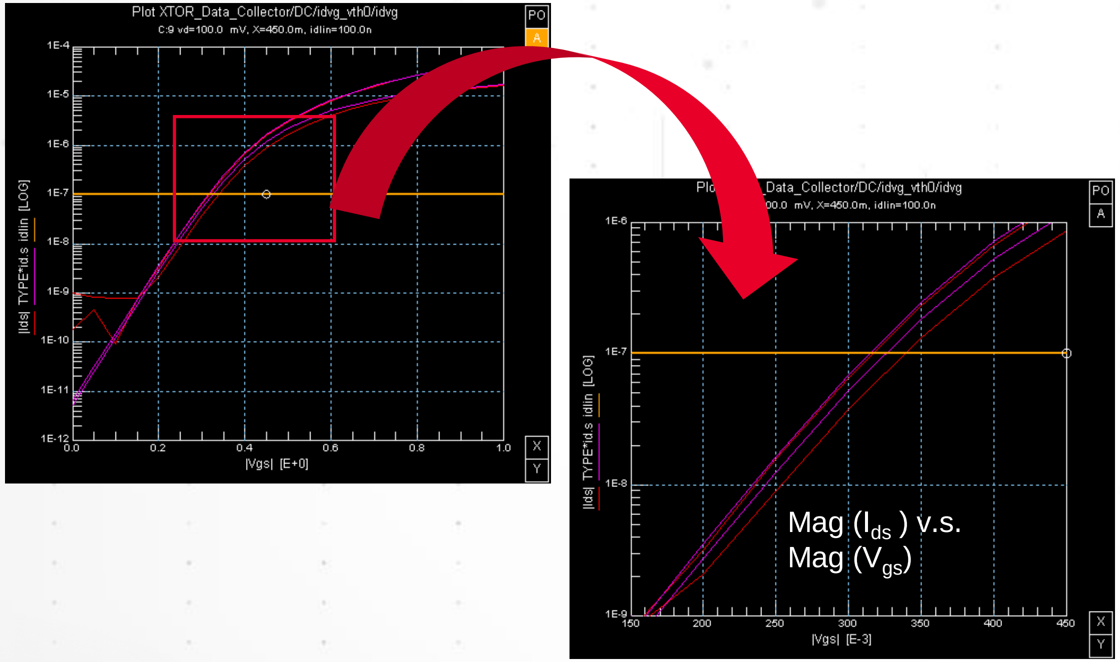


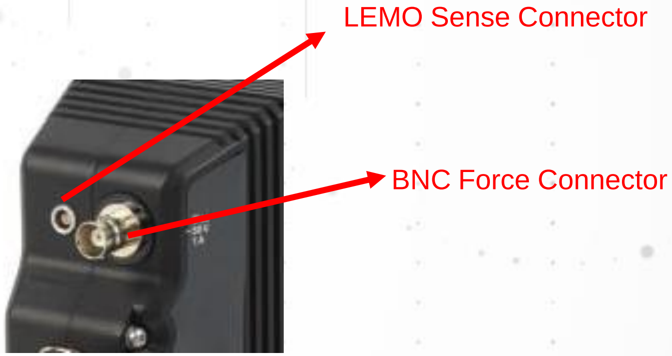
Keysight implementation of low frequency coverage 500 Hz – 100 MHz

Distributed Architectures Challenges

ACTIVE DEVICE CHARACTERIZATION

- Provide Kelvin bias at the DUT
- Limited ground loops.
- Low leakage typically less than 400 pA is desirable

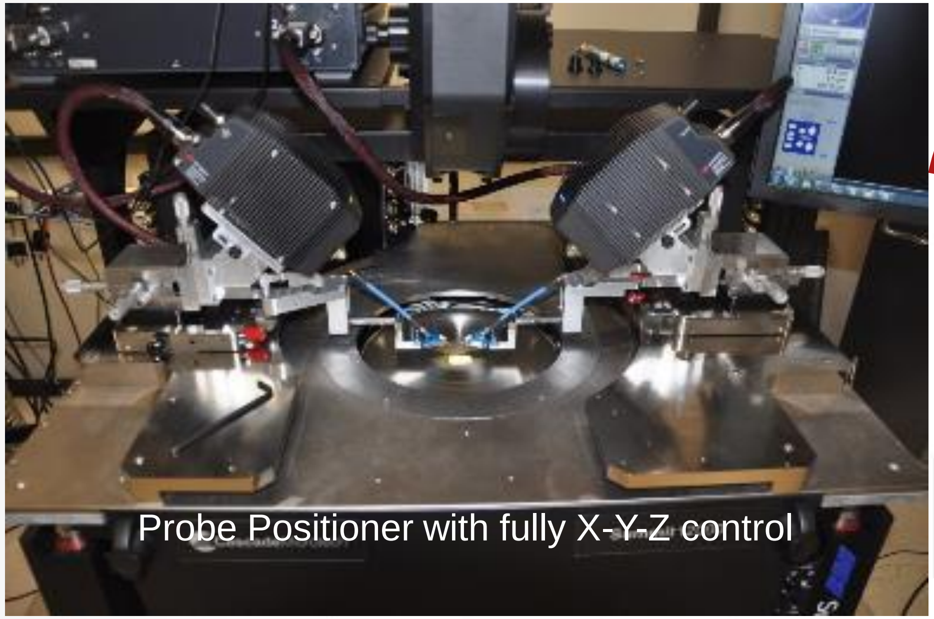


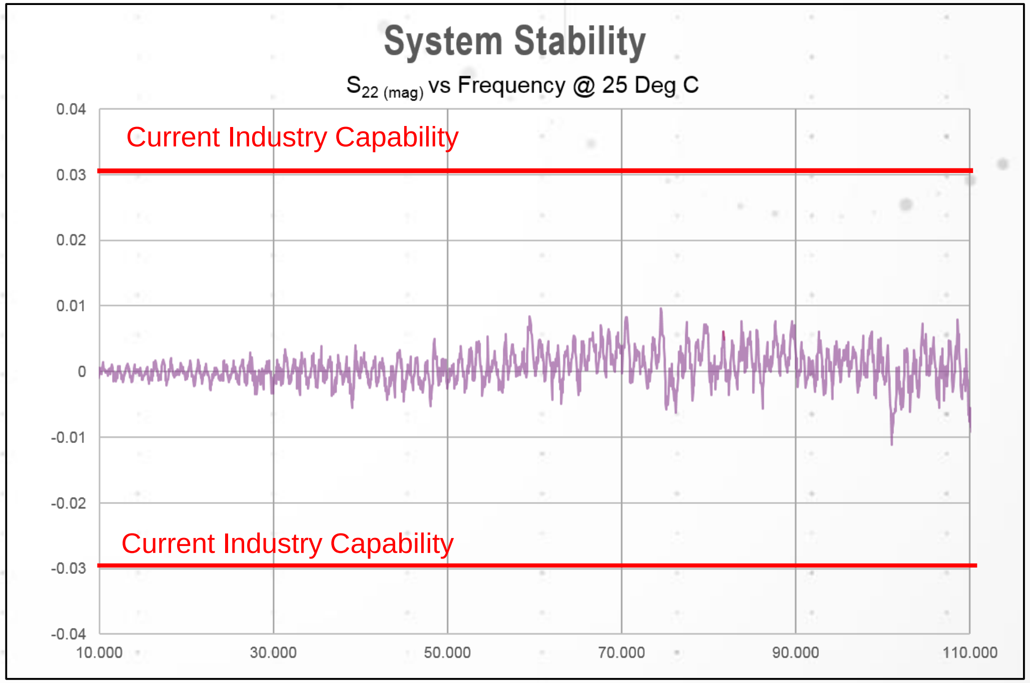


- Vd = 0.1 and 1.5V
- The measured Ids for Low Vd are different (from RF and DC).
- This will cause the differences with extraction

Distributed Architectures Challenges

SIZE STABILITY TRADEOFF





Millimeter Component Characterization

DISCUSSION TOPICS

- Millimeter Wave Component Application Space
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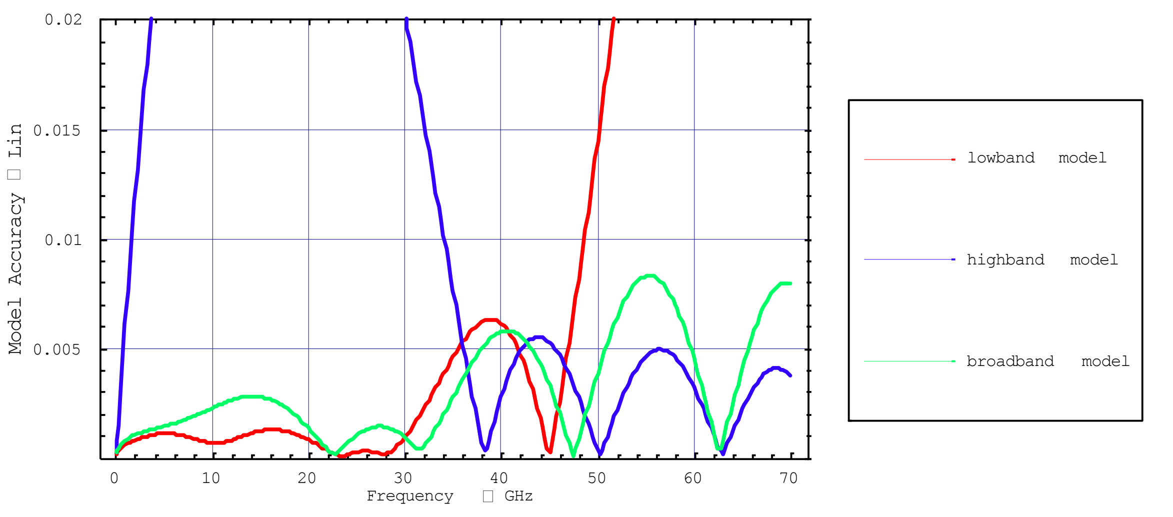
- Calibration at Millimeter Wave Frequencies
- Amplifier Characterization
- Receiver Characterization
- PNA-TDR
- USB VNA
- Conclusions

Millimeter Wave System Calibration

MILLIMETER WAVE CALIBRATION CHALLENGES

- Wide frequency coverage 500 Hz to 125 GHz
- Broadband load
- Closed form polynomial models are limited
- Inductance short model
- Capacitance open model
- Load match and delay
- Traditional SOLT methods of error extraction limited
- Limited Smith chart coverage



Calibration

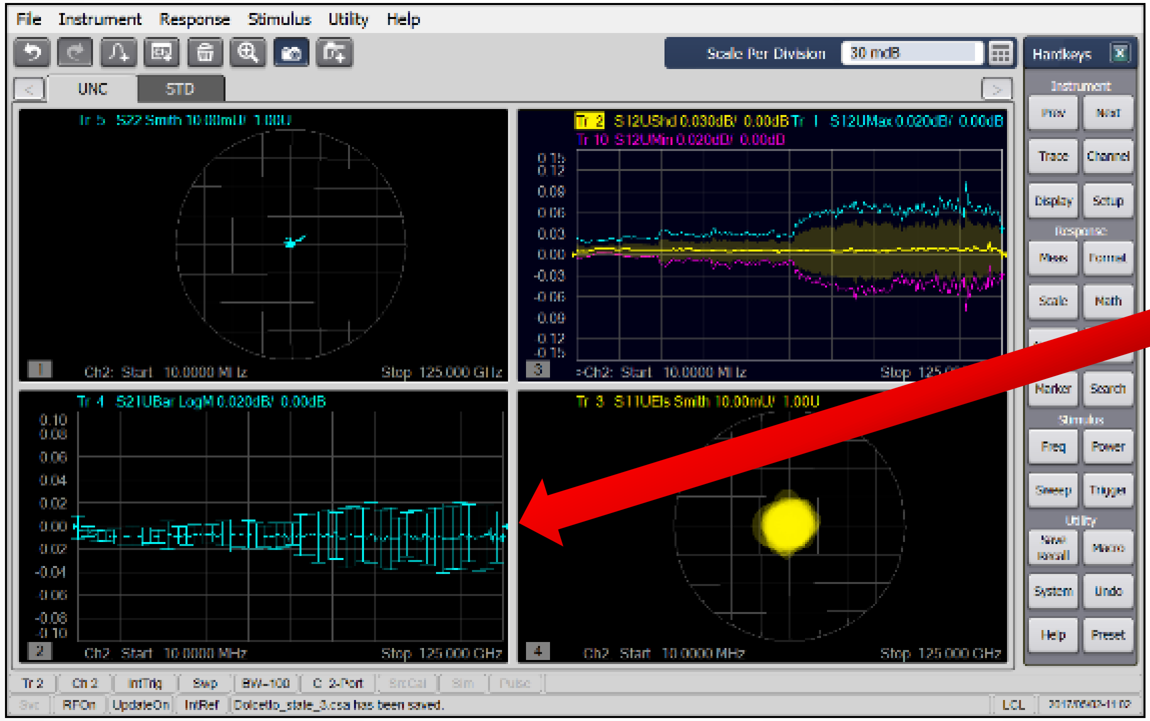
DATABASED OFFSET SHORTS

- Key features of a millimeter wave coaxial calibration kit
  - Eliminate need for broadband load
  - Implements multiple shorts to cover frequency range
  - Characterize devices using a database model
  - Enhanced least squares fit method of calibration

Millimeter Wave System Calibration

MAINTAIN TRACEABILITY AND UNCERTAINTY

- Use of standard connectors versus frequency coverage
- Standards compliant connectors imply ease of traceability
- Traceable 1.0 mm calibration through 1.0 mm calibration kit devices

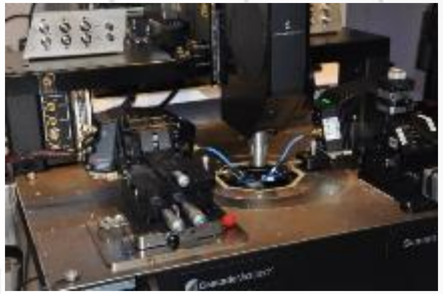


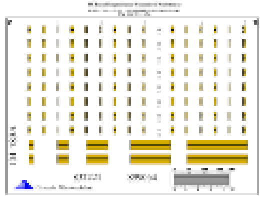
Keysight IEEE 287-2007 compliant 1.0 mm Connector

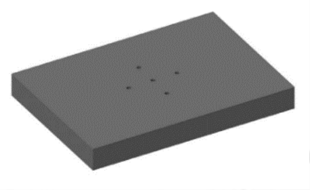
Broadband Millimeter Wave System Calibration

ON-WAFER CALIBRATION STANDARDS

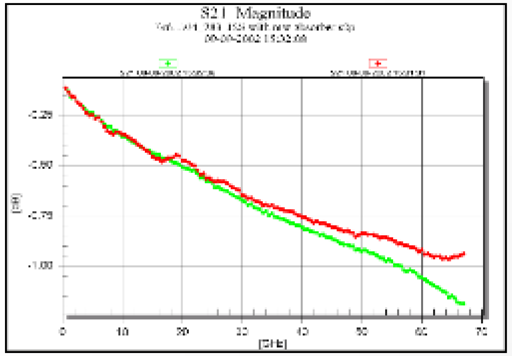
- Supported Calibration Methods
  - SOLT - Short Open Load Thru
  - SOLR - Short Open Load Reciprocal
  - LRM - Line Reflect Match
  - LRRM - Line Reflect Reflect Match
  - TRL - Thru Reflect Line







- Special requirements > 50 GHz
  - Microwave absorbing ISS holder reduces unwanted mismatch
  - Ideal Calibration applications LRRM, LRM & SOL-R calibrations
  - ISS enhanced for CPW transmission mode – thinned to 10 mils



Power Calibration

RECEIVER CALIBRATION

Traditional methods

- Utilize multiple sensors to cover frequency range
- Typically waveguide sensors
- Coaxial sensors limited to diode based detection

Broadband Power sensor technology

- Thermal based technology
- Easily expanded to 120 GHz using calorimeter characterization

