Active Device Characterization At Millimeter Wave Frequencies

Suren Singh
Lead Application Engineer Millimeter and THz Solutions
Agilent Technologies

Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - SCMM of 60 GHz Tx / Rx components
  - IMD Spectrum measurements
  - THz Power Calibration
  - Materials Measurements at THz
- **Q&A**

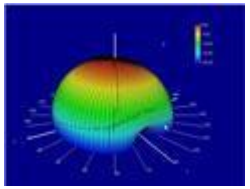
Millimeter Wave Frequency Band Applications

Millimeter Wave Component Test

- On Wafer Device Characterization
- Wireless HDMI & WiGiG (E-Band)
- Automotive Radar Components (E& W-Band)

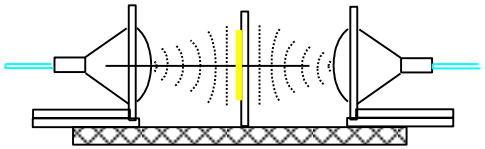
Antenna

- Integrated on-wafer antenna arrays
- (Sub) mm-wave interferometer for astrophysics (Emerging)
- Atacama Large Millimeter Array (ALMA) (NRAO, ESO, IRAM)
- Deep Space Radio Telescopes



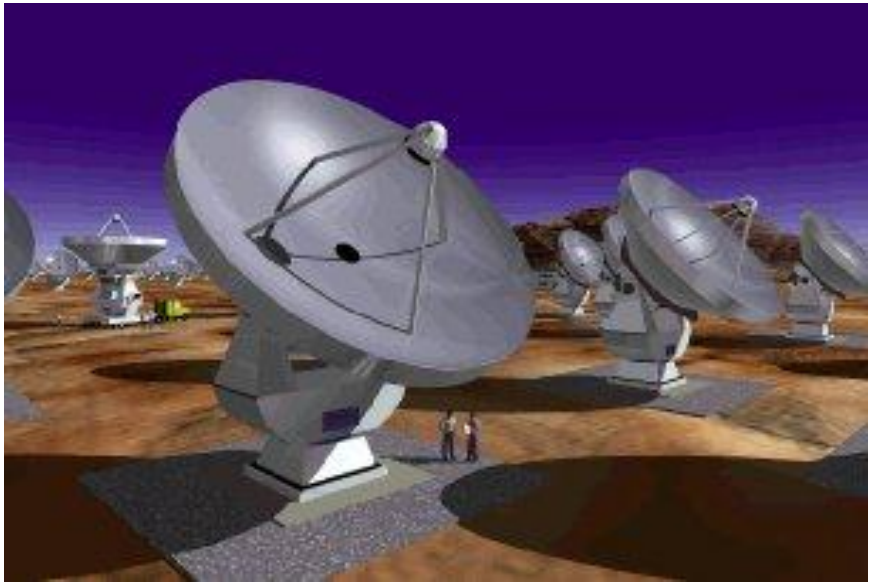
Materials and Imaging

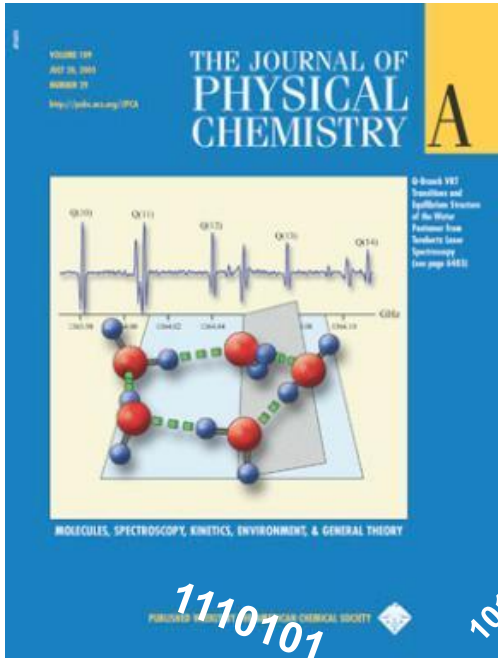
- Free space material measurements.
- Security Imaging Systems
- Corrosion Detection
- Bio-fuel (Emerging)

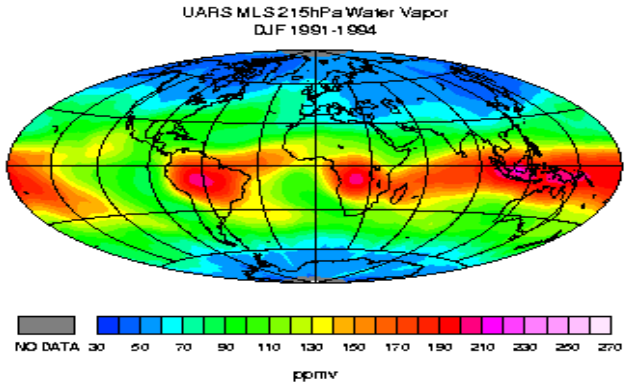


THz Frequency Applications

- Radio Astronomy
- Atmospheric Studies
- Chemical / Molecular Spectroscopy
- Plasma and Accelerator Diagnostics
- Biological Imaging
- Materials Characterization
- General Test and Measurement







Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - SCMM of 60 GHz Tx / Rx components
  - IMD Spectrum measurements
  - THz Power Calibration
  - Materials Measurements at THz
- **Q&A**

Measurement Driven Architecture

Millimeter wave Devices

- Passive Devices
- Amplifiers
- Mixers
- Semiconductors
- Antennas
- Materials

Millimeter wave Measurements

- S-Parameters (N-port, Differential)
- Absolute power
- Gain compression
- Pulsed measurements
- Material parameters
- Time domain

Measurement Driven Architecture

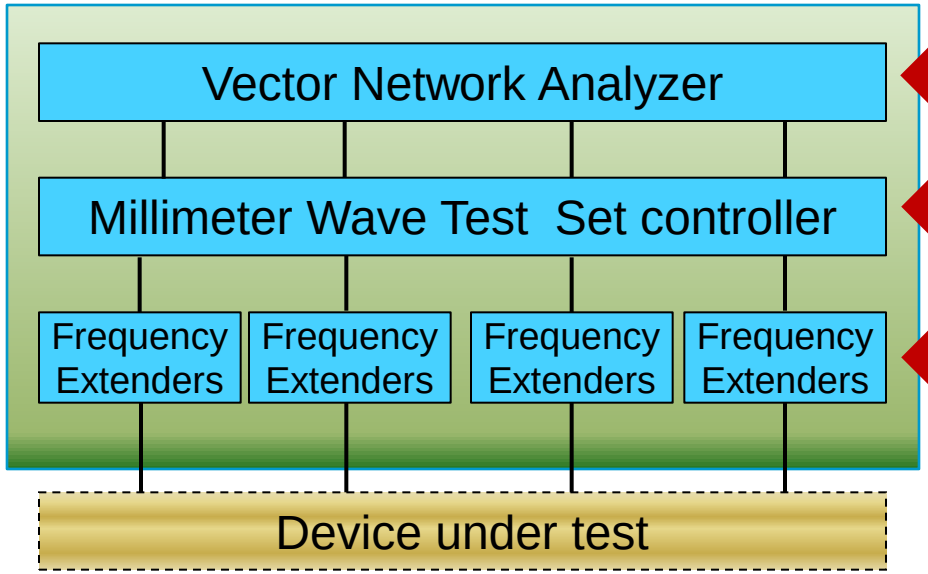
Millimeter wave Measurements

- S-Parameters (N-port, Differential, Translated)
- Absolute power
- Gain compression
- Pulsed measurements
- Material parameters
- Time domain

Millimeter wave Features

- Calibration: S-Parameters & Power
- Bias Tee
- Differential Source
- Remote Modules
- Measure & level power
- Pulse drive and measure
- Measure mixers
- Measure multi-ports
- Wide dynamic range
- Measure multiple bands
- Probing

Solution Architecture

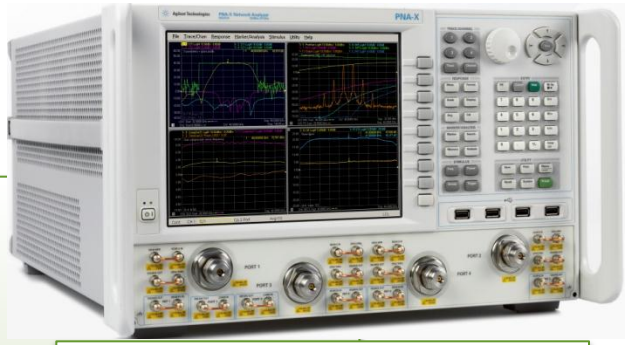


Network Analyzer is the measurement engine.

Optional Test Set Controller interfaces to modules

THz Frequency Extenders provide frequency conversion and signal coupling

PNA / PNA-X Network Analyzer



N5247A 4-Port PNA-X

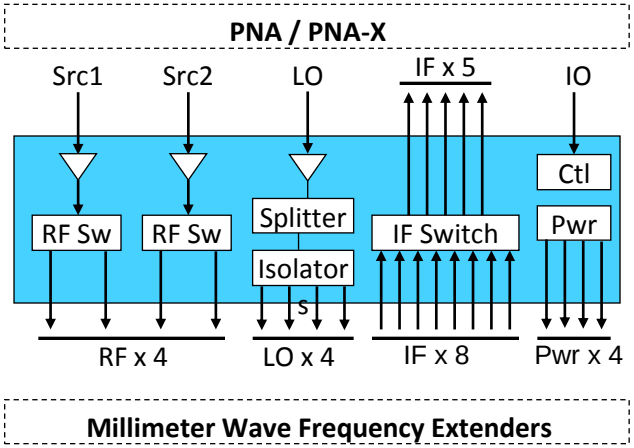
Key Enabling Features:

- 26.5 /43.5/50/67GHz versions
- Configurable Test set options
- Rear panel RF / LO Output
- Rear panel direct IF Access
- Test set controller interface
- Frequency Offset Capability
- Dual, spectrally pure sources with low phase noise
- Integrated pulse measurements
- Source Power Calibration & Receiver power leveling
- Broadband match corrected power Calibration

Millimeter Wave Test Set Controller

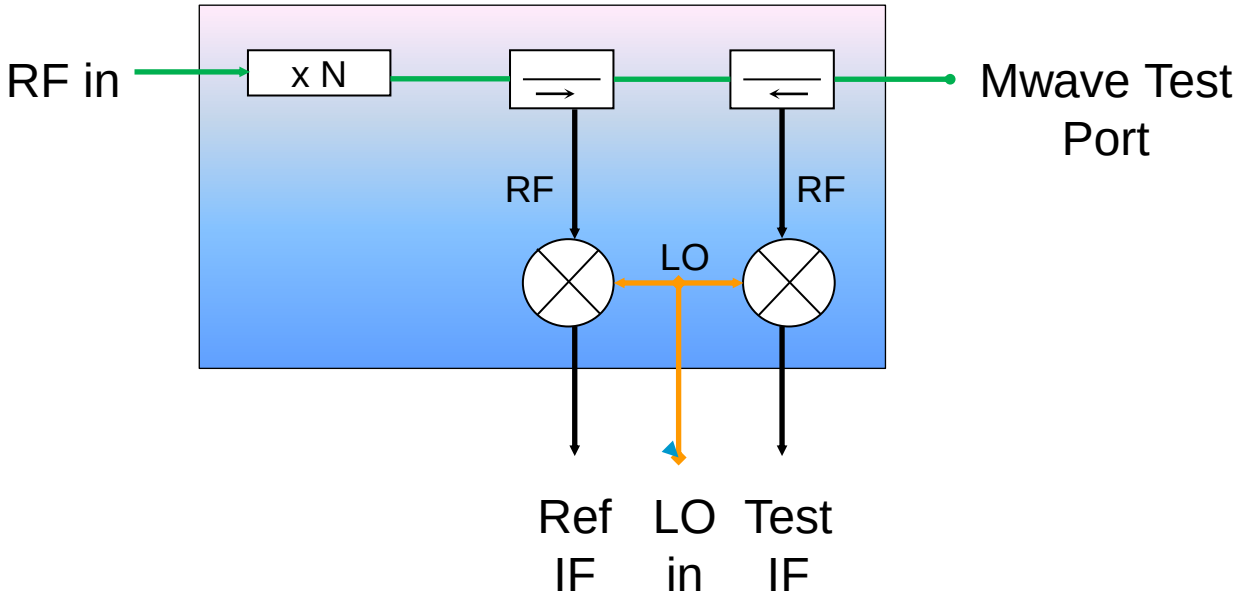
- Provides LO & RF distribution to modules
- Provides DC power to modules
- 2-port (N5261A) and 4-port (N5262A) versions
- Flexible setup: measure multiple bands
- Mixer Measurements without external Sources
- Easily switch between PNA/PNA-X and mm-wave mode

Four Port N5262 A Test Set Controller



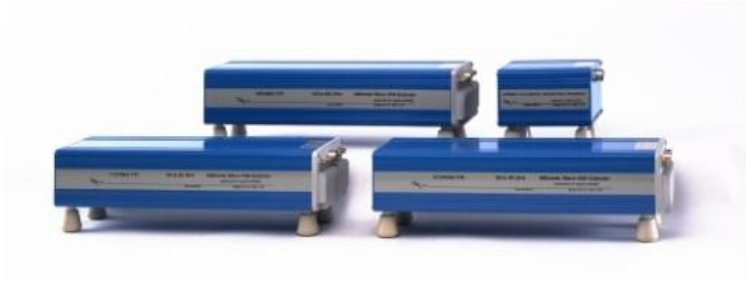
Millimeter Frequency Extenders

- Broadband Extenders: 10M-110GHz
- Banded Extenders: 50 GHz ... 1 THz



Banded Frequency Extenders

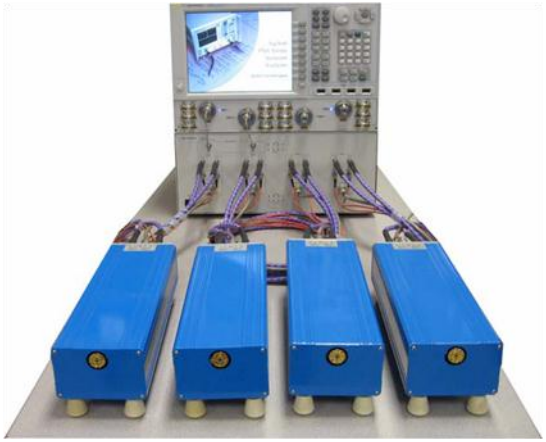
WR 15	*50 – 75 GHz*
WR 12	*60 – 90 GHz*
WR 12E	*54 – 92 GHz*
WR 10	*75 – 110 GHz*
WR 6	*110 – 170 GHz*
WR 5	*140 – 220 GHz*
WR 3	*220 – 325 GHz*
WR 2.2	*325 – 500 GHz*
WR 1.5	*500 – 750 GHz*
WR 1.0	*750 – 1.1 THz*



MHz to 110 GHz Broadband Solution

- Single-sweep over 10MHz-110GHz
- 2-port & 4-port options
- Based on N5247A 67 GHz PNA
- 1.0 mm Test Port
- Key Features:
  - Built in Kelvin Bias Tees
  - Power leveling
  - Settable Power to -50 dBm
  - True differential drive
  - Pulse measurements
  - Mixer measurements

Banded Waveguide solutions to 1.1 THz



PNA / PNA-X Banded Waveguide Solution With Test Set Controller

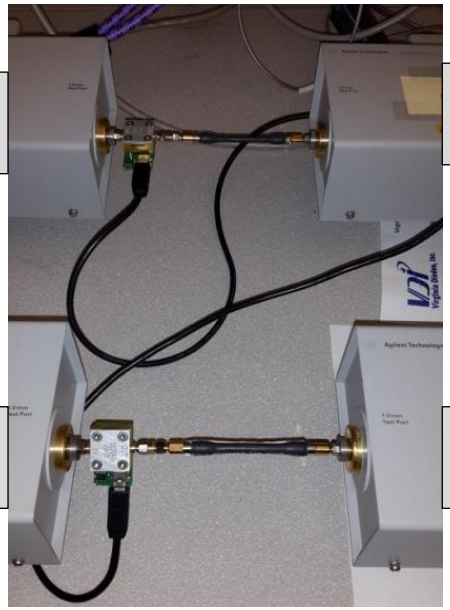
Banded Waveguide solution Without Test Controller

Banded Waveguide solution With Proprietary Test Controller

Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - **SCMM Broadband Amplifier Characterization**
  - SCMM of 60 GHz Tx / Rx components
  - IMD Spectrum measurements
  - THz Power Calibration
  - Materials Measurements at THz
- **Q&A**

