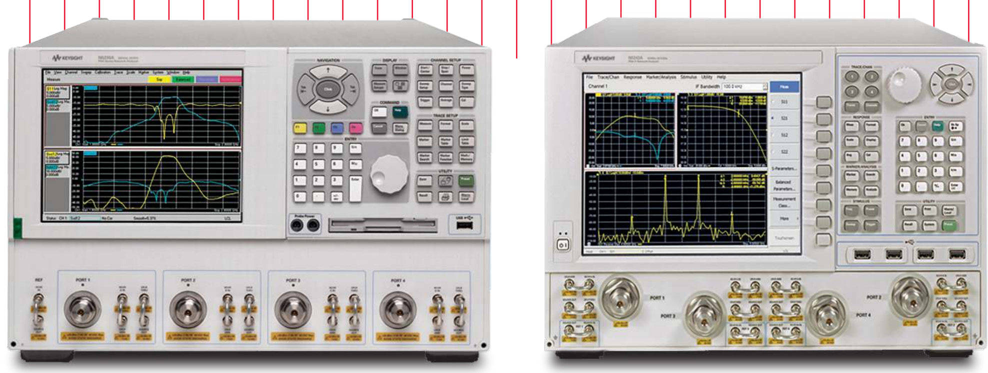
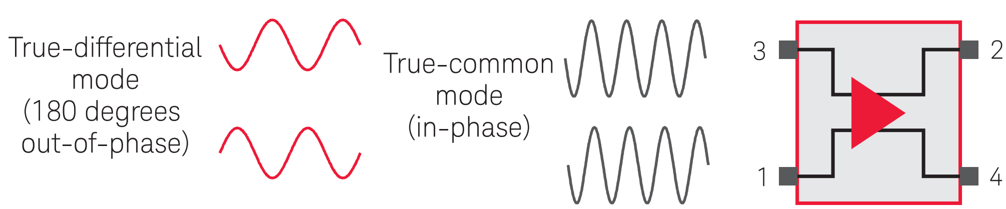
Keysight Technologies
Dual-source 4-port Network Analyzers True-Mode Stimulus Application (TMSA)

PNA-L, N5230A, 300 kHz to 13.5 or 20 GHz (Option 146 or 246)
PNA-X, N5242A, 10 MHz to 26.5 GHz (Option 400, 419 or 423)

Technical Overview





KEYSIGHT TECHNOLOGIES

Introduction

Testing balanced devices using true-mode drive

- Apply true-differential or true-common-mode stimulus in both forward and reverse direction, in frequency sweep or CW.
- Accurately characterize the performance of balanced devices while operating under real-world conditions.
- Differential sources are fully match-corrected calibrated to maintain a precise differential or common-mode drive at the reference plane of the DUT.
- All balanced parameters are fully error-corrected to account for DUT/VNA mismatch in both forward and reverse direction.
- Both the source amplitude and phase calibration, and the 4-port error correction are obtained using the same 4-port calibration established during the singled-ended measurements.
- Differential sources can generate a pair of CW signals with arbitrary amplitude and phase control.
- Configurations include balanced-input and balanced-output as well as one port single-ended and one port balanced.
- Easily access measurement results with true-mode drive as well as single-ended drive.

True-mode stimulus

By using a dual-source 4-port network analyzer, we are able to accurately control both internal sources simultaneously and therefore, to correct for the phase and amplitude differences at every frequency point for each true-mode measurement, at the reference plane of the device-under-test (DUT). This way, we can set the phase difference to zero for common-mode stimulus, or to 180 degrees for differential-mode stimulus, while maintaining the same amplitude.

In addition, we provide a mode where the user can set the phase difference of a continuous-wave (CW) to any arbitrary value between 0 and 180, as well as setting the amplitude difference to an arbitrary value. This allows for imbalanced stimulus to perform stress tests on the DUT as needed.