Millimeter Component Characterization

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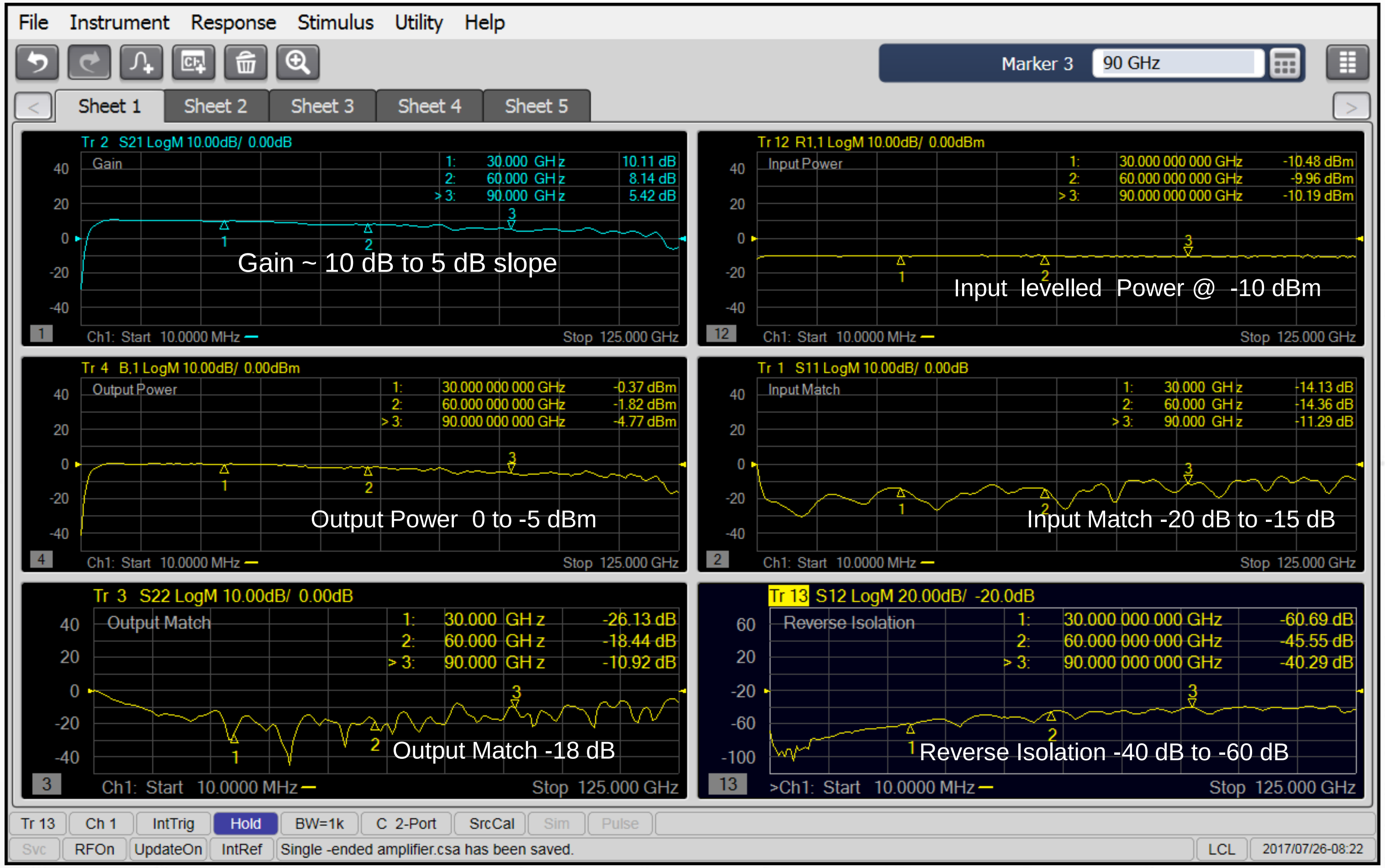
Amplifier Test

AMPLIFIER SPECIFICATIONS

- Input match
- Gain
- Output match
- Reverse isolation
- Compression
- Total harmonic distortion
- Low frequency performance

Amplifier Test

LINEAR PERFORMANCE

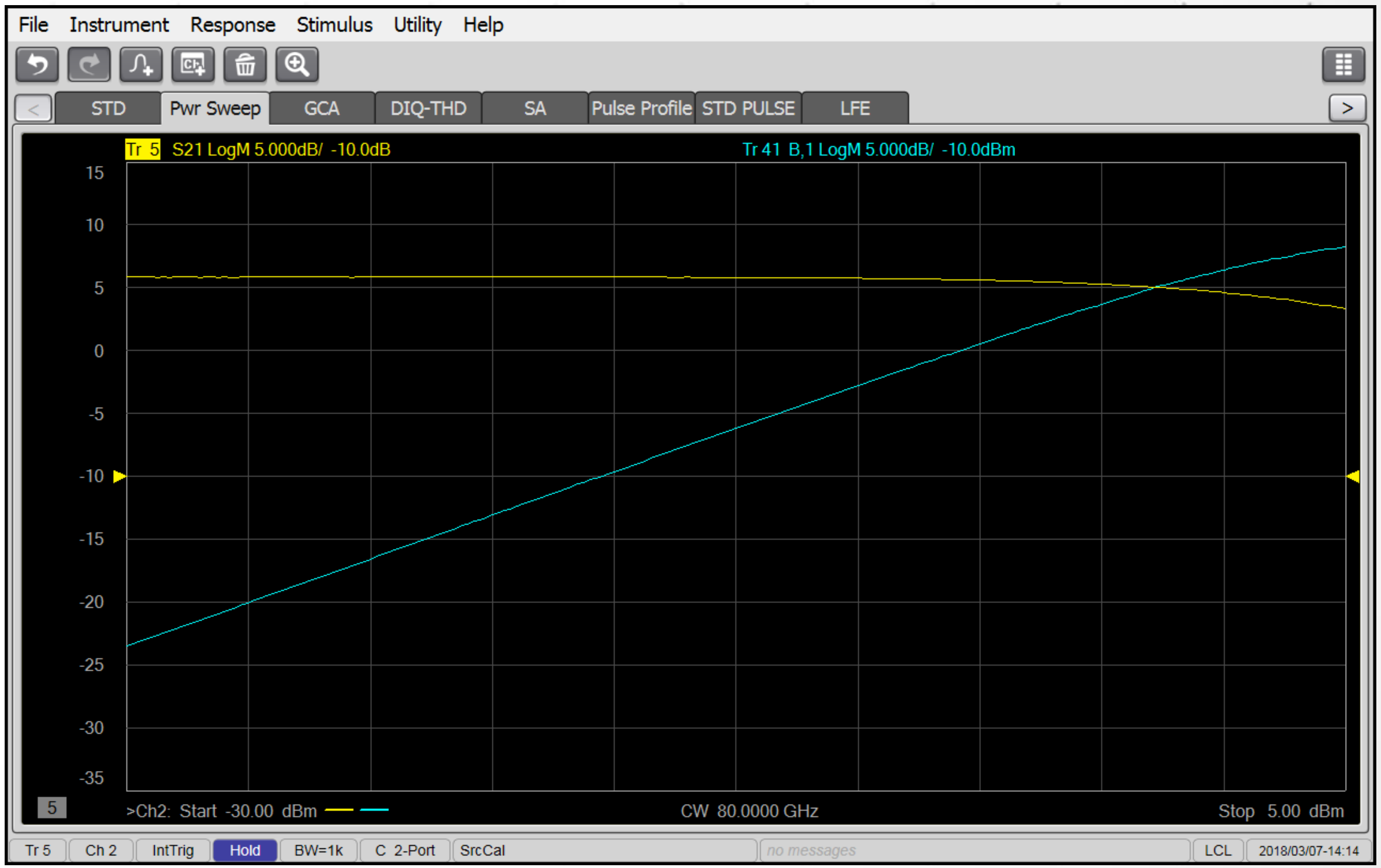


KEYSIGHT TECHNOLOGIES

Amplifier Test

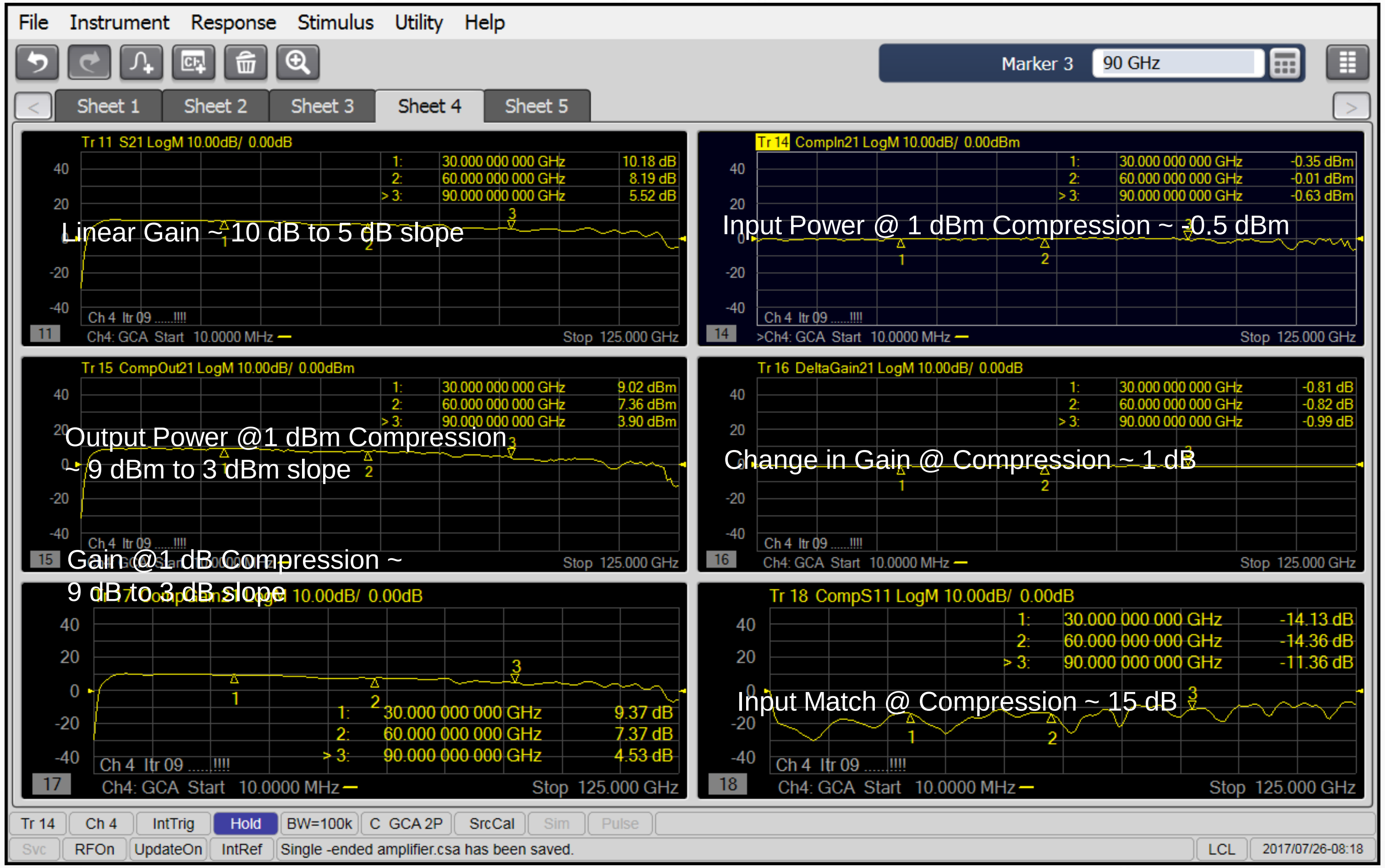
1DB COMPRESSION

- Requires accurate characterization of power
- Accurate measurement of the power
- Source power sweep versus frequency



