Fast, Simple, Accurate
Applies to Mixers Too

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All-in-one Measurement Systems

**SCMM**
Performs S-parameter, IMD, Gain Compression, Pulsed Parameter, and Noise Figure measurements with one insertion

**Gain Compression**
Simultaneously sweeps both frequency and output power at 1dB compression

**Sub-1dB Noise Figure**
Source match corrects to make high-accuracy noise figure measurements possible

**Swept IMD**
Performs a complete intermodulation distortion analysis over an entire range of frequencies

**Converters**
Accurately measures phase, frequency, and delay response of frequency translation devices, even with embedded LO’s

**NVNA**
Completely characterizes all linear and nonlinear properties of your active device by extracting X-parameters

**Pulsed Devices**
Internally generates modulated pulsed output to characterize pulse performance with up to 5 MHz bandwidth
Traditional methods of testing converters/mixers

Straightforward setup, but…

• Conversion loss only; no phase/delay info.
• Can’t measure input/output match
• Need controller for swept testing (slow, 1 sec per point)
• Low to medium accuracy (use attenuators to improve mismatch)
Block Diagram for converter and mixer measurements:

Now one of the two sources is used as an LO
Scalar Mixer Cal Measurement of a Mixer

Mini-Circuits SIM-153, driven as in the mixer setup

• Notice ripple is less than +/- 0.1 dB

• Up and down conversion shown
Until Now, SMC and VMC Were Two Best Choices for Converter Test

Scalar Mixer/Converters (SMC)
- Highest accuracy conversion-loss/gain measurements with simple setup and cal
- Removes mismatch errors during calibration and measurements by combining one-port and power-meter calibrations

Vector Mixer/Converters (VMC)
- Most accurate measurements of phase and absolute group delay
- Removes magnitude and phase errors for transmission by calibrating with characterized through mixer

Conversion gain and match
- Simple setup with no external signal source
- Match correction ELIMINATES ATTENUATORS!

Conversion gain, delay, and match
- Simple setup with no external signal source
- Match correction ELIMINATES ATTENUATORS!

Scalar Mixer/Converters (SMC):
- DUT
- Power sensor
- ECal module

Vector Mixer/Converters (VMC):
- DUT
- Reference mixer
- Calibration mixer/filter
- ECal module
- Reference mixer
- Calibration mixer/filter
- ECal module
VMC Requires Reference and Calibration Mixers

Characterizing the calibration mixer:
- RF
- LO
- IF
- \(\text{IF}^- = \text{RF} - \text{LO}\)

Calibration mixer/filter pair (cal mixer must be reciprocal)
Challenges of VMC Approach For Phase and Delay

- Difficult to find mixers that match frequency plan of DUT, especially above 26.5 GHz
- Difficult to find reciprocal calibration mixer
- Difficult to find proper filter for calibration mixer
- Often takes many mixers to cover multiple DUTs
- Often takes multiple calibrations to cover all the frequency bands of DUT
Scalar Mixer: Now with Phase and Delay
- Requires no reference or calibration mixer
- Equally effective on converters with an embedded LO
NEW! Measure Gain, Phase, and Absolute Delay with SMC+Phase

- Simple setup with no external signal source and NO REFERENCE OR CALIBRATION MIXERS!
- Will replace VMC for most applications

SMC+Phase
- Highest accuracy conversion-loss/gain and phase/delay measurements with simple setup and calibration
- Removes mismatch errors during calibration and measurements

(power sensor, Comb generator, ECaL module, DUT)
New Method Eliminates Reference and Cal Mixers*

- Simple setup – only need cables for input, output, and LO
- Easy calibration using three broadband standards
  - Power meter for magnitude standard
  - Comb generator for phase standard
  - S-parameter calibration kit (mechanical or ECal module)
- All cal standards traceable to NIST
- Works with PNA and PNA-X
- Works with embedded-LOs
- **Measure any converter within frequency range of instrument**

* Requires firmware revision A.09.50, available mid 2012
SMC+Phase Relies on Coherent Phase Measurements of Individual VNA receivers

**New:** PNA-X utilizes a high-modulus fractional-N synthesizer with an integrated phase accumulator, providing coherent single-receiver (un-ratioed) phase measurements

**Old:** Most VNAs do not produce coherent phase across frequencies for single-receiver measurements
SMC+Phase: How Does it Work?