Fully match-corrected calibrated differential sources

The match-corrected source calibration is the calibration of the waves so that the actual waveform at the reference plane of the DUT is modified to maintain a precise differential- or common-mode drive, taking into account the mis-match of the DUT and the test system. This modification does not require any extra work from the user, but it does require the network analyzer to make two measurements at each frequency point. All the necessary steps are managed and executed by the True-Mode Stimulus Application (TMSA). At each frequency point, the application will:

1. Measure the match of the DUT with an approximately differential signal.
2. Compute the required change to amplitude and phase to produce an exact differential signal at the DUT, modify the source amplitude and phase to produce this signal, and measure the DUT response to this signal.
3. Reset the sources to a common-mode signal (zero phase difference), and measure the DUT response.
4. Repeat steps 1 through 3 for each frequency point. At the end of the forward sweep, the sources are changed from the forward drive to the reverse drive, and repeat steps 1 through 3 again.
5. At the end of both forward and reverse sweeps, the full 4-port error correction is computed, and any traces that are in the display of the PNA are updated with the True-Mode results.
6. At this point, the PNA sweep is put into Hold. Since all the scattered waves have been measured, any additional traces may be added to the existing or new windows, and the True-Mode parameter result will be shown
7. These traces may be placed in memory; if the PNA trigger is changed from Hold to Single or Continuous, a single-ended sweep will occur. This way, the True-Mode results can be compared to the single-ended results.

Figure 1 shows screenshots of the actual waveforms at the reference plane of the DUT, with and without match correction. These waveforms were captured using an Keysight Technologies, Inc. Digital Communication Analyzer (DCA).

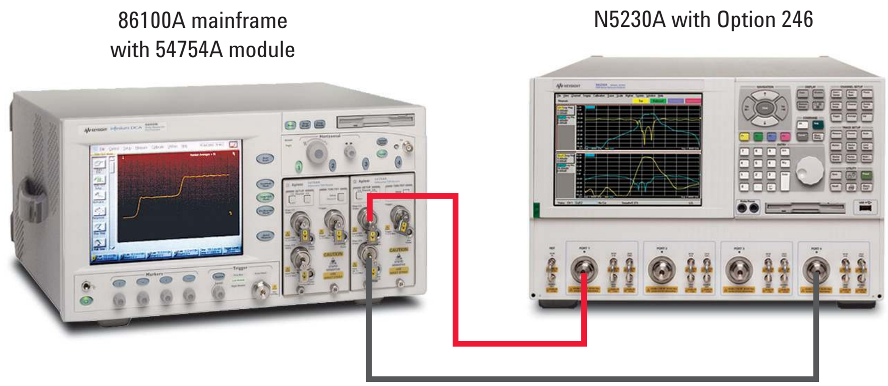


Figure 1a. Setup used to view signals coming out of the dual-source 4-port network analyzer. These signals are actual waveforms of true-mode stimulus at the end of the test port cables. All measurements were made at 10 GHz.

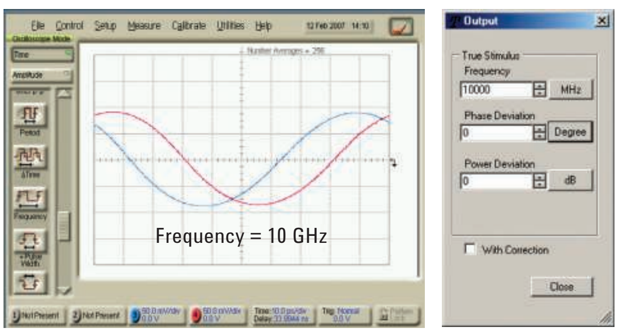


Figure 1b. Without correction, signals at the end of both cables are not in-phase, As shown, the red wave is leading the blue wave.

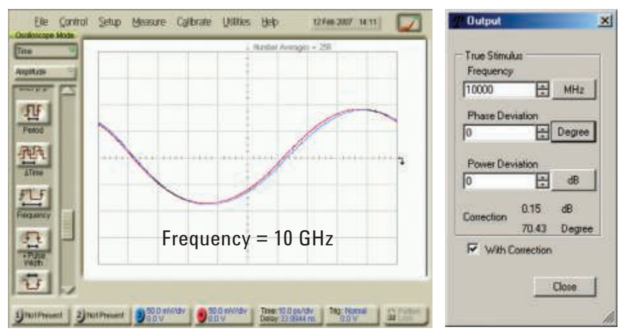


Figure 1c. With correction, signals at the end of both cables are now in-phase, the red and blue waves overlap each other.

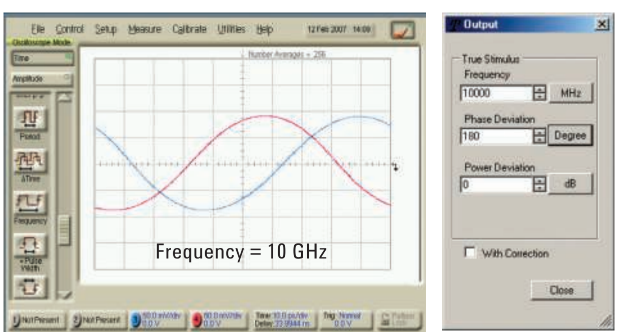


Figure 1d. Without correction, signals at the end of the cables are not 180 degrees out-of-phase, the blue wave is leading the red wave.