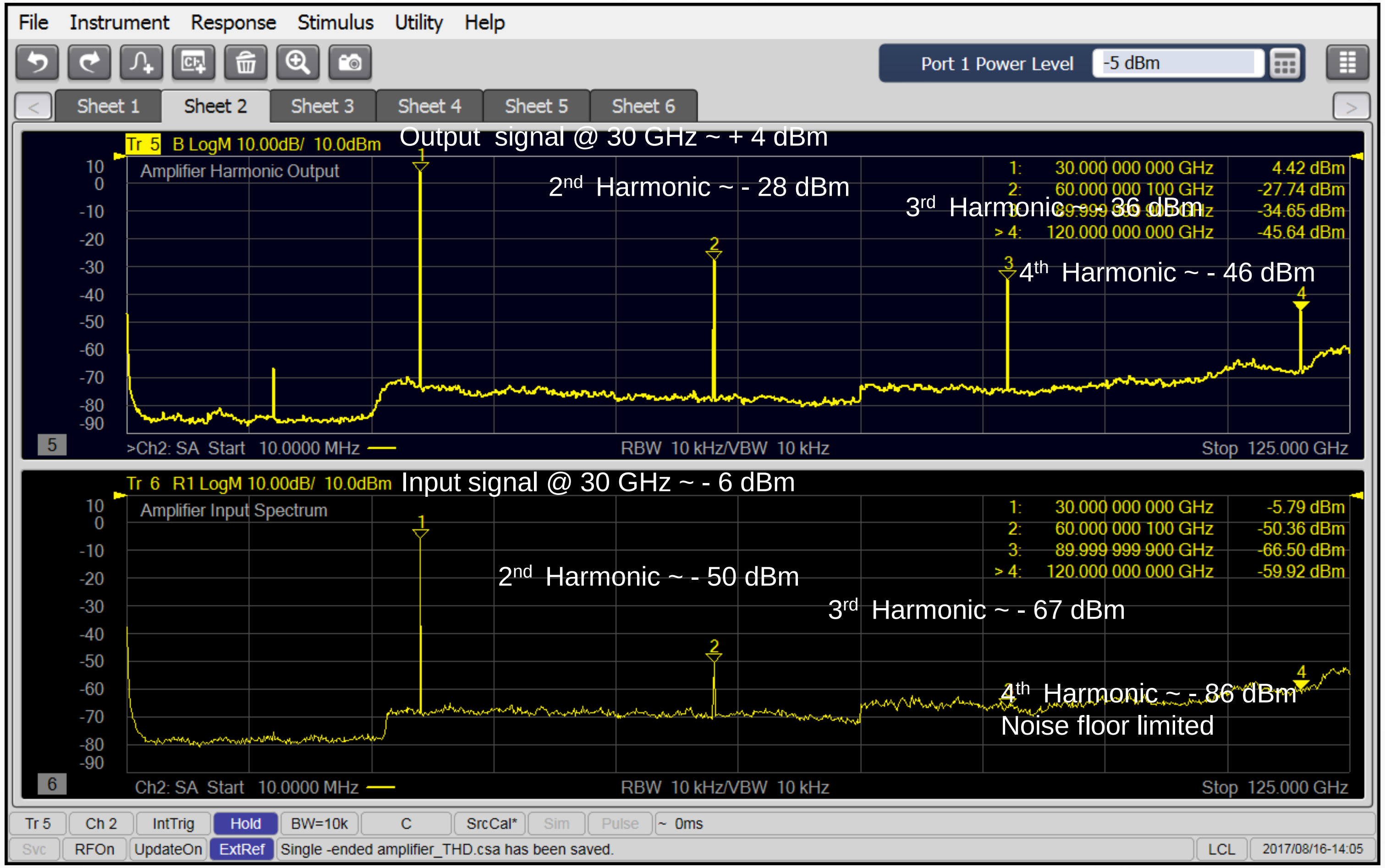
Amplifier Compression

1DB GAIN COMPRESSION



Amplifier Spectrum

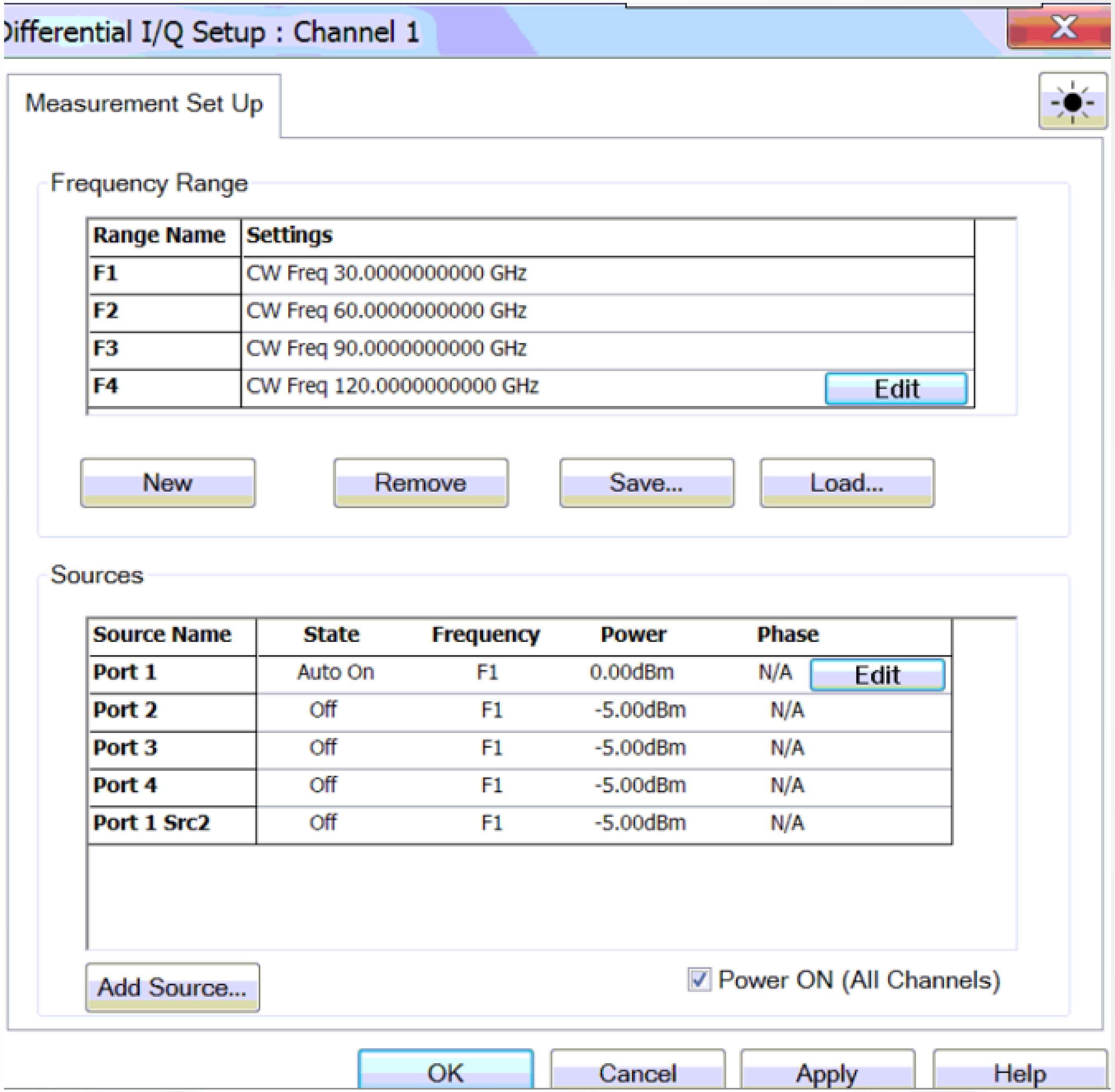
HARMONIC CHARACTERISTICS



Amplifier THD

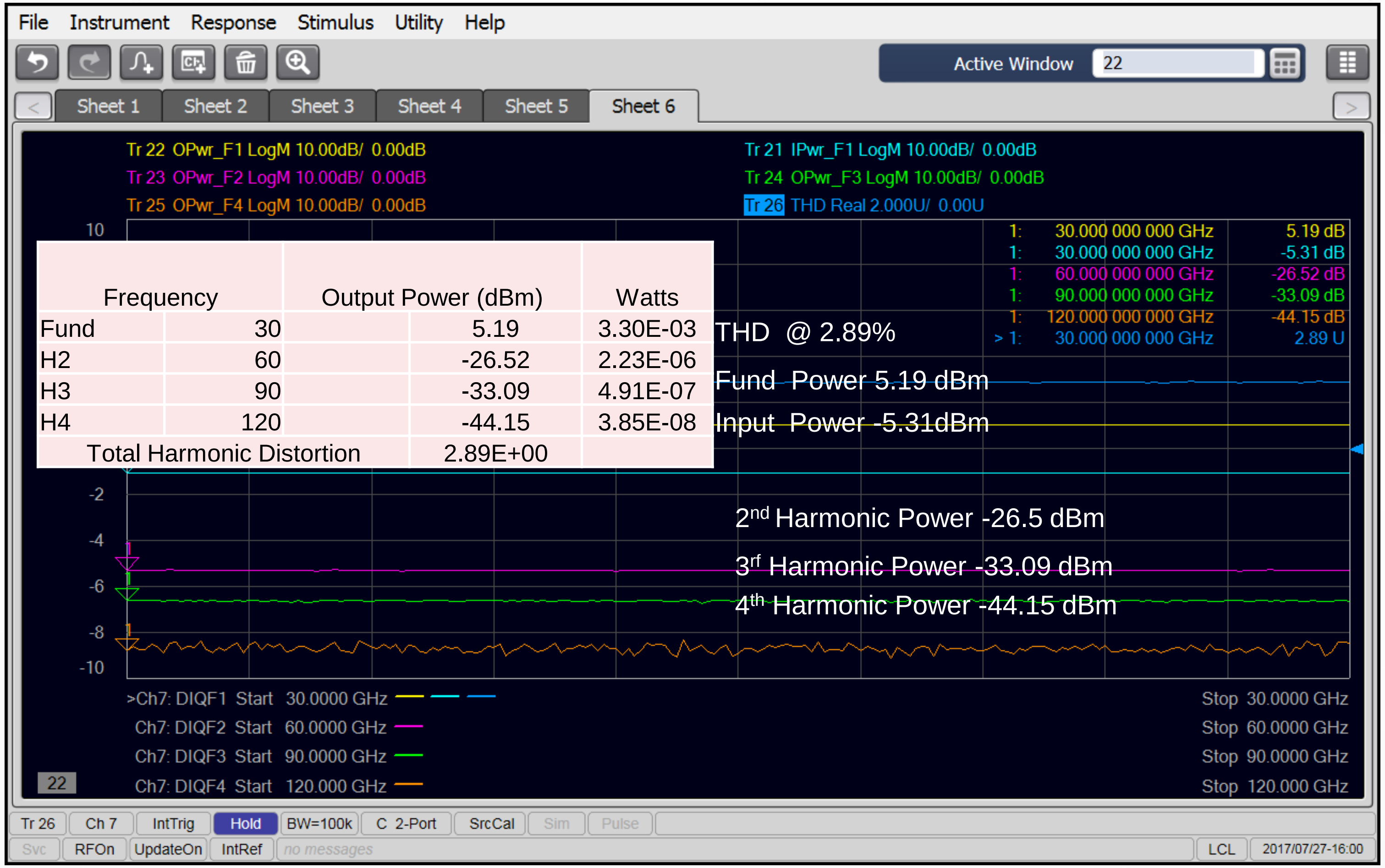
DIFF IQ THD MEASUREMENT

- Utilizes the ability to set sources and tune receivers independently on a VNA



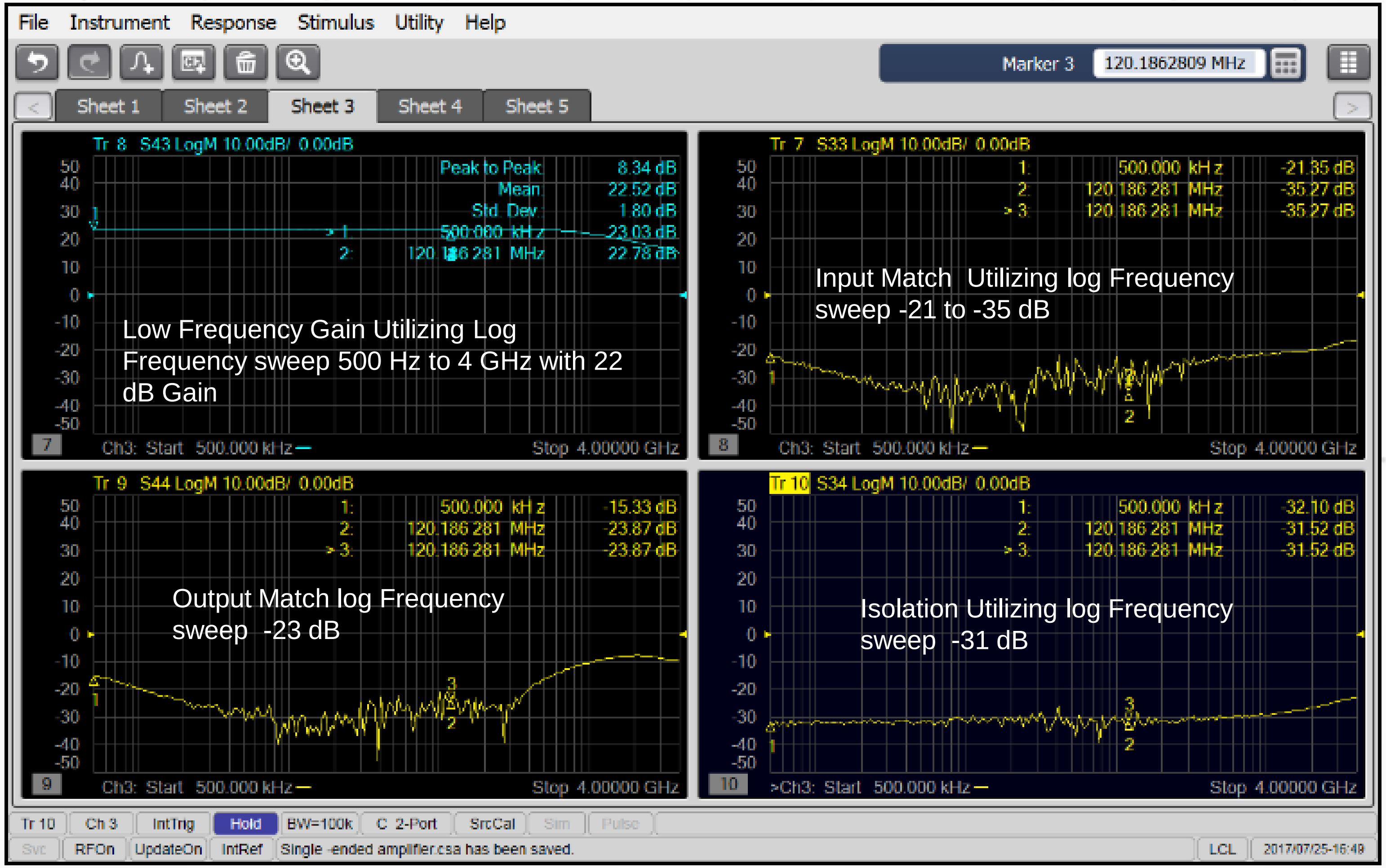
Amplifier Test

TOTAL HARMONIC DISTORTION



Amplifier Test

LOW FREQUENCY PERFORMANCE



KEYSIGHT TECHNOLOGIES

Millimeter Component Characterization

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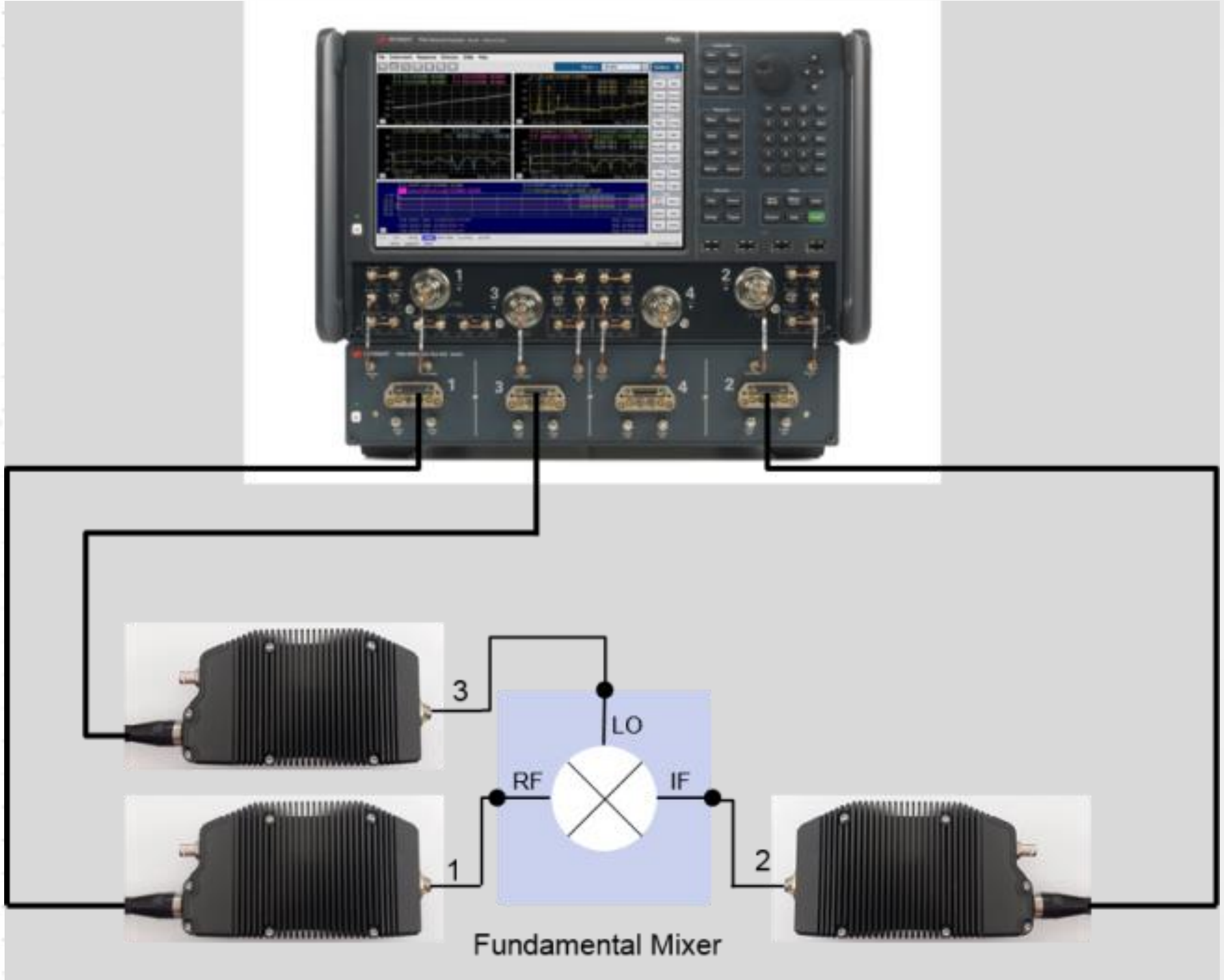
Receiver Tests