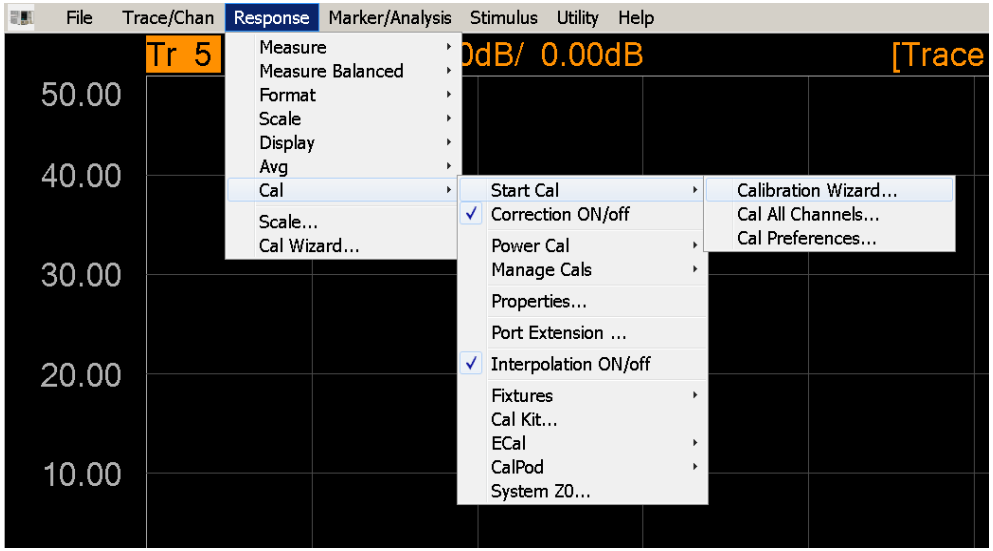
Broadband Amplifier Measurement Application

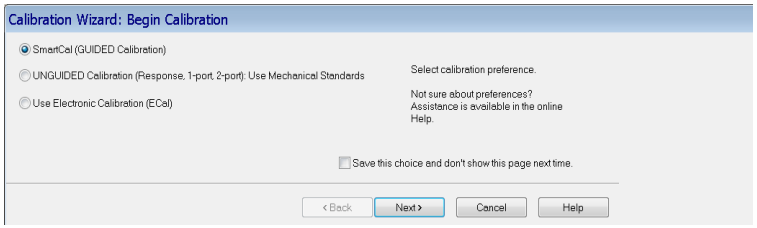


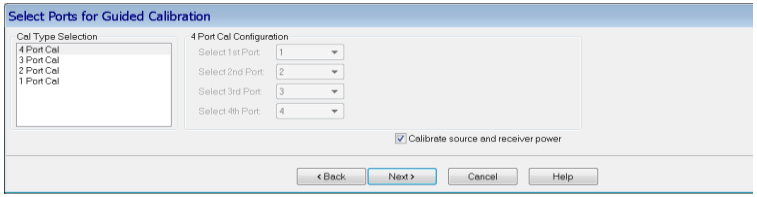
Measurement Requirements

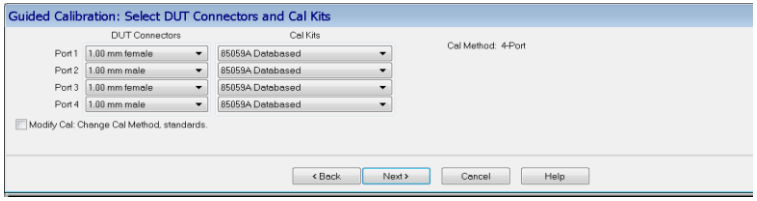
- Single Connection Measurement
- Input match
- Output match
- Amplifier gain
- Amplifier compression
- Amplifier pulsed response
- 4 Port True Differential

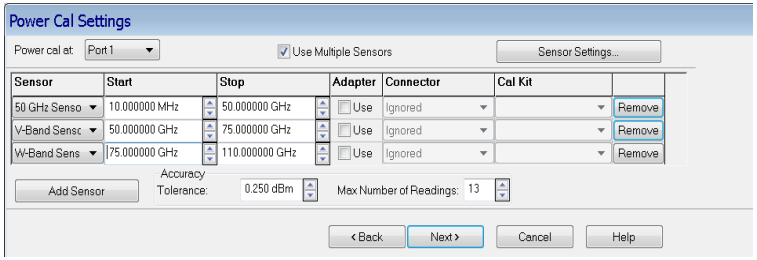
4- Port Match corrected Source power Calibration



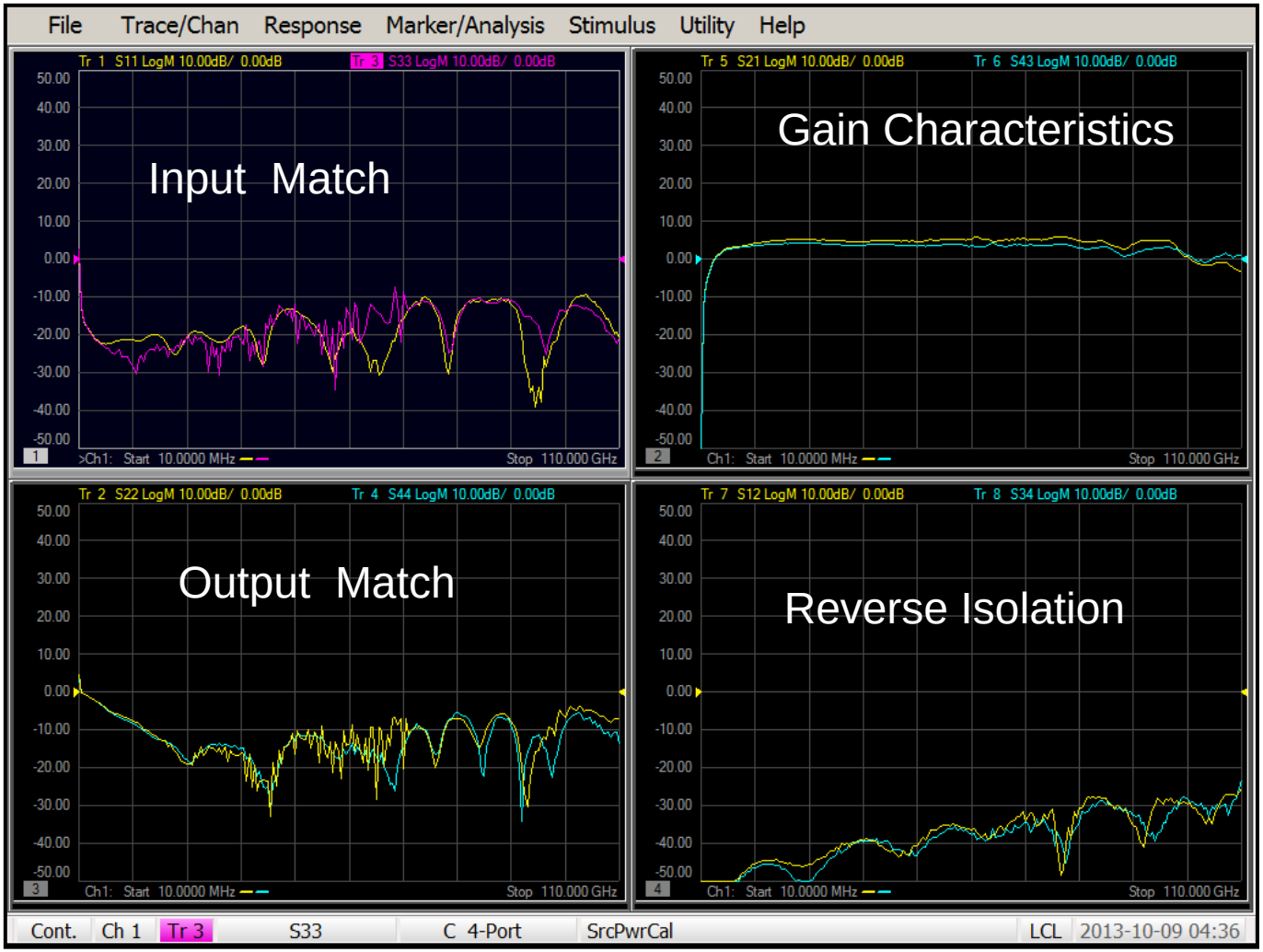




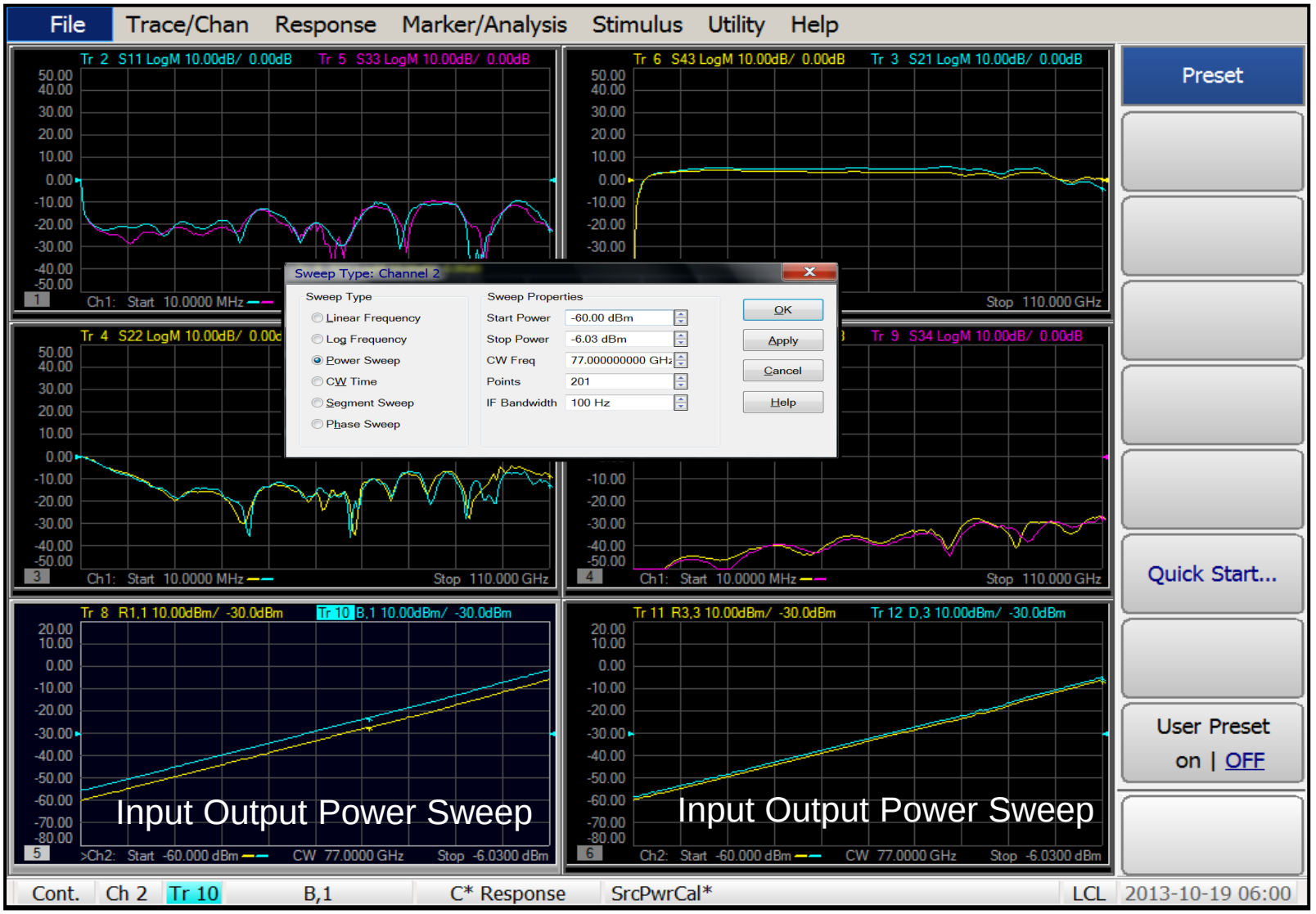




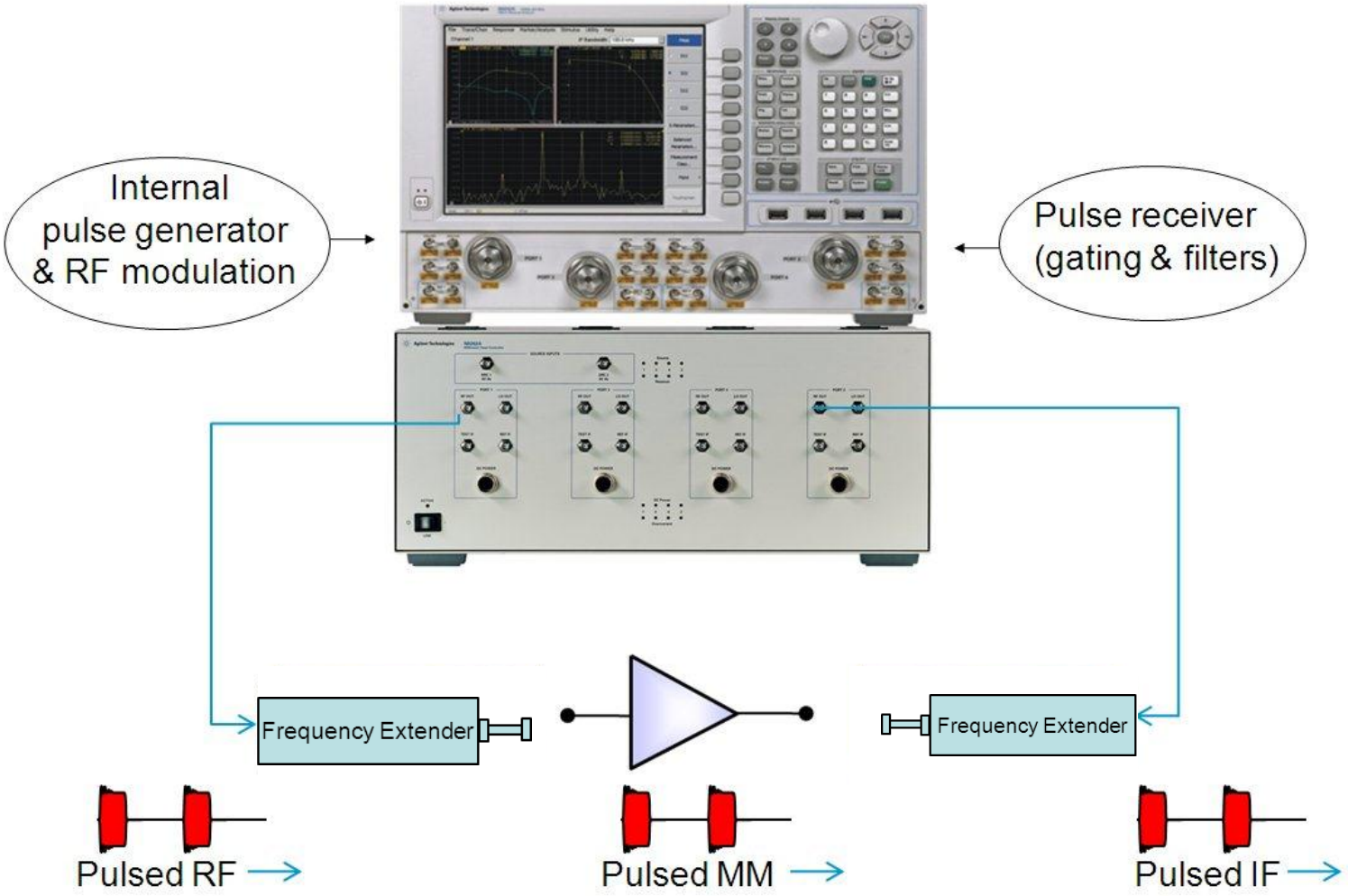
Broadband Amplifier Match and Gain Results



