Millimeter Component Characterization

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KEYSIGHT TECHNOLOGIES

Millimeter Component Characterization

DISCUSSION TOPICS

- Millimeter Wave Component Application Space
- Millimeter Vector Network Analyzer Architecture
- Calibration At Millimeter Wave Frequencies
- Passive Filter Characterization
- Amplifier Characterization
- Receiver Characterization
- Conclusions

Millimeter Wave Application Space

NEED FOR MILLIMETER WAVE COMPONENT CHARACTERIZATION

Commercial Industry

Wireless backhaul

Next Gen wireless communications
“5G”

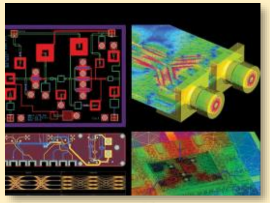
60-90 GHz

802.11 AD
Wireless HDMI

71-76 & 81-86 GHz

Automotive radar

77 GHz & 120 GHz



Millimeter Wave imaging

35 GHz to 325 GHz

Courtesy www.NIST.gov

Secure communication system

44 GHz to 93 GHz

Radar/EW

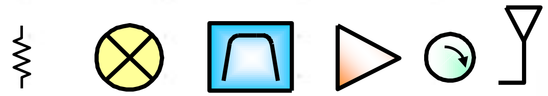
12 -18 GHz & 26-40 GHz
94 GHz to 650 GHz

Aerospace Defense
Industry

Millimeter Wave Application Space

NEED FOR MILLIMETER WAVE COMPONENT CHARACTERIZATION

- Millimeter wave components are underlying **building blocks** of systems in:
  - Automotive radars
  - Wireless 5G communication solutions
  - Imaging & Materials applications
- **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

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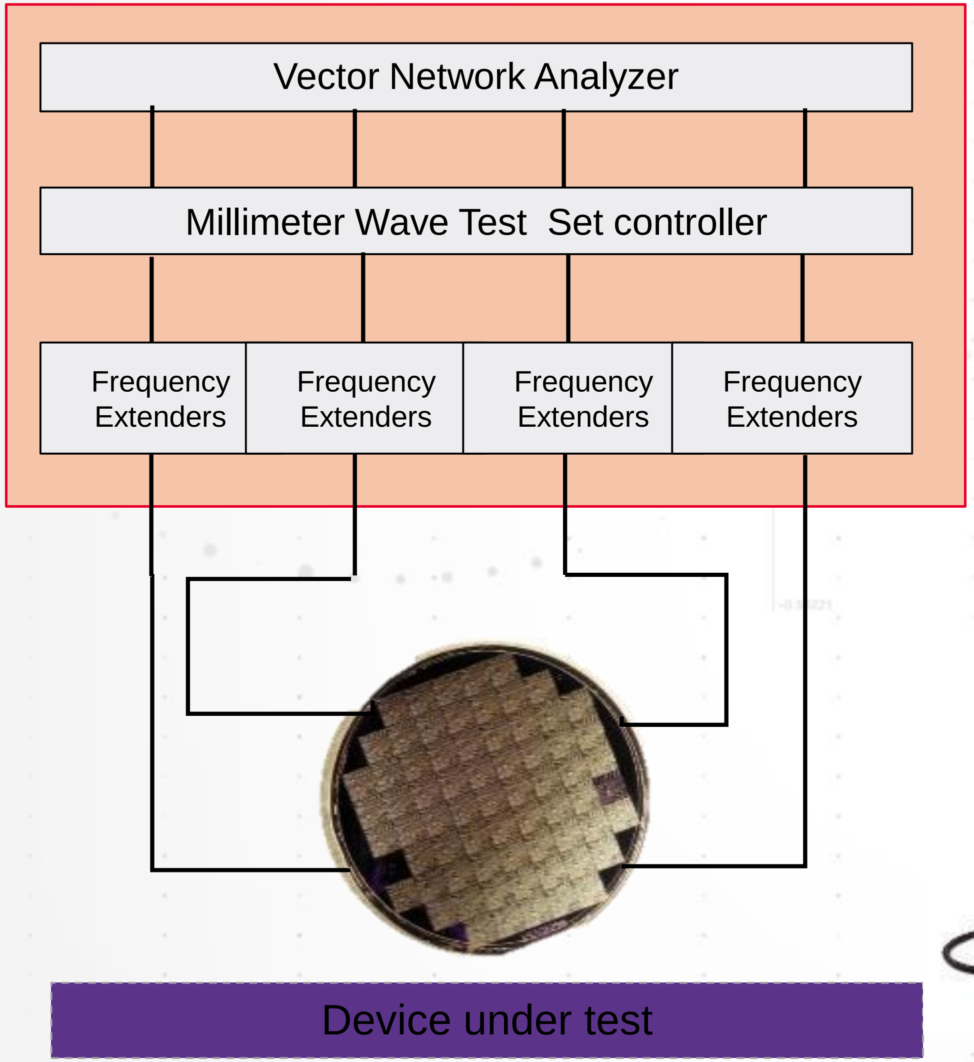
Typical Millimeter Wave System Implementation

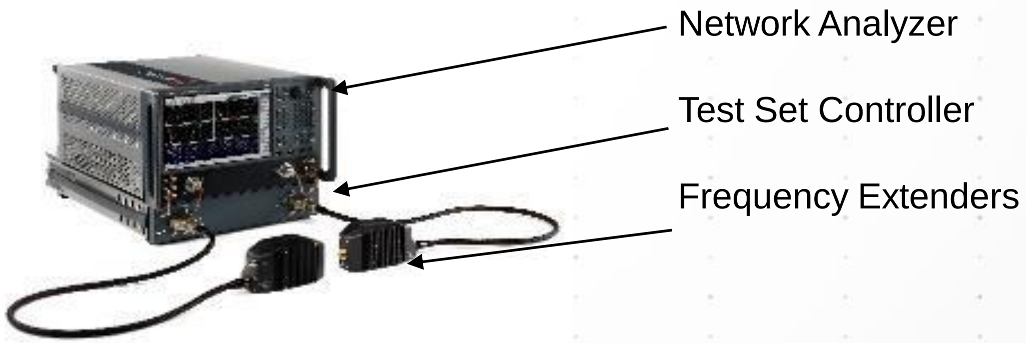
DISTRIBUTED SYSTEM ARCHITECTURE



Network Analyzer is the measurement engine

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

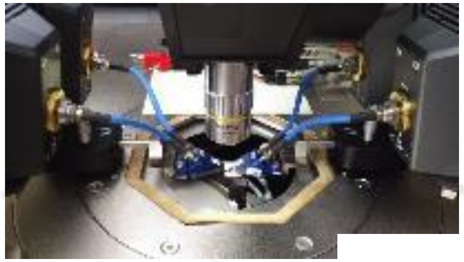
Frequency Extenders provide frequency conversion and signal coupling

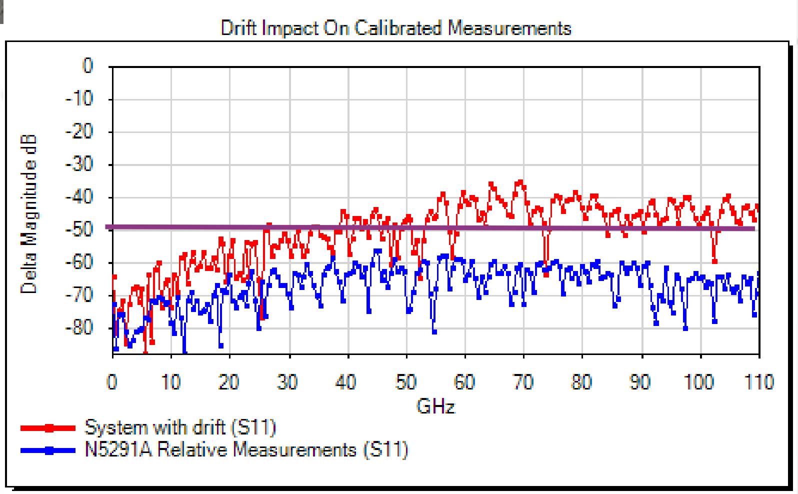


Millimeter Vector Network Analyzer Architecture

DISTRIBUTED ARCHITECTURE - BASED MEASUREMENT REQUIREMENTS

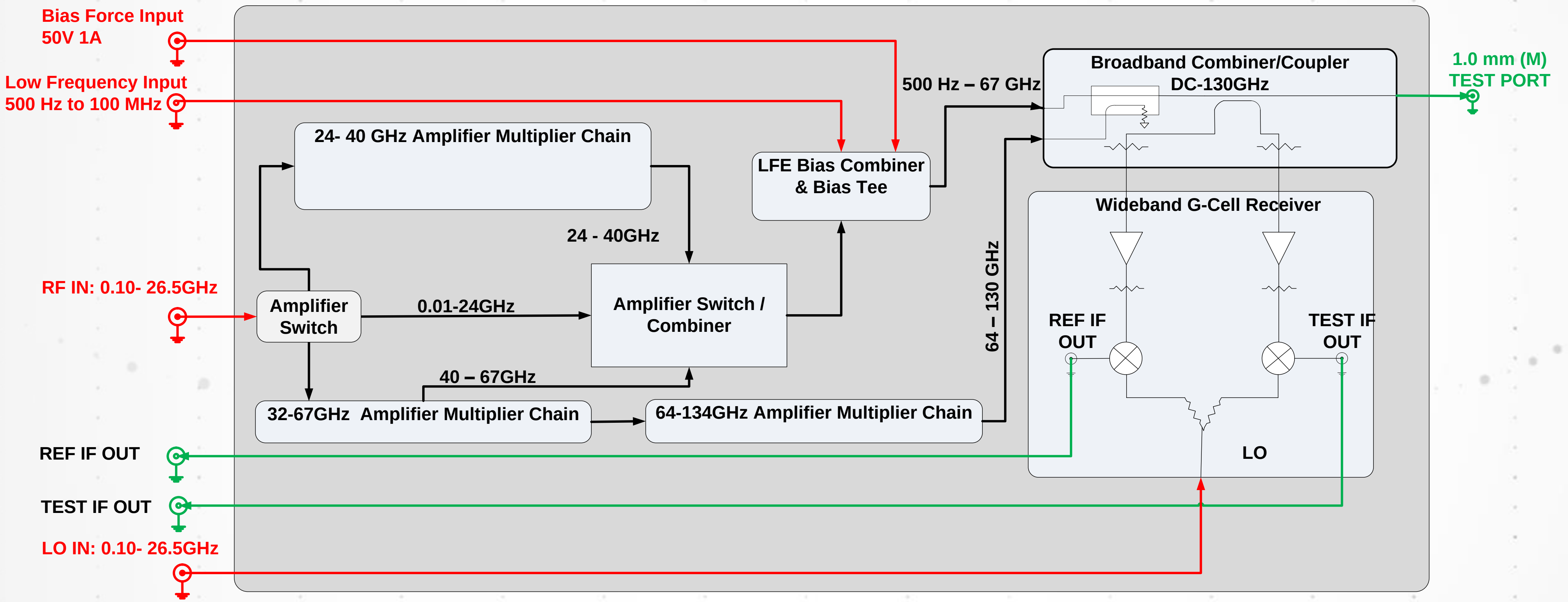
- Bring the measurement to the device
- Stable system architecture
- Sufficient power to get desired compression behavior
- Accurately control the phase of the stimulus
- Fully corrected and traceable measurements with uncertainty





Challenges of Distributed Architectures

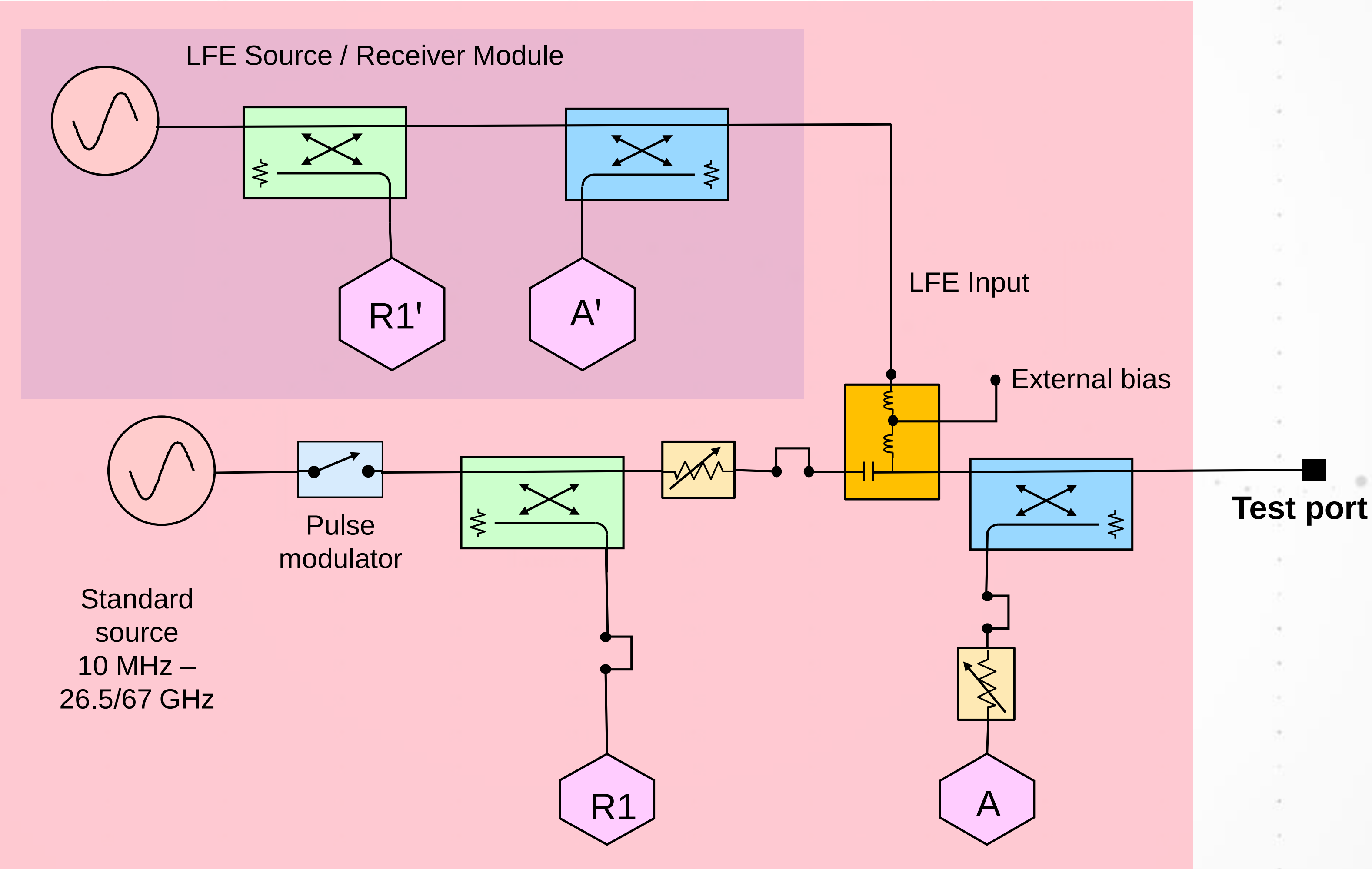
ACHIEVING MILLIMETER WAVE FREQUENCY COVERAGE



Keysight Implementation of Broadband Frequency Coverage

Challenges of Distributed Architectures

ADDING LOW FREQUENCY TO MILLIMETER WAVE VNA

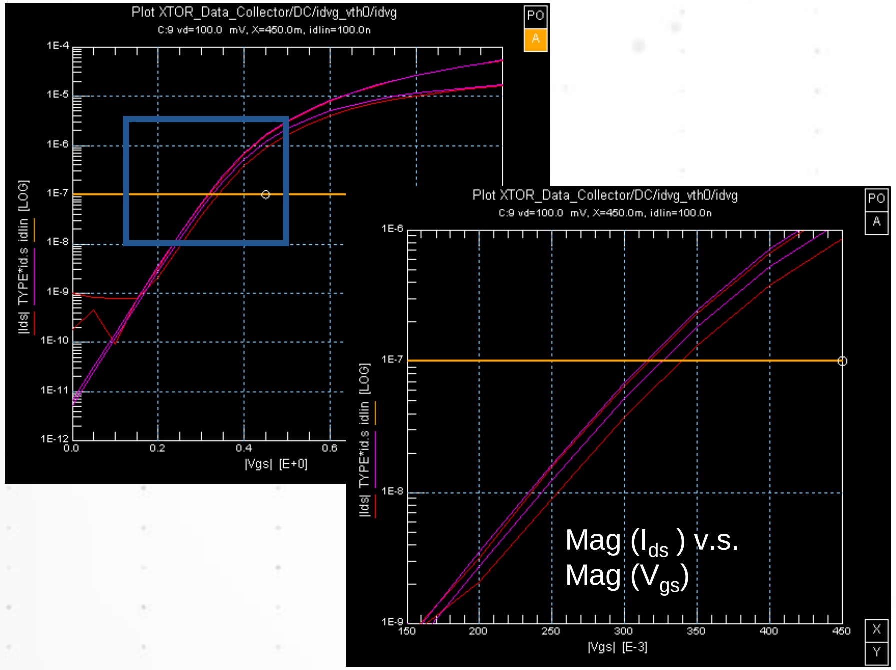


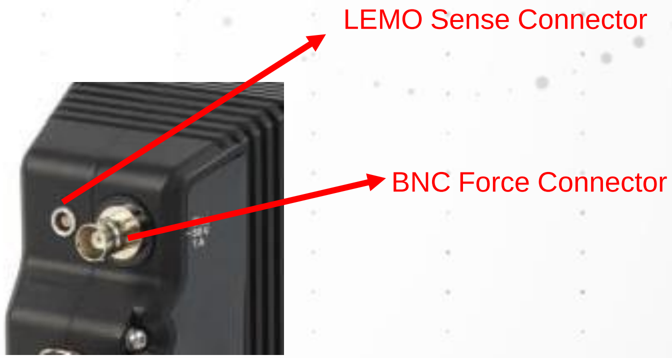
Keysight Implementation of low frequency coverage 500 Hz – 100 MHz