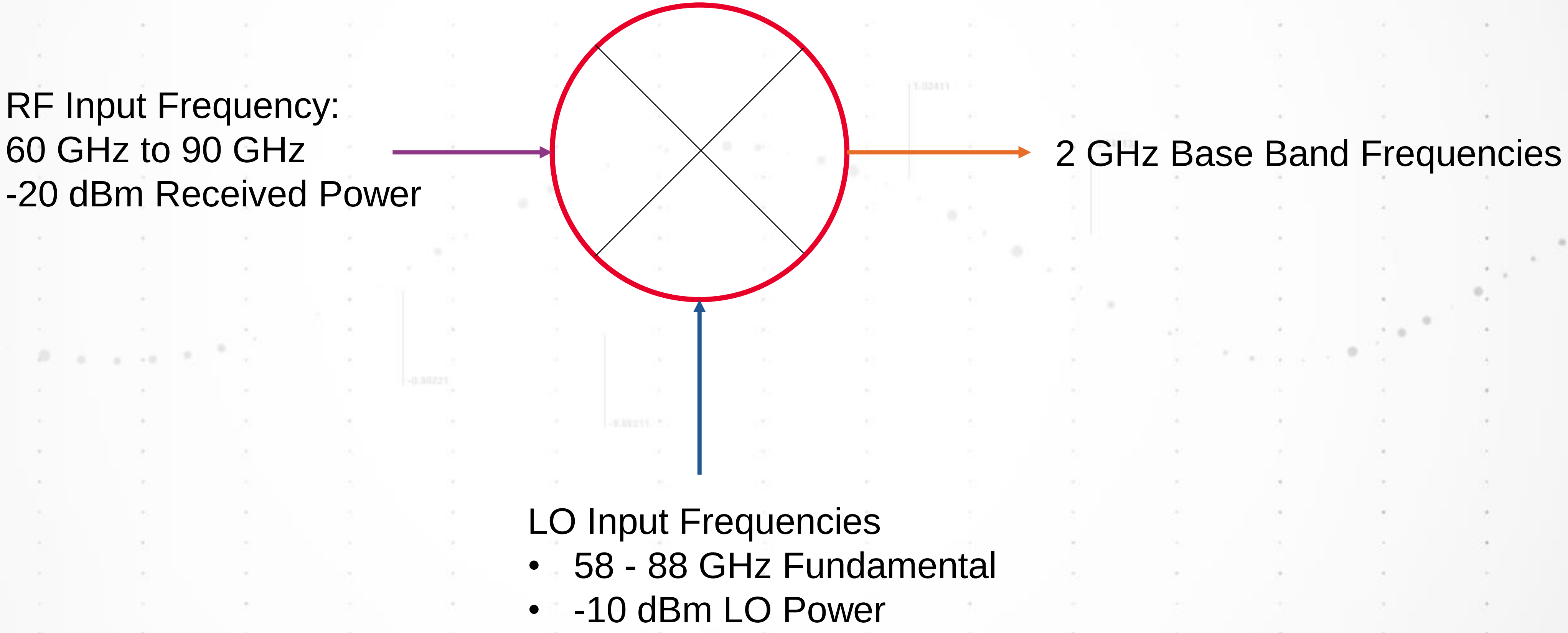
E-BAND RECEIVER

- Linear Gain
- Receiver Match
- Compression



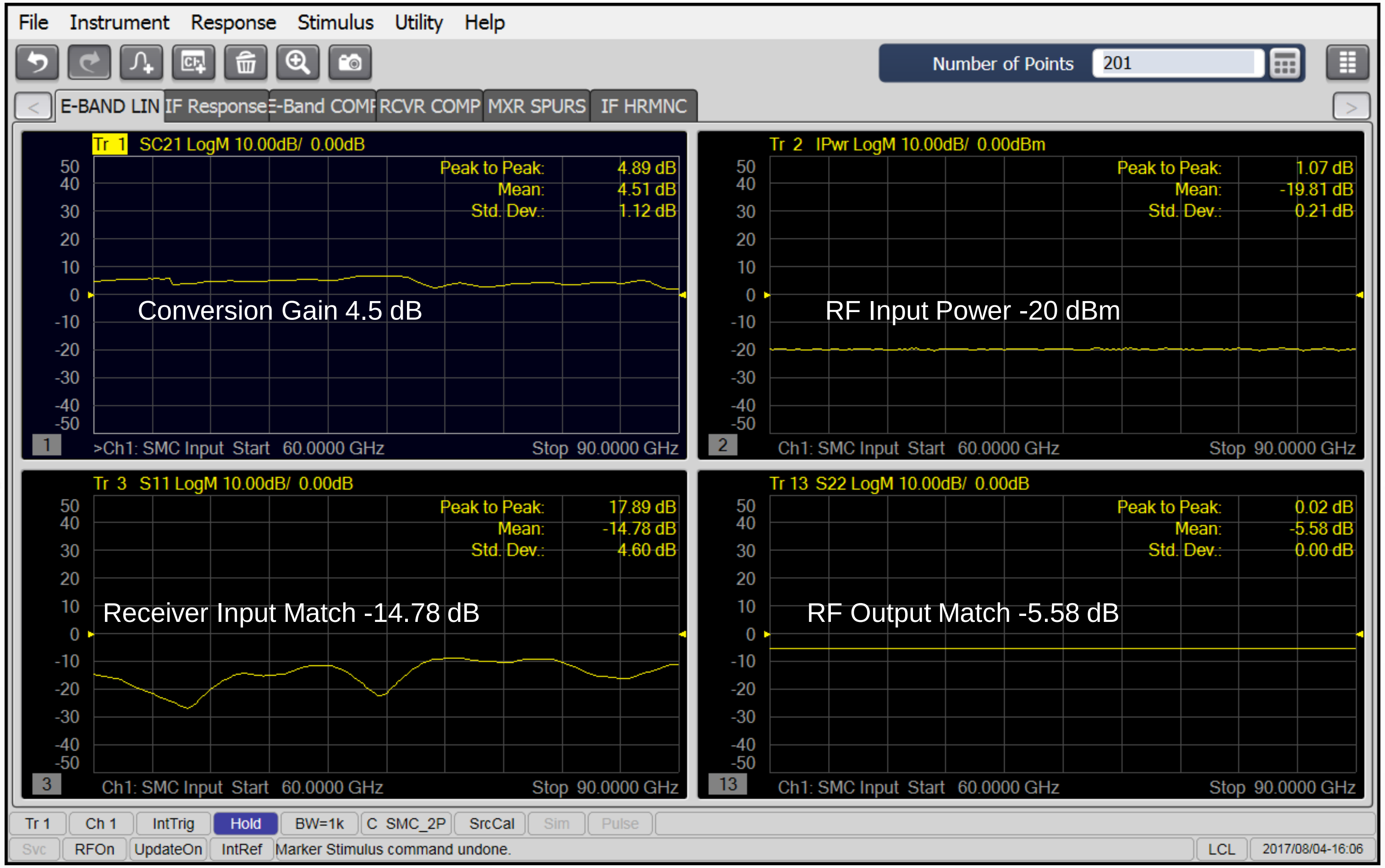
E-Band Receiver Test

RECEIVER GAIN AND MATCH PERFORMANCE



E-Band Receiver Characterization

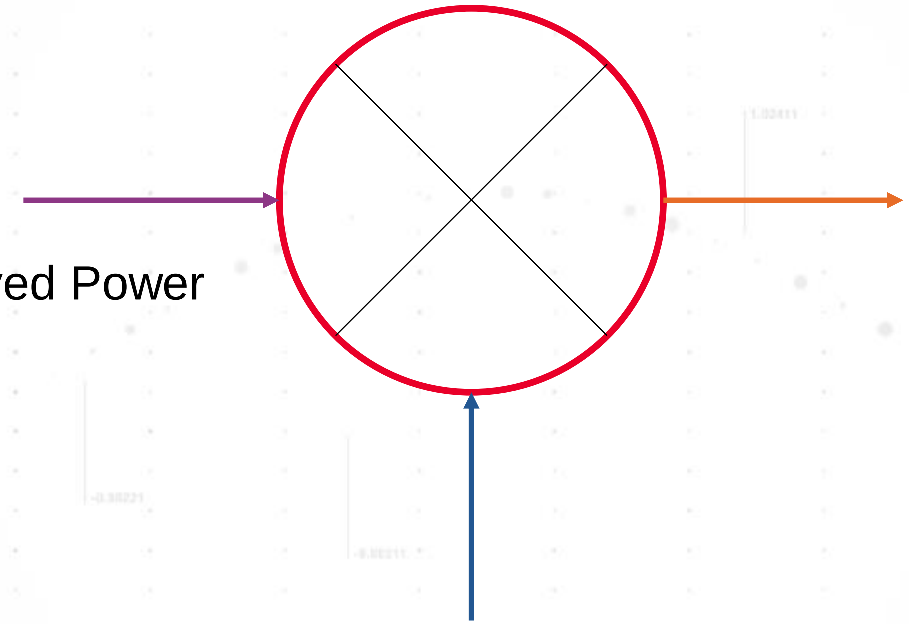
RECEIVER GAIN AND MATCH PERFORMANCE



E-Band Receiver Characterization

RECEIVER GAIN COMPRESSION

RF Input Frequency:
60 GHz to 90 GHz
-50 dBm to +5 Received Power



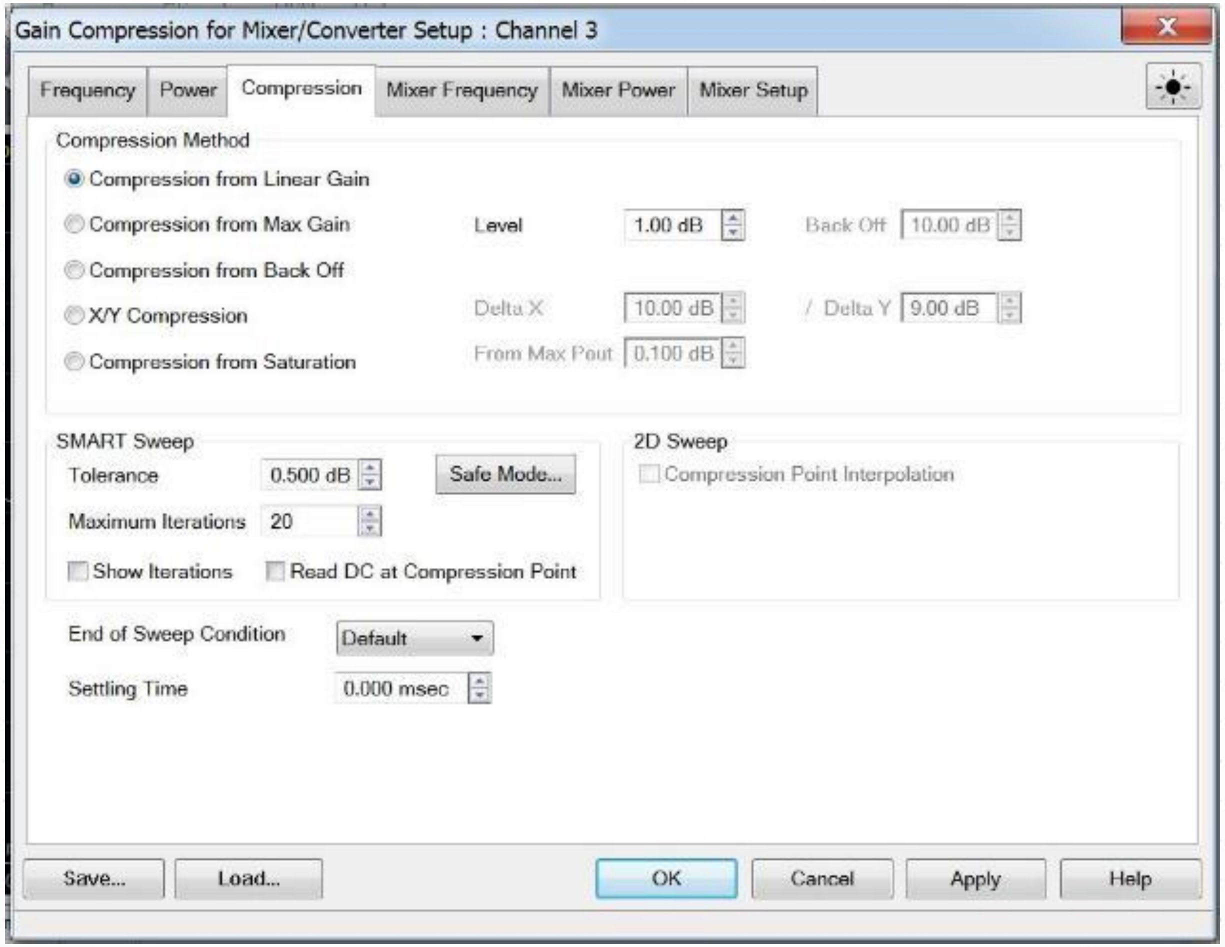
2 GHz Base Band Frequencies

LO Input Frequencies
- 58 - 88 GHz Fundamental
- -10 dBm LO Power

KEYSIGHT TECHNOLOGIES

E-Band Receiver Characterization

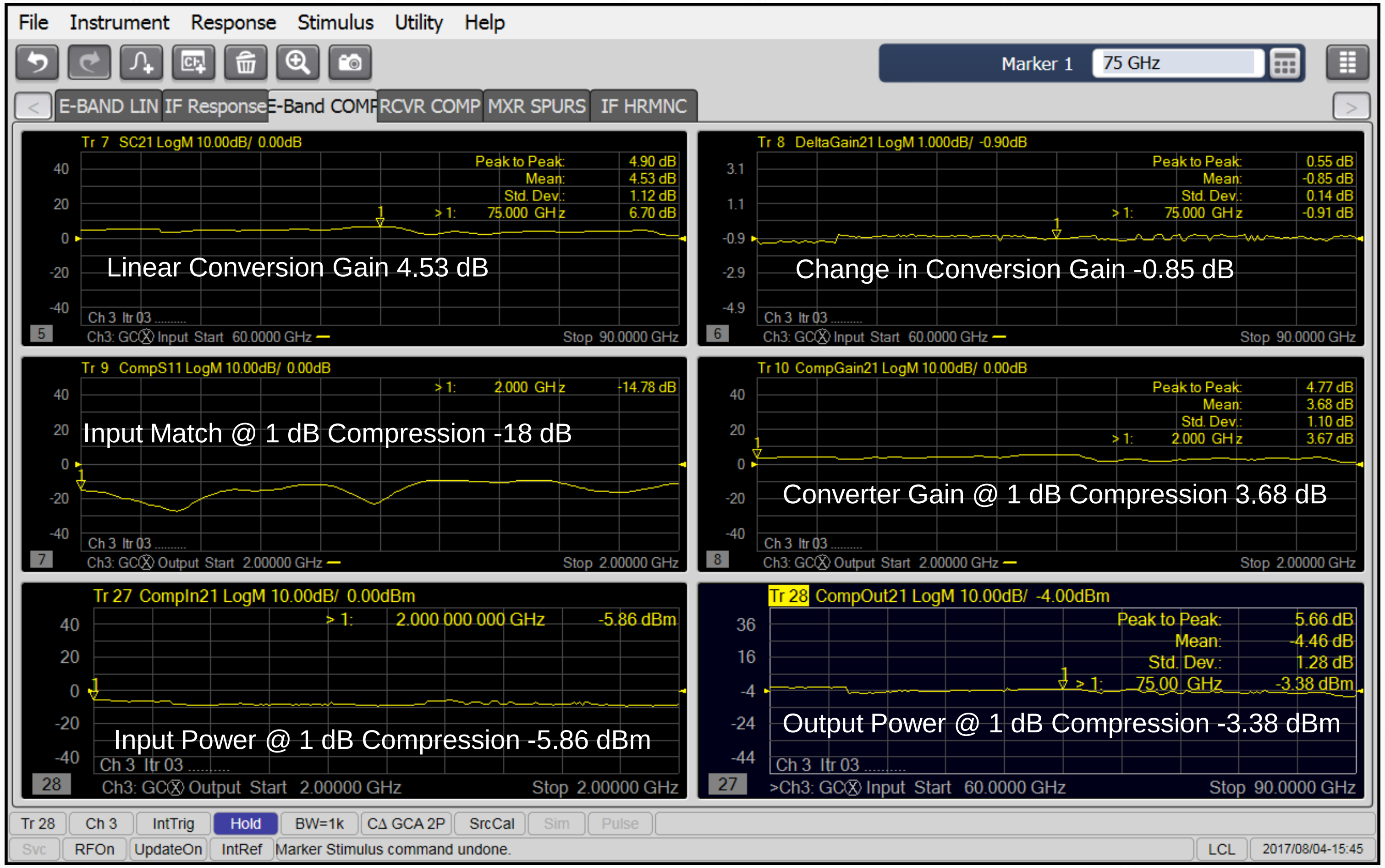
RECEIVER GAIN COMPRESSION



KEYSIGHT TECHNOLOGIES

E-Band Receiver Characterization

RECEIVER GAIN COMPRESSION



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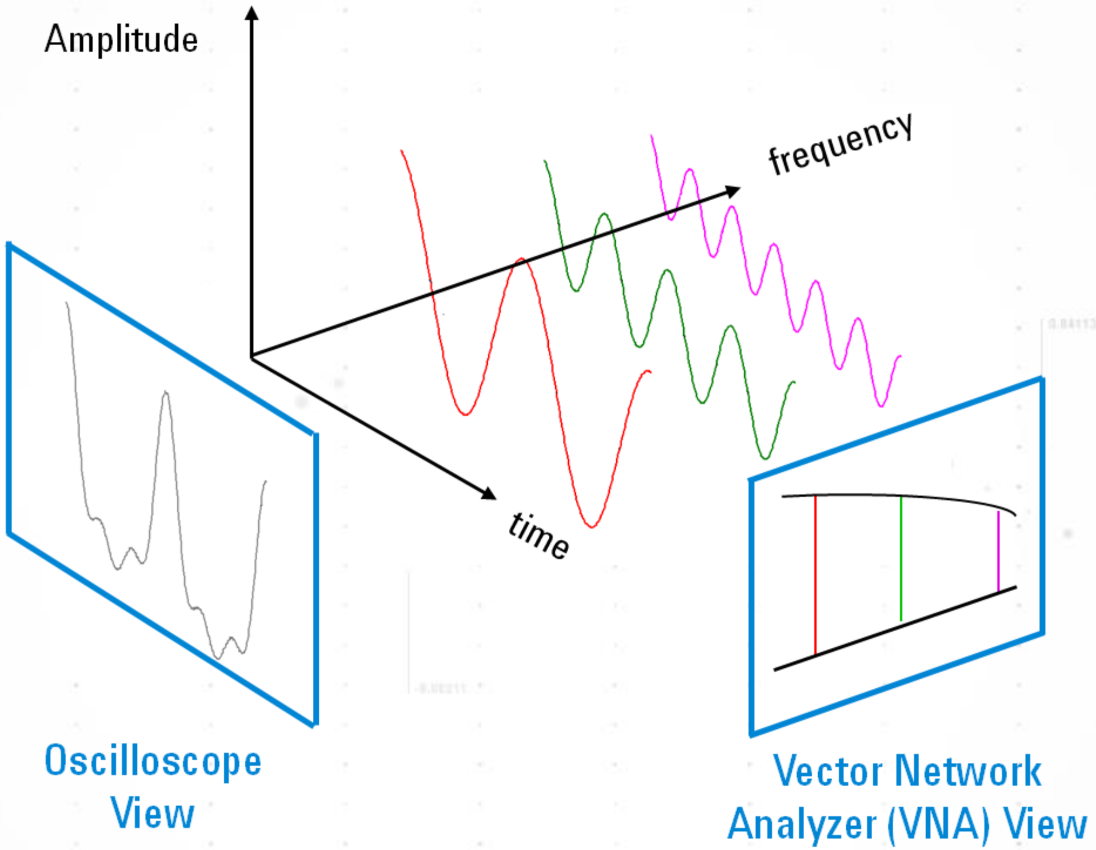
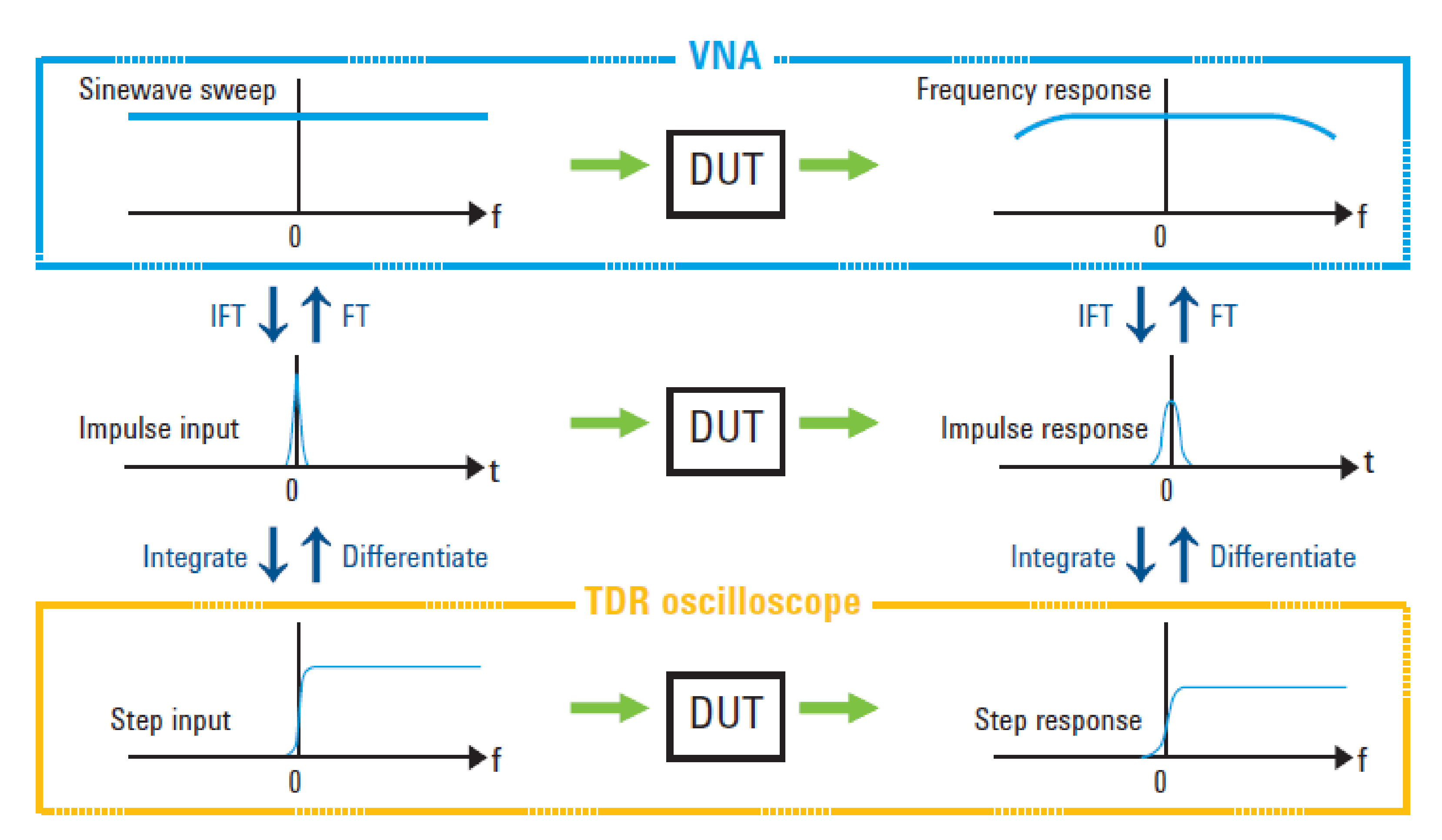
Time and frequency domain



No difference in information content between the time domain and frequency domain

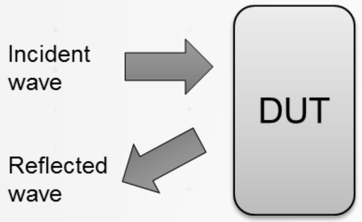
Time and frequency domain

Using Fourier Transform techniques, the time domain response can be mathematically transformed into the frequency domain response and back again without changing or losing any information.