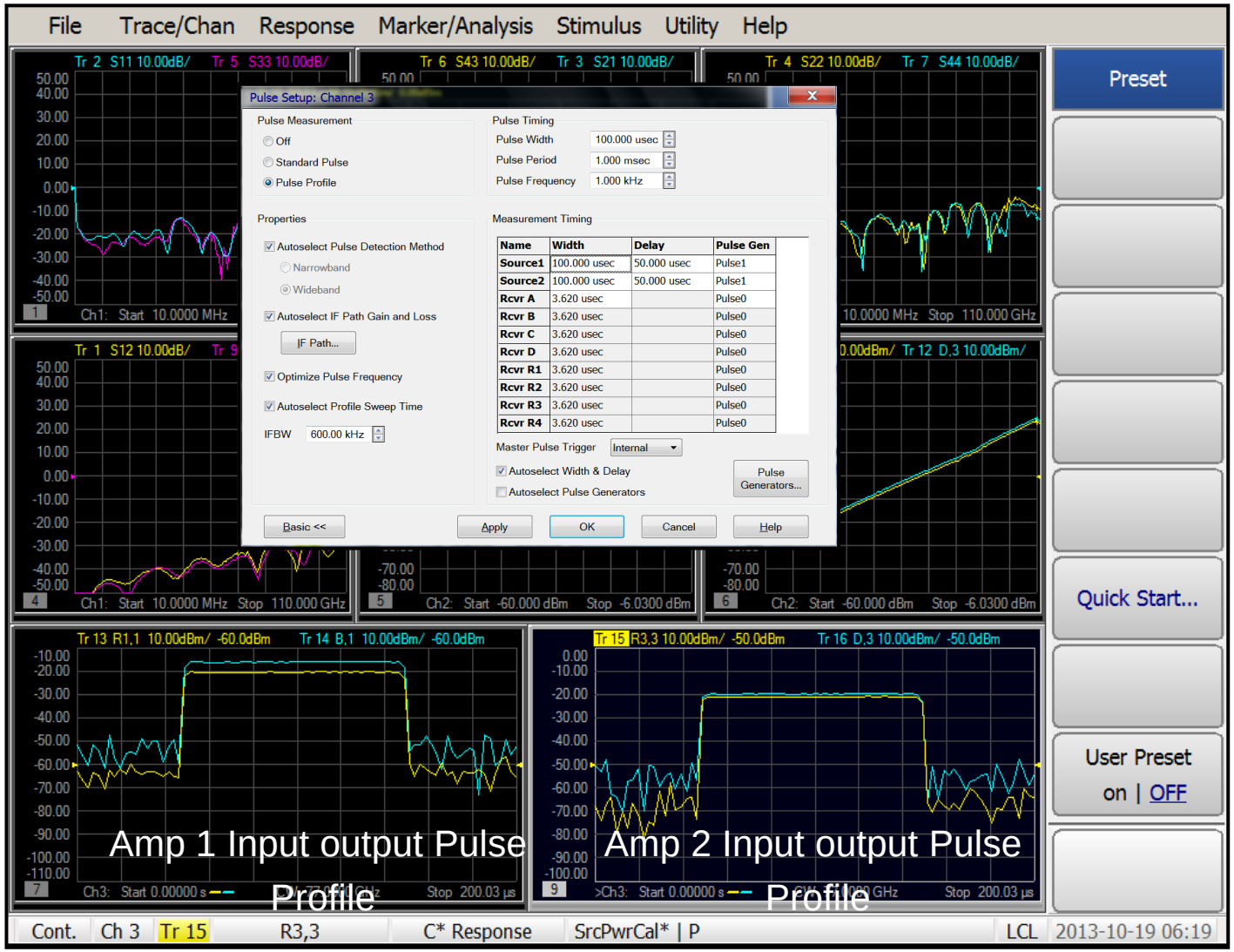
Broadband Amplifier Adding Power Sweep



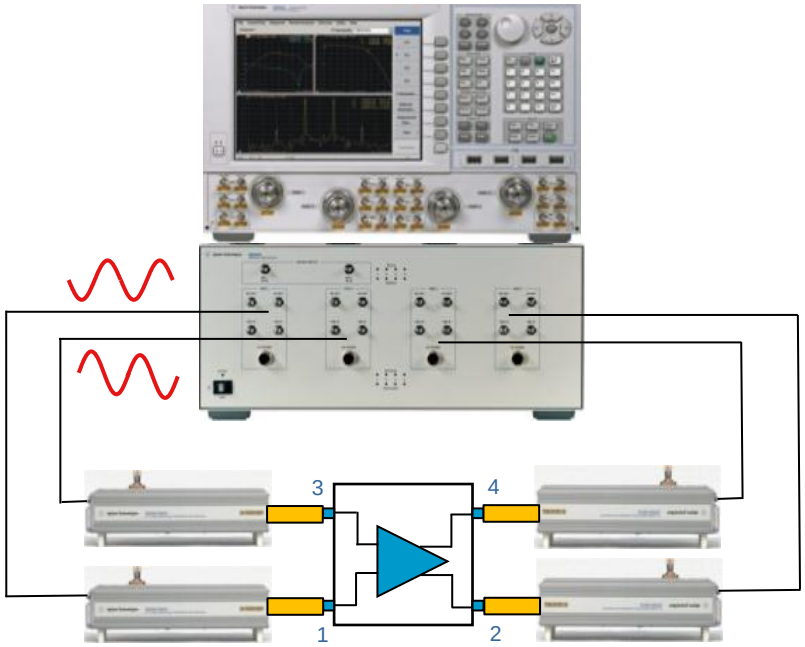
Broadband Amplifier Adding Pulsed Response

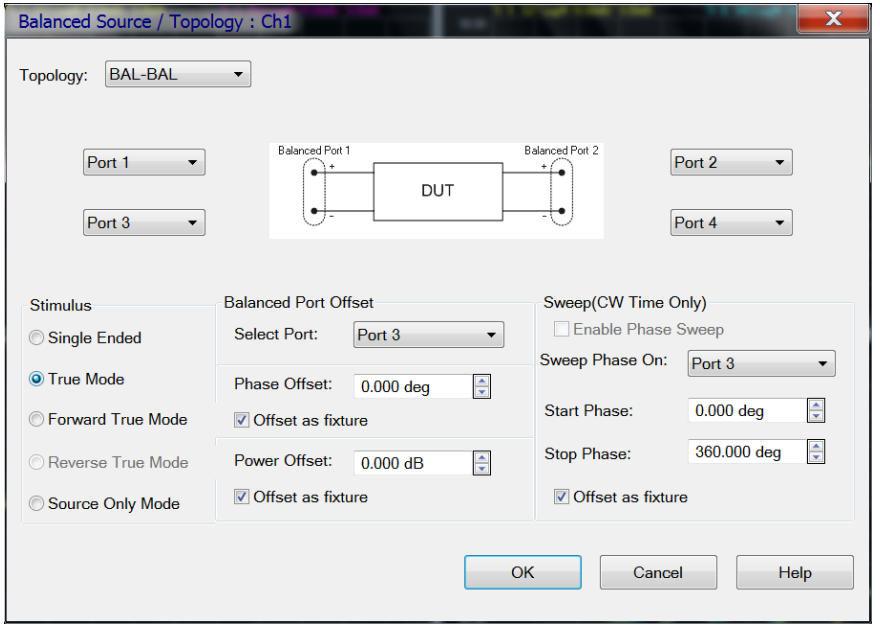


Broadband Amplifier Adding Pulsed Response



Broadband Amplifier Adding True Mode Measurements

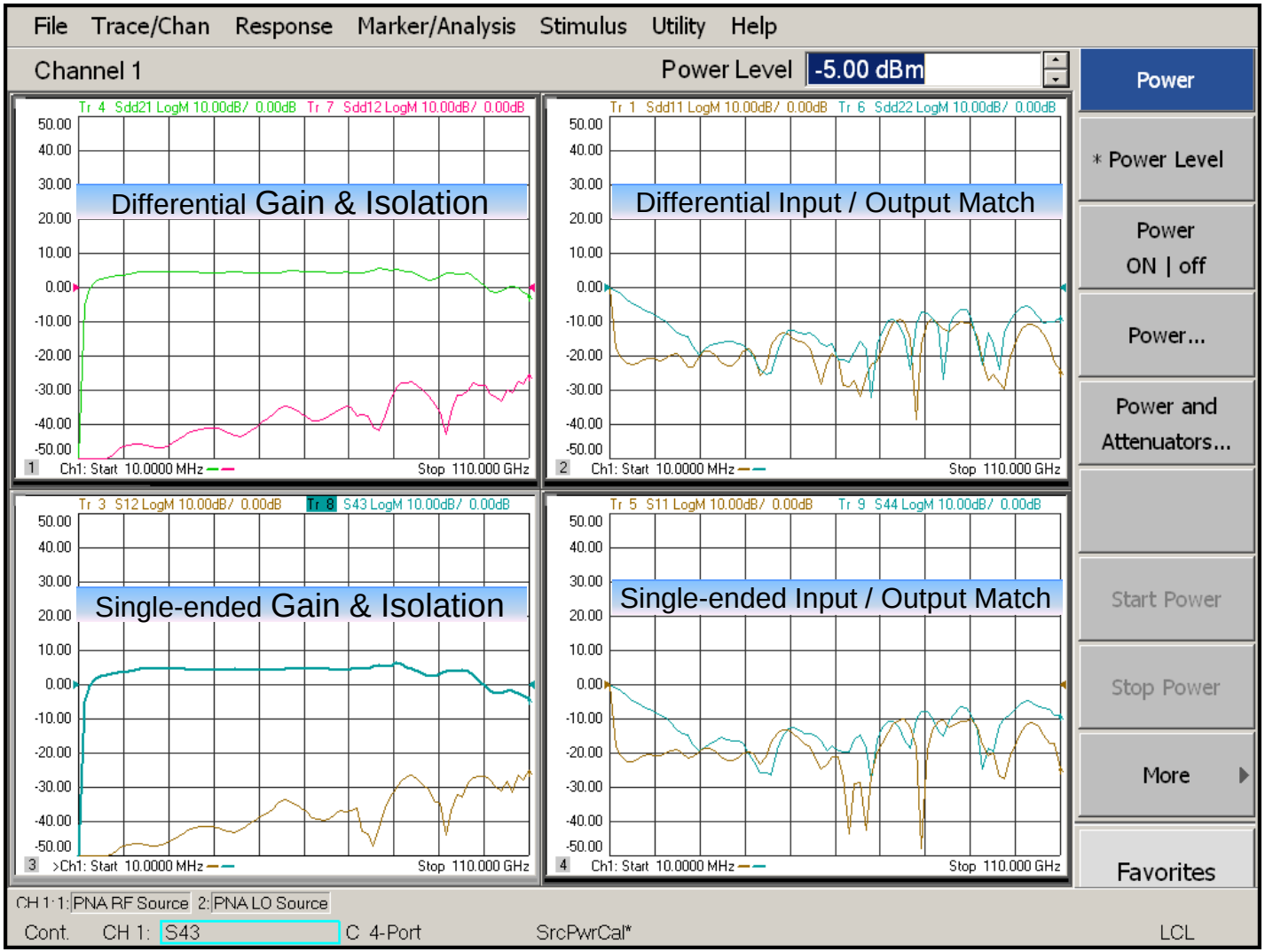




Integrated True-mode Stimulus Application: iTMSA (Option 460)

- Applies DUT/VNA mismatch-corrected true-differential or true-common-mode stimulus in forward, reverse or both directions.
- Precisely control amplitude and phase offsets.
- Make fully-error-corrected balanced measurements on balanced-input and balanced-output as well as one port single-ended and one port balanced devices.

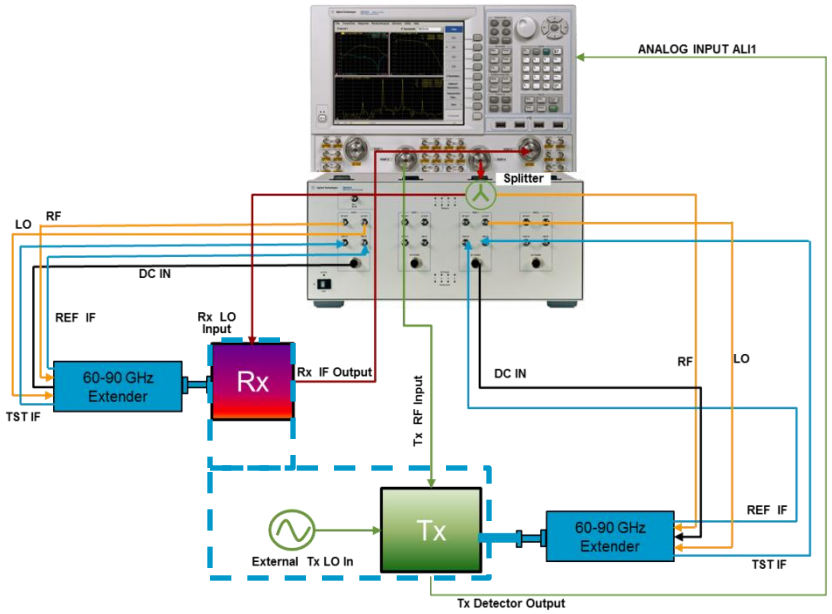
Broadband Amplifier Adding True Mode Measurements



Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - **SCMM of 60 GHz Tx / Rx components**
  - IMD Spectrum measurements
  - THz Power Calibration
  - Materials Measurements at THz
- **Q&A**

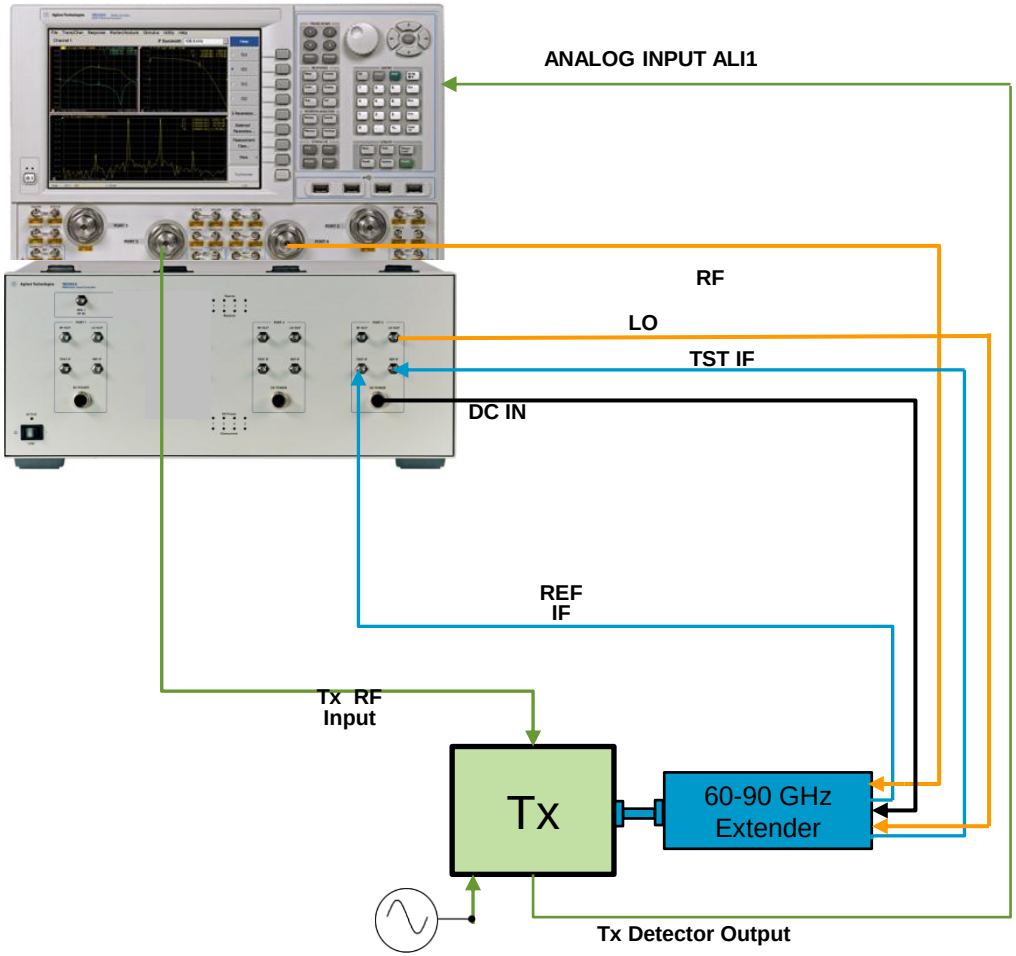
SCMM of 60 GHz Tx/Rx Components

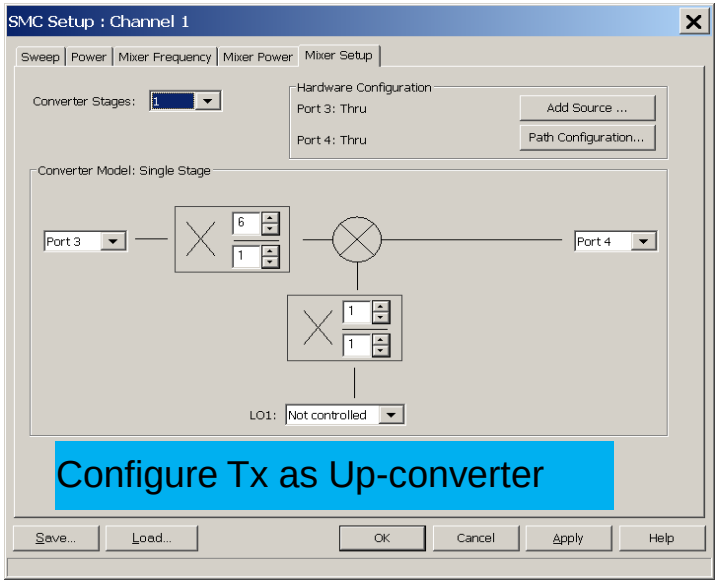


Measurement Requirements

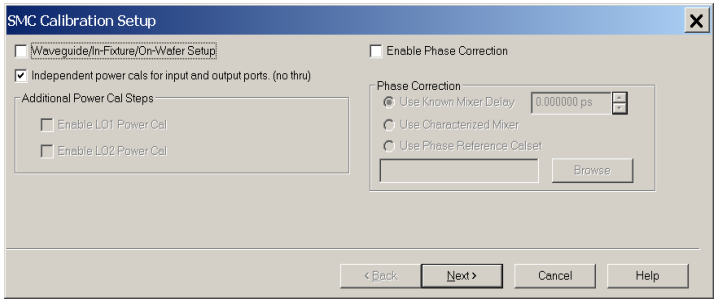
- Conversion and S-Parameters of Tx
- Spectrum of Tx output with RF applied
- Spectrum measurement of Tx output for LO Leakage
- Tx Detector versus Output power
- Tx Detector vs. Input Power Sweep
- Rx Conversion and S-Parameters
- Rx Power Sweep of input Power
- Rx Swept LO Response
- Rx Noise Figure measurement