- Technique relies on **phase coherency** of fractional-N sweeps to **eliminate reference mixer**
- Phase is **normalized** to eliminate sweep-to-sweep changes in phase offset
- Phase discontinuities removed at **band crossings**
- Absolute group delay does not depend on absolute phase, only on **change in phase versus frequency**
SMC+Phase Calibration Choices for Phase/Delay

Choice 1: Mixer with known delay
- Uses fixed value of delay (average of mixer delay versus frequency)
- Delay can be determined from simulation or measurement

Choice 2: Characterized mixer
- Uses actual delay data versus frequency
- Uses same characterization method as VMC (based on reflection measurements)
- Requires reciprocal mixer plus filter for selecting desired conversion product

Choice 3: Comb generator
- Uses a two-tier approach, where tier one is a power and phase calibration
- Second tier requires S-parameter calibration only

New!
Comb Generator

- Provides broadband phase-calibrated frequency spectrum to calibrate the phase of the VNA receivers
- Driven from VNA’s 10 MHz reference
- Calibration method is derived from electro-optical sampling, and is traceable to NIST
- Same comb generator used with NVNA
Phase Reference Characterization Wizard (Tier 1)

- Performed at VNA test ports to eliminate adverse cable effects
- Typically done over full frequency range of instrument
- Due to stability of instrument, can be done infrequently
- Includes power calibration (using power sensor)
SMC+Phase Calibration Wizard (Tier 2)

- S-parameter calibration only, at end of cables or probes
- One-step cal if ECal connectors match those of DUT
VMC (using a reciprocal mixer) and Phase-Reference Calibration Comparison
Phase-Reference Calibration Comparison with two-tone methods: two-tone does not correct for mismatch
Agenda: Making I/Q Mixer Measurements

- Describes the challenges of making measurements on IQ Mixers.
- Reviews a list of measurements typically performed on IQ Mixers.
- Presents the Single Connection setup using the 4-Port PNA-X VNA.
- Outlines the measurement setup and calibration processes.
- Presents example results.
Motivation

- Nearly all component manufacturers have IQ mixers in their catalogs.
- New radio designs incorporate IQ mixers in a push to integrate more functionality into single assemblies.
- Review of IQ mixer data sheets reveals a set of complex measurement challenges that instrument vendors must address.
- Modern multiport VNAs, with advanced active measurement applications, provide opportunities for simplification of setup and calibration, while improving repeatability and overall accuracy.
Measurement Requirements

Measurements Typically Included in IQ Mixer Data Sheets:

- Conversion Gain/Loss
- Return Loss – RF, LO, IF1, and IF2 Ports
- Input P1dB Compression over RF frequency range
- Input IP3 over RF frequency range
- Isolations – LO to RF, LO to IF1 & IF2, RF to IF1 & IF2
- Amplitude Balance – Ratio of IF1 to IF2 magnitude
- Phase Balance – Ratio of IF1 to IF2 phase
- Most measurements performed over multiple LO drives and/or Temperatures
- Other measurements may include image rejection, Noise Figure, and bidirectional performance – i.e. Up/Down Converter
Measurement Challenges

- Setting up and calibrating frequency offset measurements are typically harder and requires more equipment.
- An IQ mixer is actually two mixers.
- Single Ended IQ mixers have 4 ports – Differential versions can have as many as 8 ports.
- Conversion Phase measurements are complicated and normalized phase can’t be used in this application.
Hardware Configuration
Measurement Configuration

Divide & Conquer Strategy

- Separate out the measurement that require Frequency Offset Mode (FOM) from the ones that don’t.
  - Isolation and return loss types of measurements don’t require FOM.
  - Conversion Gain/Loss, P1dB, IMD, … do require FOM

- Identify measurements that can be corrected with simple response corrections versus the ones that require Vector corrections
  - Isolation, Return Loss, Gain measurements require Vector corrections.
  - IMD, Power and Phase ratios can be response corrected
Measurement Configuration
(Cont.)