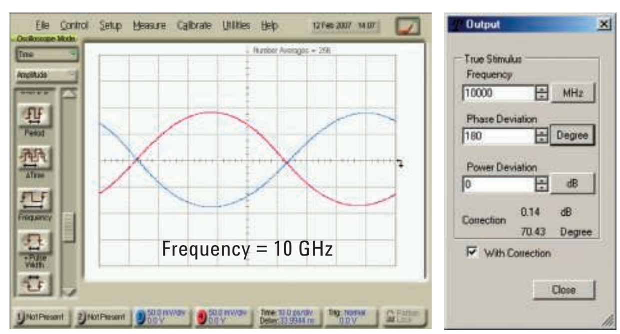


Figure 1e. With correction, signals at the end of the cables are 180 degrees out-of-phase, the red and blue waves are off-cycle to each other.

Fully error-corrected measurements

After the fully-calibrated true-mode drive signal is applied, all the scattered waves (S-parameters) from the DUT are measured, and the effects of the re-reflections from the network analyzer are removed through a modified full 4-port error-correction. A modification is required because, unlike the single-ended measurement, only two of the ports are terminated during a measurement, the other two ports are being driven by the true-mode signal. Once again, all necessary steps are managed and executed by TMSA with no added work required from the user.

Because error correction is possible by applying standard 4- or 3-port calibration techniques and then modifying the error-term matrix, the error-correction process is simply to perform a full 4- or 3-port single-ended calibration (depending on the topology being measured), using either an Electronic Calibration (ECal) module or mechanical calibration kit, before launching the true-mode stimulus application. An ECal module, either 2- or 4-port, would provide the fastest and most convenient approach.

Measurement process overview

Whether you are measuring a 4-port device, with balanced-input and balanced-output (BAL-BAL), or a 3-port device, with one port single-ended and one port balanced (SE-BAL), a dual-source 4-port network analyzer is required for true-mode stimulus.

To obtain true-mode stimulus parameters, the user only needs to add one more step to the measurement process and that is to activate TMSA. In general, the following steps do apply:

1. Setup device topology (BAL-BAL or SE-BAL), see Figure 2 for details.
2. Setup measurement parameters such as: frequency range, number of points, IF BW, power level, etc.
3. Setup display (if desired, 16 parameters for BAL-BAL, 9 parameters for SE-BAL). Mixed-mode S-parameters will be displayed as "Sdd12," for example. See Figure 2.
4. Perform calibration using Calibration Wizard — easiest and quickest with an ECal module (4-port calibration for BAL-BAL, 3-port calibration for SE-BAL).
5. Connect the DUT and perform measurements. At this point, mixed-mode S-parameters are available from single-ended stimulus.
6. To obtain true-mode S-parameters, press the front panel hardkey [Macro], press the software [TMSA], and then click "Launch TMSA." (Make sure the active trace is one of the traces in the channel that is intended for true-mode stimulus.) Although the display will not be updated, a status bar will appear during measurements. See Figure 3 for details. Depending on the number of points and the IF BW, measurements can take a while due to the number of corrections being applied at each measurement point.

7. After all the measurements have been made, mixed-mode S-parameters will be displayed as “TM_Sdd12,” for example. The “TM” prefix is to designate that the mixed-mode S-parameters were made using true-mode stimulus. See Figure 3.