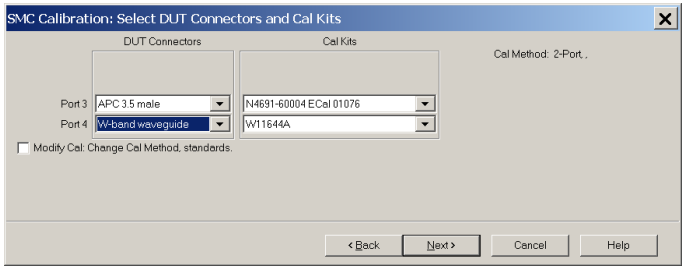
Tx Measurement Configuration Using SMC

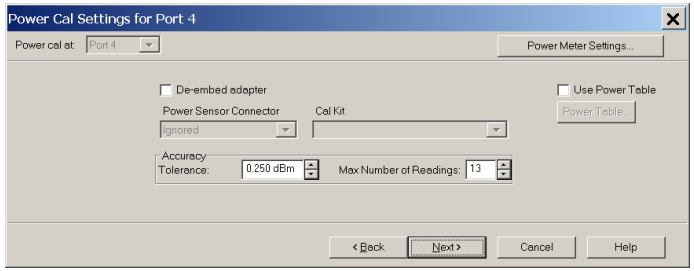


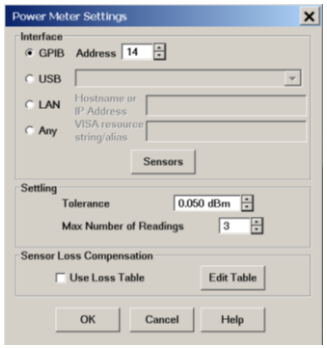


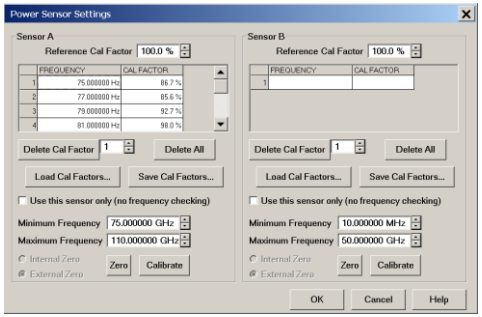
Tx Measurement Configuration - Calibration

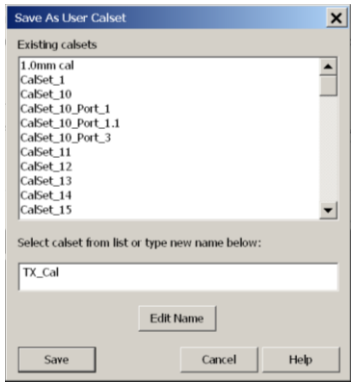






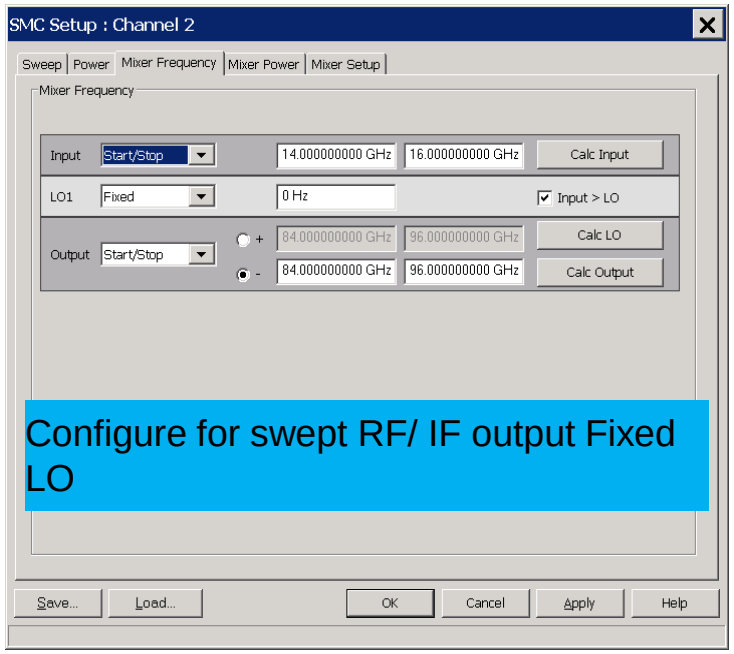




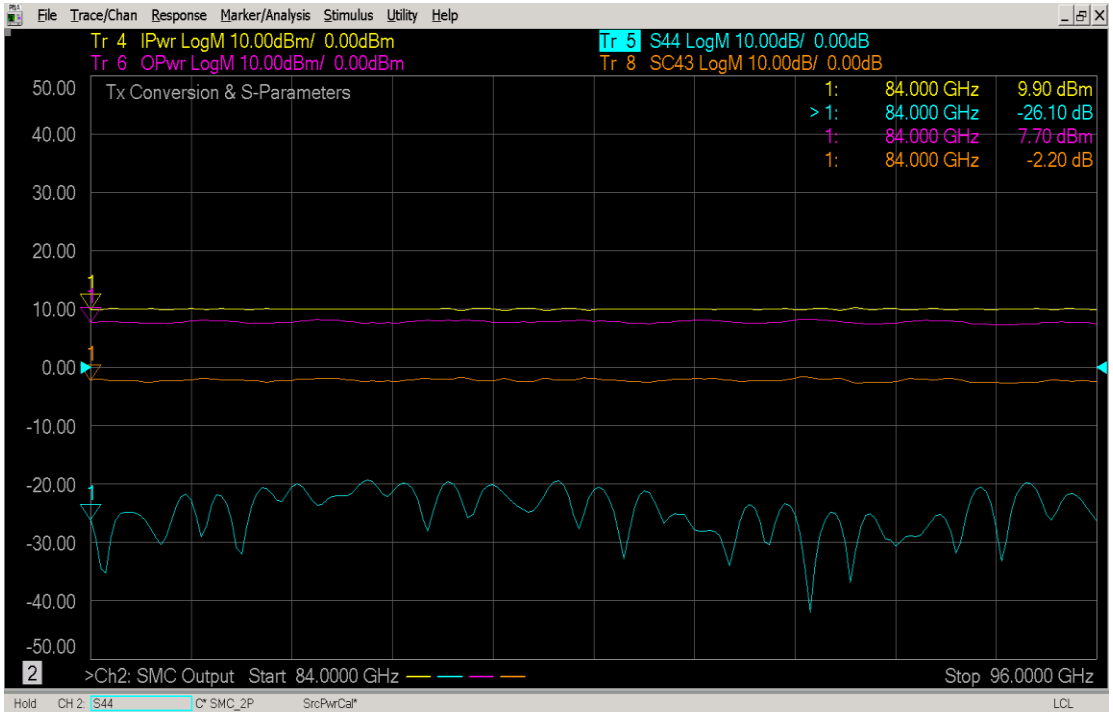


Using SMC Calibration allows for independent calibration of each port.

Adding Conversion and S-Parameters of Tx

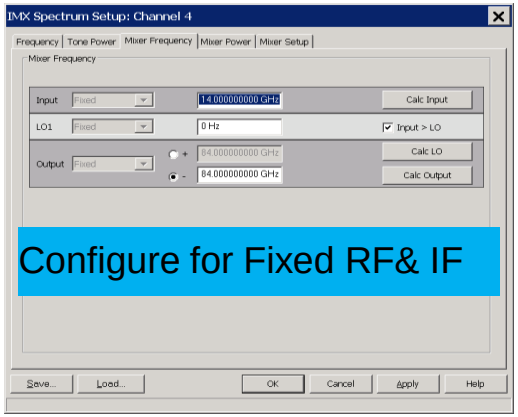


Configure for swept RF/ IF output Fixed LO

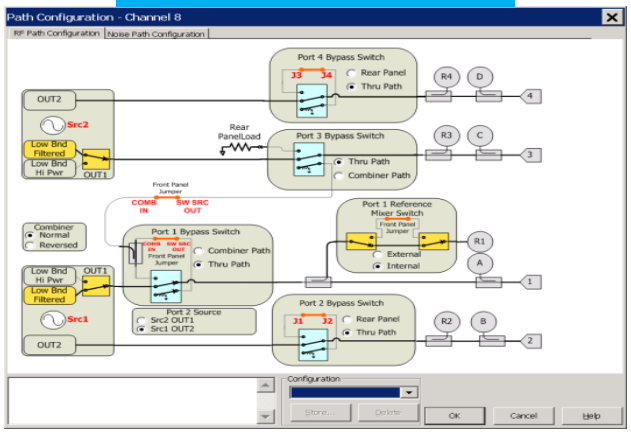


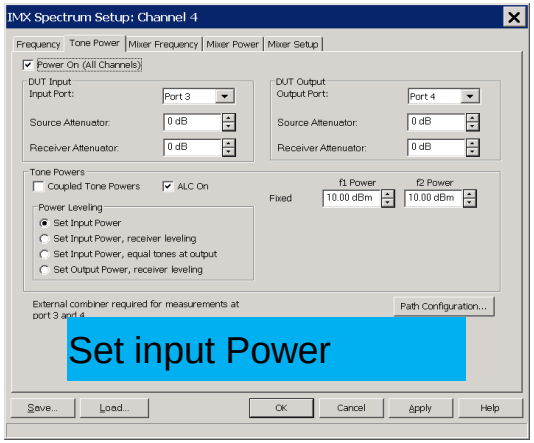
Adding Spectrum of Tx output with RF applied Using IMDx

Configure Signal Path

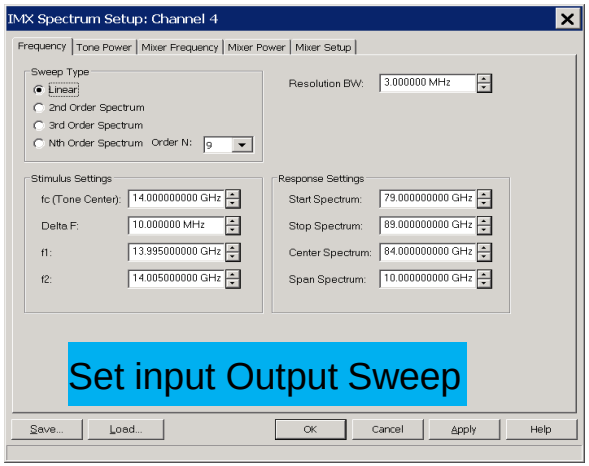


Configure for Fixed RF& IF

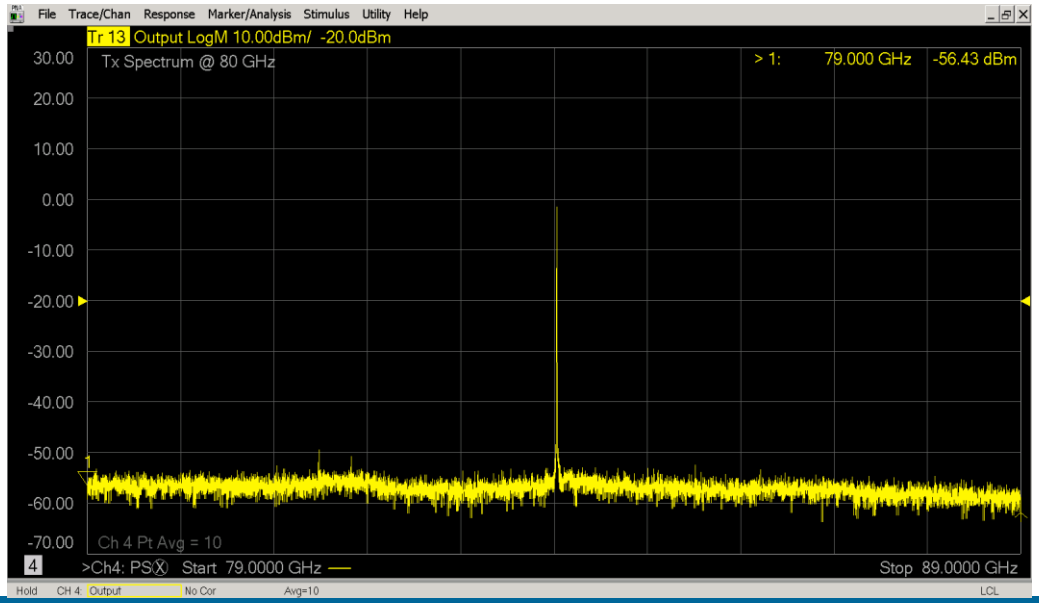




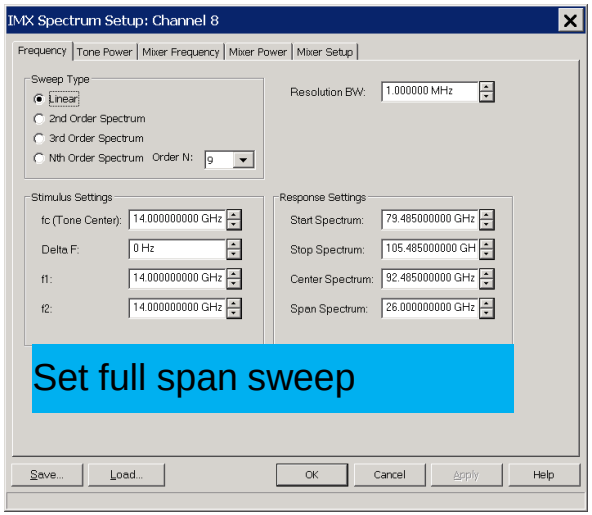
Set input Power

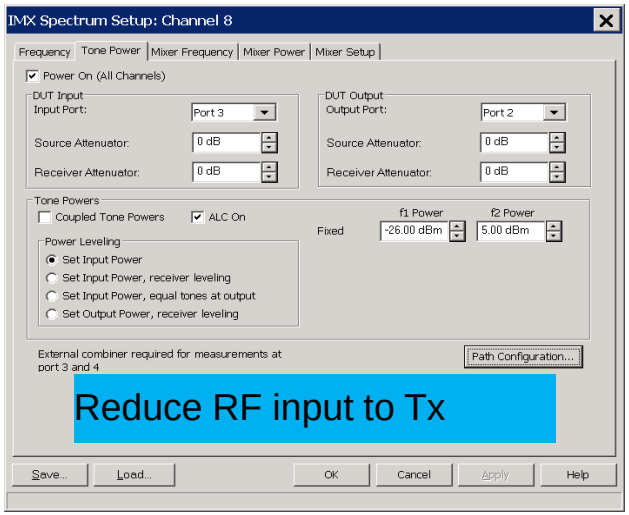


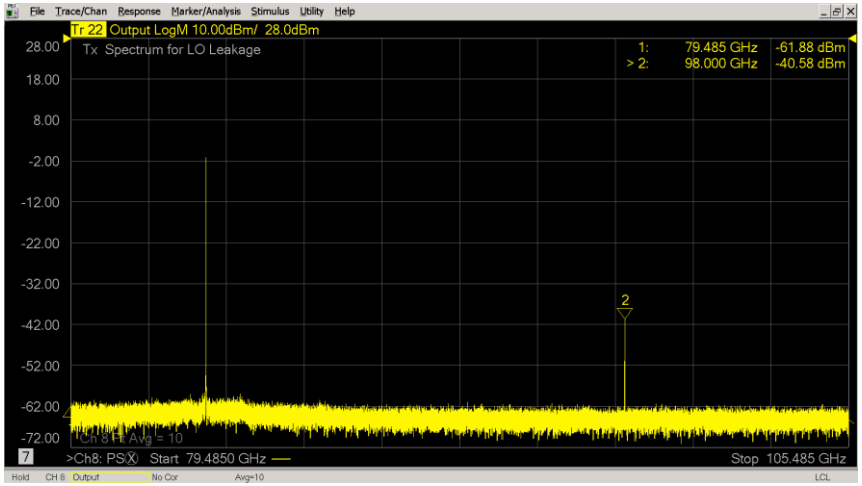
Set input Output Sweep



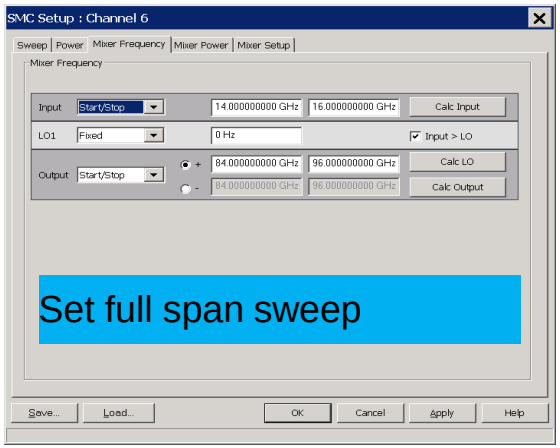
Adding Spectrum measurement of Tx output for LO Leakage – Uses IMDx