Planning Ahead

- Measurements that share the same stimulus and response conditions can share the same channel
  - Example: All the LO to RF and IFx isolation measurements can be grouped in one channel. Same is true for RF to IFx isolation measurements
  - The same channel that measures the RF port return loss can also measure the incident power
- Specialized measurements such as IMD or swept frequency Gain Compression require their own channels and calibrations
- Make use of the Equation Editor
  - Many times more complex results can be computed based on simpler underlying measurements.
Measurement Configuration
(Cont.)

Using New Calibration Technology To Your Advantage

- PNA-X’s new Guided Power Calibration can make short work of calibrating all sources and receivers as well as producing n-port S-Parameter calibrations.

- Don’t be afraid of $C^*$ and $C\Delta$ (i.e Interpolation)

- For more complex calibrations, let the wizards guide you.
### Measurement Configuration (Cont.)

<table>
<thead>
<tr>
<th>File</th>
<th>Trace/Chan</th>
<th>Response</th>
<th>Marker/Analysis</th>
<th>Stimulus</th>
<th>Utility</th>
<th>Help</th>
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<td>Tr 1</td>
<td>0 P1_LogM 5.000 dBm -12 dBm</td>
<td>Tr 2</td>
<td>0 P1_LogM 5.000 dBm -12 dBm</td>
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<tr>
<td></td>
<td>Tr 16 P1_LogM 5.000 dBm / -12 dBm</td>
<td>Tr 17 P1_Chr_LOGM 5.000 dBm / -12 dBm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tr 18 P2_ChrLOG 5.000 dBm / -12 dBm</td>
<td></td>
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</tbody>
</table>

**4-Port Guided Power Cal**

**GCX CAL**

**IMD Cal**

**Contours CH 1 Phase Imbal CH 4-Port SrcPwrCal**

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Mixer Setup
Mixer Frequency Setup

Gain Compression for Mixer/Converer Setup: Channel 5

- **Input**: Start/Stop, Frequency options: 11.00000000 GHz, 14.00000000 GHz, Calc Input
- **LO1**: Fixed, Frequency: 10.00000000 GHz, Input > LO
- **Output**: Start/Stop, Frequency options: +21.00000000 GHz, +24.00000000 GHz, Calc LO, -1.00000000 GHz, -4.00000000 GHz, Calc Output
Results: Conversion Loss computed use test receivers (B, and D) and reference receiver

Conversion Loss

> 1: 12.500 GHz -8.62 dB
1: 12.500 GHz -8.18 dB

Q_pwr

I_pwr
Results
(Cont.)

Return Loss

Tr 7: RF_RL LogM 5.000dB/ -15.0dB
Tr 9: IF2_RL LogM 5.000dB/ -15.0dB
Tr 10: LO_RL LogM 5.000dB/ -15.0dB

Ch2: Source Start 11.0000 GHz Stop 14.0000 GHz
Ch3: Source Start 1.00000 GHz Stop 4.00000 GHz
Ch4: Source Start 8.00000 GHz Stop 14.00000 GHz
FOM Setup

Frequency Offset: Channel 1

- Frequency Offset (ON/OFF)
  - Primary: Segment Sweep 11.0000000000 GHz - 14.0000000000 GHz, 2 segments
  - Source: Segment Sweep 11.0000000000 GHz - 14.0000000000 GHz
  - Receivers: Coupled Segment Sweep 1.0000000000 GHz - 4.0000000000 GHz
  - Source2: Coupled Segment Sweep 11.0000000000 GHz - 14.0000000000 GHz
  - PSG: Un-Coupled CW Time CW Freq 10.0000000000 GHz

X-Axis Display
- Annotation: Source
- X-Axis Point Spacing

Primary (Segment Sweep)

- Seg # | State | Start | Stop | Points
  - 1  | ON    | 10.010000 GHz | 10.010000 GHz | 201
  - 2  | ON    | 11.000000 GHz | 14.000000 GHz | 401

Sweep Properties
- Independent Power Levels
- Independent IF Bandwidth
- Independent Sweep Time

Total Number of Points
- Channel: 602
- Active Segments: 602

Add Segment | Delete Segment

OK | Cancel | Help
Results

(Cont.)