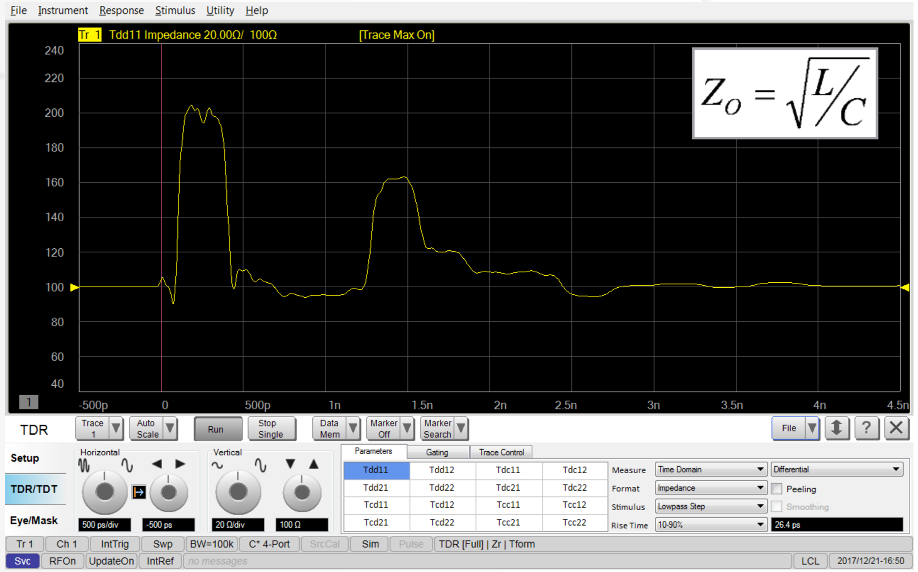


Time domain measurements

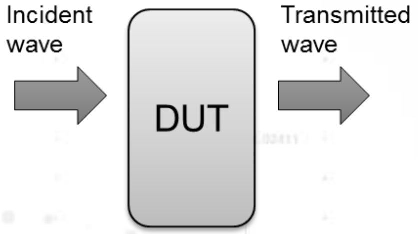
TDR (Time Domain Reflection)



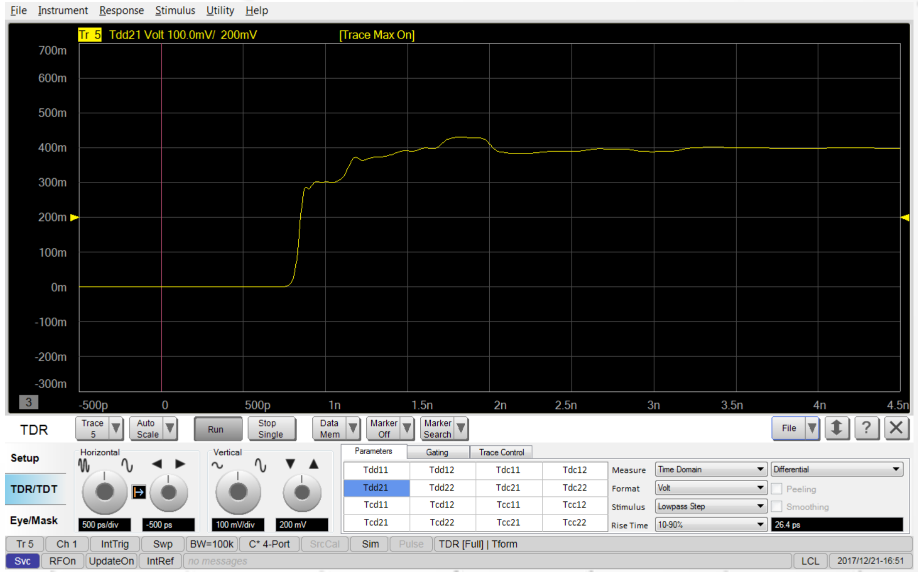
- Evaluate the impedance profile to locate discontinuities
- Shape and polarity of the reflections provide insight about the line



TDT (Time Domain Transmission)

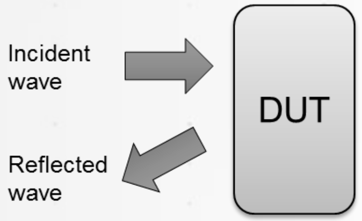


- Evaluate propagation delay and rise time degradation
- Propagation delay important for differential signals
- Useful for monitoring crosstalk and mode conversion



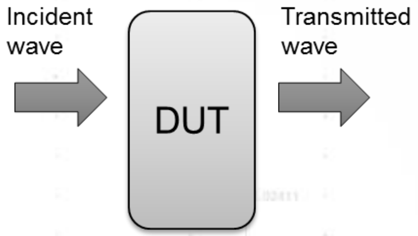
Frequency domain measurements

Return Loss (Sdd11)



- Evaluate reflection of signal through interconnect

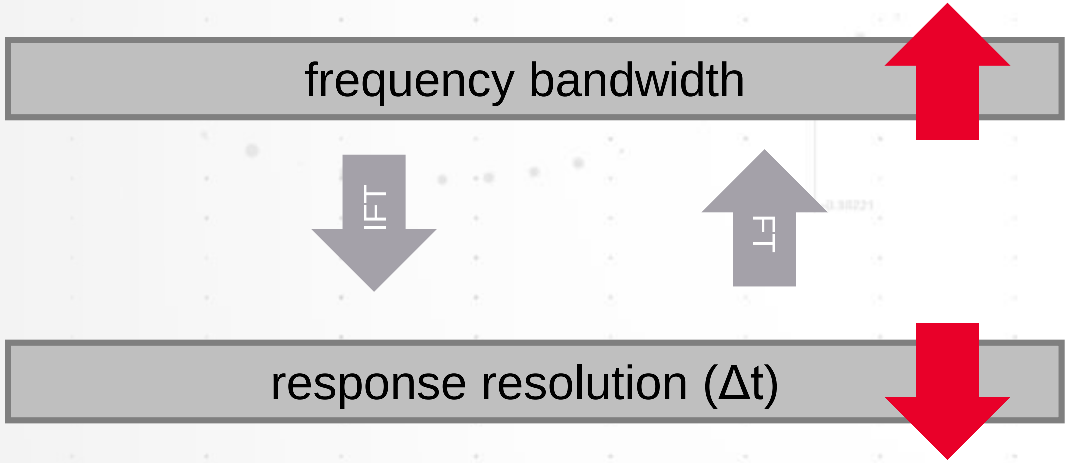
Insertion Loss (Sdd21)

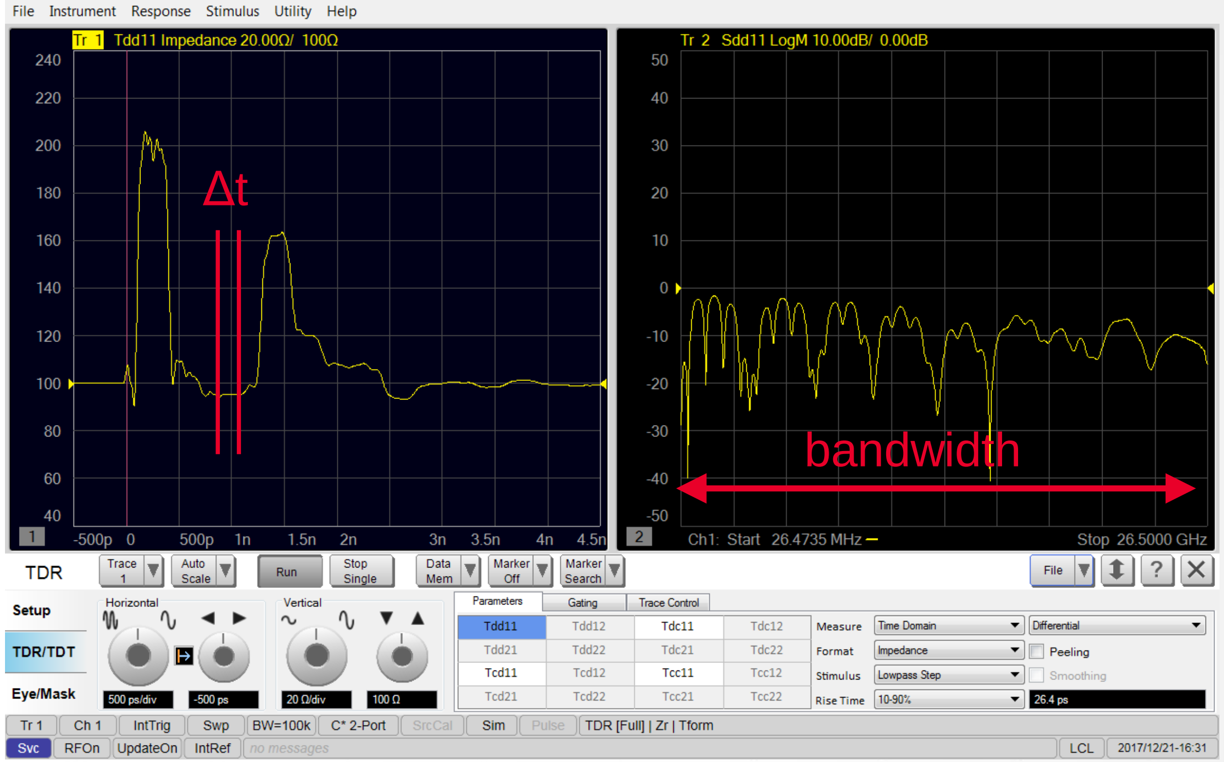


- Evaluate attenuation of signal through the interconnect
- Useful for estimating highest useable frequency, or the bandwidth of the interconnect

Time domain response resolution

- Determines the degree to which closely spaced impedance mismatches can be resolved
- Inversely related to the frequency bandwidth