Challenges of Distributed Architectures

ACTIVE DEVICE CHARACTERIZATION

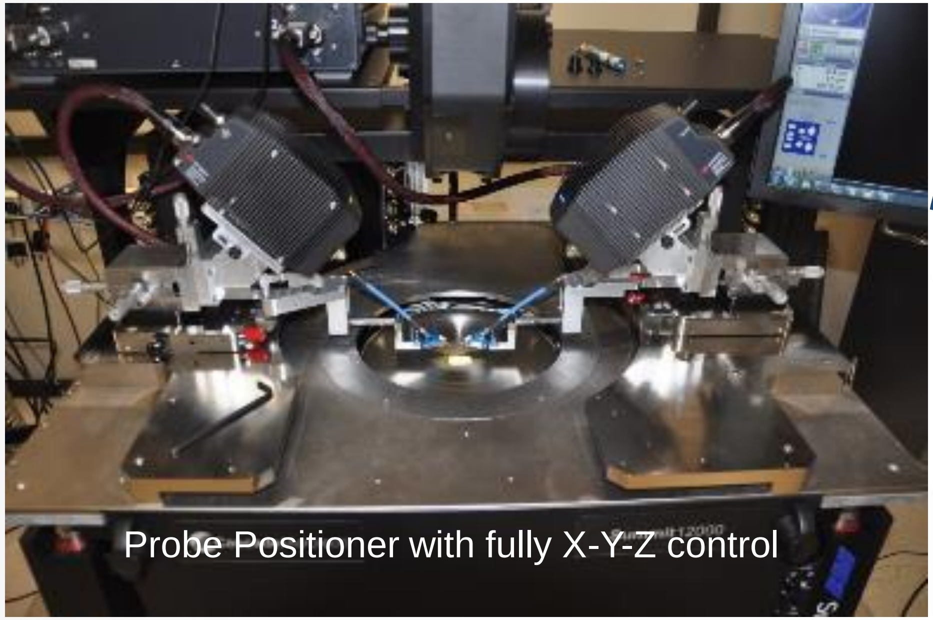
- Provide Kelvin bias at the DUT
- Limited ground loops.
- Low leakage typically less than 400 pA is desirable



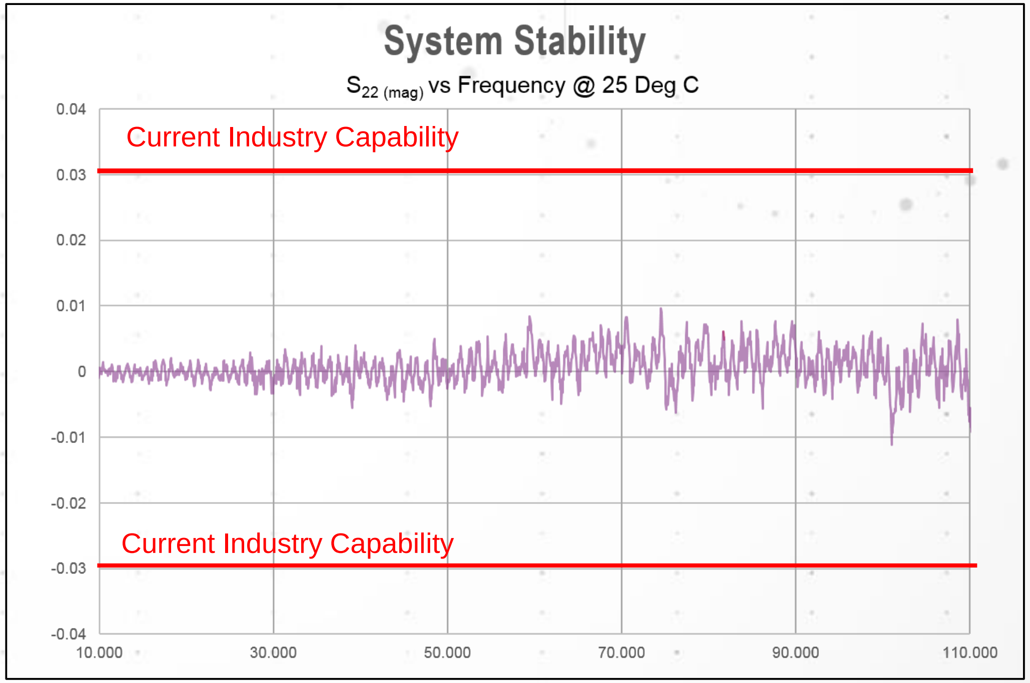


Challenges of Distributed Architectures

COMPACT PROBE STATION INTEGRATION VS THERMAL STABILITY



Trade off size versus stability



Millimeter Component Characterization

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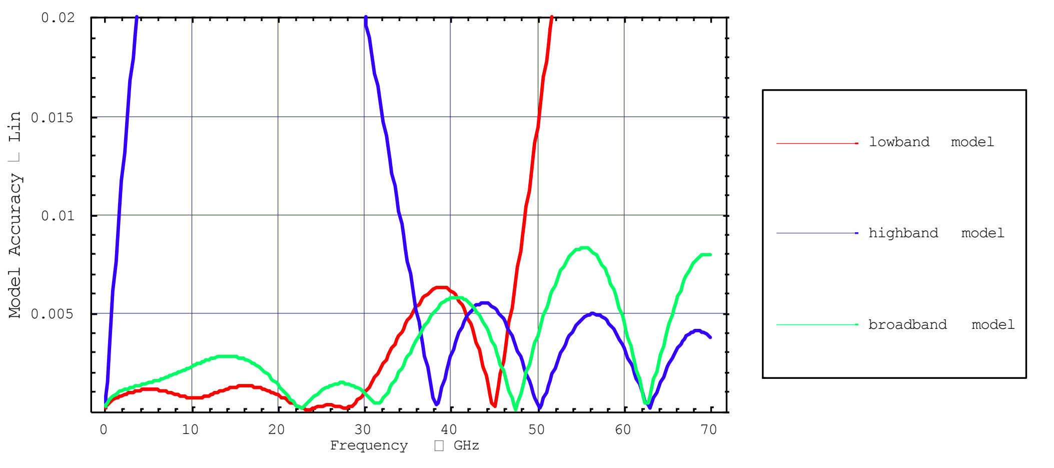
Broadband Millimeter Wave System Calibration

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



Broadband Millimeter Wave System Calibration

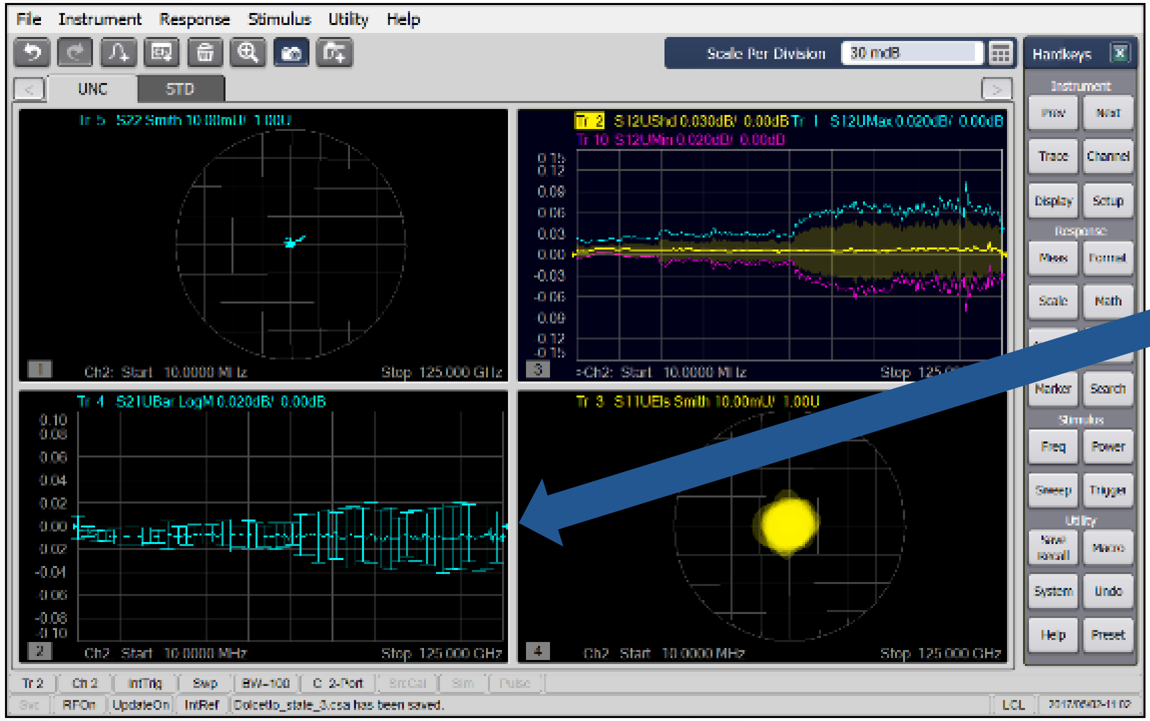
DATABASED OFFSET SHORT CALIBRATION

- Key features of a Millimeter Wave Coaxial calibration kits
  - Eliminates need for broadband load
  - Implementation of multiple shorts to cover frequency range
  - Devices are characterized using a database model
  - Method of calibration is enhanced least squares fit

Broadband 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

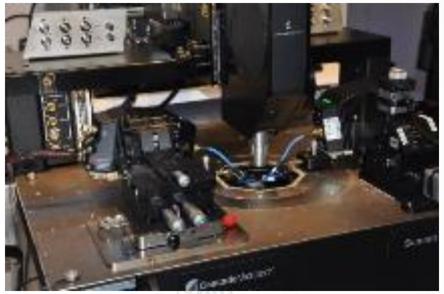


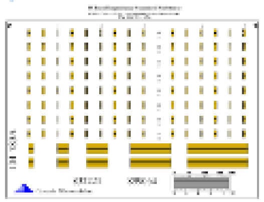
Keysight IEEE 287-2007 compliant 1.0 mm Connector

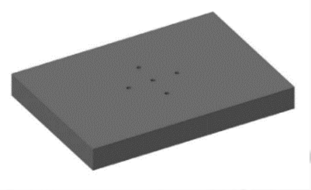
Broadband Millimeter Wave System Calibration

ON-WAFER CALIBRATION STANDARDS

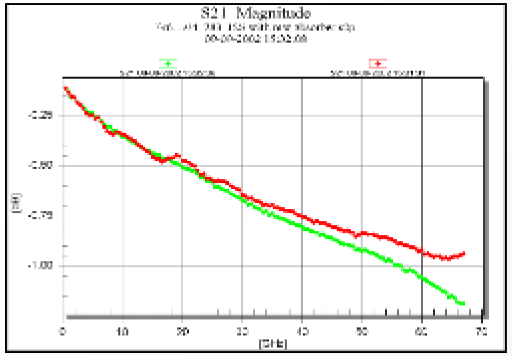
- Supported Calibration Methods
  - SOLT S**hort** O**pen** Load Thru
  - SOLR S**hort** O**pen** Load Reciprocal
  - LRM L**ine** R**eflect** Match
  - **LRRM Line Reflect Reflect Match**
  - TRL T**hru** R**eflect** L**ine**







- 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



Broadband Millimeter Wave Power Calibration

MILLIMETER WAVE RECEIVER POWER 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

1.0 mm DC-120 GHz Power Sensor

V & W Band Power Sensors

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Passive Device Characterization

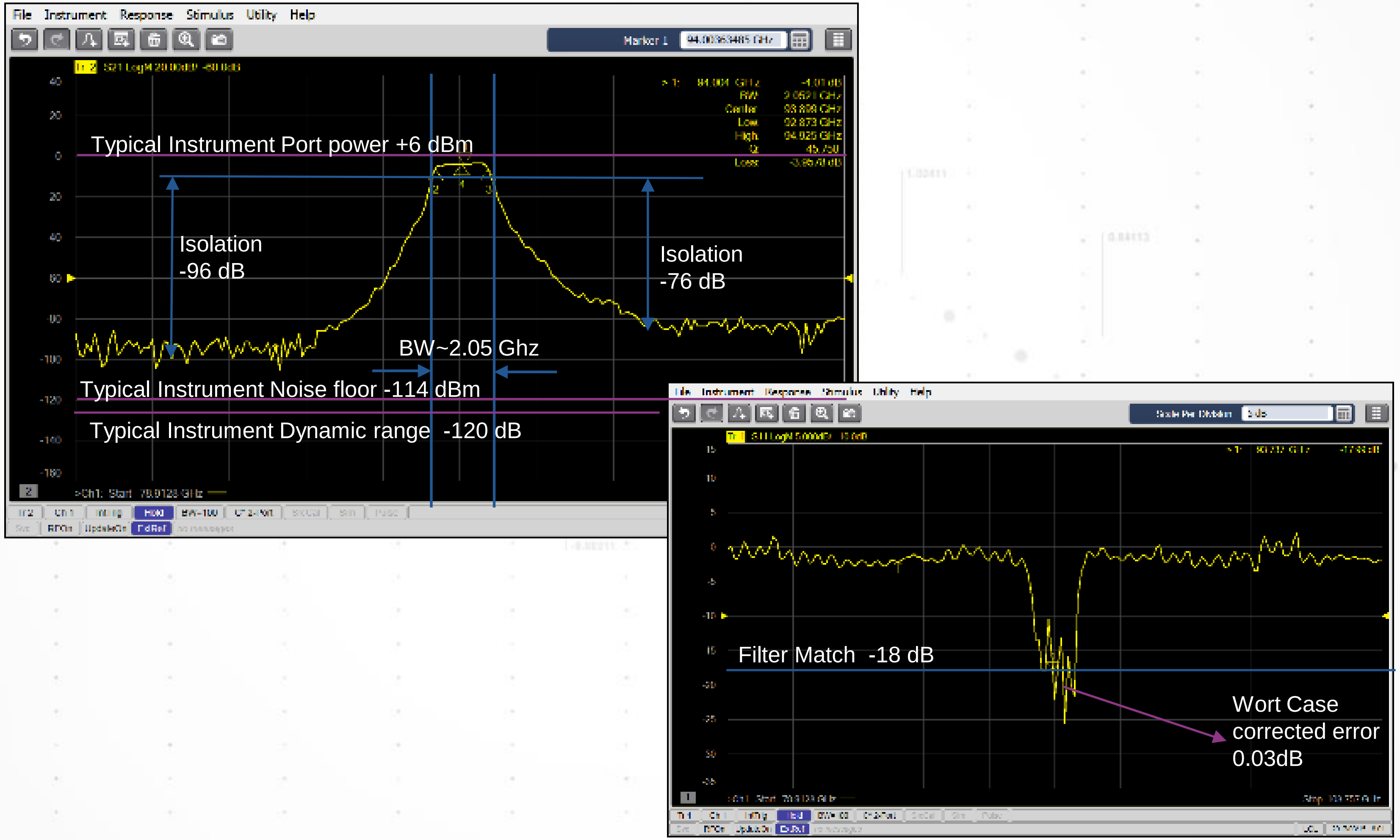
RECEIVER 93 GHZ BANDPASS FILTER CHARACTERISTICS

- Measurement System Capability
  - Accurate S-Parameter Calibration
  - Dynamic range
  - Noise floor / isolation
  - Trace noise

- Measurement Requirements
  - Filter Bandwidth
  - Filter rejection
  - Match in passband