IQ Imbalance

1: 12.500 GHz -0.44 dB

> 1: 12.500 GHz 93.22°
Results: Isolation Measurements

(Cont.)

![Graph showing isolation measurements with different channels and frequencies.](image)

- Tr11 LO_RF_Iso LogM 10.00dB/ -50.0dB
- Tr13 LO_IF2_Iso LogM 10.00dB/ -50.0dB
- Tr15 RF_IF2_Iso LogM 10.00dB/ -50.0dB

- Ch4: Source Start 8.00000 GHz, Stop 14.0000 GHz
- Ch2: Source Start 11.0000 GHz, Stop 14.0000 GHz
Summary

- Complete characterization of a single ended IQ mixer can be achieved
  - With a simple test setup
  - With only one connection to a 4 port PNA-X

- New Calibration Techniques can be used to simplify calibration procedures

- Phase Imbalance can be measured without the need for a reference mixer, using a simple response correction.
FCA Segment Sweep
What Is It?

• Segment Sweep in FCA is a way to combine multiple mixer setup configurations into a single measurement channel with some restrictions:
  • All segments share the settings that are on the Mixer Setup Tab
    • The Input, Output, and the LO port selections.
    • The Converter Stages selection
    • The Input and LO multipliers and divisors.
  • All segments share the same source and receiver attenuation values
  • In a segment, input, output, and LO frequency ranges can be independently specified, where each segment can have a different set of fixed or swept ranges.
FCA Segment Sweep (Continued)

What Is It?

• Each segment can have a different IF Bandwidth

• Each segment can have a different input port, output port, and LO port power level (the power levels must all fall within the ALC range of the associated source, given a fixed attenuation value for all segments)

• Each segment can have a different number of points, but the total points must be less than or equal to the maximum points (currently 32001)

• Each segment can be independently turned on or off, but at least 1 segment must always remain on when in Segment Sweep mode.
Why Use FCA Segment Sweep

• There are a number of different mixer measurement scenarios where currently PNA users are forced to create multiple SMC/VMC channels to get the results they want.

• When multiple channels are used, often time, each channel has to be independently calibrated and that results in repeated calibration steps using the same standards over and over again. An FCA channel in segment sweep mode, requires only a single calibration process to calibrate all segments.

• If you have to create more than 1 SMC or VMC channel to measure your mixer/ converter today, then using FCA Segment Sweep will most likely simplify your task.
Segment Sweep Scenarios

• Measuring a multi-channel converter (a converter with a switched RF or IF filter bank)

• Measuring conversion loss and other attributes at different LO power levels

• Measuring conversion loss and other attributes at different input power levels.

• Measuring the group delay of a multiple LO frequency mixer/converter
Setting Up FCA Segment Sweep

• Currently the segment sweep type is only available for SMC and VMC measurement classes.
• The mechanics of setting up segment sweep is the same in both measurement classes.
• Start by selecting the sweep type:
Setting Up FCA Segment Sweep (Continued)

• Some settings are common for all segments, so they should be set first
Setting Up FCA Segment Sweep (Continued)

• The segment mixer settings are managed through the Mixer Frequency Tab

Remote Programming
For COM/DCOM use the IConverter Interface
For SCPI use the SENSe:MIXer:SEGMenT commands
See PNA Help for examples