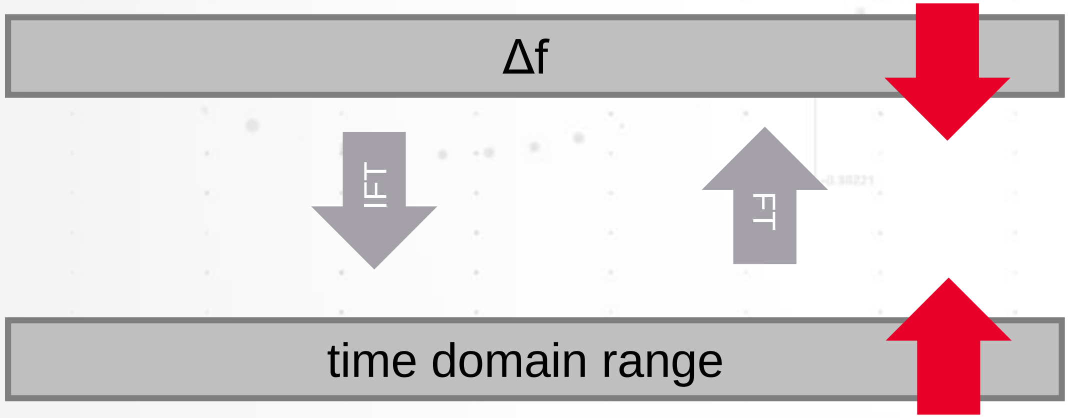


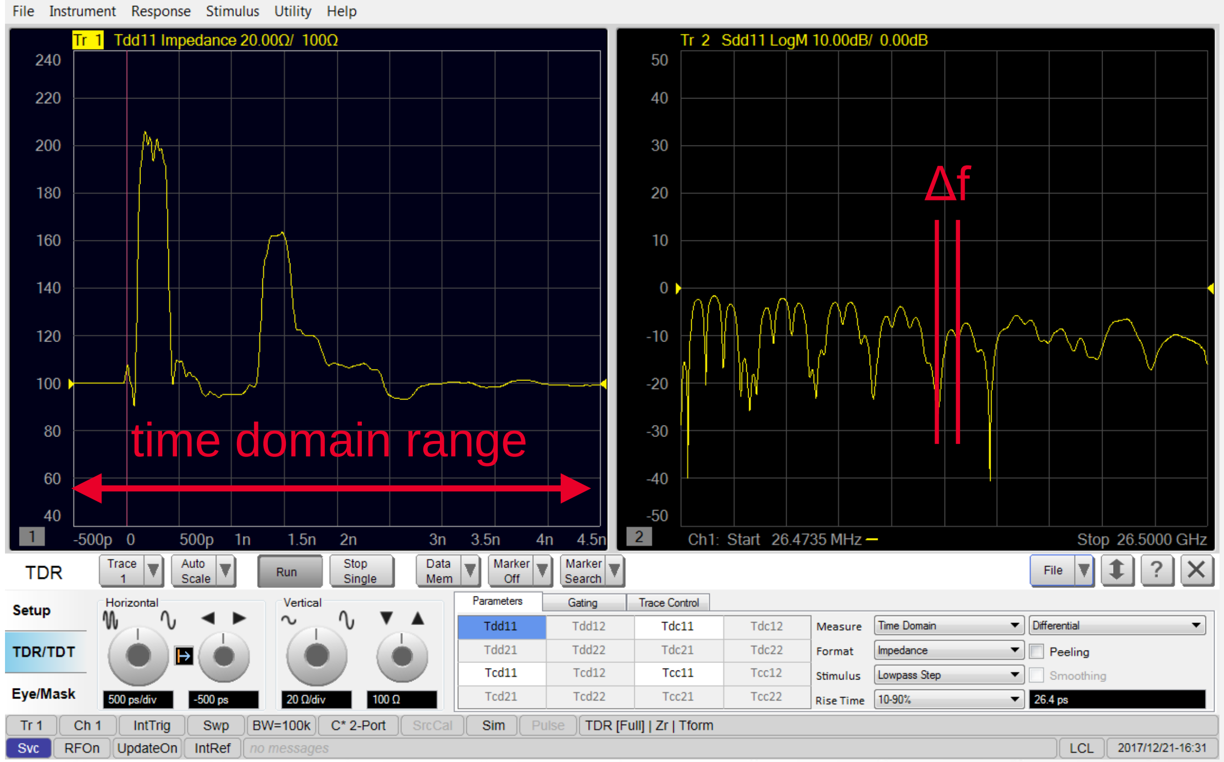


Increasing frequency bandwidth leads to finer time domain resolution

Time domain range (alias-free range)

- Discrete frequency points obtained by the VNA causes time domain response to repeat every 1/Δf seconds (**aliasing** in the time domain)
- Limits maximum DUT length that can be measured



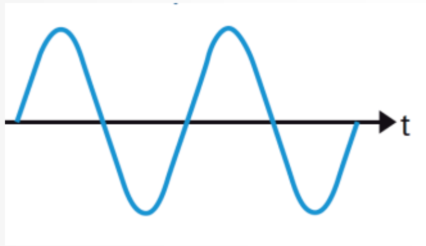


Finer frequency domain resolution leads to longer time domain alias-free range

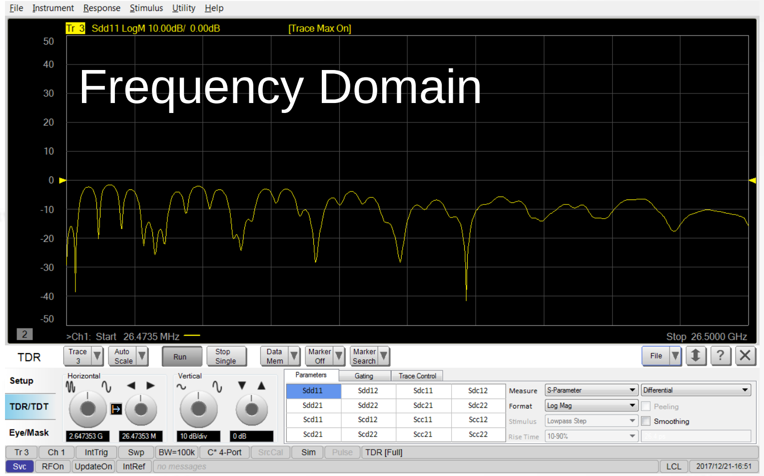
VNA or TDR Scope?

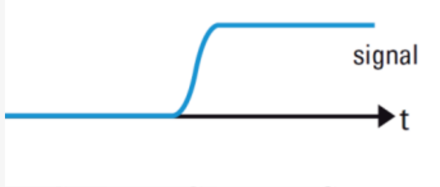
Measurement domain

Display domain

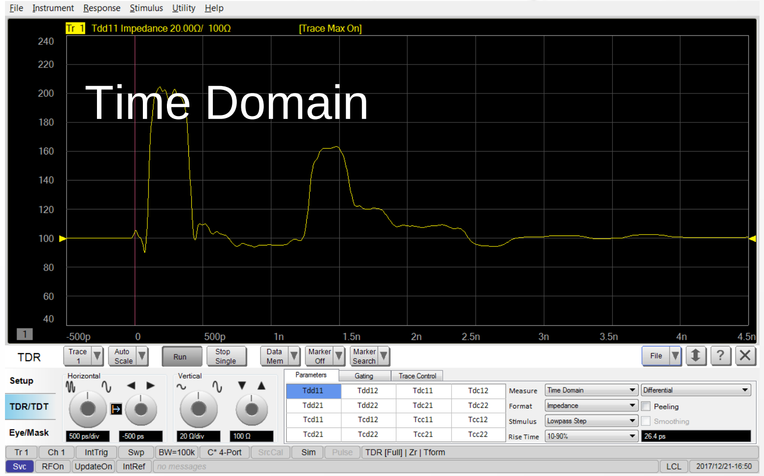


VNA





TDR Scope



VNA or TDR Scope?



Measurements (Modes)	S93010A Time domain	S93011A PNA-TDR	TDR Scope
Frequency Domain (S-parameters)	Yes	Yes	Yes
Time Domain (TDR/TDT)	Yes	Yes	Yes
Eye Diagram / Mask Testing	No	Yes (simulated)	Yes (live)
Oscilloscope (measure waveforms)	No	No	Yes
Jitter Analysis	No	No	Yes

Features	S93010A Time domain	S93011A PNA-TDR	TDR Scope
Speed and Accuracy	Best	Best	Fair
ESD Robustness	Best	Best	Fair
Simple and Intuitive Operation	Fair	Yes	Yes

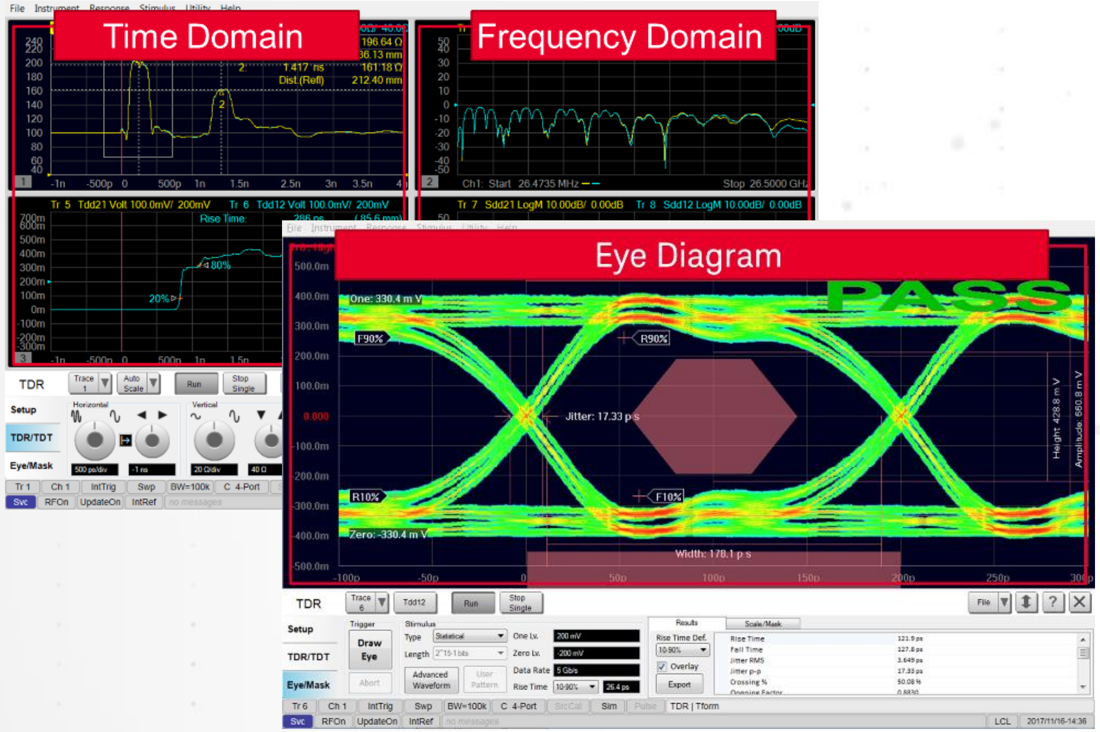
S93011 PNA-TDR vs S93010A Time domain

	S93010A Time domain	S93011A PNA-TDR
Measurements		
Frequency Domain (S-parameters)	Yes	Yes
Time Domain (TDR/TDT)	Yes	Yes
DC Estimation Method	Fair	Good
Eye Diagram / Mask Testing	No	Yes (simulated)
Advanced Signal Integrity Analysis Features		
Gating	Yes	Yes
Stressed Eye Diagram Analysis of Interconnects	No	Yes
Hot TDR (Avoid Spurious)	No	Yes
User Interface	Fair traditional VNA soft-key architecture	Good Similar look-and-feel to TDR scopes

S93011A PNA-TDR is a superset of S93010 Time domain

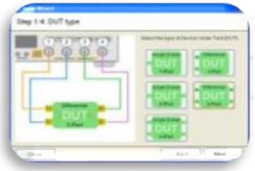
What is S93011A PNA-TDR?

S93011A PNA-TDR is an enhancement of the S93010A Time domain analysis software. The software, running on the PNA-X/PNA/PNA-L Series B-model Vector Network Analyzers, offers digital signal integrity engineers an **one box solution** for characterizing high speed serial interconnects.

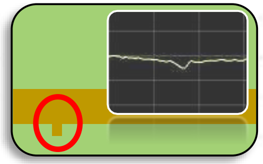


3 Breakthroughs

for Signal Integrity Design and Verification



Simple and Intuitive Operation

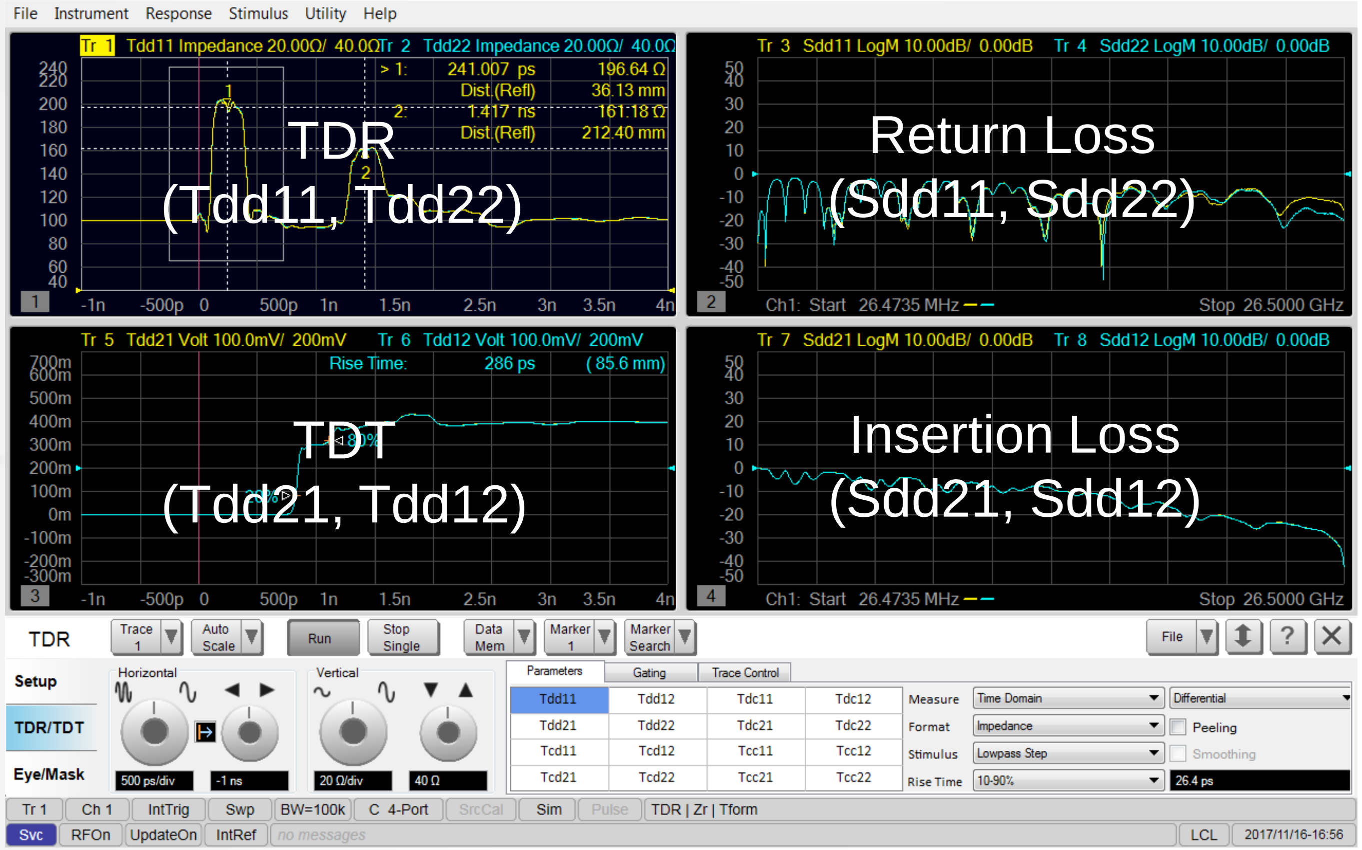


Fast and Accurate Measurements

High ESD Robustness

www.keysight.com/find/pna-tdr

Simple and intuitive operation



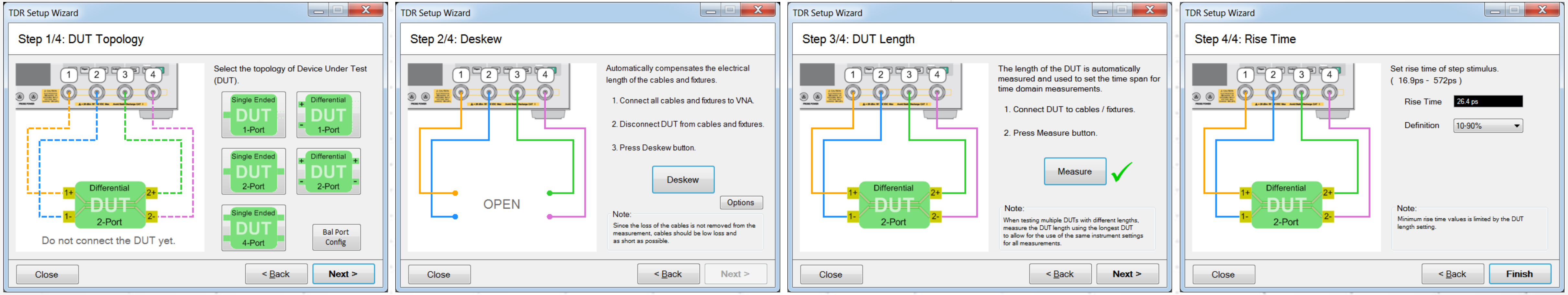
- Dedicated GUI for TDR analysis provides intuitive operation for users not familiar to VNAs and S-parameter measurements
- Easily locate source of loss, reflections and crosstalk by simultaneous analysis of both time and frequency domains