Passive Device Characterization

93 GHZ BAND-PASS FILTER MEASUREMENT RESULTS



Passive Device Characterization

HIGH-PASS FILTER

Measurement Requirements

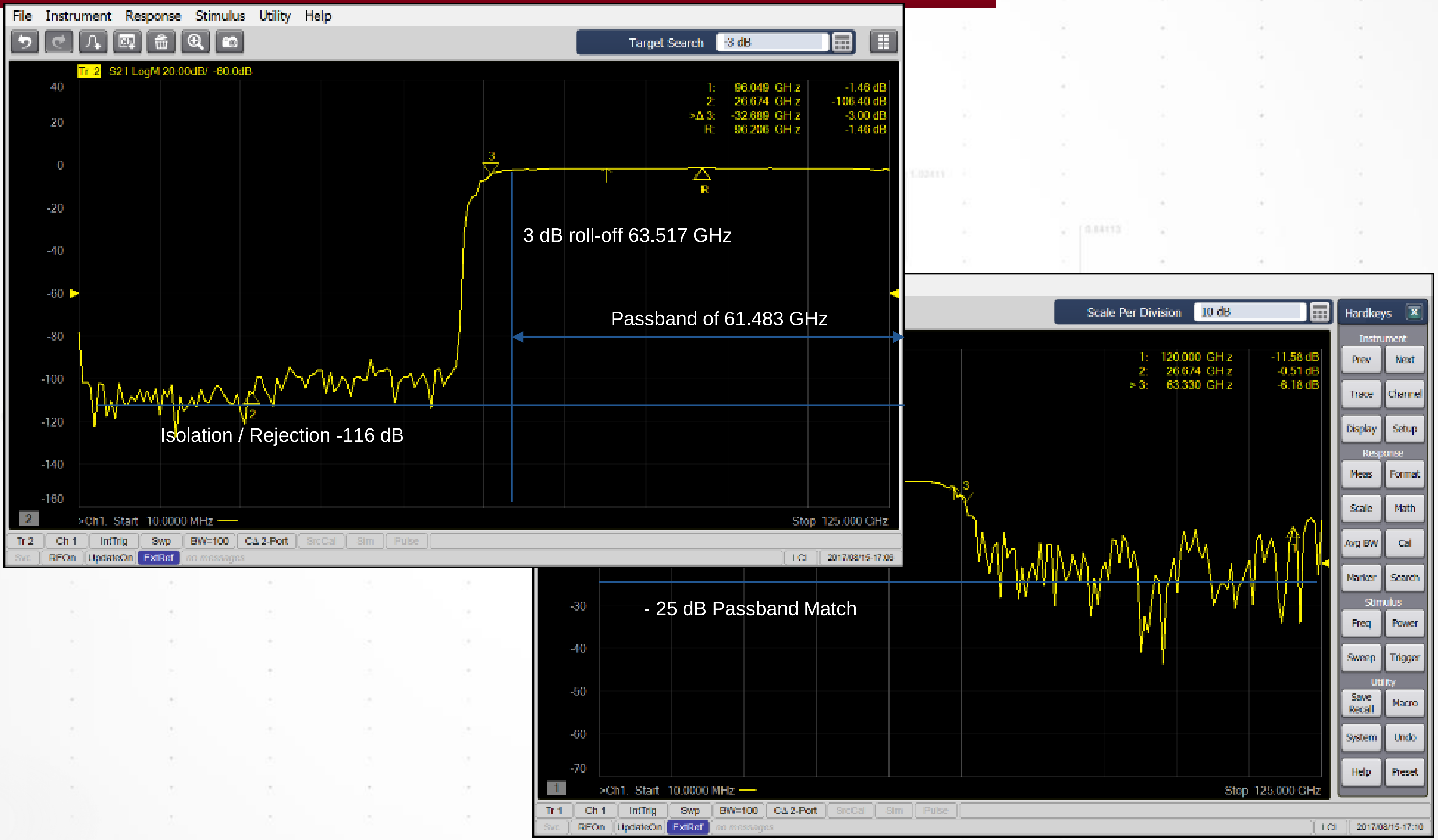
- Filter 3dB roll-off
- Low frequency rejection
- Match in Passband

Measurement System Capability

- Accurate S-Parameter Calibration
- Dynamic range
- Noise floor / isolation
- Trace noise

Passive Device Characterization

HIGH-PASS FILTER 3 DB BANDWIDTH



KEYSIGHT TECHNOLOGIES

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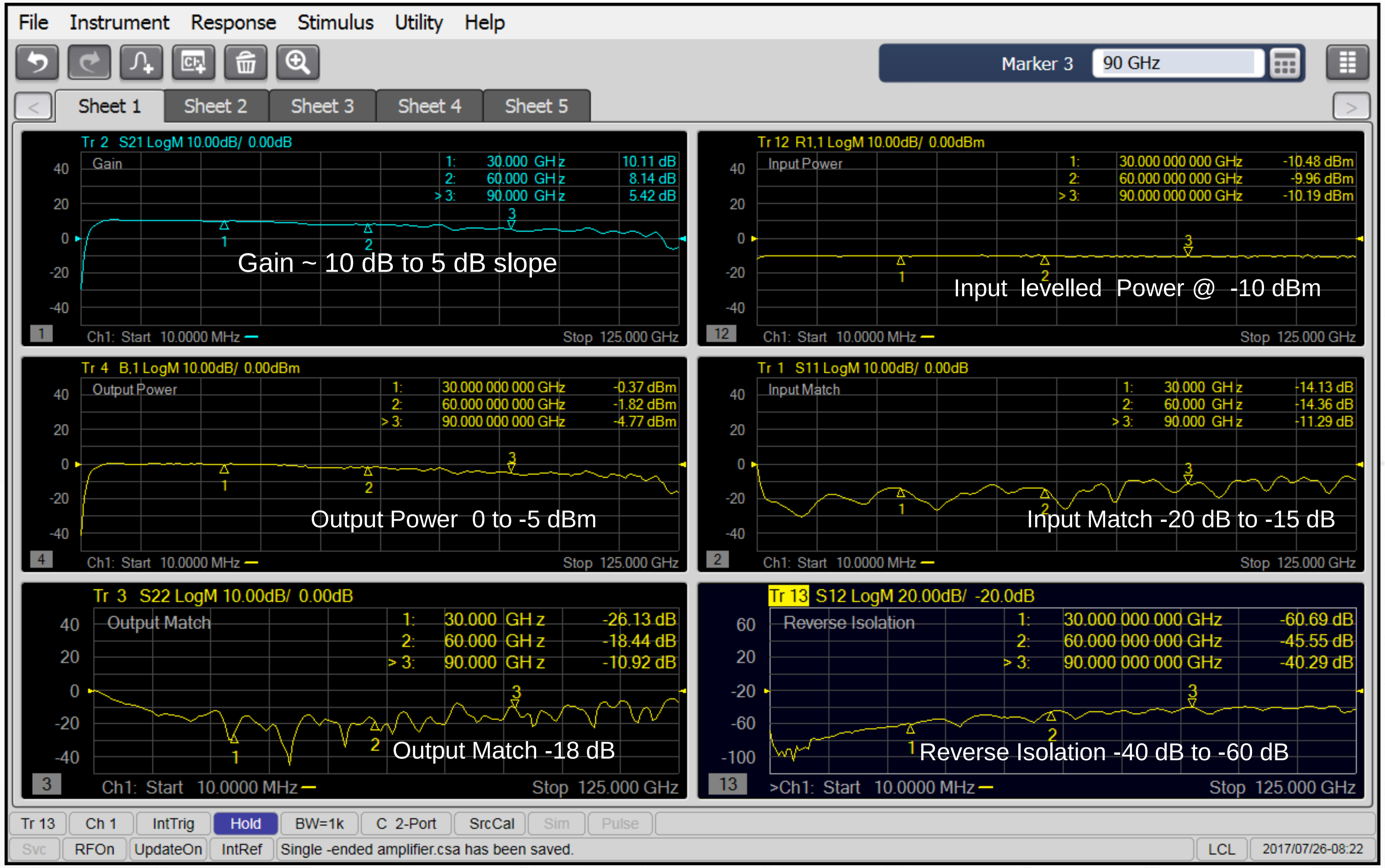
Millimeter Wave Amplifier Characterization

AMPLIFIER PERFORMANCE SPECIFICATIONS

- Input Match
- Gain
- Output Match
- Reverse Isolation
- Compression
- Total Harmonic distortion
- Low Frequency performance

Millimeter Wave Amplifier Characterization

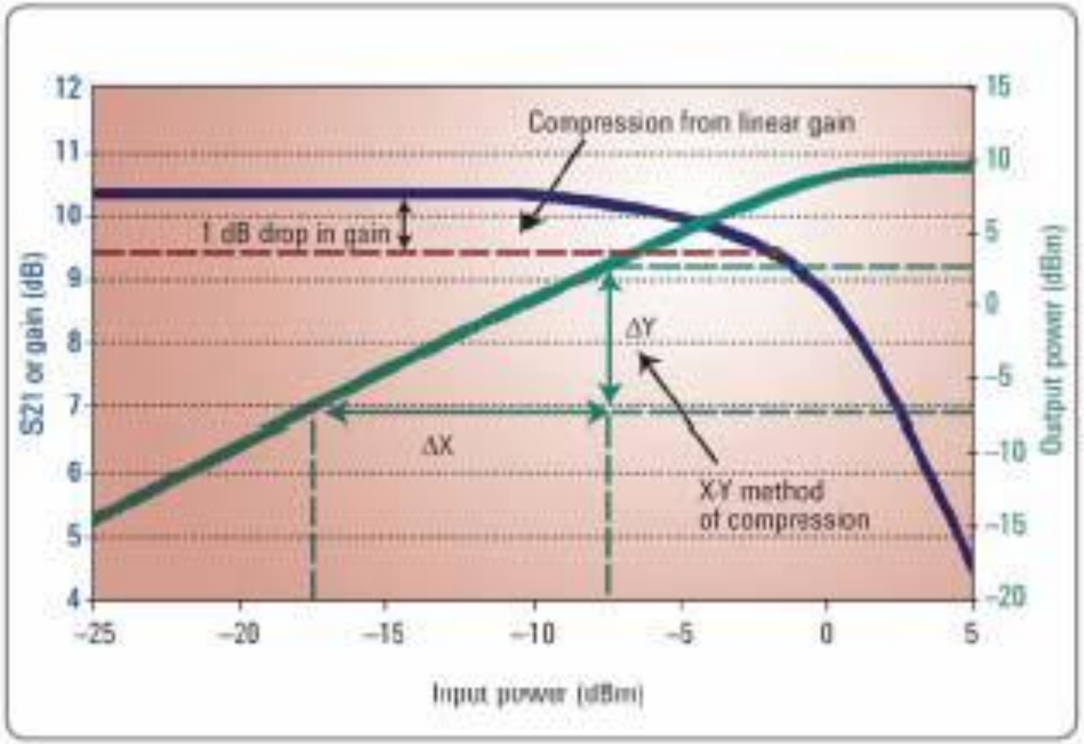
AMPLIFIER LINEAR PERFORMANCE SPECIFICATIONS



Millimeter Wave Amplifier Characterization

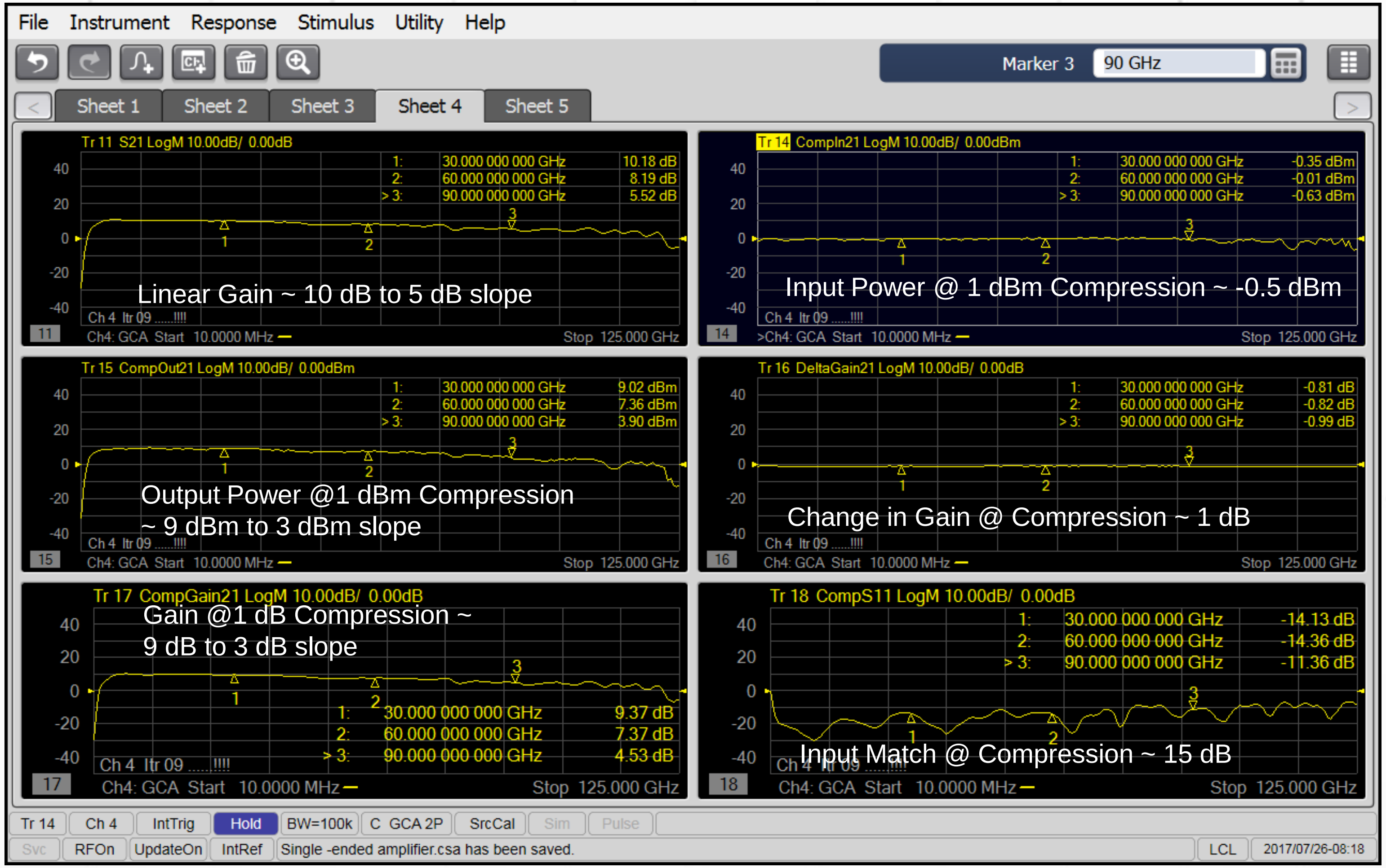
AMPLIFIER 1DB COMPRESSION PERFORMANCE

- Requires accurate characterization of Power
- Accurate measurement of the Power
- Source power sweep vs Frequency