1) Segment Number – Use this entry to navigate through all the segments.
2) State – You can use this entry to turn individual segments on or off.
3) Add/Delete – You can add or delete segments.
   ✓ There are no limits on the number of segments that can be added as long as the total number of points does not exceed the maximum.
   ✓ When segments are deleted, the remaining ones are renumbered.
   ✓ Any segment can be deleted as long as there is at least 1 segment remaining.
   ✓ For convenience, when a segment is added, it is a copy of the previous segment.
4) Mixer Frequencies – This part of the setup works just like the standard mixer setup.
   ✓ A segment can consist of any valid mixer configuration.
   ✓ Different segments can have overlapping input, output, or LO frequency ranges.
5) Num Pts – Use this entry to set the number of points for the selected segment. Each segment can have as few as 1 point and as many as needed as long as the total remains at or below the maximum.
6) IF Bandwidth – Each segment can have a different IF Bandwidth if needed.
7) Port Powers – Each segment can have a different set of power levels for input, output and LO.
Displaying Segment Sweep Results

• In segment sweep mode, the traces can be displayed in two different modes, Normal and X-Axis Point Spacing

  • **Normal**: This is the default configuration and in this mode the data corresponding to each segment is displayed in order of frequency from low to high.
  
  • The frequency range used is determined by the trace’s X-Axis selection (Response->Measure->Select X-Axis-> menu)

  • If for the selected x-axis range (Input, Output, or LO), the segments are not overlapping, then the first segment displayed will be the one with the lowest frequency. This means that segments may be displayed in a different order than they appear in the segment table.

  • If the segments are overlapping then the results will be re-traced on the screen such that two or more data points may appear at the same x-axis value.

![Graphs showing Normal and Overlapping Segment Display](image)
Displaying Segment Sweep Results (Continued)

- Issues to Consider With Normal Mode:
  - In the overlapping case, markers have to be placed using a bucket index number rather than frequency.
  - In the overlapping case, different limit masks cannot be created for the results from different segments, where they overlap.
  - In the overlapping case, marker search user ranges cannot be used to restrict the search to a specific segment.
Displaying Segment Sweep Results (Continued)

• X-Axis Display Mode:

  • In this mode all the data points in in all the segments are given equal display space in consecutive order without any gaps in the display where there are gaps in frequency. For example a segment with 11 points spanning 10 MHz of the frequency band, takes the same amount of trace display space as an 11 point segment spanning 10 GHz of the frequency band.

  • If the segments overlap in any way and the user selects the X-Axis Display mode, then the x-axis variable becomes the actual index of the data points and the segment results appear on the trace in the order they appear in the segment table. For example if there are two segments with 201 points each, then the first point on the trace is at index 1 and the last point on the trace is at index 402.

  • In the X-Axis Display mode with overlapping segments, markers are placed using the index number, but the marker displays shows the corresponding frequencies based on the traces x-axis selection (Input, Output, or LO).
Displaying Segment Sweep Results (Continued)

• X-Axis Display Mode Limits & Data Analysis:

• In the X-Axis Display mode with overlapping segments, just as with markers, limits and user ranges are created using the data point index values, so it is very easy to setup different limits for different segments and to confine the search range of markers or data analysis functions to individual segments using the user ranges.
Example 1 – Measuring a Dual Channel Downconverter

In this example we’ll see how to setup an SMC segment sweep measurement to measure the conversion loss and the group delay of a two channel downconverter that downconverts from 20 GHz to two 75 MHz channels at about 1.8 and 1.9 GHz. The DUT has a common RF band centered around 20 GHz and the channel selection is done through the LO frequency. We’ll also go through the calibration process for this measurement.
Example 1 - Calibration

Start the calibration wizard and setup for an SMC+Phase calibration using a calibration mixer with known delay.
Example 1 - Results
Example 2 – Measuring Conversion Loss At Multiple LO Power Levels

• In this example we’ll use the first channel of our dual channel converter and see how the conversion loss of that path changes with varying LO power levels. We’ll test our device at 5 different LO power levels: 0 dBm, 4 dBm, 7 dBm, 10 dBm, and 13 dBm.

• Because these measurements are done at the same frequencies as our previous example, we can reuse the calibration from example 1.

• We will simplify creating our setup by using the Copy Channel feature to make a copy of our SMC channel from example 1 and then delete the 2nd segment and add 4 new identical segments with only a change in LO power.