Similar look-and-feel to TDR scopes

Simple and intuitive operation

Setup Wizard

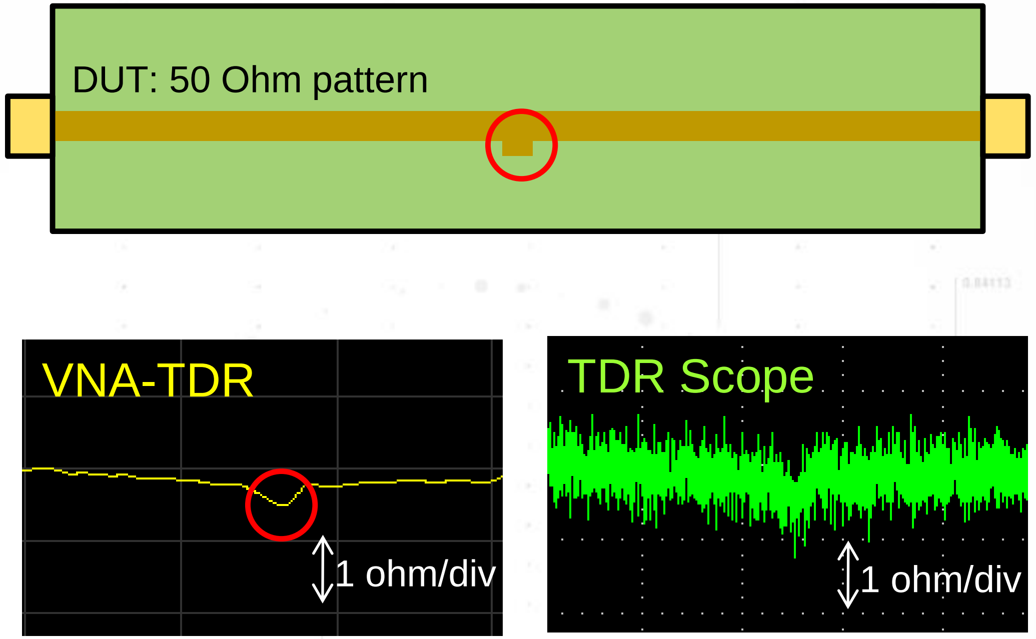
- The Setup Wizard guides you through all of the steps, making setup intuitive and error-free
- Automatically sets the optimum parameters (range, resolution, windowing, etc.) for your DUT



Simple 4-step operation

KEYSIGHT TECHNOLOGIES

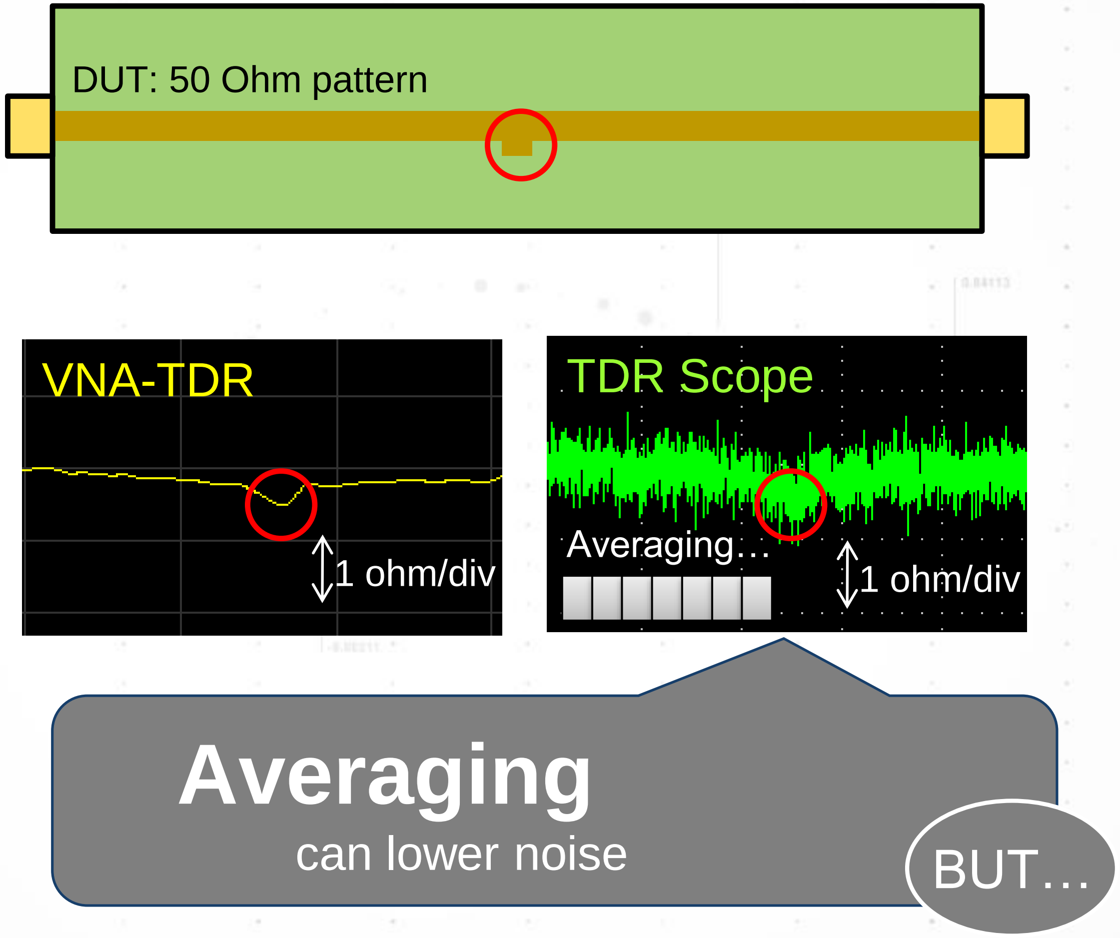
Fast and accurate measurements



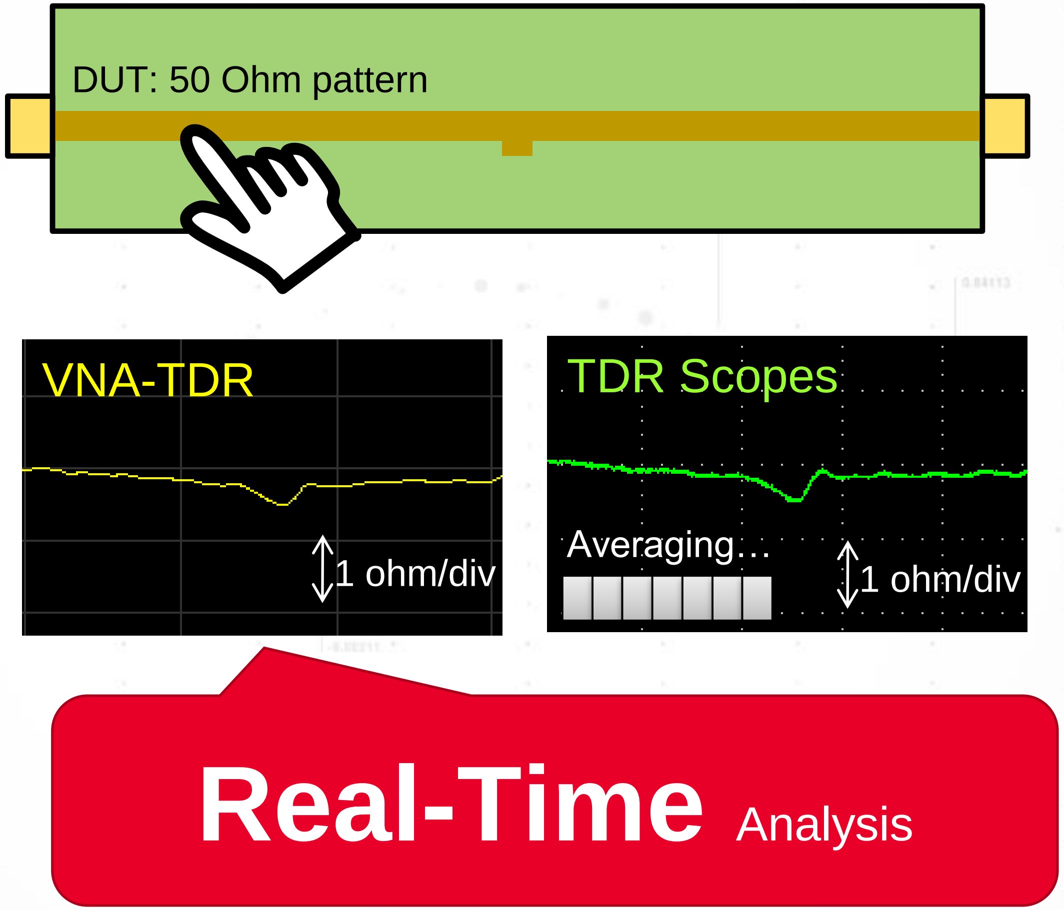
VNA Based TDR measurements

= Low Noise

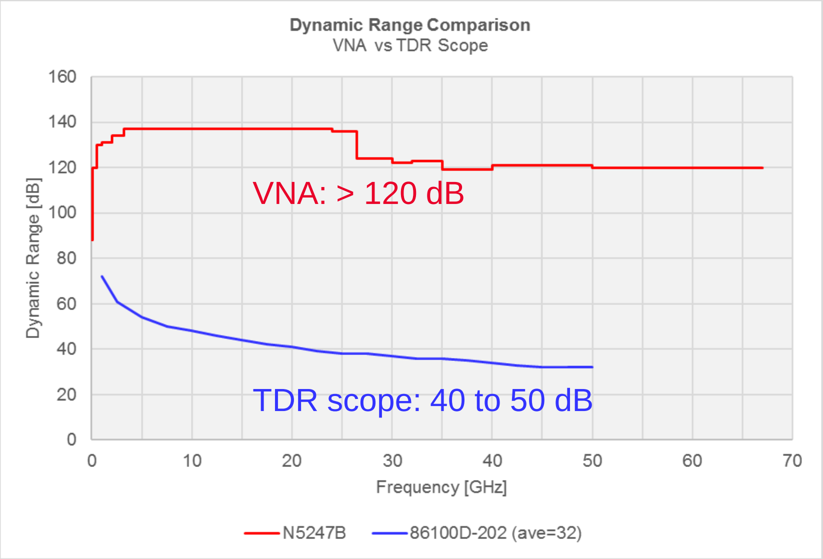
Fast and accurate measurements



Fast and accurate measurements

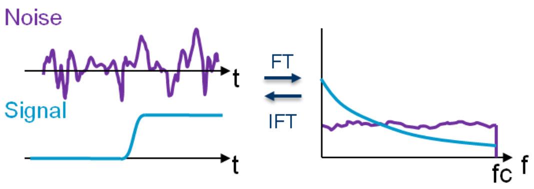


Fast and accurate measurements

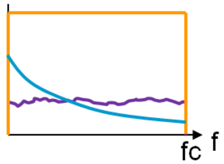


TDR Scope

[Source]
•Source power rapidly decreases with increase in frequency
=> loss of accuracy for higher frequencies

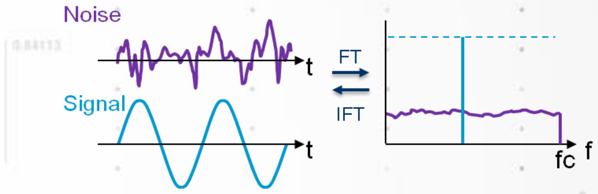


[Receiver]
•Broadband
•All noise up to the bandwidth of the system is observed
=>NO noise reduction

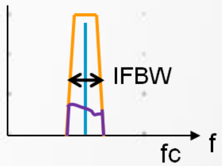


S93011A PNA-TDR

[Source]
•Source power leveled and constant across entire frequency range
=> NO loss of accuracy for higher frequencies



[Receiver]
•Narrowband
•Noise attenuated in stopband of filter
=> Noise reduction



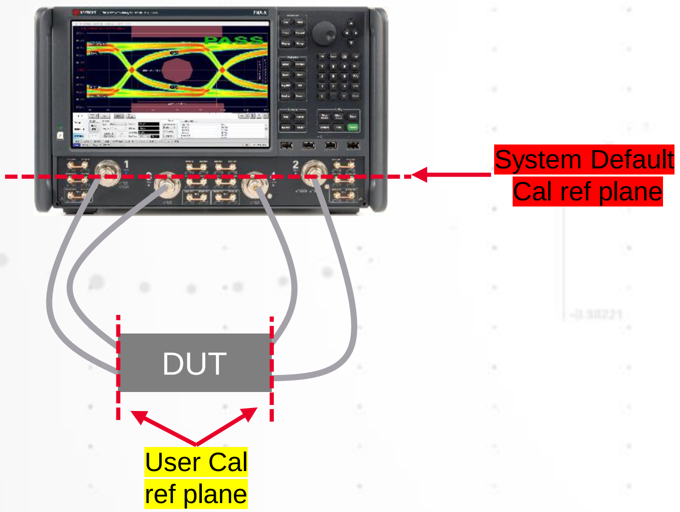
For further details (including mathematical analysis), refer to the White Paper "Comparison of Measurement Performance between Vector Network Analyzer and TDR Oscilloscope" (5990-5446EN).

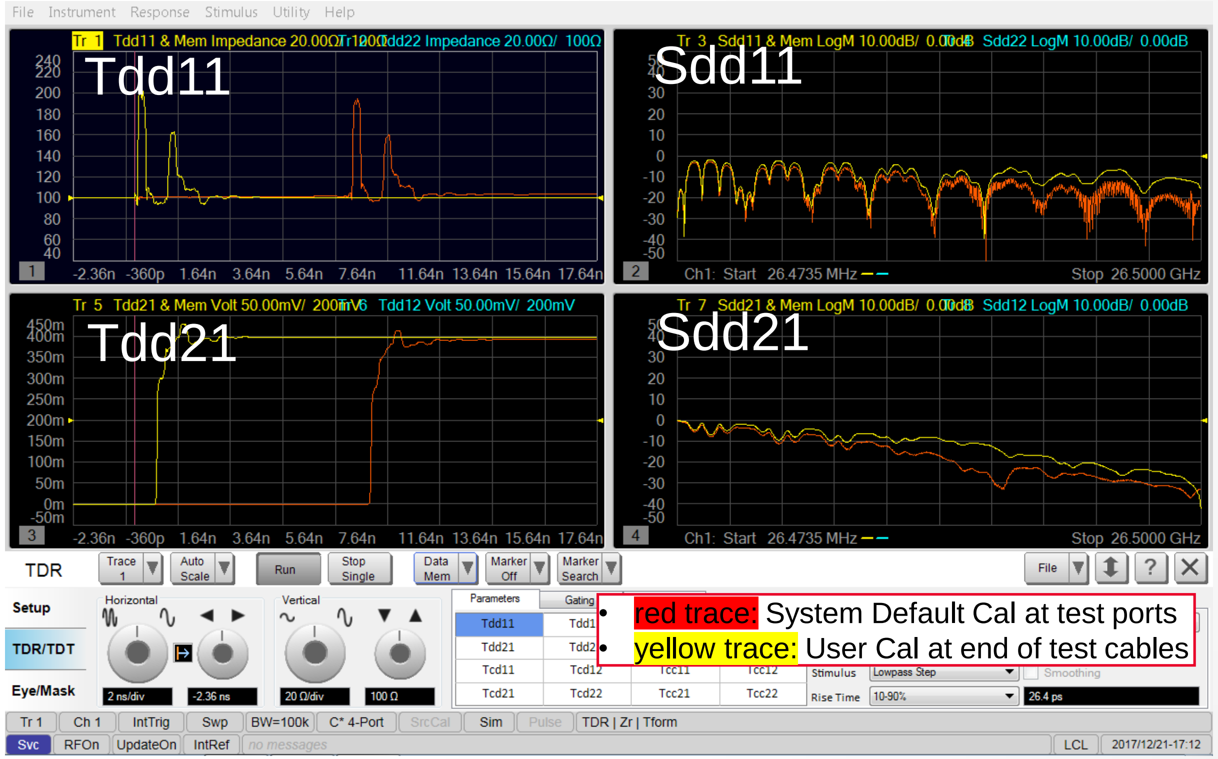
Significant differences in performance due to the instrument architecture

Fast and accurate measurements

System default calibration

To achieve reasonable accuracy without user calibration, calibration at the test ports is performed at the factory ("**System Default**" calset) and applied in the TDR Measurement Class.