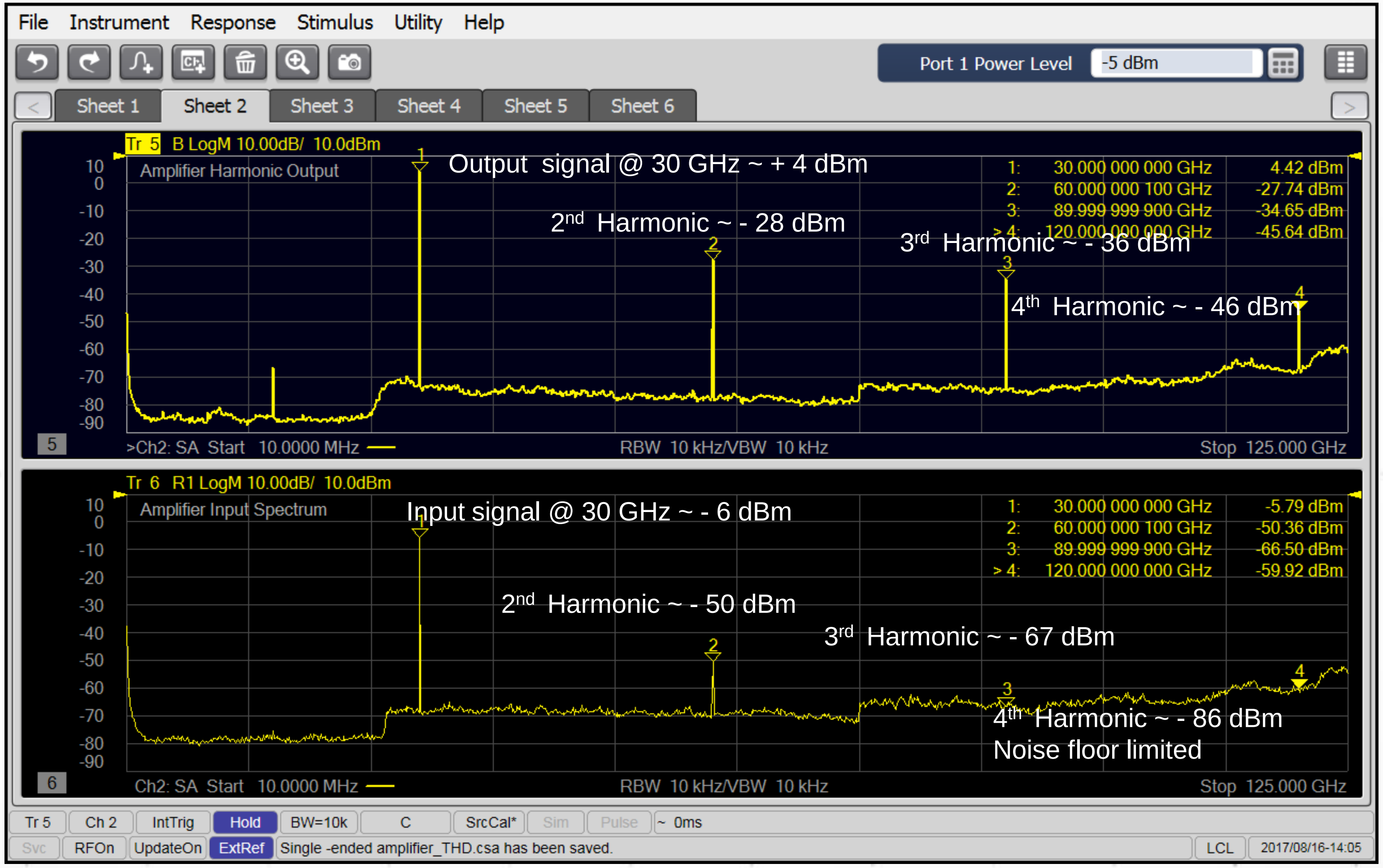
Millimeter Wave Amplifier Characterization

AMPLIFIER 1DB COMPRESSION PERFORMANCE



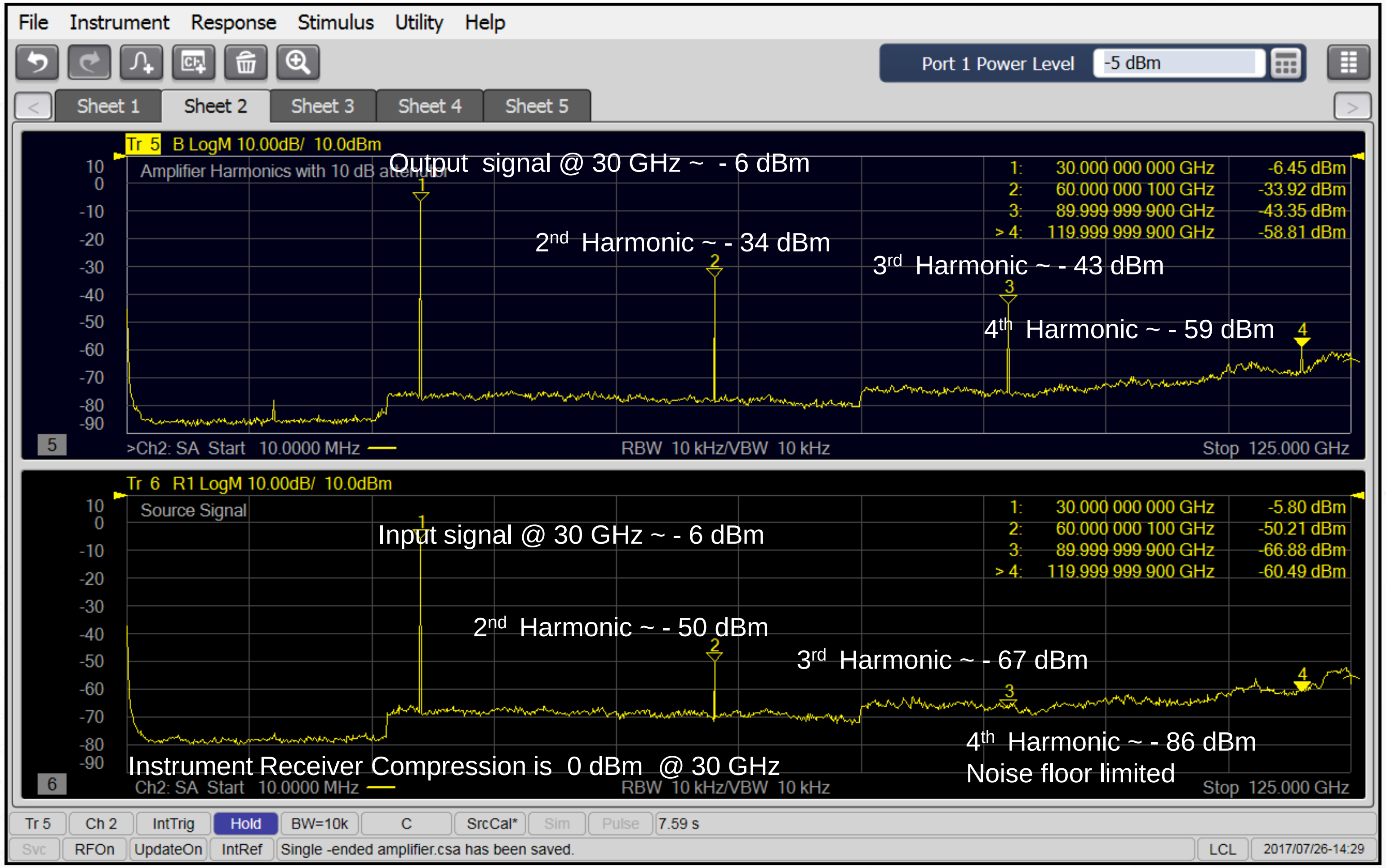
Millimeter Wave Amplifier Characterization

AMPLIFIER HARMONIC CHARACTERISTICS



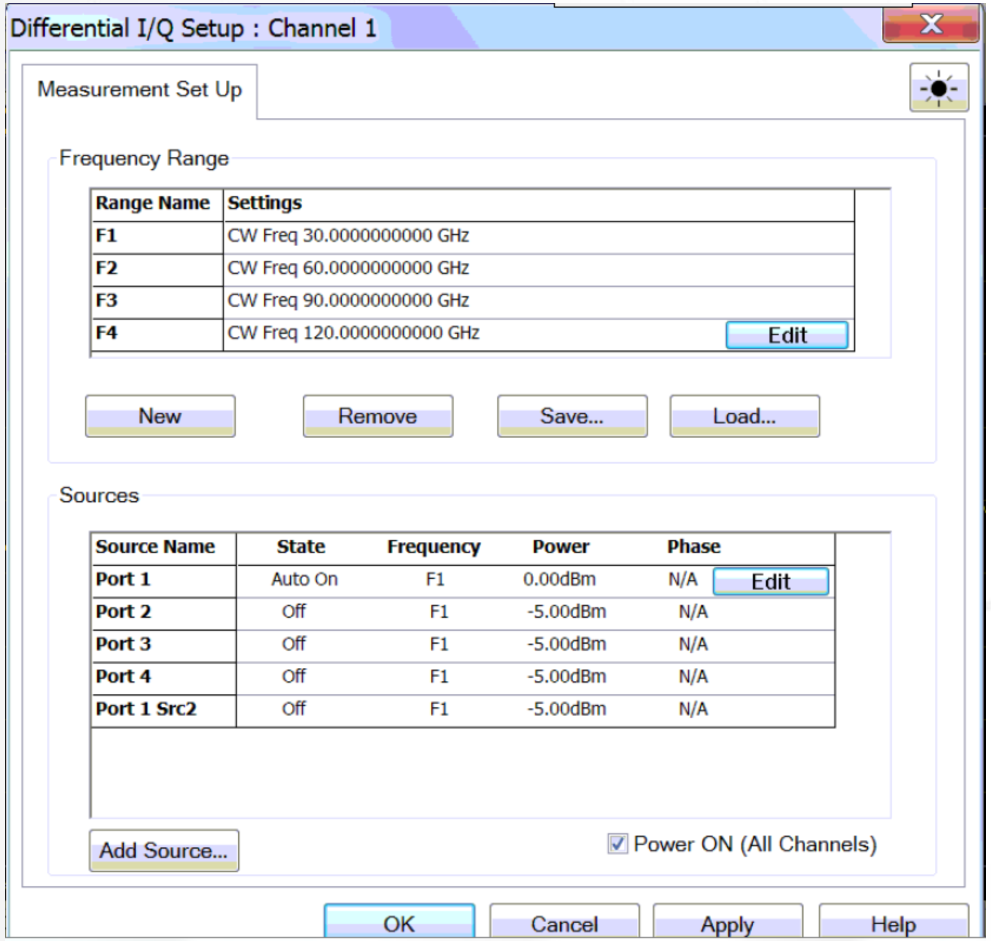
Millimeter Wave Amplifier Characterization

VERIFYING HARMONIC CHARACTERISTICS ADD 10 DB ATTENUATION



Millimeter Wave Amplifier Characterization

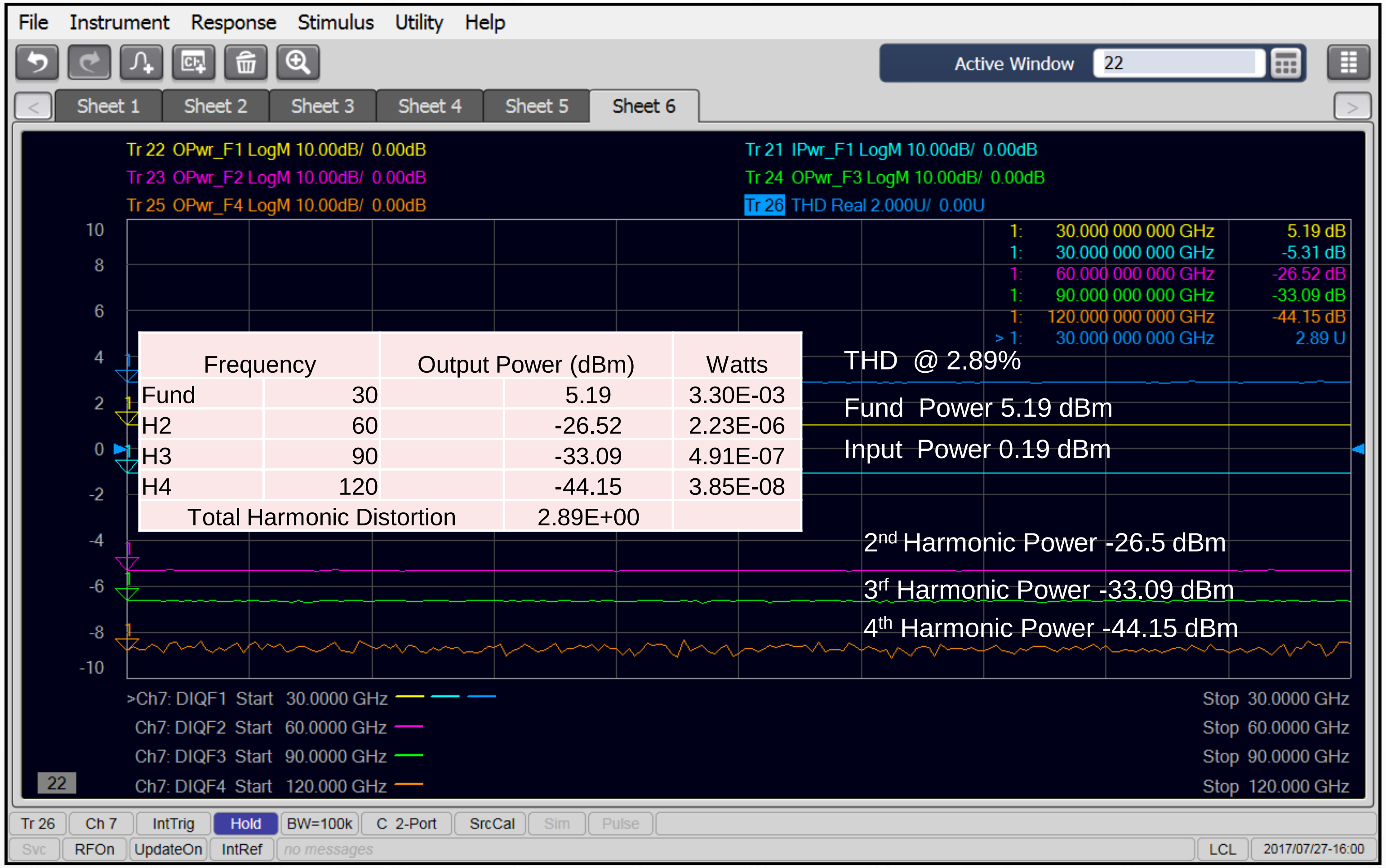
A UNIQUE APPLICATION FOR TOTAL HARMONIC DISTORTION MEASUREMENT



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

Millimeter Wave Amplifier Characterization

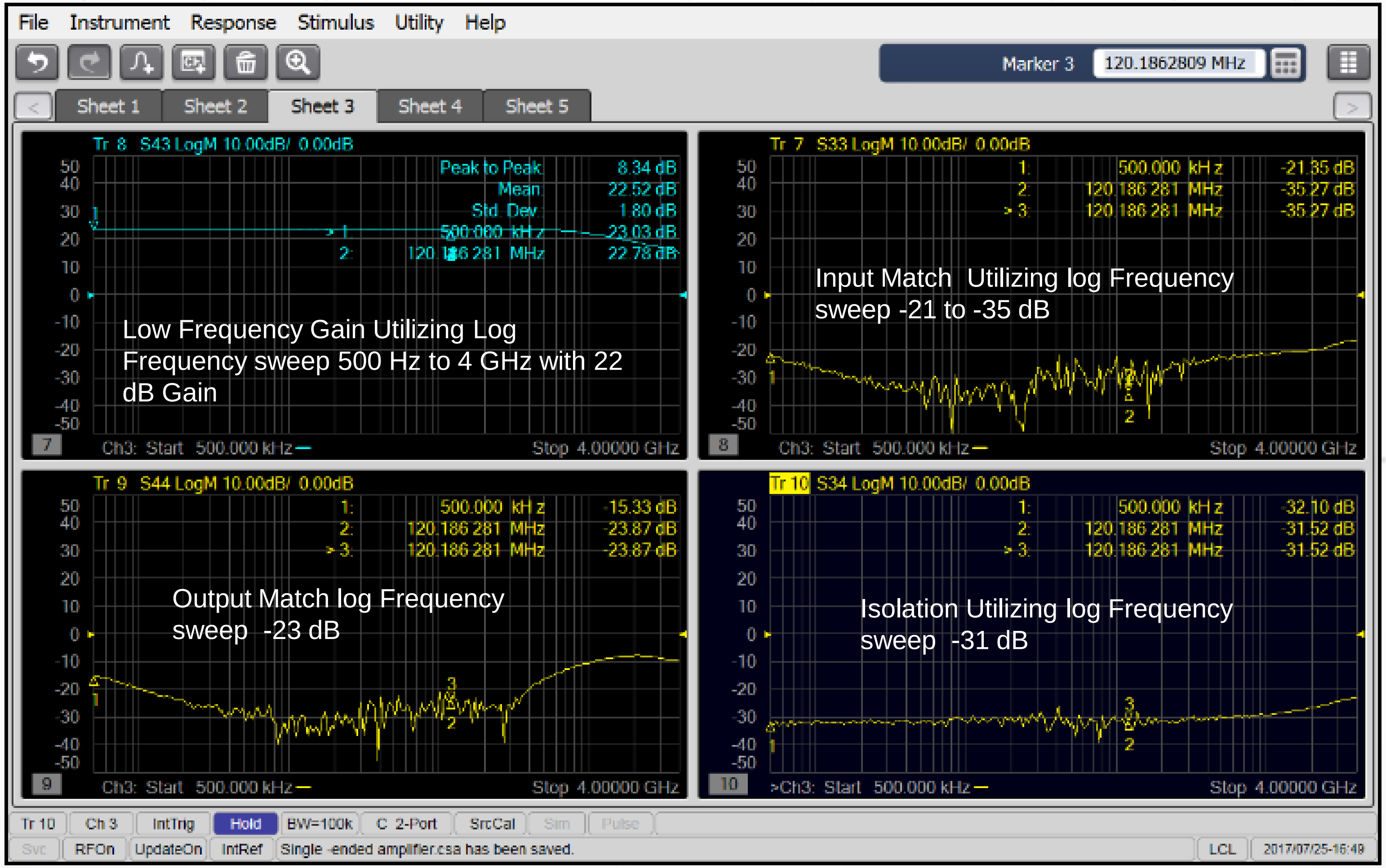
POWER AMPLIFIER TOTAL HARMONIC DISTORTION