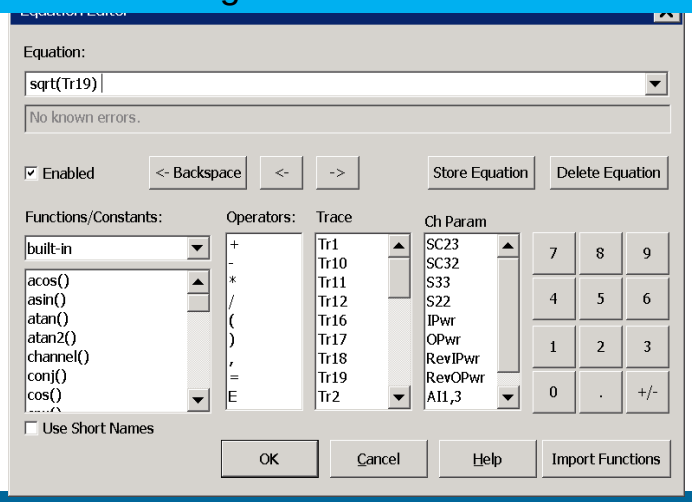


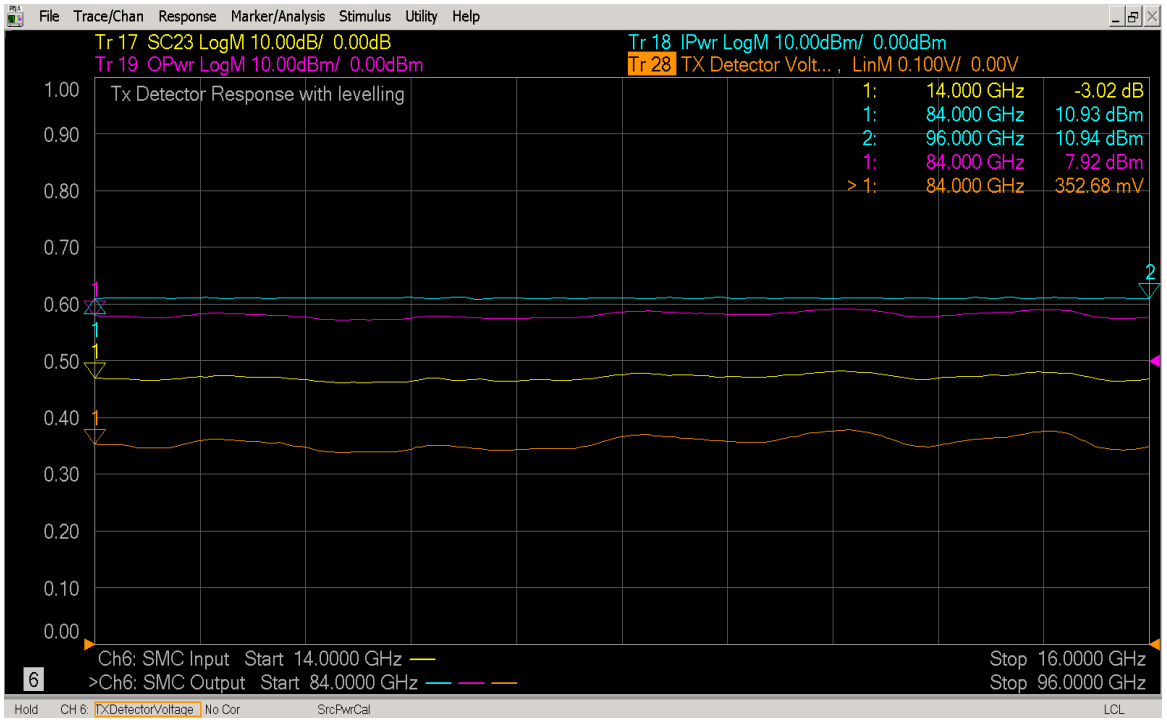


Adding Tx Detector versus Output power - Simulated

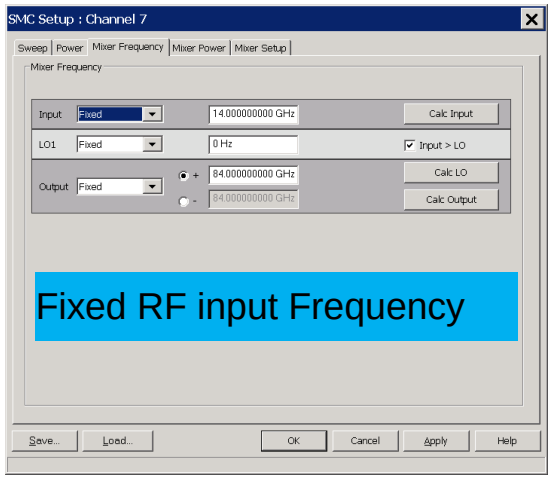


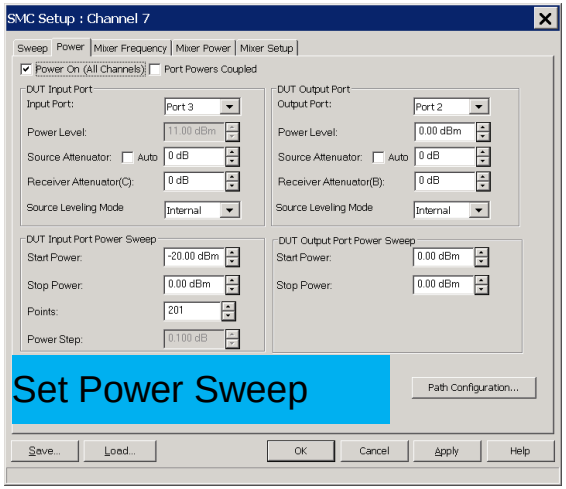
Use Equation Editor to simulates Detector voltage



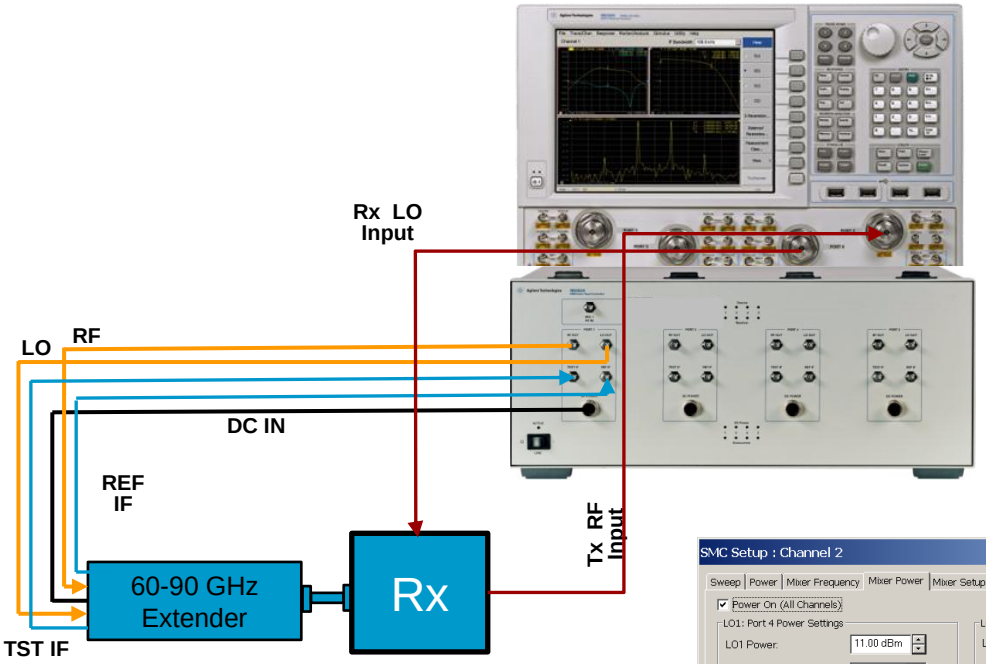


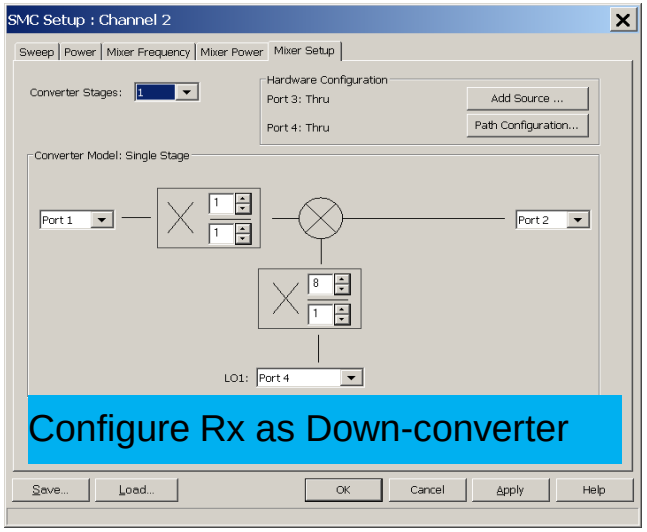
Adding Tx Detector vs. Input Power Sweep - Simulated