• We will then look for the maximum conversion gain in each segment by utilizing the user range feature.
Example 2 - Results

These results show that our converter starts to compress at LO Power levels above 10 dBm.
Example 3 – Measuring Conversion Loss At Multiple Input Power Levels

• In this example we’ll again use the Copy Channel feature to simplify our setup task, by copying the channel from example 2 to a new channel, deleting all but the last segment and creating 4 new segments.

• With 5 identical segments with LO power set to 13 dBm (the optimal level from example 2), we’ll set the input power levels of the 5 segments to -30, -27, -24, -21, and -18 dBm respectively.

• Again we will look at the conversion loss, this time as a function of input power.

• This technique will allow us to look at the conversion loss profile as a function of input power and the results can be used to for example easily analyze gain flatness at different power levels. However if we want to find the actual compression point of the converter at different frequencies, we can use the GCX measurement class. We will take a more detailed look at GCX later in this presentation.
Example 3 - Results

These results show that our converter starts to compress at Input Power levels above -30 dBm
Example 4 – Measuring The Group Delay Of a Fixed IF Converter

• Measuring the group delay of a converter with both swept input and LO frequencies has always been a difficult challenge. Group Delay is given by:

\[
\text{Group Delay}(IF) = -\frac{df}{dw}
\]

\[
df = F(RF_j) - F(RF_i)
\]

\[
dw = \Phi(IF_j) - \Phi(IF_i)
\]

• This equation assumes that \( dw \) is measured on the IF, which by definition means the output frequency of the converter cannot be fixed in a group delay measurement. Secondly the equation also assumes that the only contributor to the IF Phase change is phase change on the RF or input.

• Both these assumptions make measuring the group delay of a fixed IF converter in a traditional way impossible.

• The problem can be simplified if a fixed IF measurement was divided into a number of fixed LO measurements where each measurement represented one of the LO frequencies used in the fixed IF measurement and the span of the swept IF represented the required Group Delay aperture.
Example 4 – Measuring The Group Delay Of a Fixed IF Converter (Continued)

• In this example we will use the FCA segment sweep capability in conjunction with the PNA-X’s SMC+Phase feature to do just that.

• We start by setting up a normal Fixed IF mixer measurement of our test converter, setup with an IF centered in the lower channel of the converter and a swept Input and LO range that cover the 75 Mhz width of the channel.

• Because this measurement is within the frequency range of our previous examples, we use the copy channel feature again and also use our existing calibration from example 1.

• You can see the conversion loss and the group delay of the this Fixed IF measurement in the bottom window of the results.

• The conversion gain looks reasonable and matches our previous results at the center frequency, but the group delay is negative!!!

• This is because the phase of the LO changes across the aperture used to measure the group delay at each point.
Example 4 – Measuring The Group Delay Of a Fixed IF Converter (Continued)

• The next step is to create a new channel based on our Fixed IF measurement, where we will have 1 segment for every data point in the Fixed IF channel.

• Each of these segments will have swept input and output range and a fixed LO. The swept output range will be centered at the Fixed IF frequency and the swept Input range will be centered at the corresponding input frequency.

• The span of the swept ranges will be based on the width of the desired group delay aperture. For example in our example the total channel width is 75 MHz and if we want to use a 5% aperture, then the span of each segment will be 3.75 MHz.

• The fixed LO frequency for each segment will be calculated for each input and output range.

• Ideally we would only need 2 points in each of these segments, but in special cases where a segment straddles one of PNA-X band break frequencies, that segment will require additional points.

• All the other attributes of each segment (power levels and IF Bandwidth) will be copied from the original Fixed IF channel.