KEYSIGHT TECHNOLOGIES

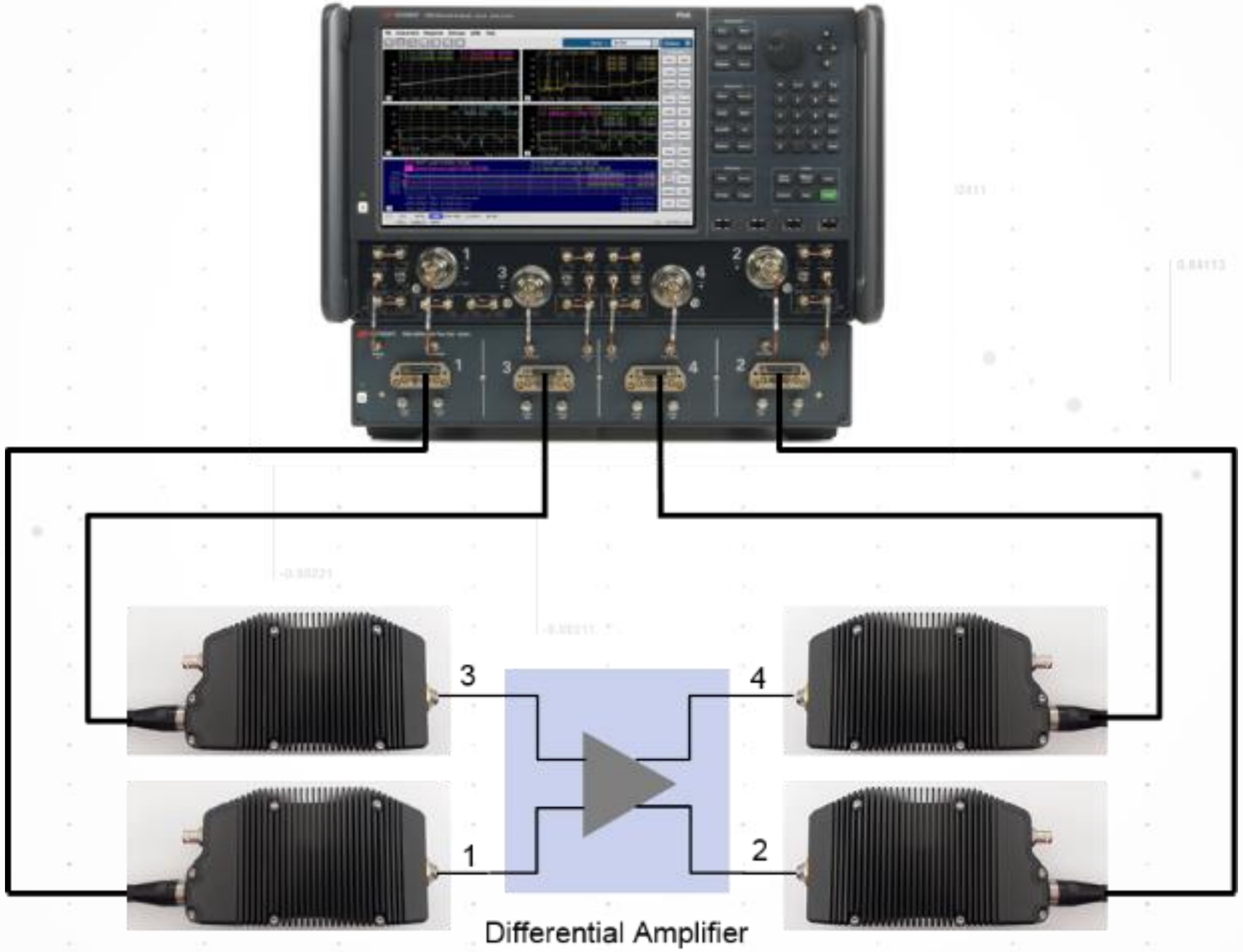
Millimeter Wave Amplifier Characterization

LOW FREQUENCY PERFORMANCE CHARACTERIZATION



Millimeter Wave Amplifier Characterization

DIFFERENTIAL AMPLIFIER CHARACTERIZATION



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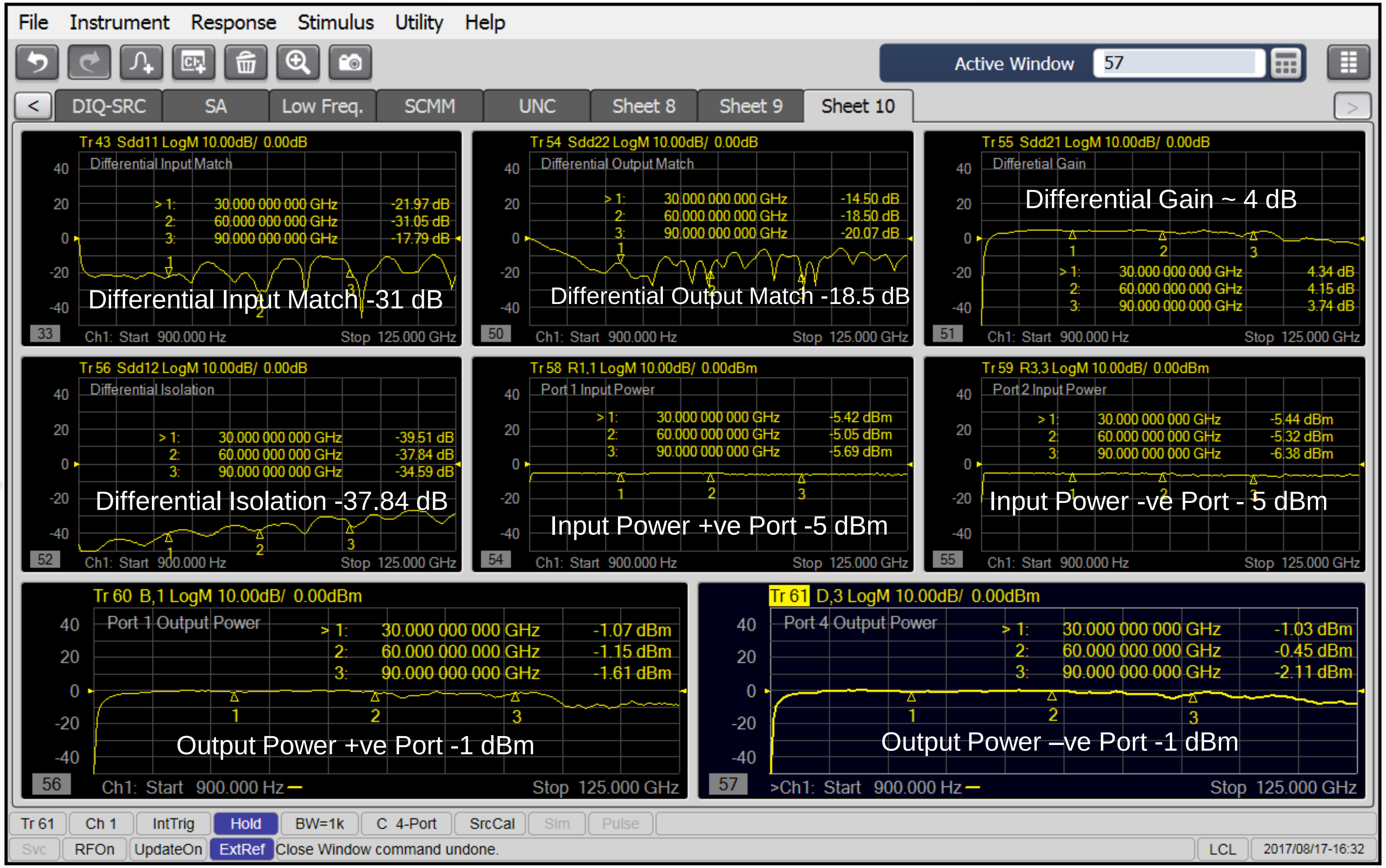

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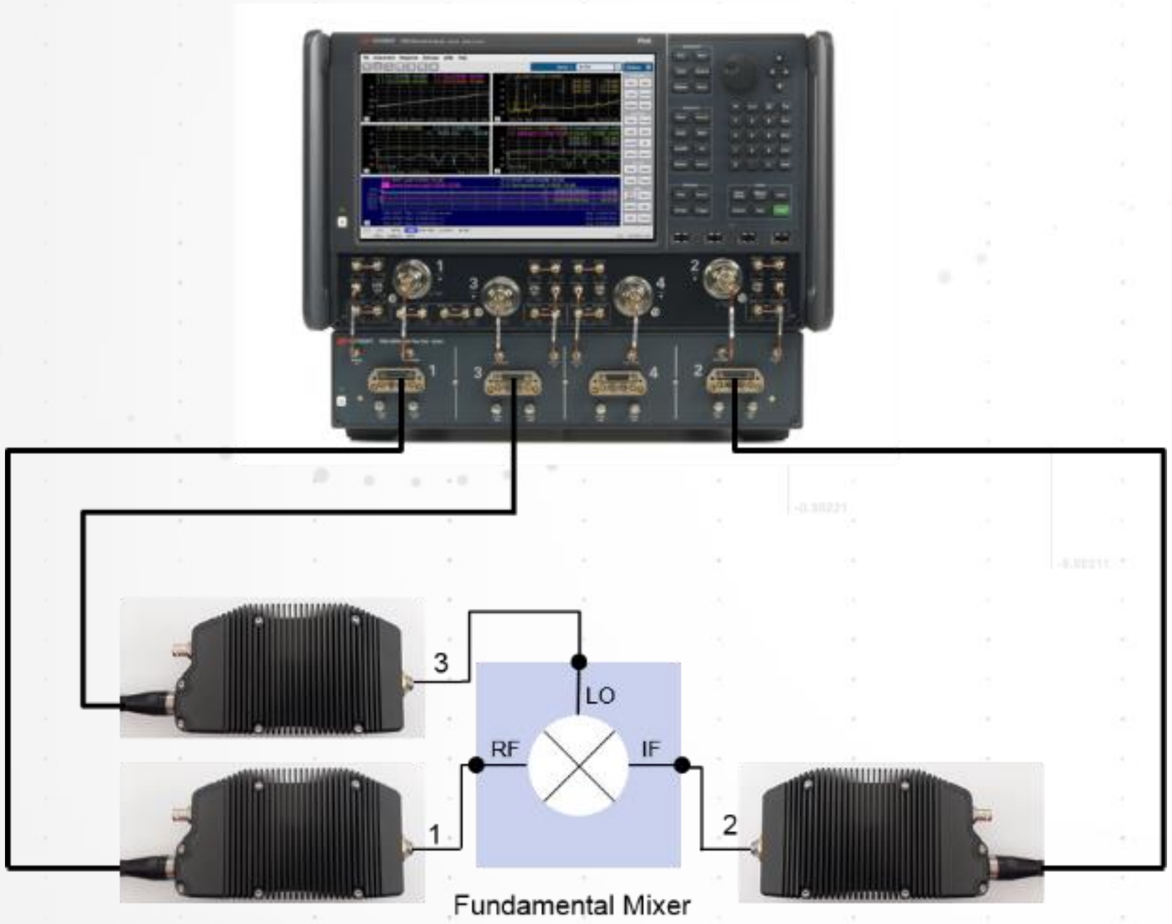
Millimeter Receiver Characterization

E-BAND RECEIVER CHARACTERIZATION

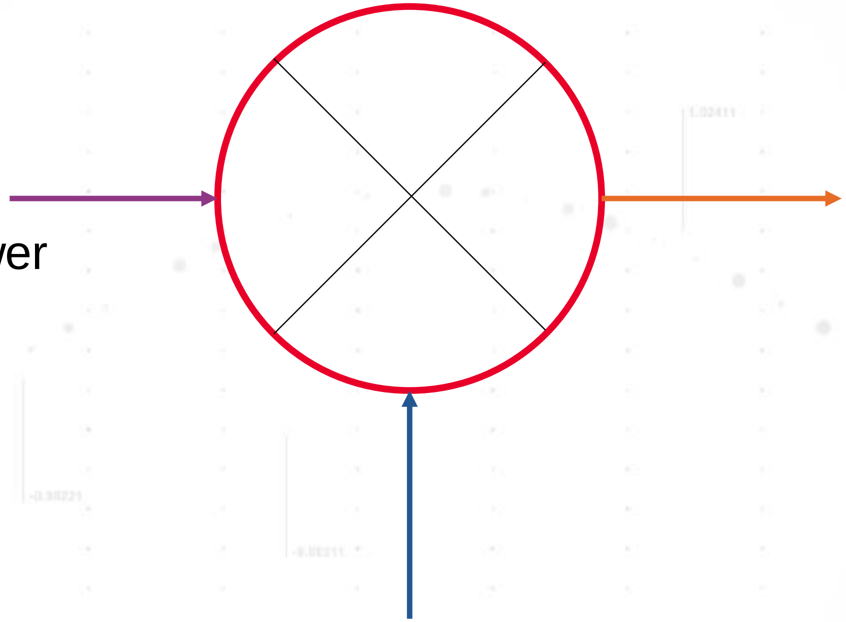


- Receiver Gain and Match
- Receiver Gain Compression
- Receiver IF Bandwidth Performance
- Receiver LO Harmonics