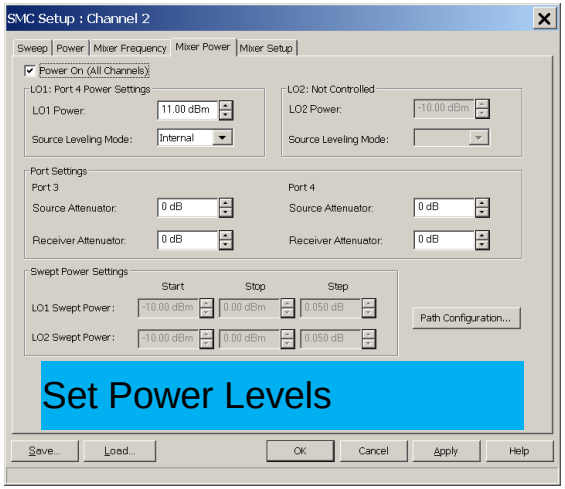




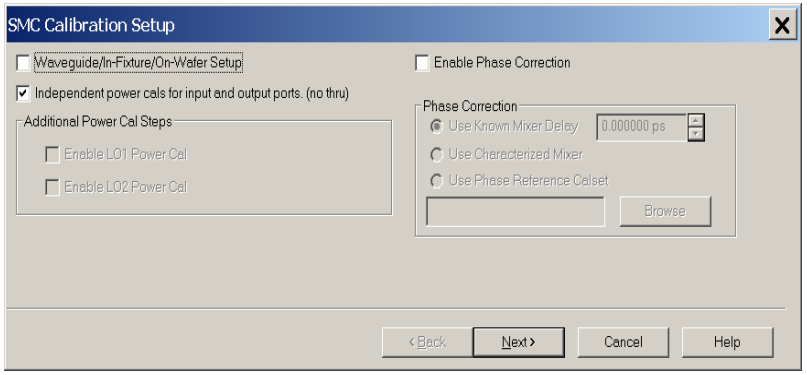
Rx Measurement Configuration Using SMC

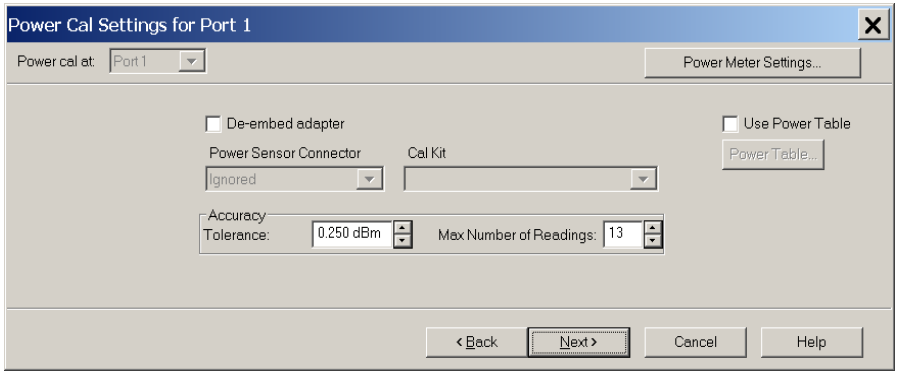


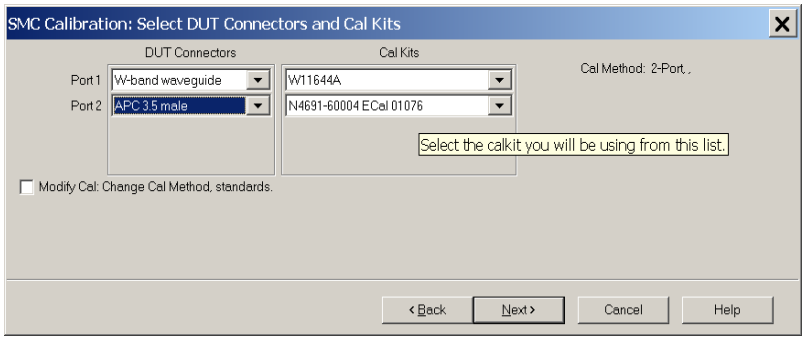


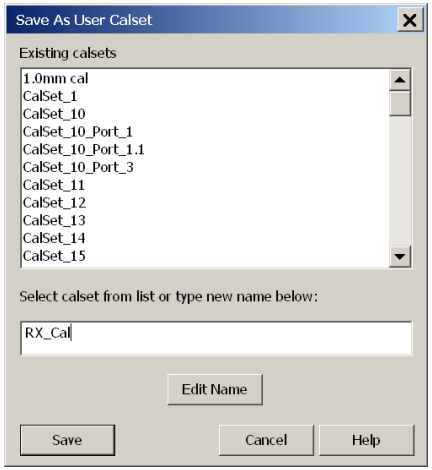


Rx Measurement Configuration - Calibration



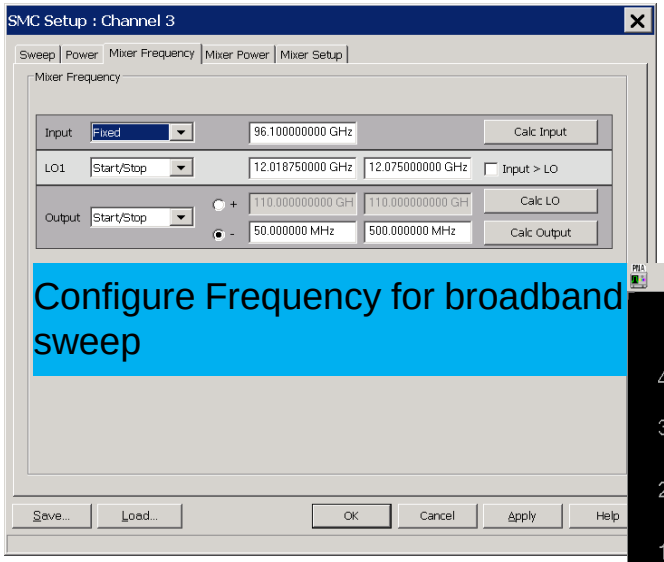


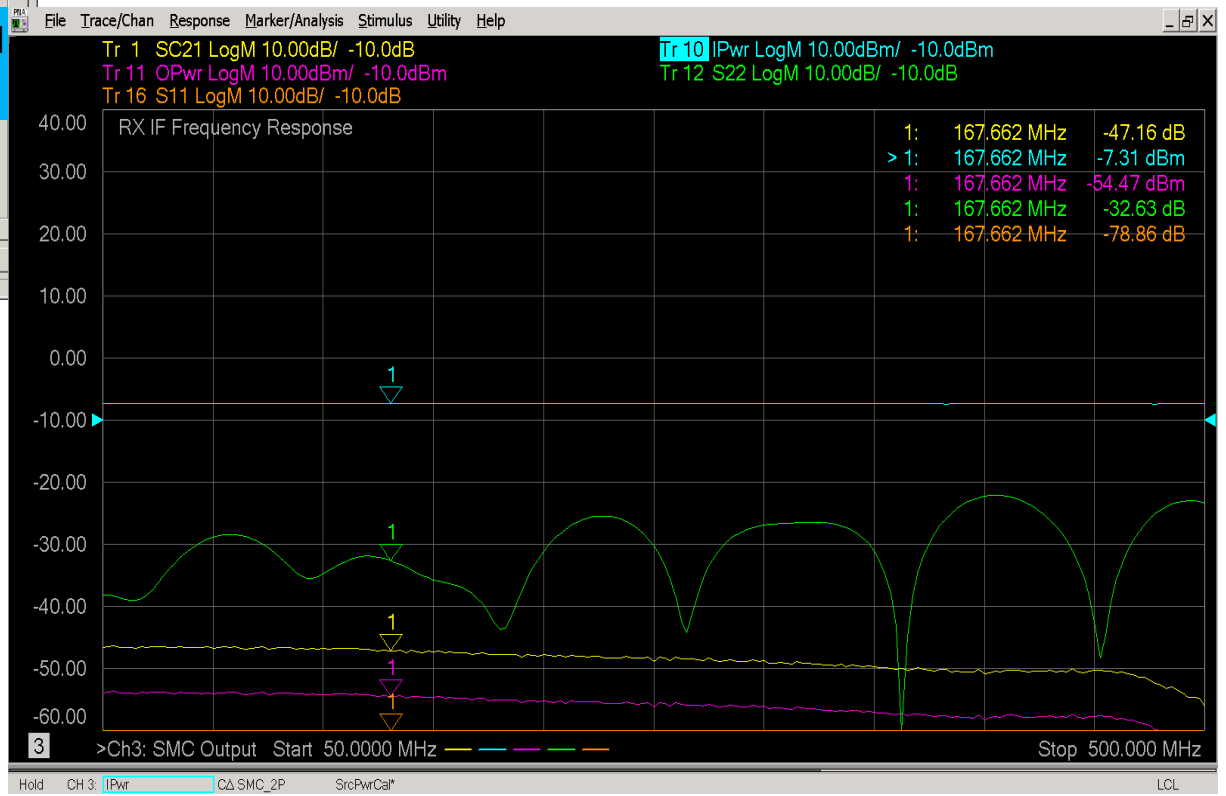




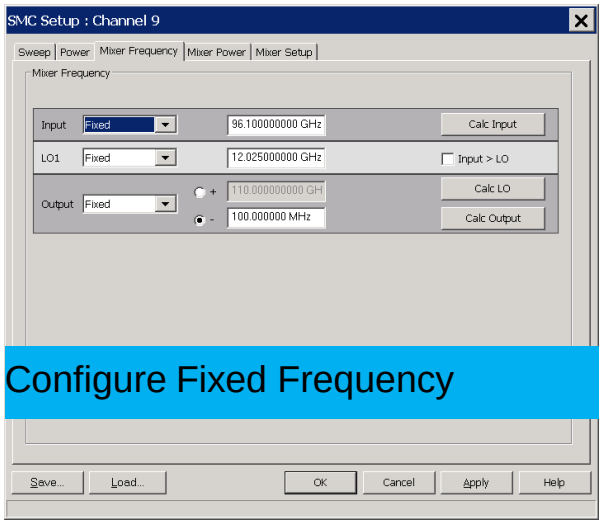
Using SMC Calibration allows for independent calibration of each port.