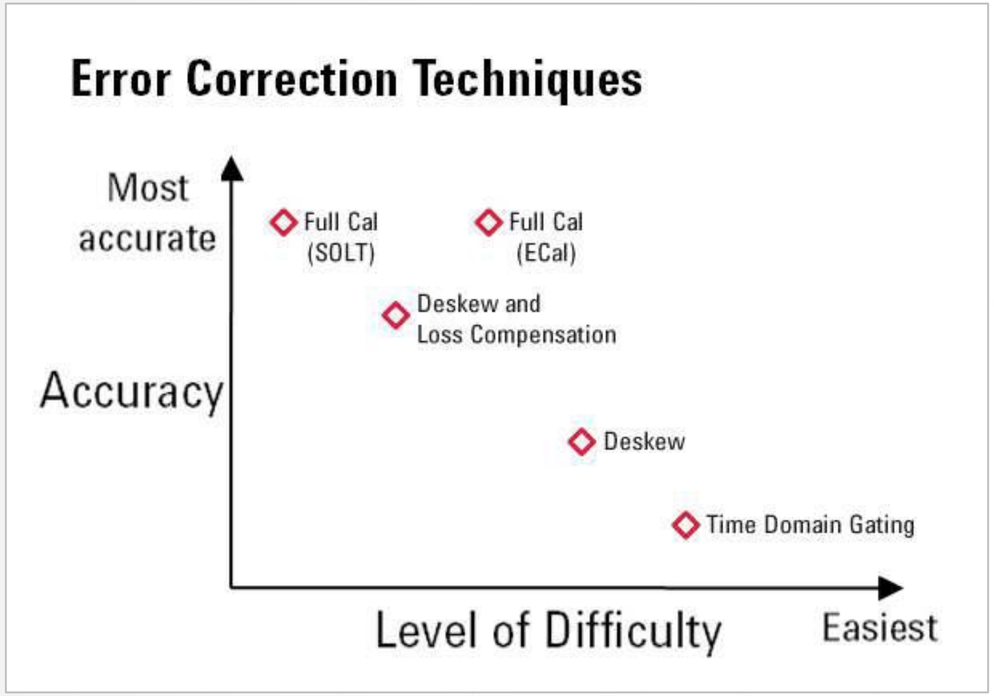




User calibration is recommended for higher accuracy

Fast and accurate measurements

Error correction technique comparison



Deskew

- Commonly used in time domain instruments
- Simple to perform
- Only corrects for delay

Full calibration (ECal)

- Commonly used in frequency domain instruments
- Requires more standards
- Accounts for all major sources of error

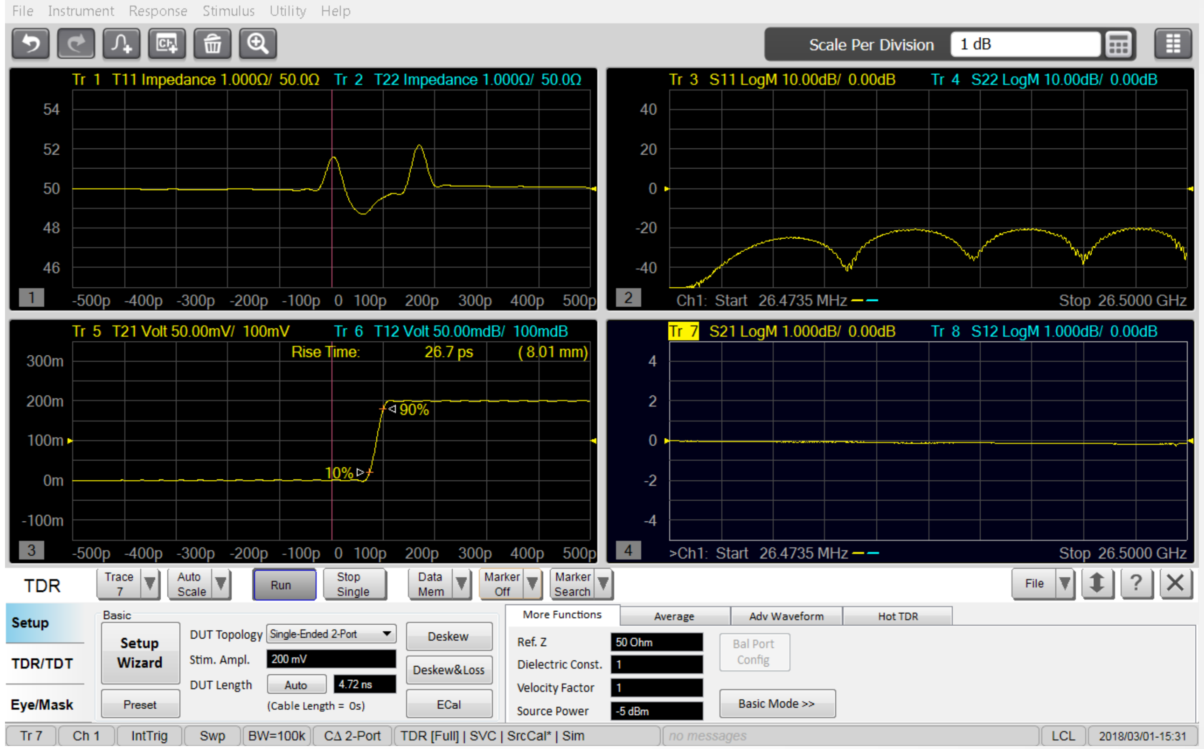
Measure the true performance of your device

Fast and accurate measurements

Measurement comparison: Deskew vs Ecal (DUT = thru adapter)

Deskew

Full calibration (ECal)



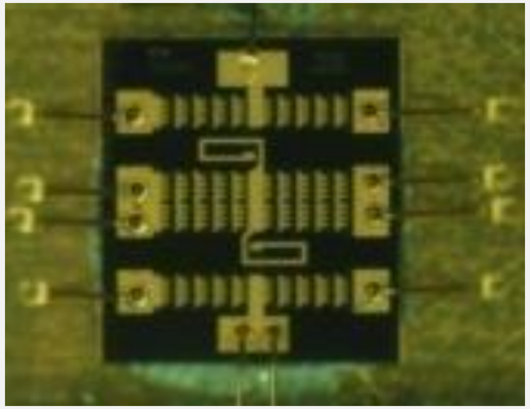
Full calibration (Ecal) recommended for higher accuracy

Higher ESD Robustness

PNA-TDR

Higher robustness against ESD, because protection circuits are implemented inside the instrument for all ports, while maintaining excellent RF performance.

Proprietary ESD protection chip

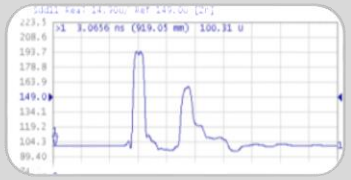


Reduce instrument repair fees and downtime

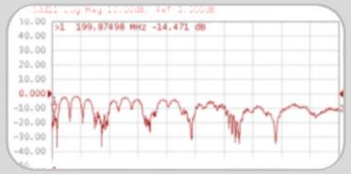
The S93011A PNA-TDR application…

…provides a **one-box solution** for high speed serial interconnect analysis

Time domain



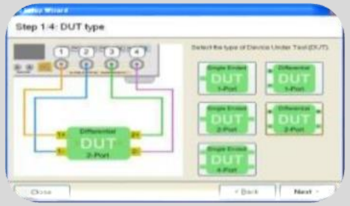
Frequency domain



Eye diagram

…brings **three breakthroughs** for signal integrity design and verification

Simple & Intuitive Operation



Fast & Accurate Measurements

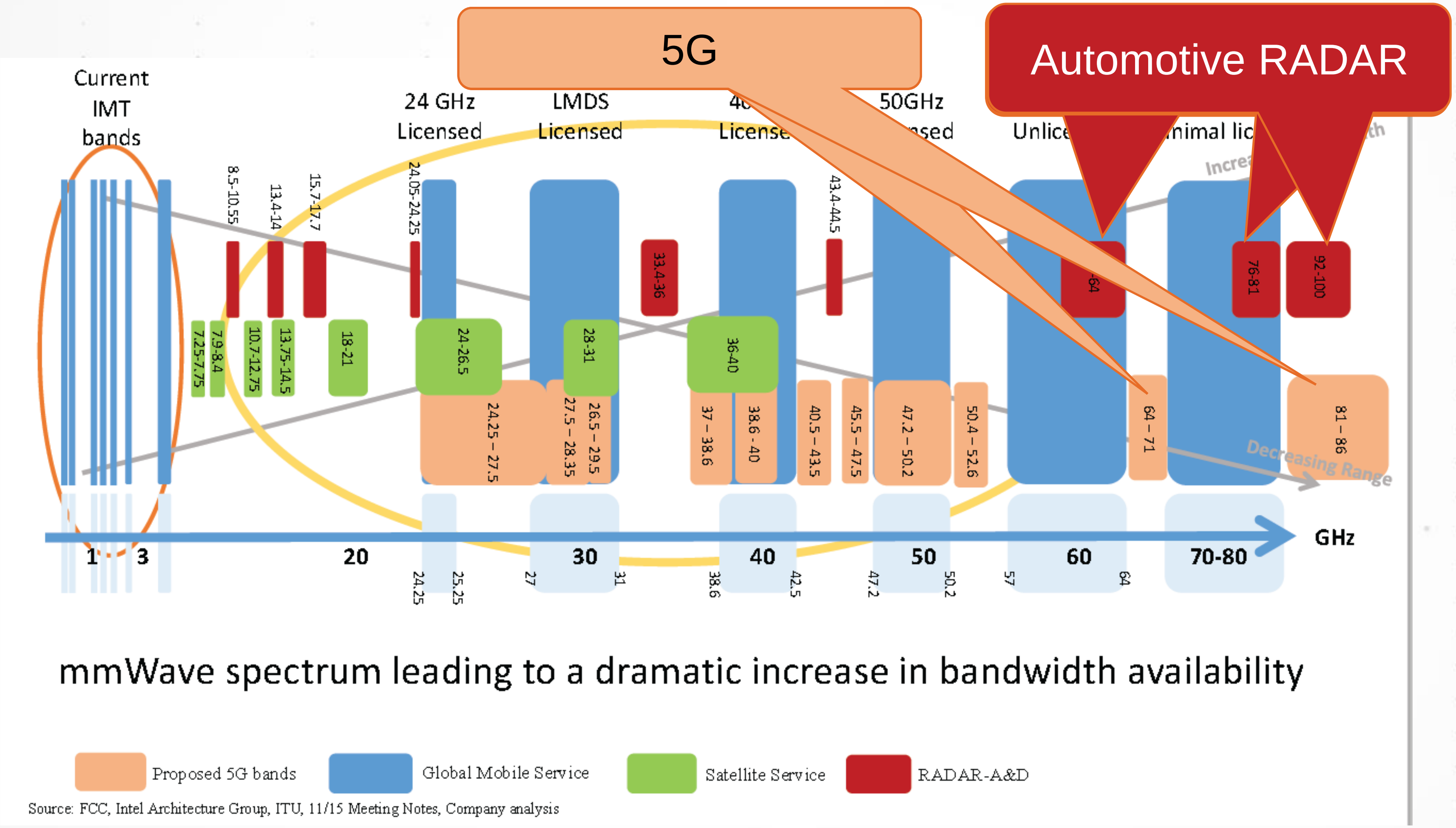
High ESD Robustness

www.keysight.com/find/pna-tdr

New E-band VNA system, N5252A

Automotive and 5G

E-BAND APPLICATIONS

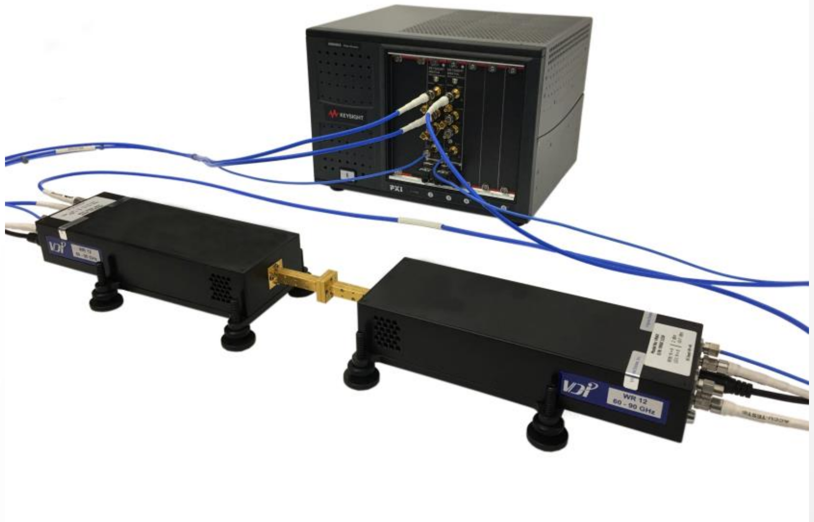


N5252A E-band (60 G - 90 GHz) VNA system

- More affordable E-band VNA than PNA-based E-band VNA
- 2 or 4-port S-parameter measurements using PXI-VNA modules
- Power calibration at test ports with an external waveguide sensor
- LO signal supplied by a PXI-VNA card is daisy-chained to the other modules
- Dedicated modules for the use only with Keysight PXI VNA’s
- Controlled by a desktop computer

Key measurement performance

- Frequency range: 60 GHz to 90 GHz
- Dynamic Range (BW=10Hz): 100 dB minimum / 110 dB typical
- Test Port Power: +13 dBm typical
- Magnitude Stability : +/- 0.15 dB, typical (over 1 hour in stable environment after warm-up)
- Phase Stability: +/- 2 degree, typical (over 1 hour in stable environment after warm-up)
- Test Port Interface: WR-12 IEEE 1785-2a compatible with UG-387/UM
- Test cable length: 1.2m



Configuration

Item	Description	2-port	4-port
N5252A	PXI-based E-band (60 G – 90 GHz) VNA system	Option 200	Option 400
Items included in the N5252A		qty	qty
VDI VNAX WR-12 modules	WR-12, 60 GHz - 90 GHz, TxRx Mini VNAX with 1.2m cable	2	4
N5262AC12	60 GHz - 90 GHz, WR12 Calibration kit from VDI	1	1
M9374A	PXIe Network Analyzer 300 KHz - 20 GHz	2	4
M9374A-551	N-Port Calibration Software	1	1
Y1242A	PXI Jumper Cables	2	4
M9005A with opt 002	5 slot PXI Mainframe with PCIe Desktop adapter	1	1
Y1213A	PXI EMC Filler Panel kit	3	1
Y1212A	PXI Slot Blocker	3	1

Optional items	Description
M9374AU-010	Time Domain
U8489A and E281CS	120 GHz USB power sensor, and 1mm coax (f) to WR-12 waveguide adapter
E8486A and N1913/4A or E4416/7A	E-band waveguide power sensor, and power meter

A desktop computer is required.

Desktop computer requirement

- Operating systems: Windows 7 64 bit or Windows 10 64 bit
- Processor speed: 2.4 GHz recommended, (1.5 GHz dual core x64 minimum)
- Available memory: 8 GB recommended; 1 GB minimum
- Available disk space: 1.5 GB available hard disk space minimum
- Instrument driver: Keysight IO libraries Ver. 18.1.23218.2
- An open PCIe slot

Millimeter Component Characterization

DISCUSSION TOPICS

- Millimeter Wave Component Application Space
- Millimeter Vector Network Analyzer Architecture
- Calibration at Millimeter Wave Frequencies
- Amplifier Characterization
- Receiver Characterization
- PNA-TDR
- N5252A E-band VNA system
- Conclusions

Component Characterization

CONCLUSIONS

- Clearly a big drive for utilization of millimeter wave frequencies
- Millimeter vector network analyzer architecture is key to support characterization of these components
- Capability to fully calibrate impedance and power ensures that millimeter wave measurements are accurately computed
- Software applications key to make measurements simple
  - Amplifier characterization
  - Receiver characterization
- PNA-TDR

Thank you!