E-Band Receiver Characterization

RECEIVER GAIN AND MATCH PERFORMANCE

RF Input Frequency:
60 GHz to 90 GHz
-20 dBm Received Power



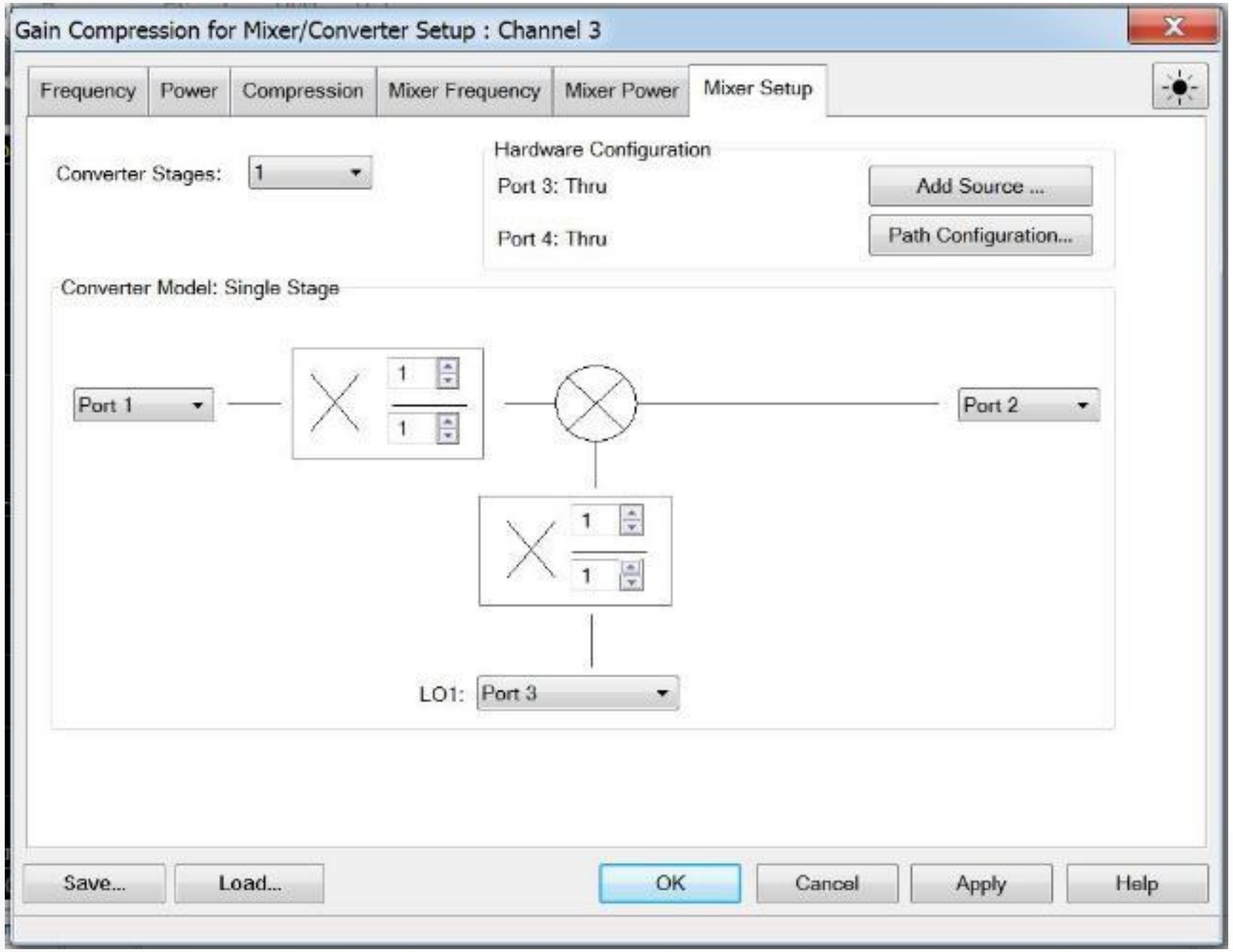
2 GHz Base Band Frequencies

LO Input Frequencies

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

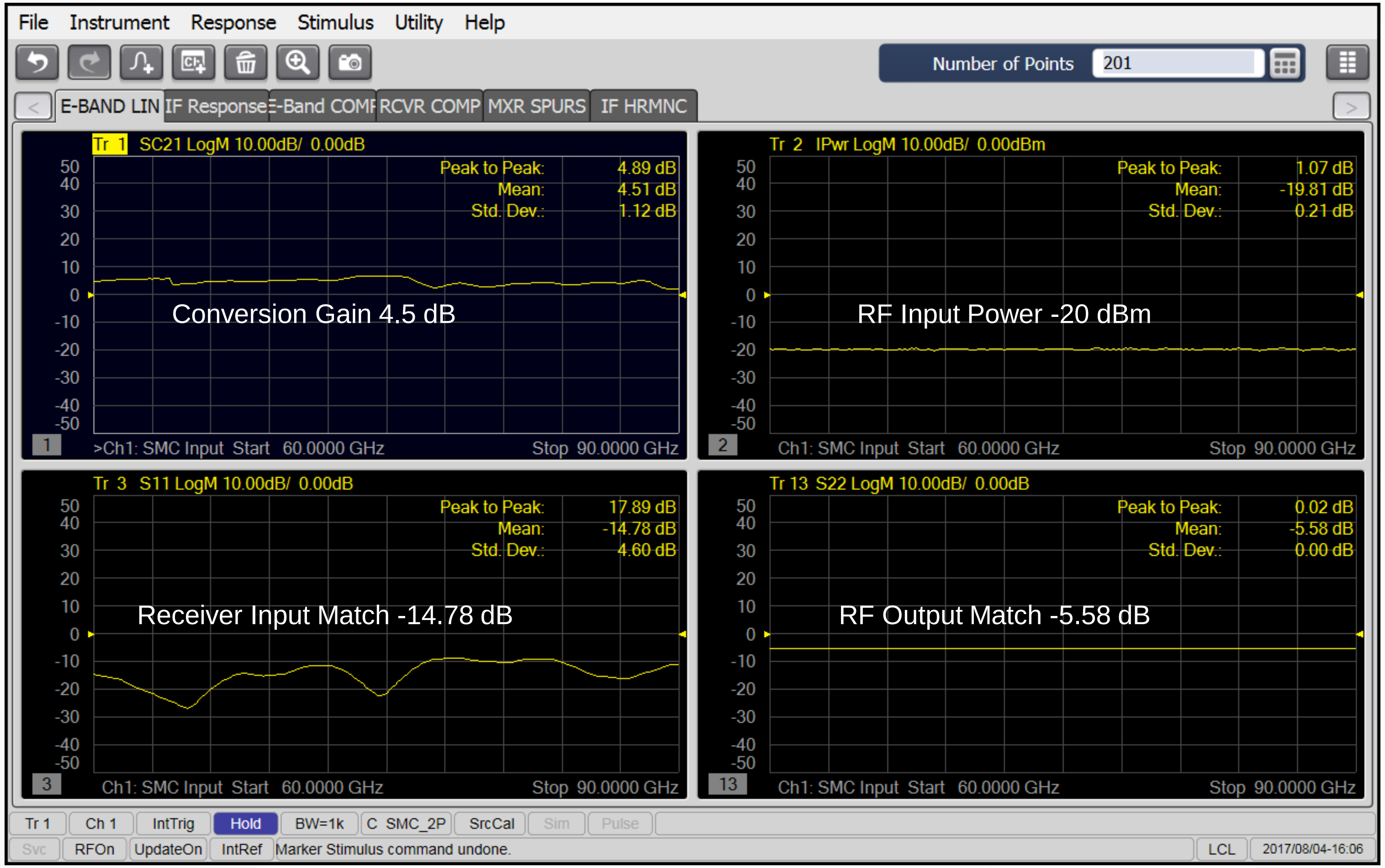
E-Band Receiver Characterization

RECEIVER GAIN AND MATCH PERFORMANCE



E-Band Receiver Characterization

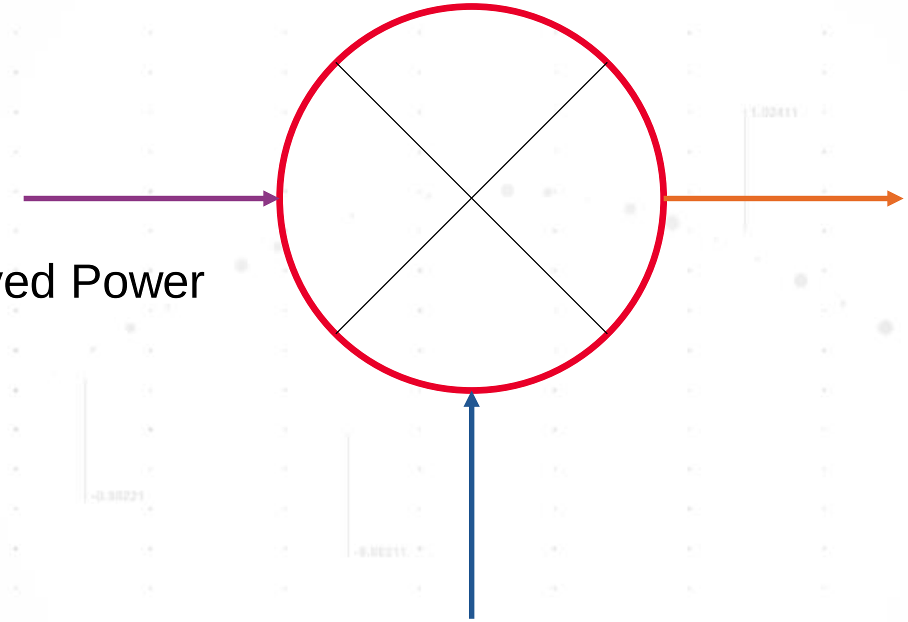
RECEIVER GAIN AND MATCH PERFORMANCE



E-Band Receiver Characterization

RECEIVER GAIN COMPRESSION

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



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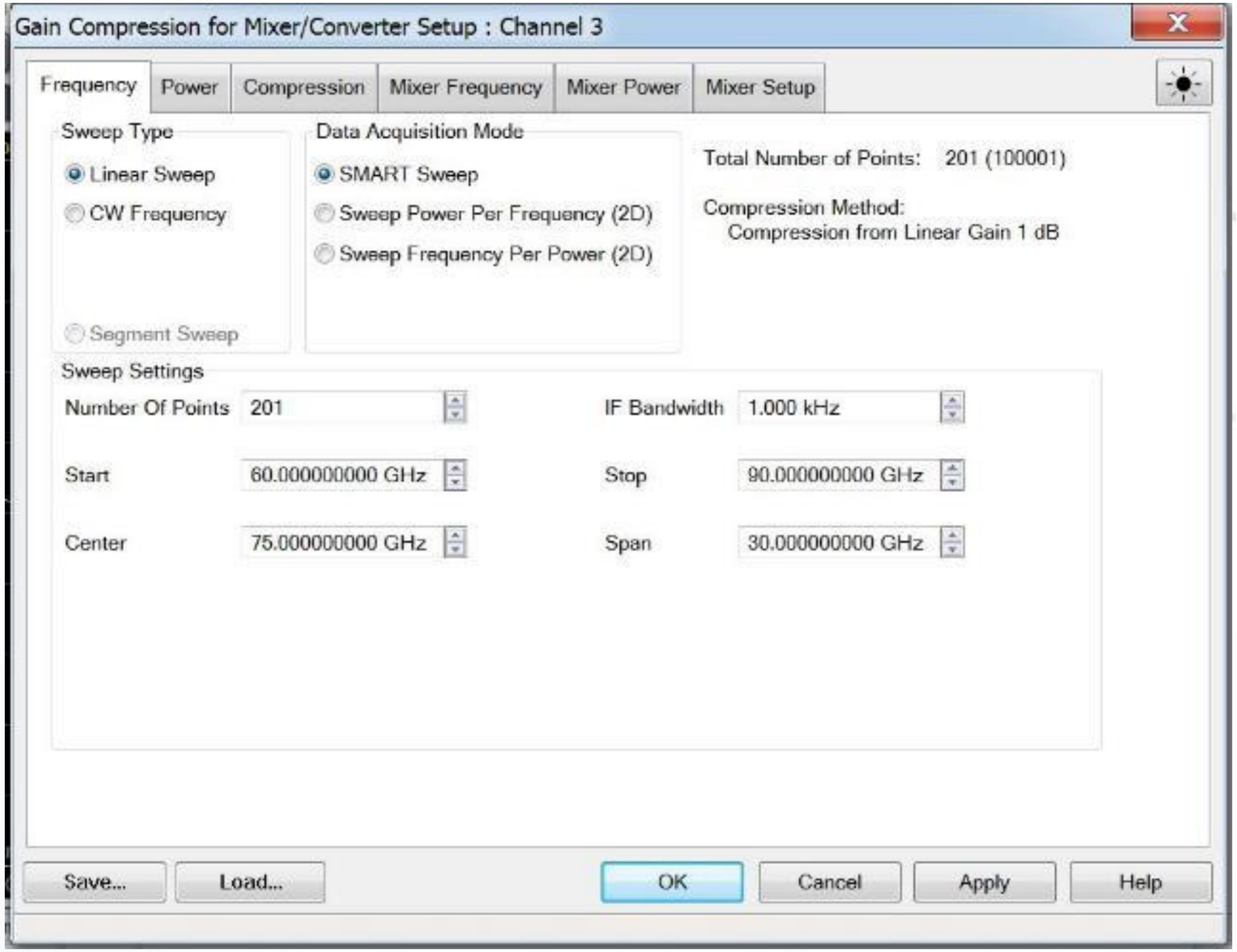
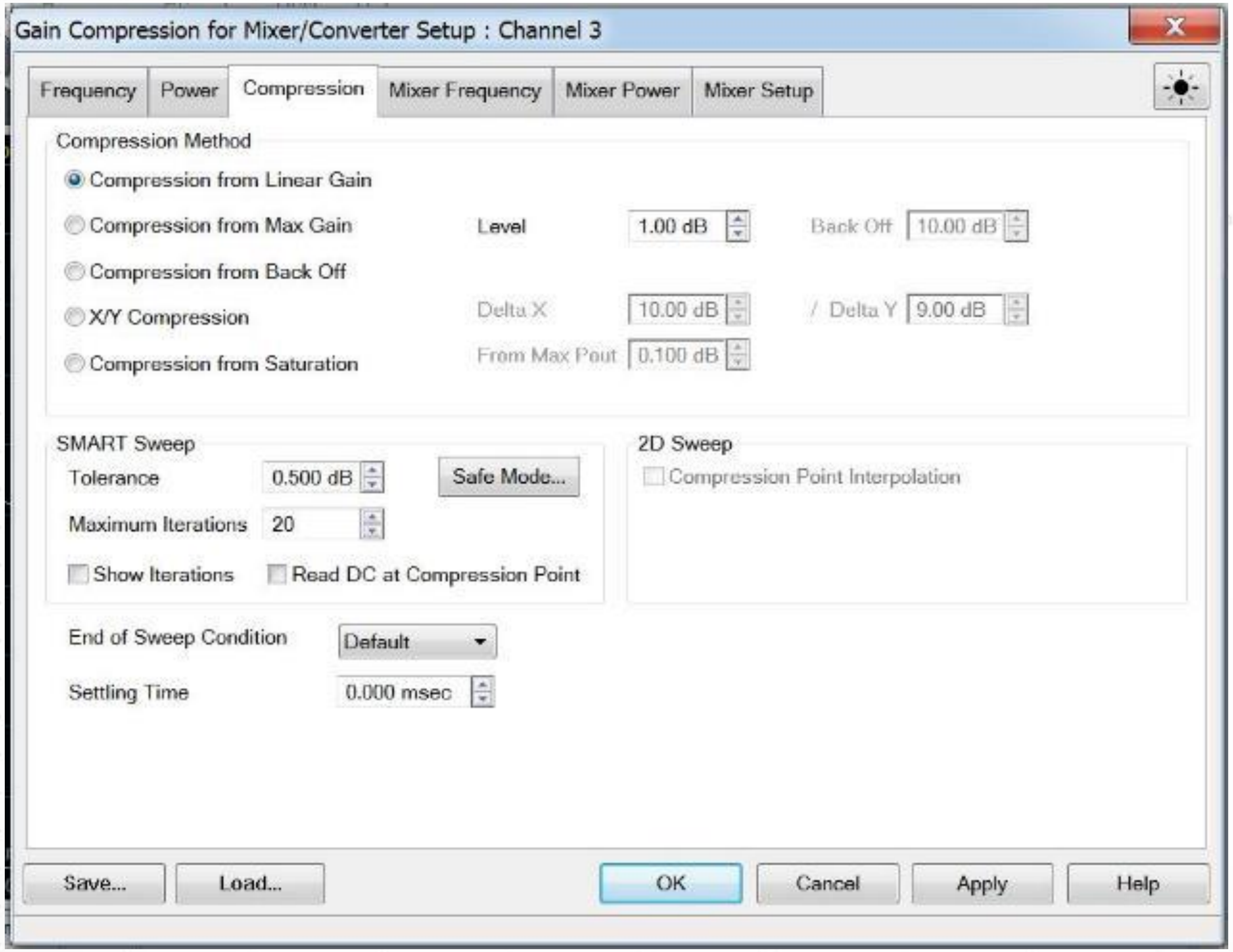
E-Band Receiver Characterization