Adding Rx Conversion and S-Parameters

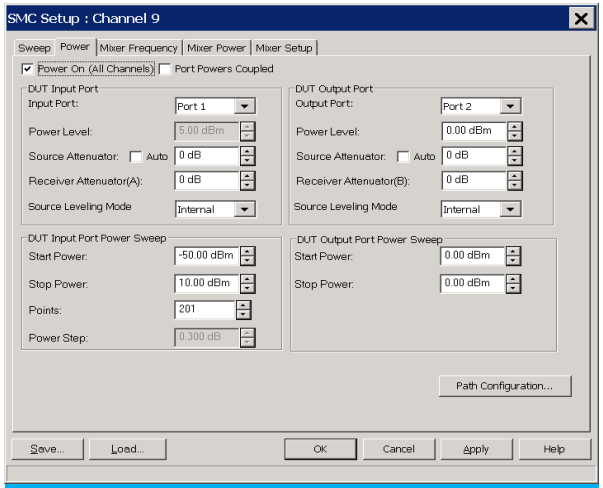




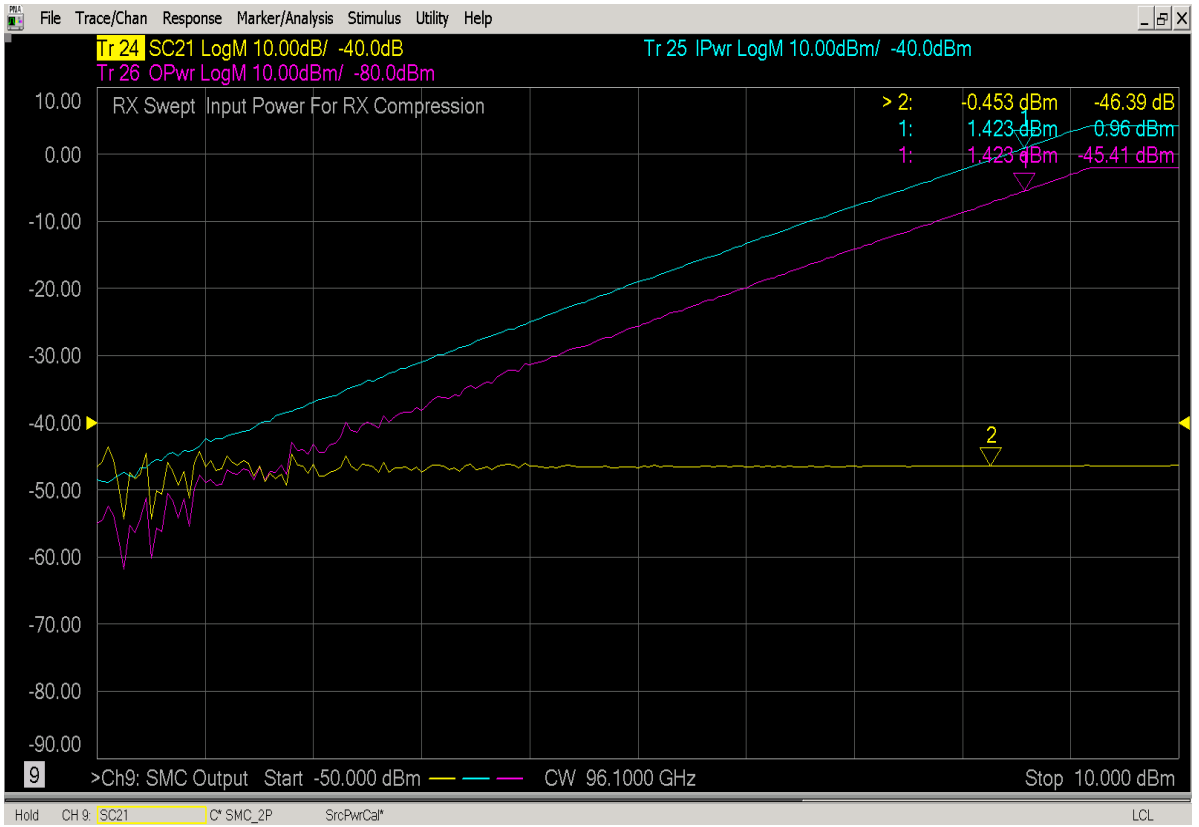
Adding Rx Power Sweep of Input Power



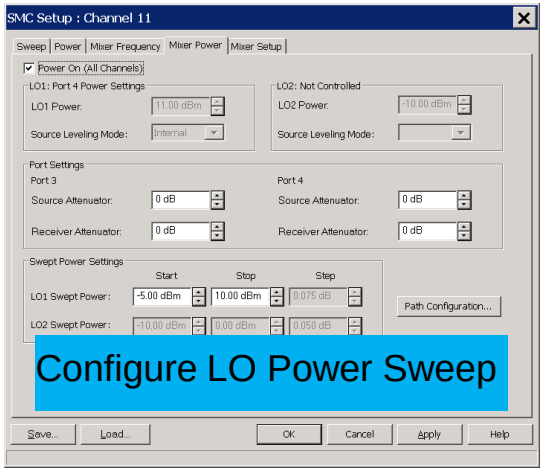
Configure Fixed Frequency

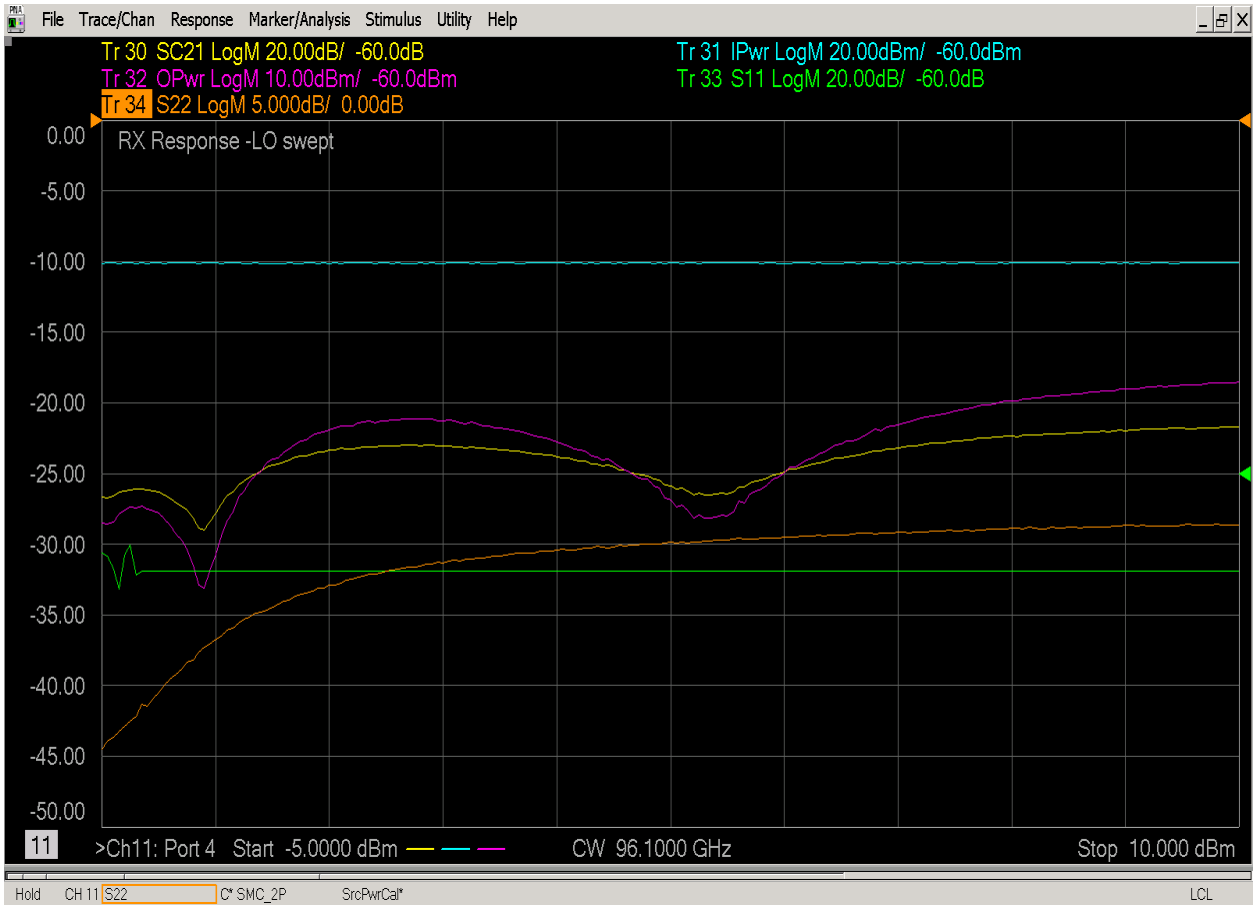


Configure RF Power Sweep

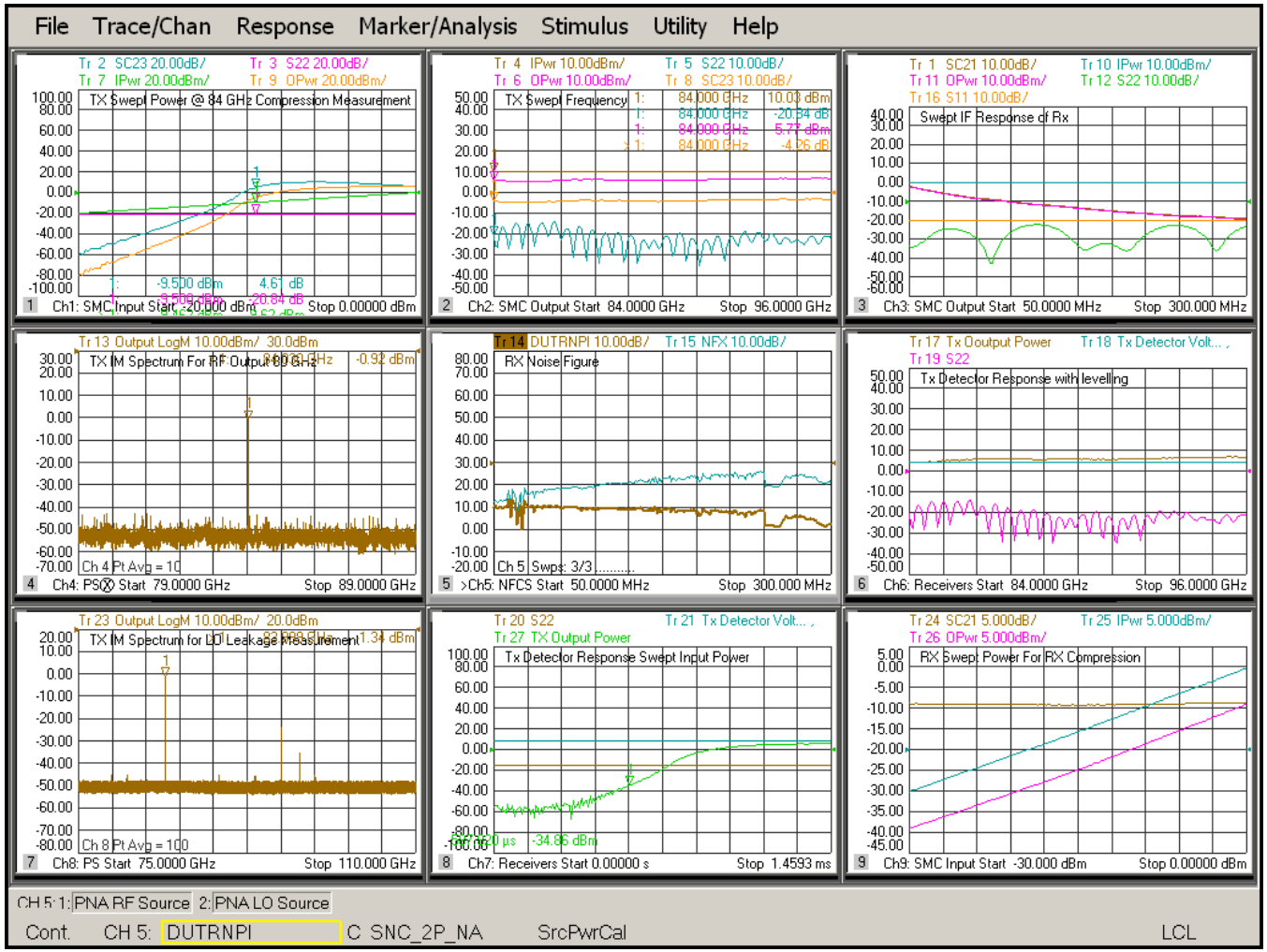


Adding Rx Swept LO Response





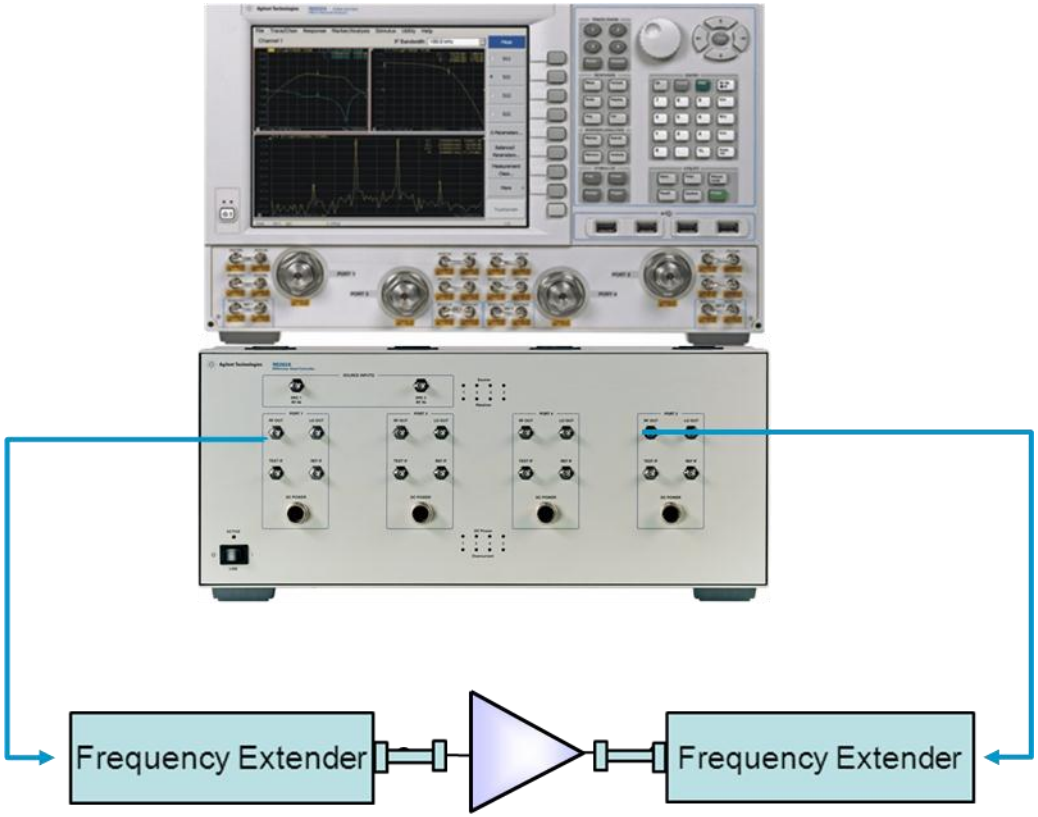
Summary SCMM of 60 GHz Tx / Rx components



Agenda

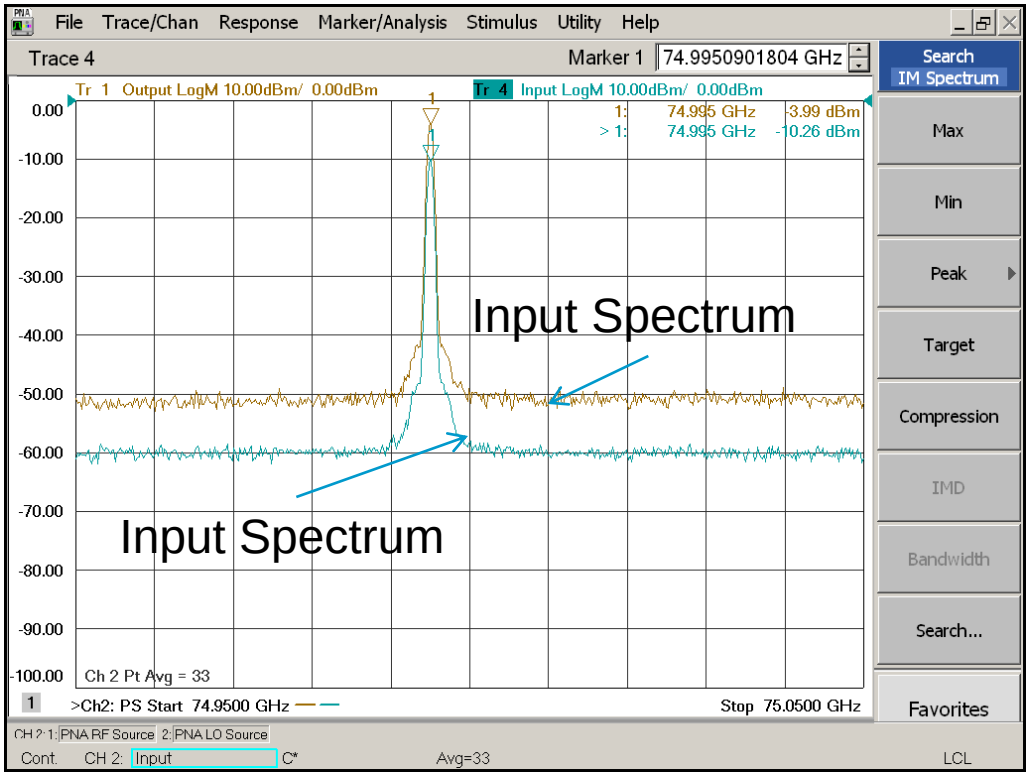
- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - SCMM of 60 GHz Tx / Rx components
  - **IMD Spectrum measurements**
  - THz Power Calibration
  - Materials Measurements at THz
- **Q&A**

Measurement Setup



IM Spectrum: Measurement

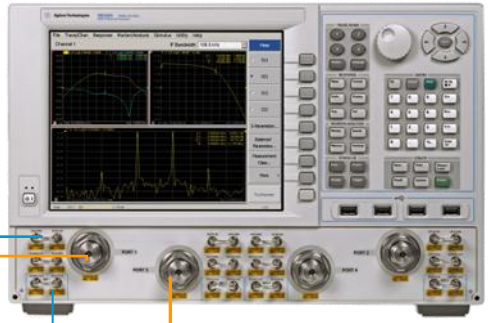
- Measurement Setup
  - Assign Measurement class
  - Set Path configuration to Thru path
  - Setup the port power to correct
- Stimulus
  - Set start and stop frequency
- Measure
  - Input and output Spectrum



Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - SCMM of 60 GHz Tx / Rx components
  - IMD Spectrum measurements
  - **THz Power Calibration**
  - Materials Measurements at THz
- **Q&A**

THz Power Calibration
WR1.5 System Configuration



Analogue Input (AI1)

LO

TEST IF

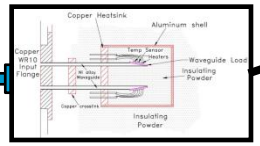
REF IF

0-10 Volt Output
Per Power Range

Power Supply

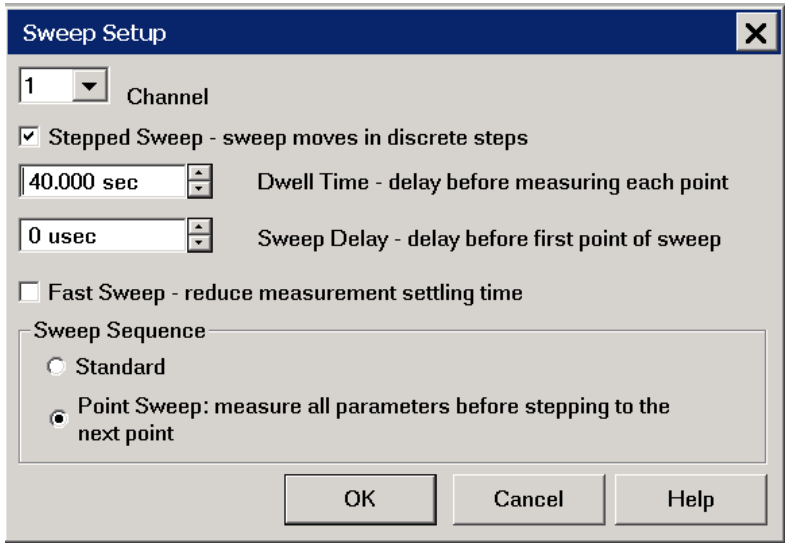
DC

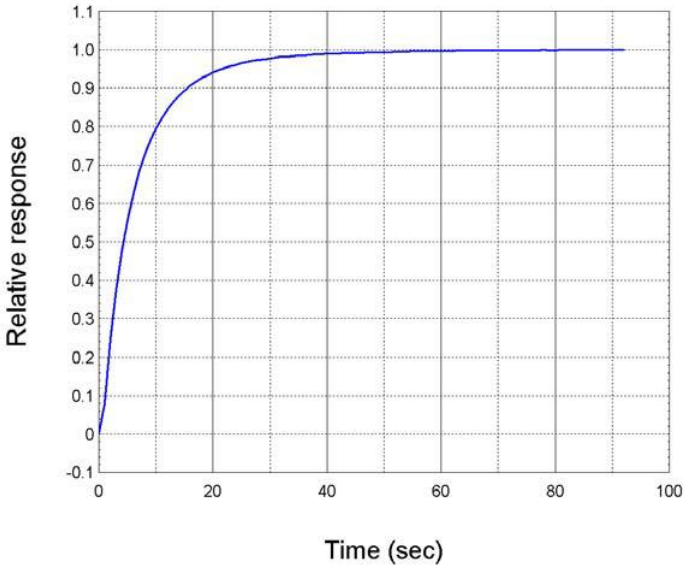
Calorimeter Module



WR-1.5
500 – 750 GHz

Sweep Setting – PM-4 200 µWatt Range

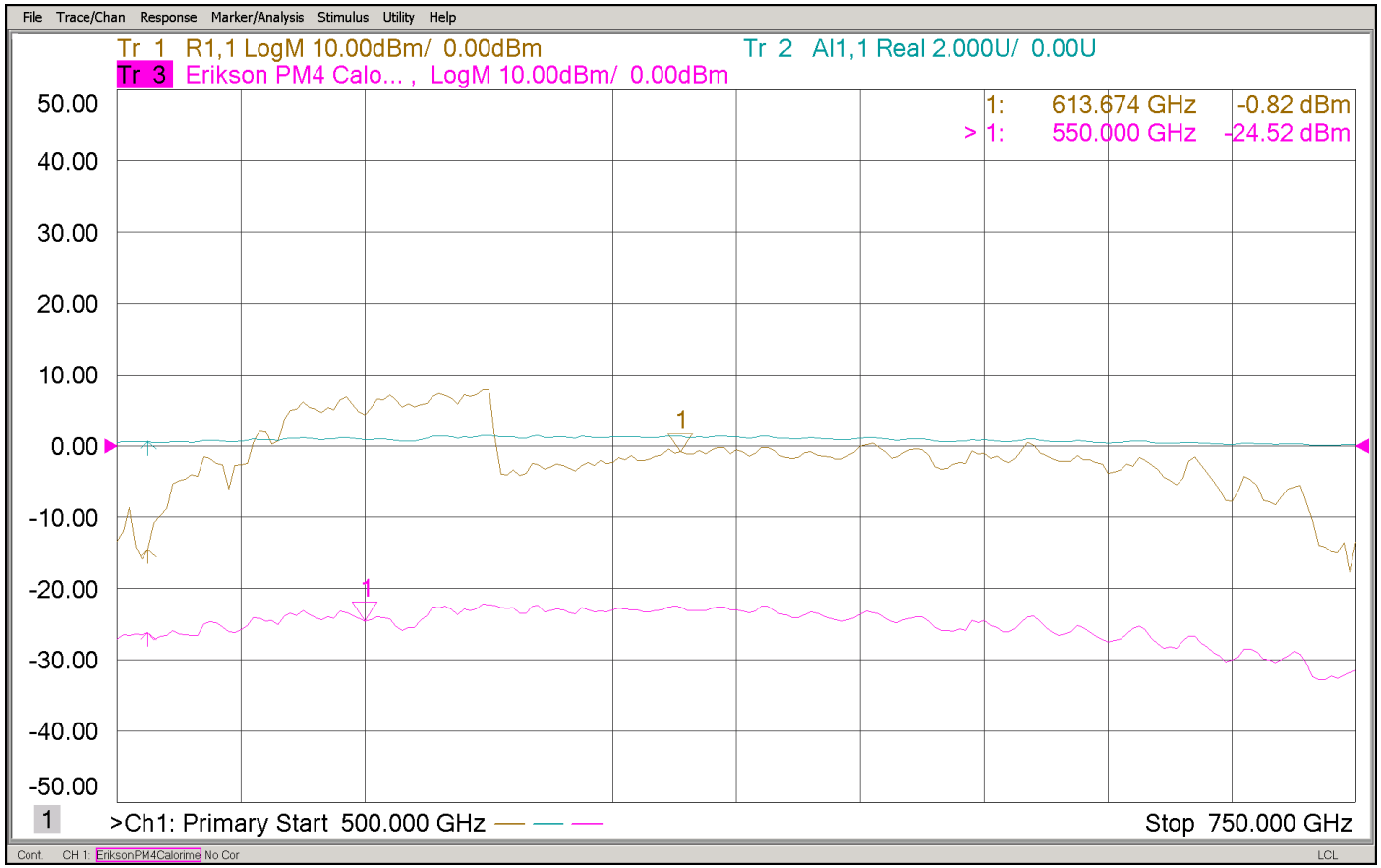




PM4 Port Power Characterization

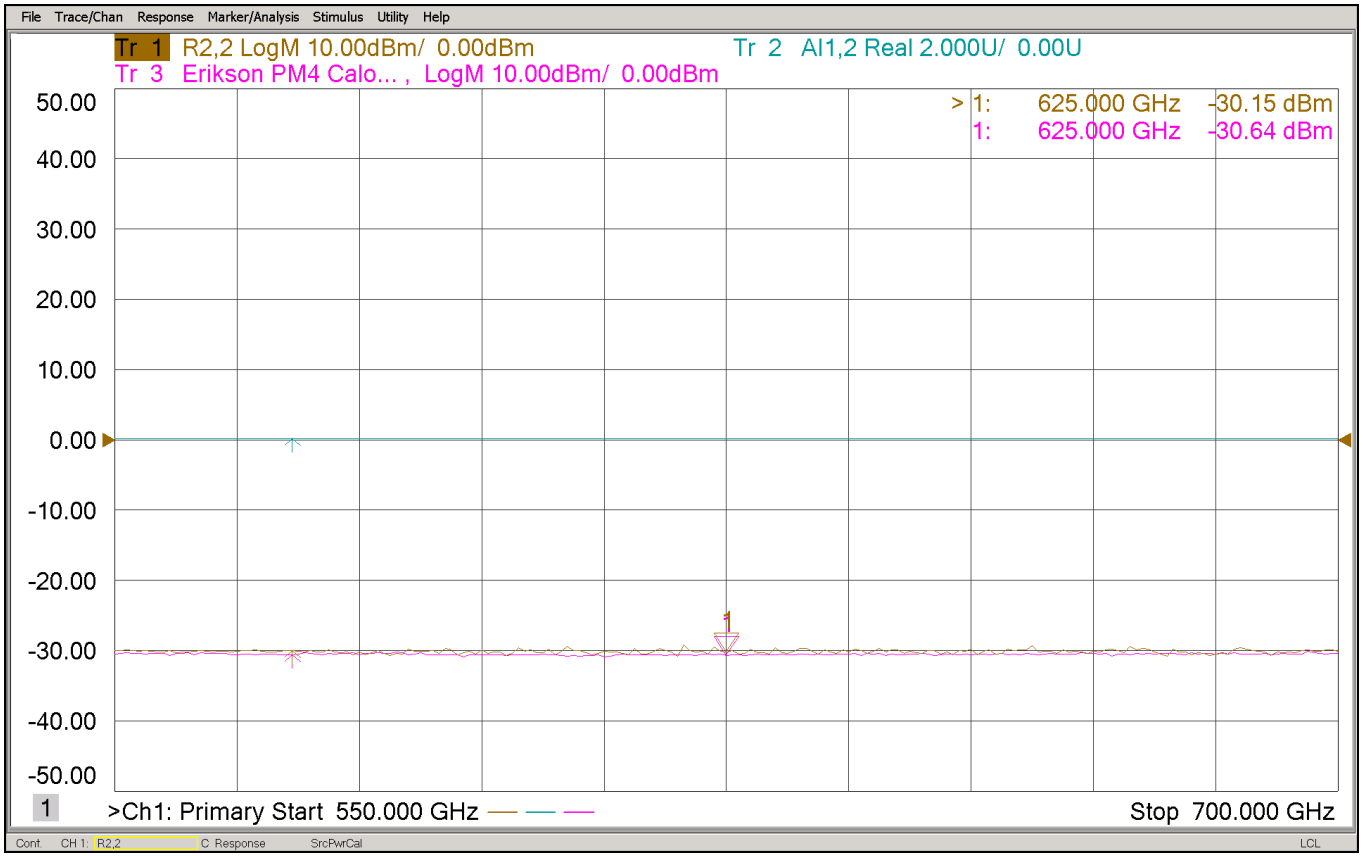
1. Measurement of power with the PM4 at these frequencies are very sensitive and require at least a 20 second settling time for a valid measurement
2. Configure the system to sweep the frequency range of interest as well as the number of points
3. In this example we use 500 GHz - 750 GHz with 201 point characterization, while it is not required for the source calibration it provides the full characterization
4. Turn off RF to the Frequency extender zero and calibrate the Calorimeter
5. Turn on the RF and save the measurement results as a file.