• The resulting segment sweep channel can be calibrated by itself, using the SMC+Phase calibration, but since we have kept the measurement frequencies within the range of our example 1 calibration we can simply reuse the same calset.
Example 4 – Measuring The Group Delay Of a Fixed IF Converter (Continued)

• If we were measuring only a few frequencies, the setup steps from the previous slide could be done manually by using the copy channel feature. However, in our example we have 101 frequency points in the Fixed IF measurement, so a simple VEE program is used to create the Fixed IF Group Delay Channel

A new channel with 101 segments is created
Example 4 - Results

As you can see, the Fixed IF group delay matches closely the group delay at the center of the band in example 1 results and the conversion gain is also a close match.
Example 5 – Wide-band swept LO, fixed IF

For swept LO delay, each segment makes 1 group delay measurement; the span is the effective group delay aperture.
Example 5 – Wide-band swept LO, fixed IF

Here the Blue trace is LO and RF are stepped in segments over 500 MHz, with a fixed IF offset.
Upper Yellow trace is sweeping the RF and IF, lower Yellow trace is sweeping LO and RF
Introduction

Frequency converters:

- Output frequency is different from input frequency
- Combination of mixer, amplifiers, filters
- May contain embedded local oscillators (LOs)

Integral component for satellite transponders, and for both transmit and receive portions of radar and EW systems
Converter Characterization

Complete characterization of RF performance is essential

- R&D: simulations for system optimization require accurate data
- Manufacturing: ensure sub-assembly specifications are met

Many measurements are same as for amplifier

- Gain, gain flatness
- Phase deviation, group delay
- Port matches
- Compression
- Intermodulation distortion
- Noise figure
Why Consider Changing Test Methods?

**Traditional methods...**

- Slow
- Less accurate
- Require a large suite of test equipment
- Difficult and expensive to configure
- Often require software to synchronize multiple instruments
Using Spectrum Analyzer Plus
Standalone Signal Generators

Conceptually simple, but…

• Difficult to set up (need instruments, combiner, filters, adapters, etc.)
• Magnitude measurements only – no phase or delay information
• Need to add couplers to measure input/output return loss
• Low to medium accuracy (use attenuators to improve mismatch)
• Synchronization among instruments is slow
• Need computer for swept testing
Using Traditional Vector Network Analyzer

Fast for swept testing of:

- Conversion gain, group delay, port matches, and CW compression

But…

- Reference mixer required
- Relative group delay only (compare to a "golden" DUT)
- Cannot test IMD, noise figure
- Medium to high accuracy (1-port, source/receiver cals)
- Older analyzers had problems with phase locking of source
- Cannot measure devices with fully embedded LOs
Modern Approach Using Vector Network Analyzer

With a single connection to DUT, you can measure:

- Conversion gain and absolute delay
- Port matches
- Intermodulation distortion
- Gain compression versus frequency
- Noise figure
- And more….

Plus…

- Fast measurements (up to 100x improvement)
- High accuracy using advanced error correction
- Easy setups with intuitive user interface and guided calibrations
Modern VNA Block Diagram (PNA-X)

Block diagram shown is for 26.5 GHz model. Higher frequency models (43.5, 50, 67 GHz) are similar, but with some variations.
Modern Approach Using Vector Network Analyzer

With a single connection to DUT, you can measure:

- Conversion gain and delay
- Port matches
- Compression versus frequency
- Intermodulation distortion
- Noise figure
Fixed and Swept LO Measurement Examples

Fixed LO

Swept LO

Fixed IF

Swept IF
Speed Improvements with Internal Second Source

SMC Cycle Time (Swept LO/Fixed IF)

- PSG (SW trig) 113x
- PSG (HW trig) 19x
- MXG (HW trig) 6x
- Internal 2nd source 162x
- Correction ON 28x
- IF bandwidth = 100 kHz

Trace points:
- 51: 1x
- 201: 9x
- 1601: 10x

Correlation ON
Embedded LO Problem For Delay Measurements

Problem:
• Can’t lock internal LO of DUT to VNA
• VNA receivers won’t be tuned to exact output frequency resulting in unstable phase/delay measurements

Solution:
• Set frequency of receivers close enough so phase change versus time is small compared to group-delay measurement time
• Normalize phase sweep-to-sweep
Adjusting PNA-X Receivers with Option 084

Coarse-tune process:
- Set input to nominal RF frequency
- Calculate IF based on nominal LO frequency of DUT
- Perform broadband receiver sweep
- Identify center frequency offset
- Adjust receiver tuning of PNA-X