RECEIVER GAIN COMPRESSION



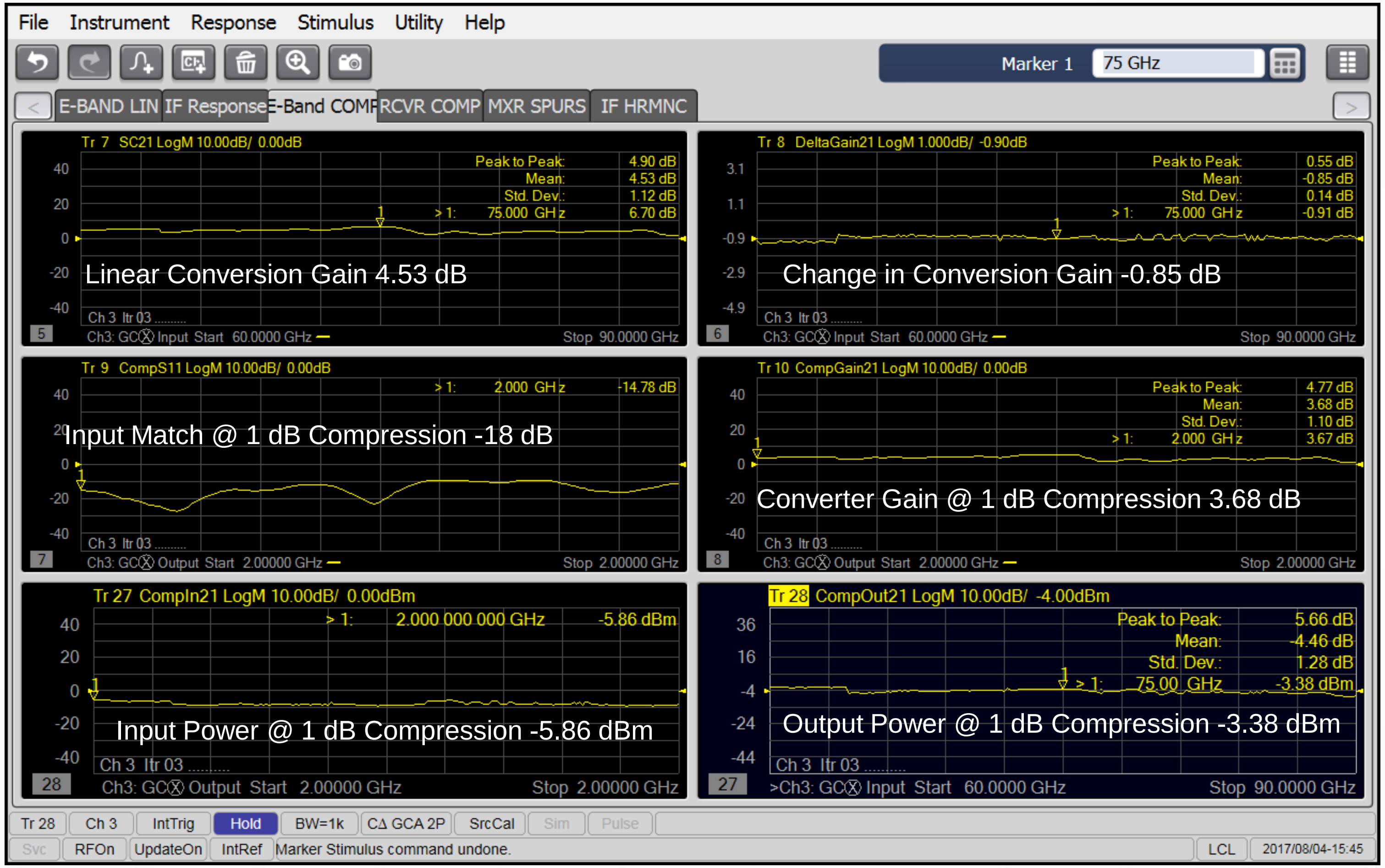
E-Band Receiver Characterization

RECEIVER GAIN COMPRESSION



E-Band Receiver Characterization

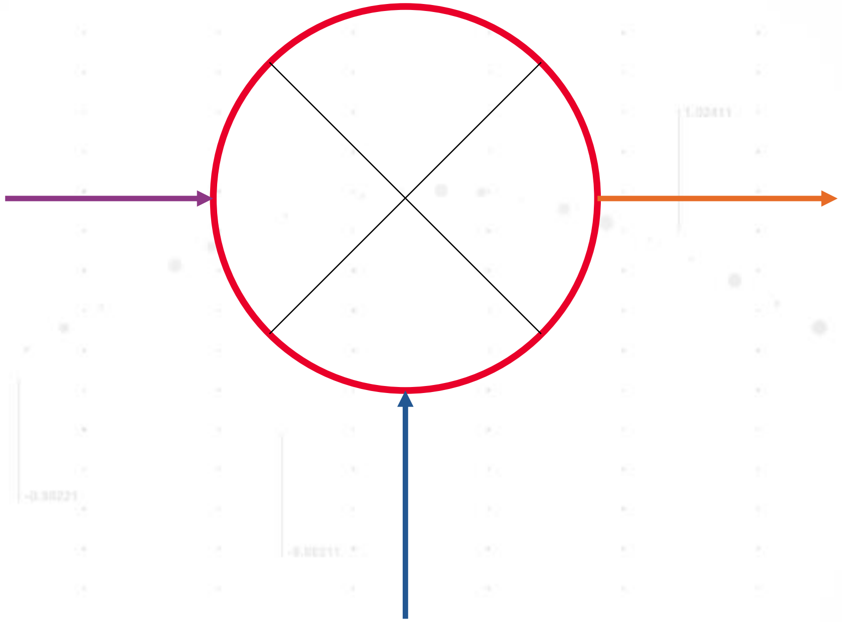
RECEIVER GAIN COMPRESSION



E-Band Receiver Characterization

RECEIVER IF BANDWIDTH PERFORMANCE

RF Input Frequency:
Fixed 77 GHz
-20 dBm Received
Power

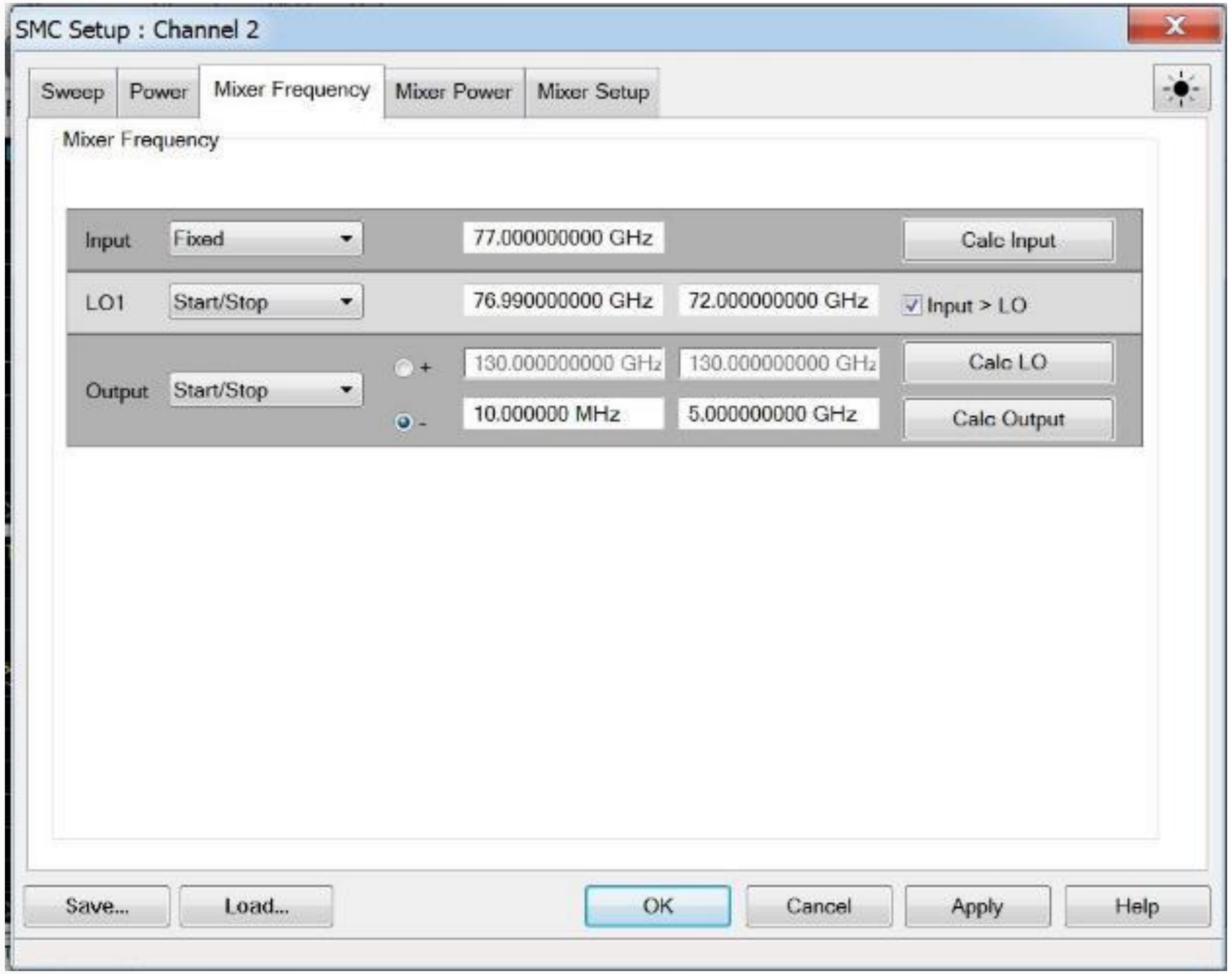


10 MHz – 5 GHz Base Band
Frequency

LO Input Frequencies
Swept 76.99 - 72 GHz
Power -10 dBm LO Power

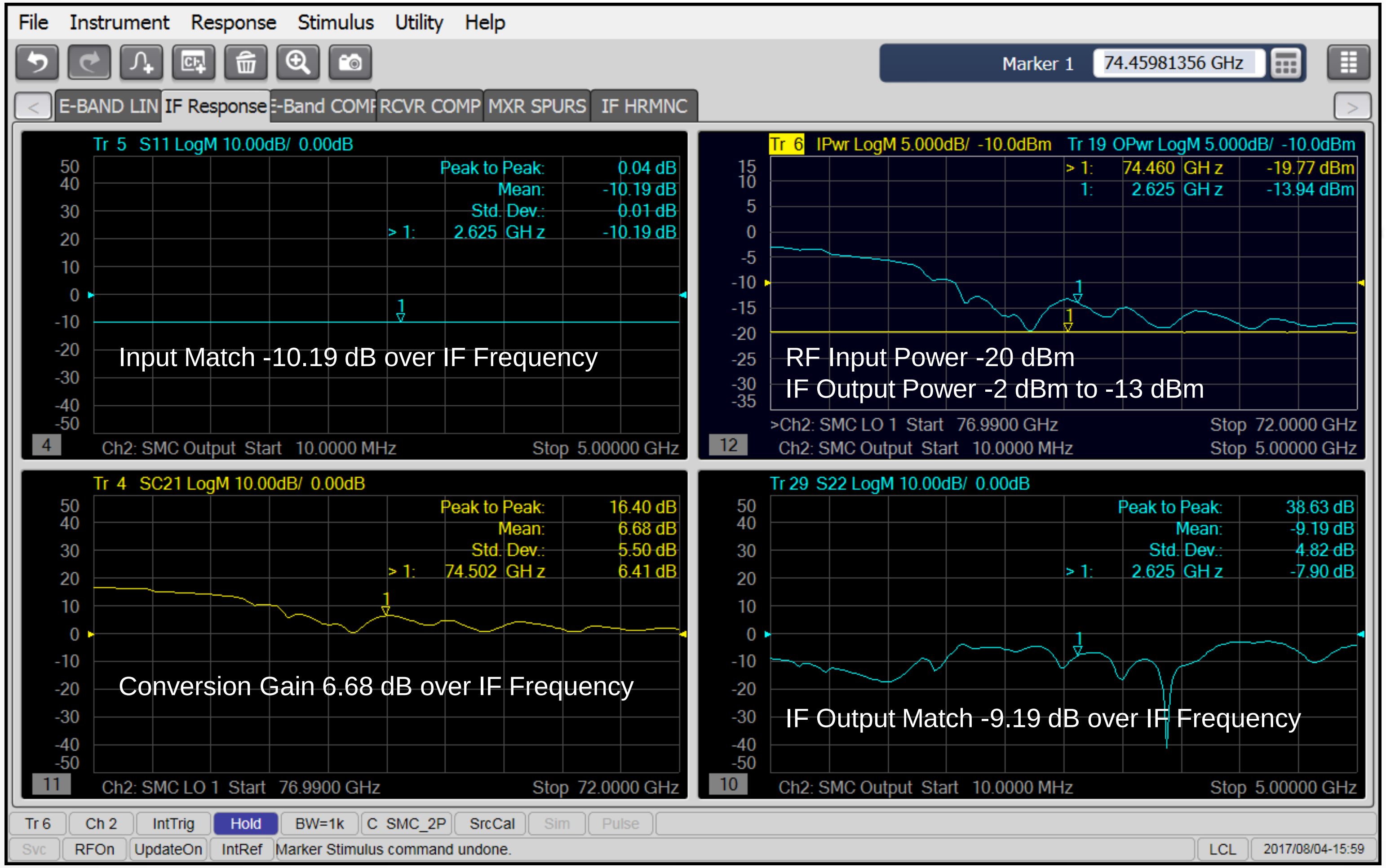
E-Band Receiver Characterization

RECEIVER IF BANDWIDTH PERFORMANCE



E-Band Receiver Characterization

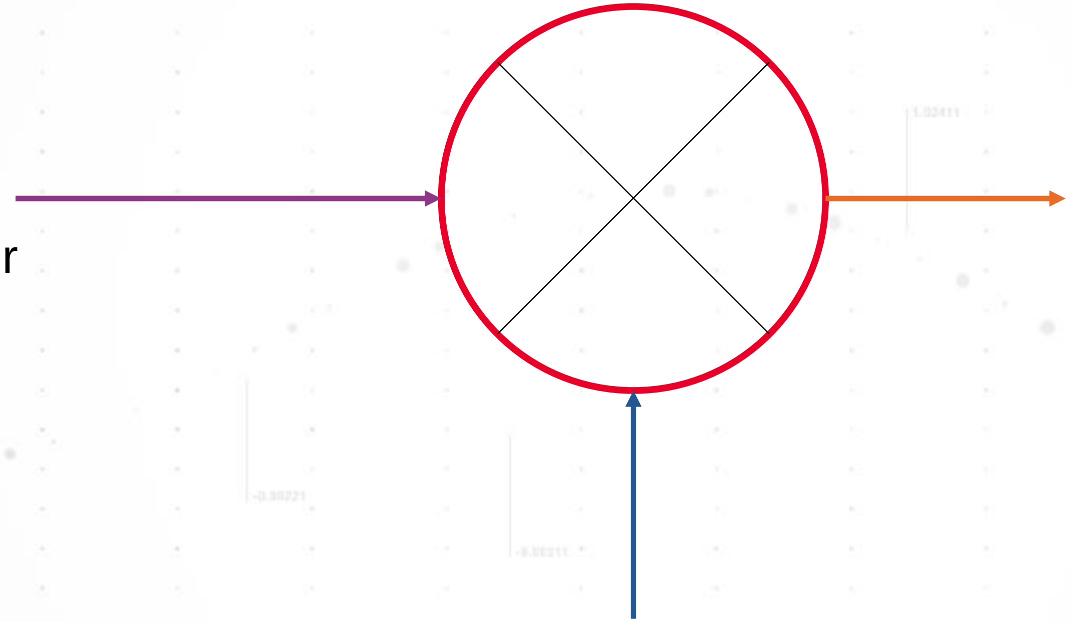
RECEIVER IF BANDWIDTH PERFORMANCE



Receiver Harmonic Characterization

RECEIVER LO HARMONICS IMPACT

RF Input Frequency (F1)
71 GHz to 76 GHz
-20 dBm Received Power



Base Band Frequencies

- 1 GHz Fundamental (F2)
- 2 GHz (F3)
- 3 GHz (F4)

LO Input Frequencies

- 70 - 75 GHz Fundamental (F5)
- 69 - 74 GHz (F6)
- 68 - 73GHz (F7)
- -10 dBm LO Power

Receiver Harmonic Characterization

RECEIVER HARMONIC – VNA FREQUENCY CONFIGURATION

RF & IF Input/ Measurement Frequencies

Differential I/Q Setup : Channel 5

Measurement Set Up

Frequency Range

Range Name	Settings
F1	71.0000000000 GHz - 76.0000000000 GHz
F2	CW Freq 1.0000000000 GHz
F3	CW Freq 2.0000000000 GHz
F4	CW Freq 3.0000000000 GHz

New Remove Save... Load...

Sources

Source Name	State	Frequency	Power	Phase
Port 1	Auto On	F1	-20.00dBm	N/A
Port 2	Off+Match	F2	-5.00dBm	N/A
Port 3	Always On	F5	-10.00dBm	N/A
Port 4	Off	F1	-5.00dBm	N/A
Port 1 Src2	Off	F1	-5.00dBm	N/A

Add Source... ☑ Power ON (All Channels)