PM4 Port Power Characterization



- Note Trace 3 above is created by using the equation editor to convert the analog input AI1,1 into a power reading of dBm.
- In this example we do this by taking the displaying the (sqrt (Tr2/50)), in which 50 is the 10V to 200 uWatt range
- Save Trace 3 above into a file and add the RF power setting used, in this example we used +3 dBm

Verification of calibration

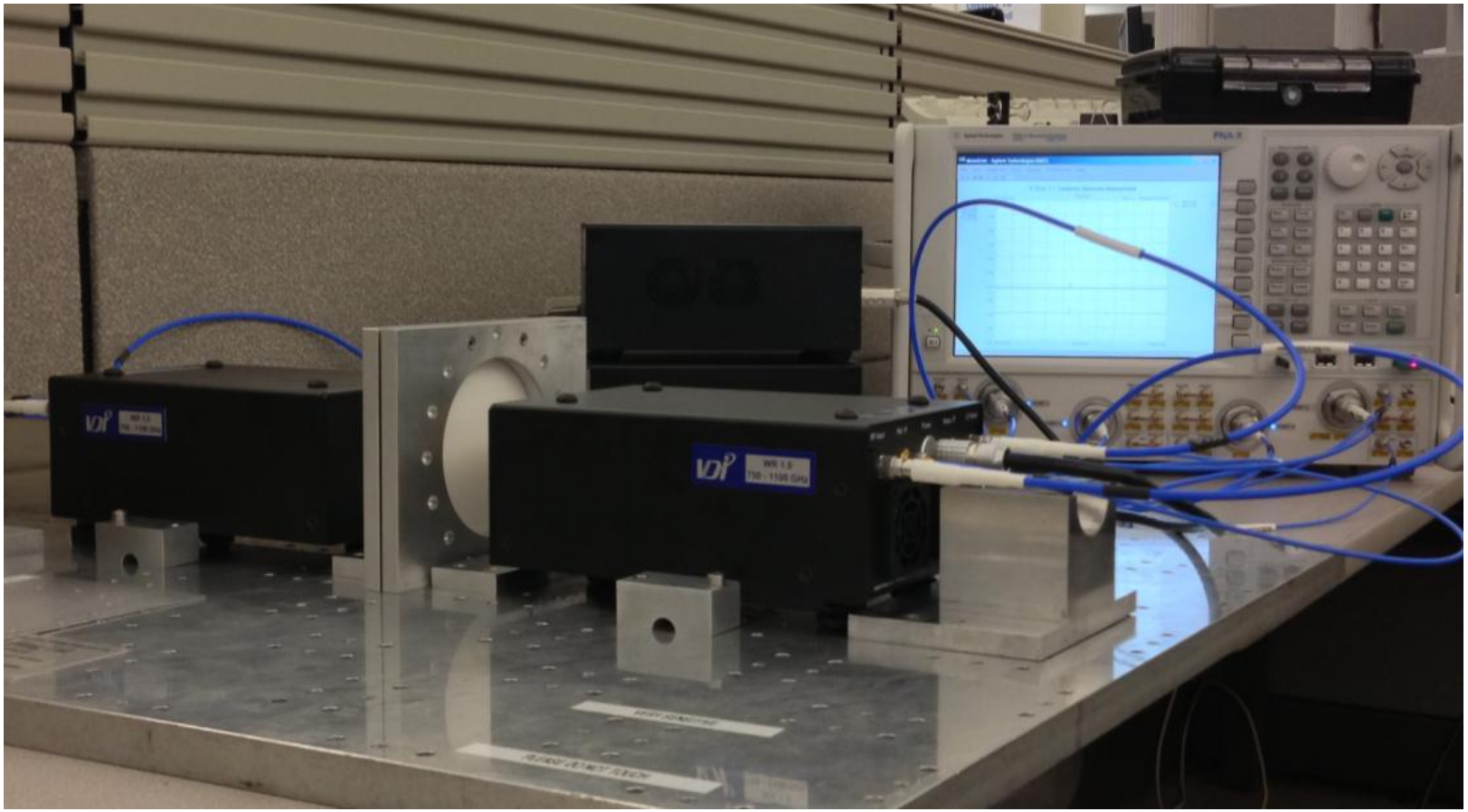


Measurement of port 2 source power as shown by the PNA-X receiver R2,2 in comparison to the actual measured PM4 power at port 2.

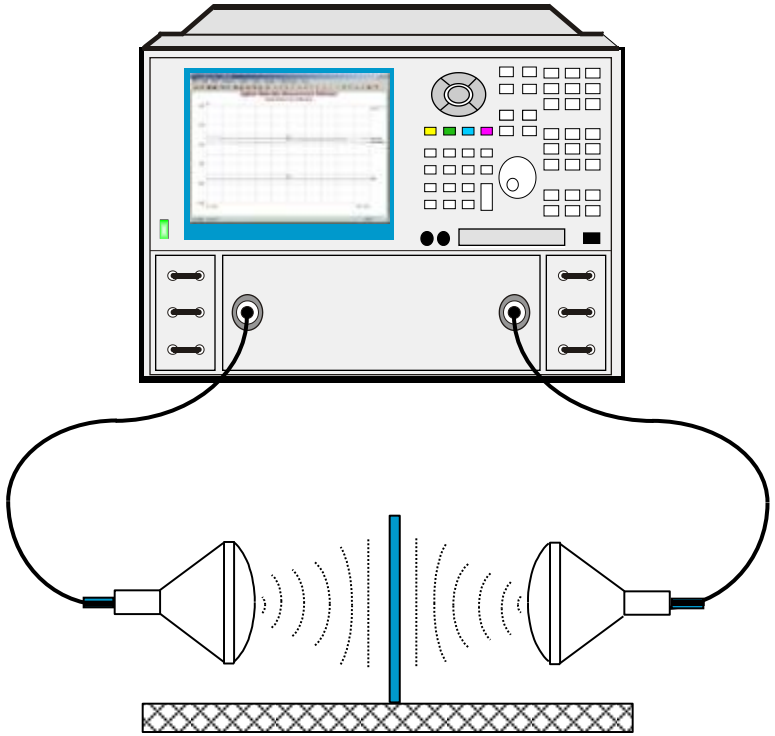
Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - SCMM of 60 GHz Tx / Rx components
  - IMD Spectrum measurements
  - THz Power Calibration
  - **Materials Measurements at THz**
- **Q&A**

THz Materials Measurement Solution

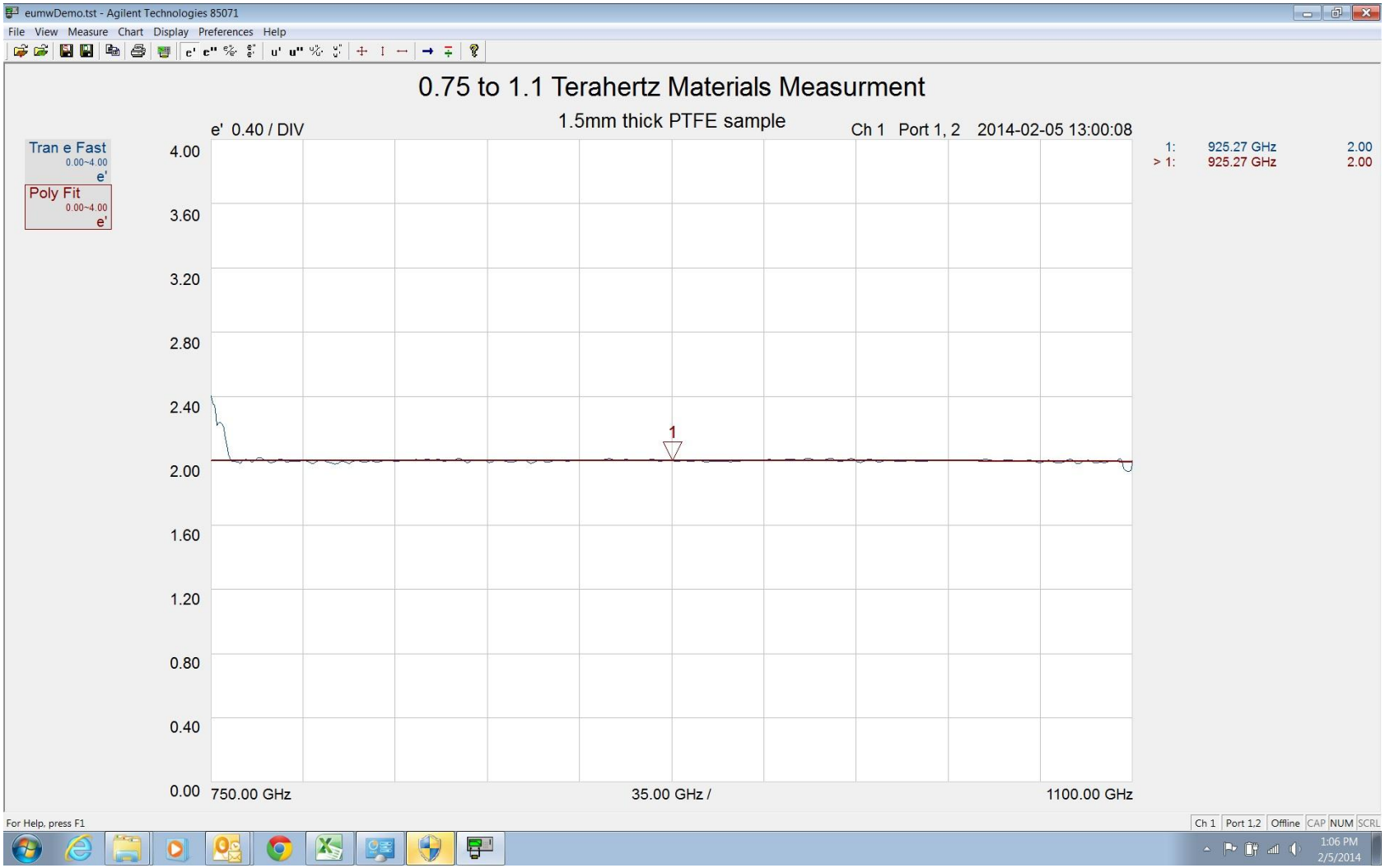


Calibration is Required

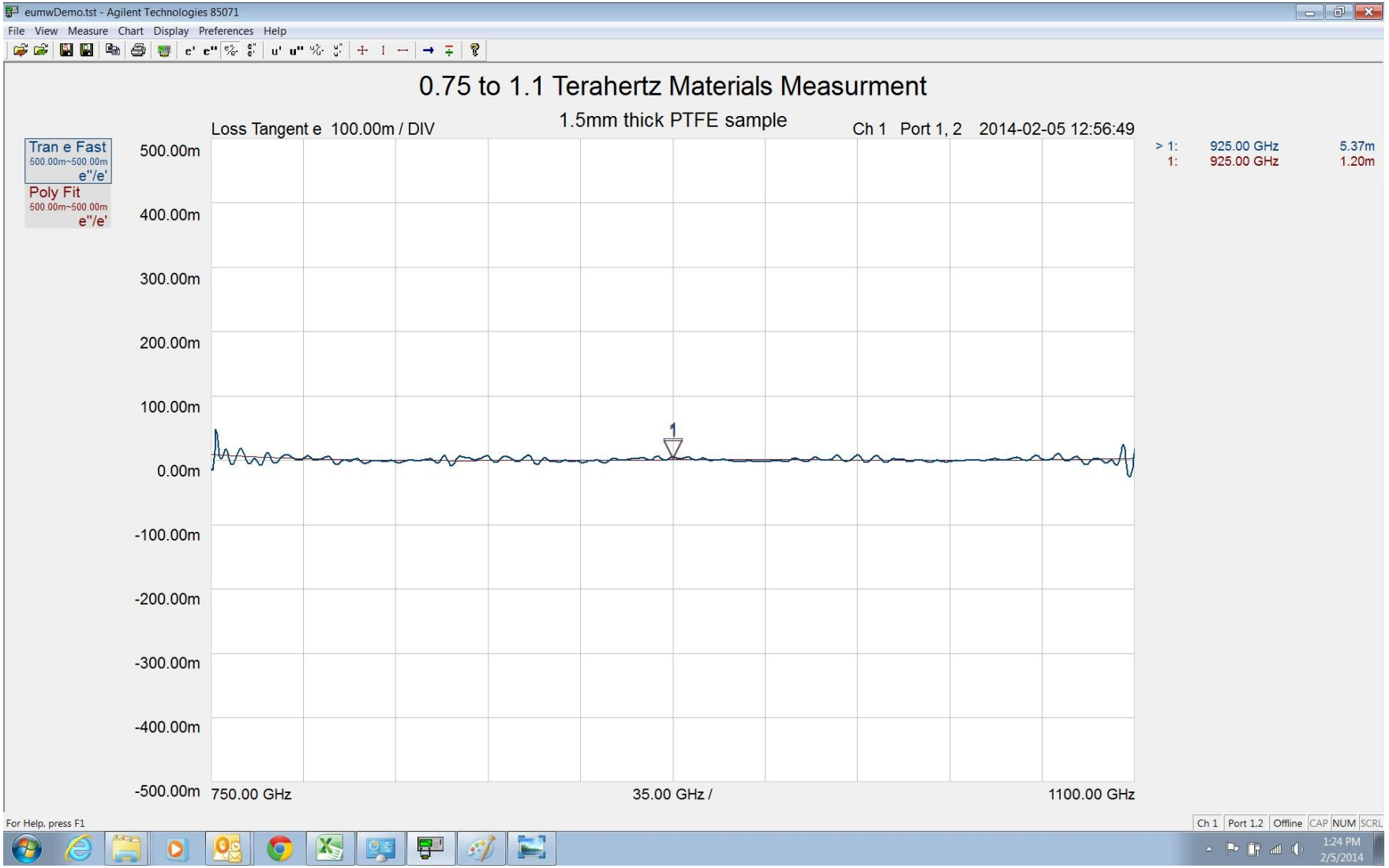


Before a measurement can be made, a calibration must be performed to remove systematic errors.

THz Materials Measurements e' Real Part Permittivity



THz Materials Measurements e'/e" Tan Delta



Agenda

- **Millimeter wave and THz applications**
- **Measurement Solution**
  - Basic system architecture
  - Capability Enabling Active Device Measurements
- **Active Device Measurements**
  - SCMM Broadband Amplifier Characterization
  - SCMM of 60 GHz Tx / Rx components
  - IMD Spectrum measurements
  - THz Power Calibration
  - Materials Measurements at THz
- **Q&A**

Thank You