Fine-tune process:
- Perform ratioed phase measurement using R1 and B receivers
- Measure phase versus time
- Use slope to calculate fine offset for receiver tuning

\[ \Delta \text{freq} = \frac{\Delta \text{phase}}{360 \cdot \Delta \text{time}} \]

\[ \Delta f \]

\[ \phi \]

B/R1 sweep

Expected signal → Actual signal

B receiver sweep

|A|
Embedded-LO Group Delay Results

- Memory trace: locked LO
- Active trace: unlocked LO, using embedded-LO application

- Averaging & modest smoothing increases accuracy and precision
- Embedded-LO option also works with IMD, gain compression and noise figure applications
Gain Compression For Converters
For single-frequency measurements, conversion gain can be characterized vs RF or LO drive power.

Magnitude vs. RF Drive

Phase vs. RF Drive
For single-frequency measurements, conversion gain can be characterized vs RF or LO drive power.
Multi-channel sweeps or Gain and Phase vs RF drive level, at several LO power levels
Gain Compression Converter Application (GCX)

### Gain Compression for Mixer/Converter Setup: Channel 6

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Power</th>
<th>Compression</th>
<th>Mixer Frequency</th>
<th>Mixer Power</th>
<th>Mixer Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Sweep</td>
<td>-30.00 dBm</td>
<td>0 dB</td>
<td>Port 1</td>
<td>0 dB</td>
<td>Internal</td>
</tr>
<tr>
<td>CW Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment Sweep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Points: 201</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IF Bandwidth: 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start: 19.962500000 GHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stop: 20.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center: 20.000000000 GHz</td>
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</tr>
<tr>
<td>Span: 751</td>
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<td></td>
</tr>
</tbody>
</table>

**Path Configuration...**

[Agilent Technologies](https://www.agilent.com)
GCX – What’s New In the Setup Dialog?

These 3 new tabs are essentially identical in all converter applications.
GCX – What New Parameters?

- In GCX the linear s-parameters are replaced with the SMC parameters SC21, SC12, S11, and S22.
- In addition the power parameters, such as IPwr and OPwr are also added.
- The power parameters are measured at the Linear Input power level.
- All other parameters are identical to the GCA application.
• GCX has its own calibration wizard, but it is identical in all respects to the SMC cal wizard.
• GCX channels can also recognize and use calsets created by an SMC channel.
• We will use this fact to quickly configure a calibrated GCX channel using the calset from example 1.
Example 5 – Calibrated Swept Frequency P1dB measurement

- The Calibration Selection dialog shows that a common calset can be used for all the measurements we have created in our examples so far.
- With our swept frequency compression measurement (GCX), we can very simply verify the 1 dB compression point of our converter over the entire frequency range of each channel.
Noise Figure For Converters
Noise Figure Converter Application (NFX)

1st 3 tabs identical to NFA

Last 3 tabs identical to other Converter Apps
NFX – What New Parameters?

• In NFX the linear s-parameters are replaced with the SMC parameters SC21, SC12, S11, and S22.
• In addition the power parameters, such as IPwr and OPwr are also added.
• All other parameters are identical to the NFA application.
NFX – What About Calibration?

• NFX has its own calibration wizard and it is nearly identical with the NFA calibration with the addition of an LO power calibration and an additional power calibration for the mixer.
• Both NFA and NFX can utilize the vector or the scalar noise calibration and measurement techniques and both have the option of using the dedicated Noise Receiver or the PNA receiver.
Example 6 – Calibrated Noise Figure Measurement
Important considerations for Noise Figure Measurements on Mixers: Image Rejection

Y-Factor method is often wrong if a mixer does NOT have sufficient image rejection: The noise figure measurement will measure LOW due to excess gain being recorded during the hot measurement.
NFx (cold source measurement) does NOT have this issue (no hot noise source measurements)
All Mixer Noise Figure Measurements are affected by Broadband Noise in the LO.
Filtering the LO can eliminate this error

Red: With LO Filter

Yellow: Without LO Filter

Note: Almost no effect on gain