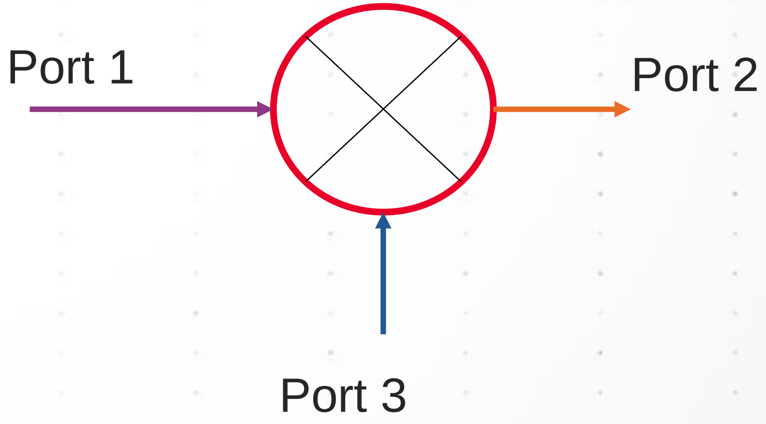
OK Cancel Apply Help

LO Input Frequencies

Frequency Range

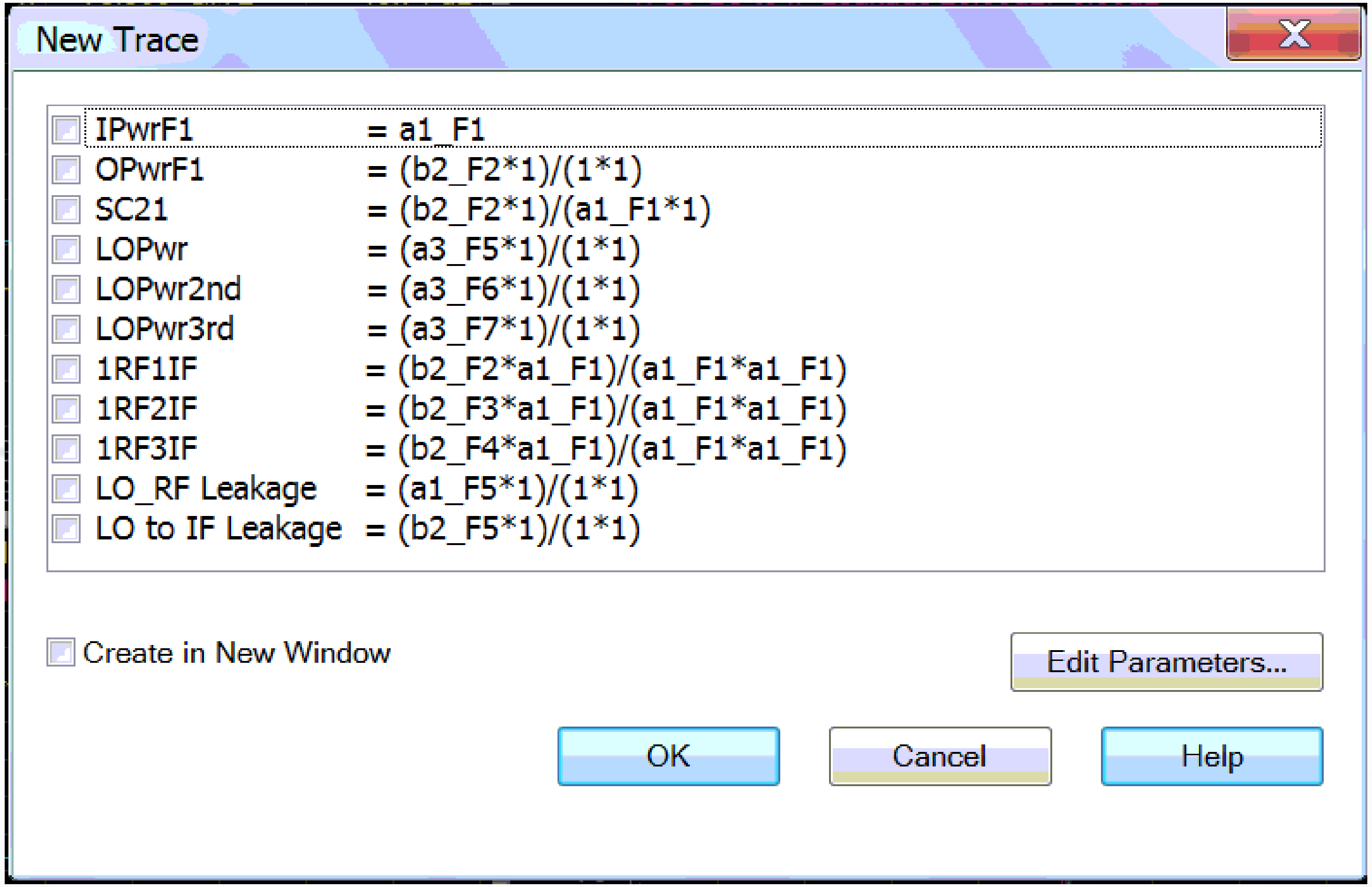
Range Name	Settings
F4	CW Freq 3.0000000000 GHz
F5	70.0000000000 GHz - 75.0000000000 GHz
F6	69.0000000000 GHz - 74.0000000000 GHz
F7	68.0000000000 GHz - 73.0000000000 GHz

New Remove Save... Load...



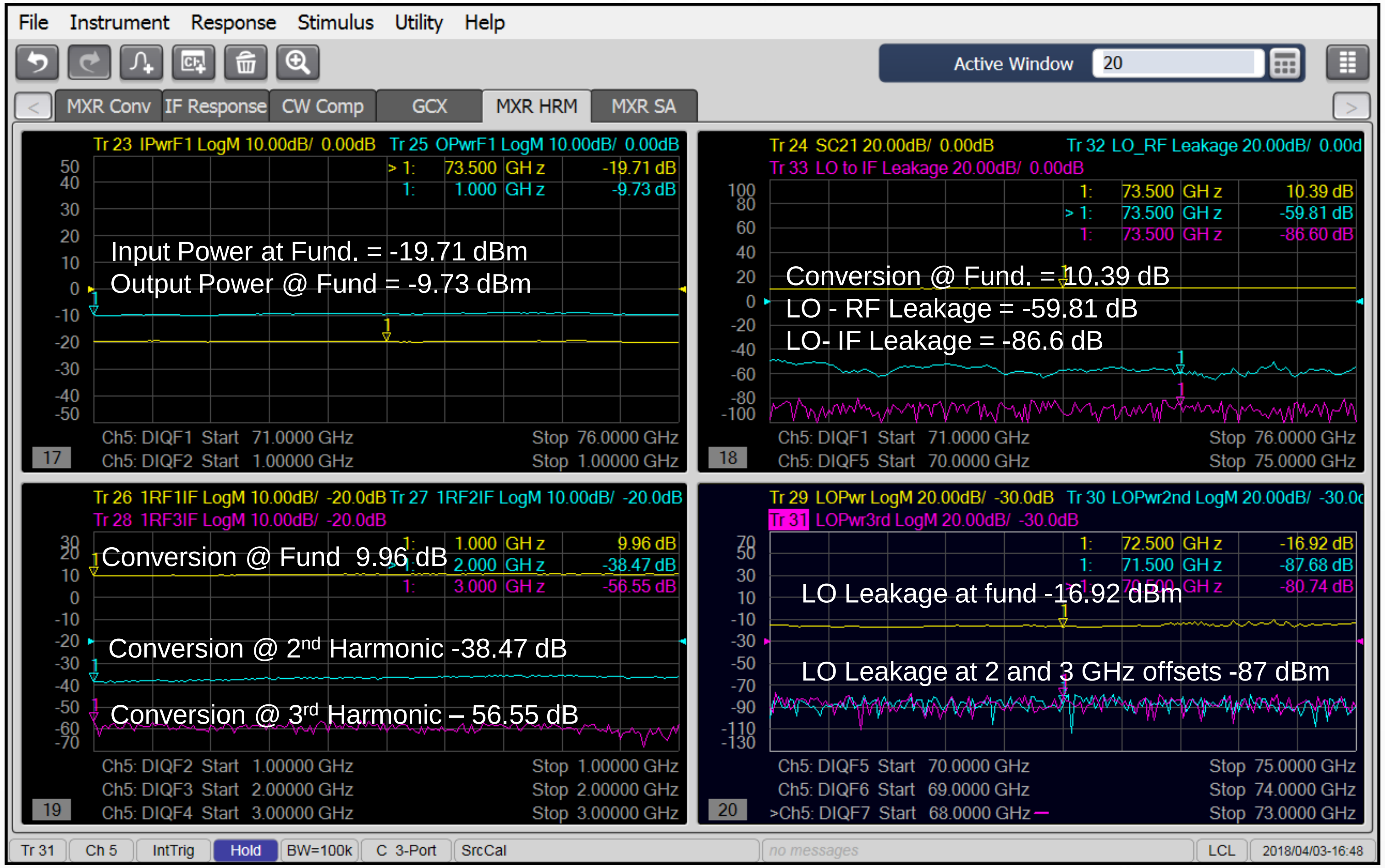
Receiver Harmonic Characterization

DEFINE MEASUREMENTS



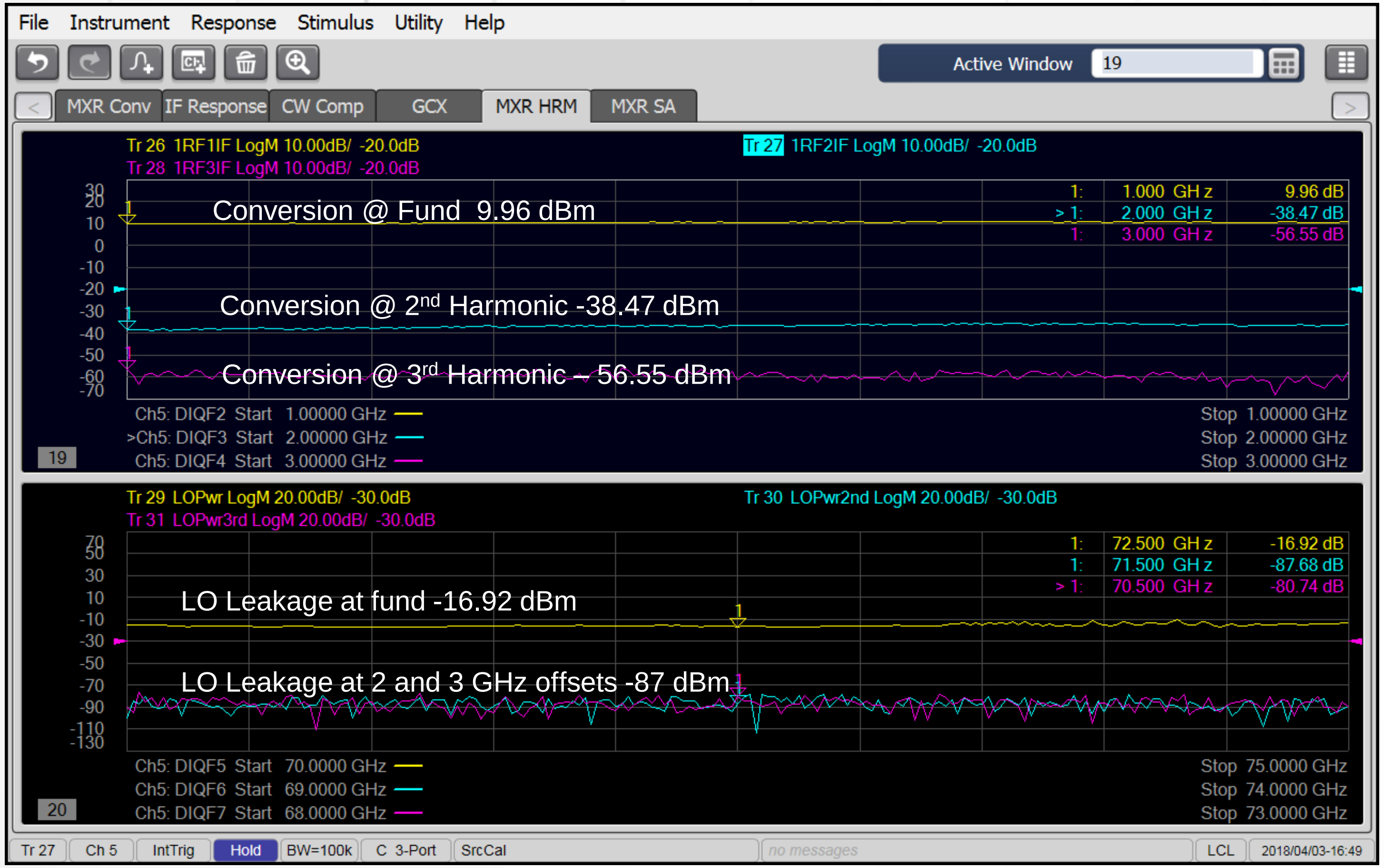
Receiver Harmonic Characterization

LO HARMONICS AND LEAKAGE

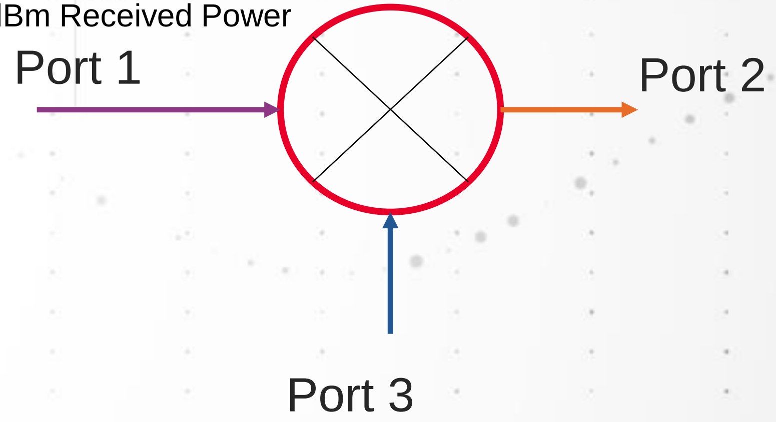


Receiver Harmonic Characterization

RECEIVER LO LEAKAGE – CLOSER LOOK



RF Input Frequency (F1)
71 GHz to 76 GHz
-20 dBm Received Power

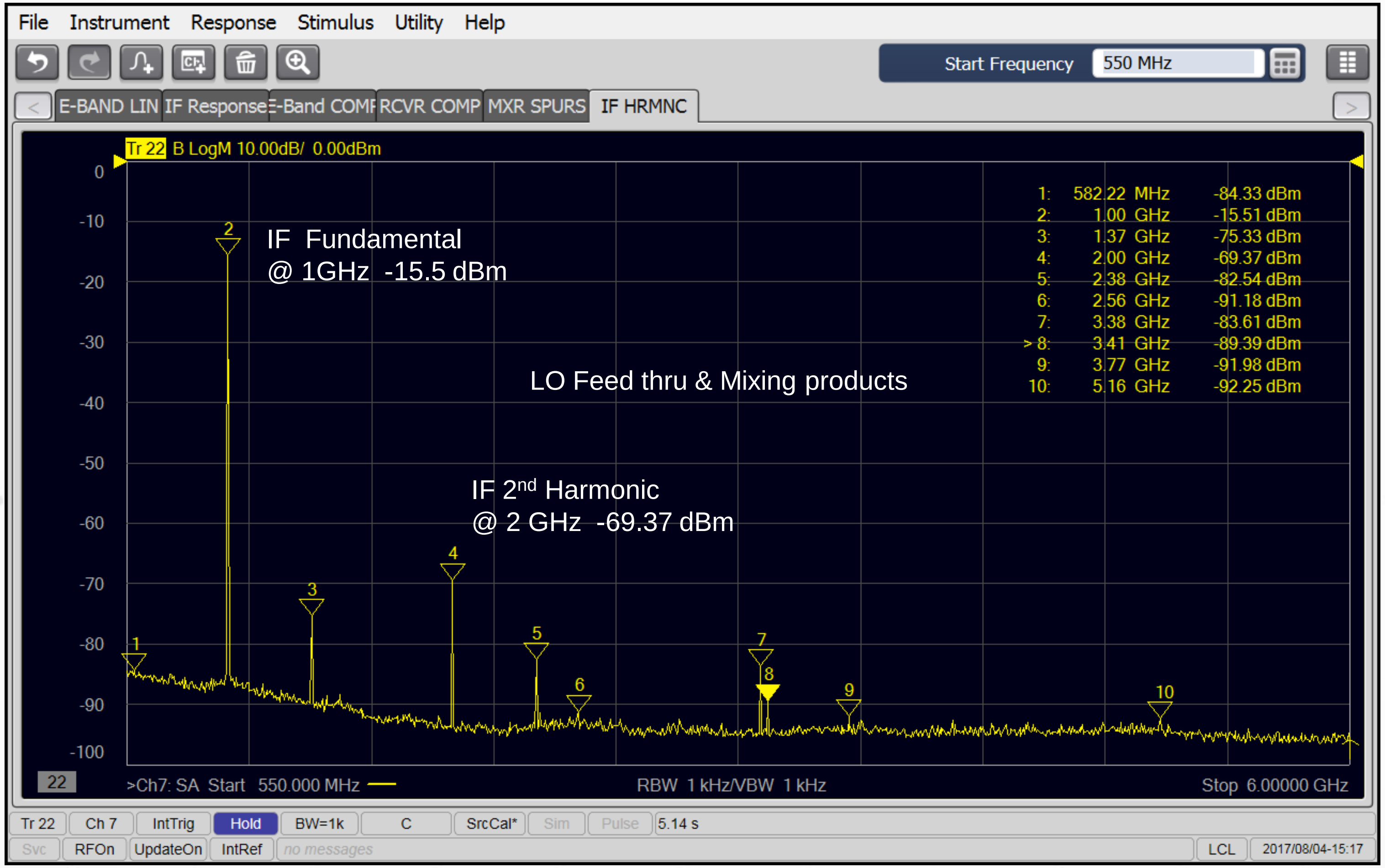


LO Input Frequencies

- 70 - 75 GHz Fundamental (F5)
- 69 - 74 GHz (F6)
- 68 - 73GHz (F7)
- LO Power set at -10 dBm

Receiver Harmonic Characterization

RECEIVER LO HARMONIC LEAKAGE SPECTRUM ANALYSIS



Millimeter Component Characterization

DISCUSSION TOPICS

- Millimeter Wave Component Application Space
- Millimeter Vector Network Analyzer Architecture
- Calibration At Millimeter Wave Frequencies
- Passive Filter Characterization
- Amplifier Characterization
- Receiver Characterization
- Conclusions

Millimeter Component Characterization

CONCLUSIONS

- Clearly a big drive for utilization of Millimeter wave frequencies
- Millimeter Vector Network Analyzer architecture is key to support characterization of the components
- Capability to fully calibrate impedance and power
- Software applications key to make measurements simple
  - Passive Filter Characterization
  - Amplifier Characterization
  - Receiver Characterization

Thank you!

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