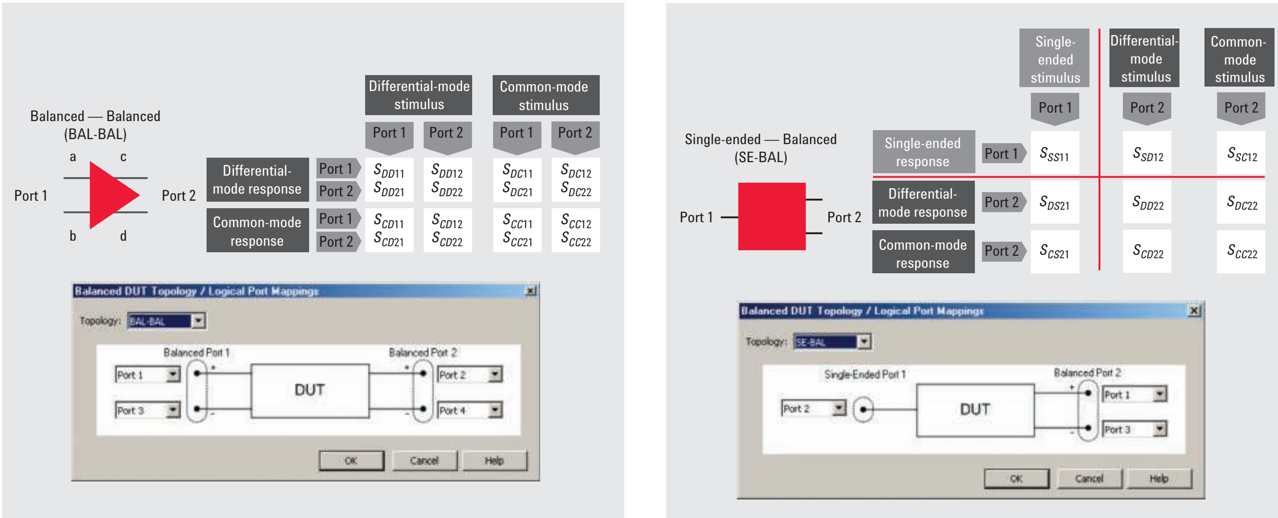


Figure 2. Port mapping for a BAL-BAL device (left), and port mapping for a SE-BAL device (right). When executing TMSA, port mappings must be exactly as shown above.

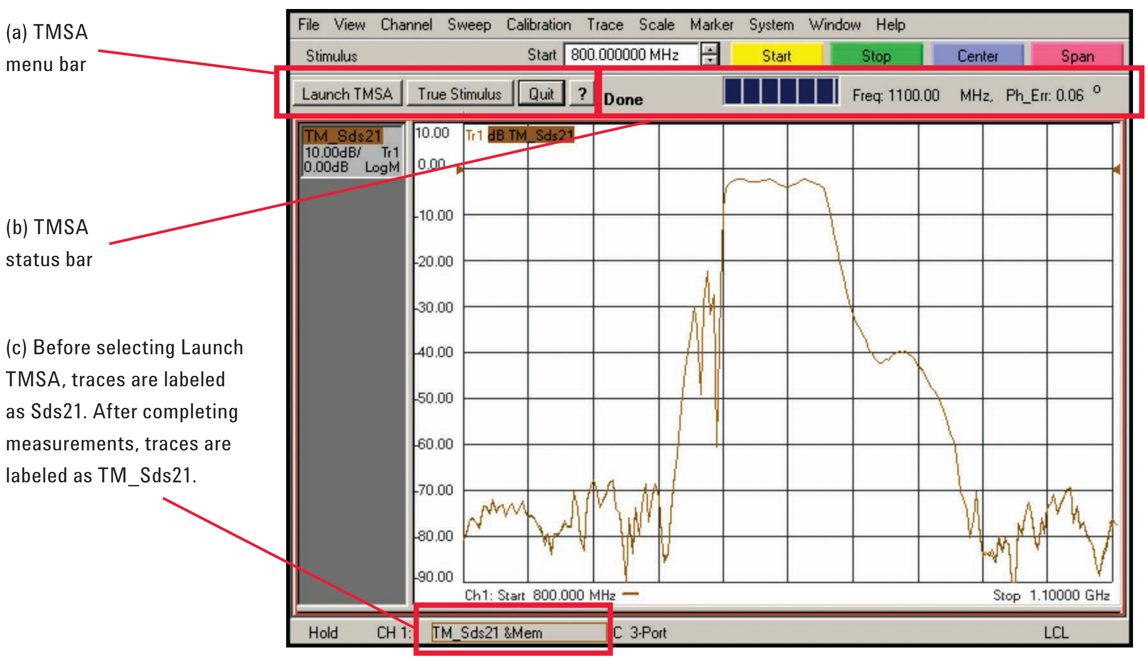


Figure 3. TMSA menu bar and trace titles: (a) activating TMSA will display its menu bar, (b) while data is being collected, sweep status bar appears along with frequency and phase error data, (c) traces made with true-mode stimulus have “TM” prefix to their trace titles.

In addition, the PNA can be used as a true-mode source by clicking on "True Stimulus" on the TMSA menu bar, see Figure 3 for details. Once this function has been selected, a True Stimulus dialog box appears. Examples of these are illustrated in Figure 4. In this mode, users can enter arbitrary phase and/or amplitude (power) deviation and the PNA will produce a pair of CW signals using these values.

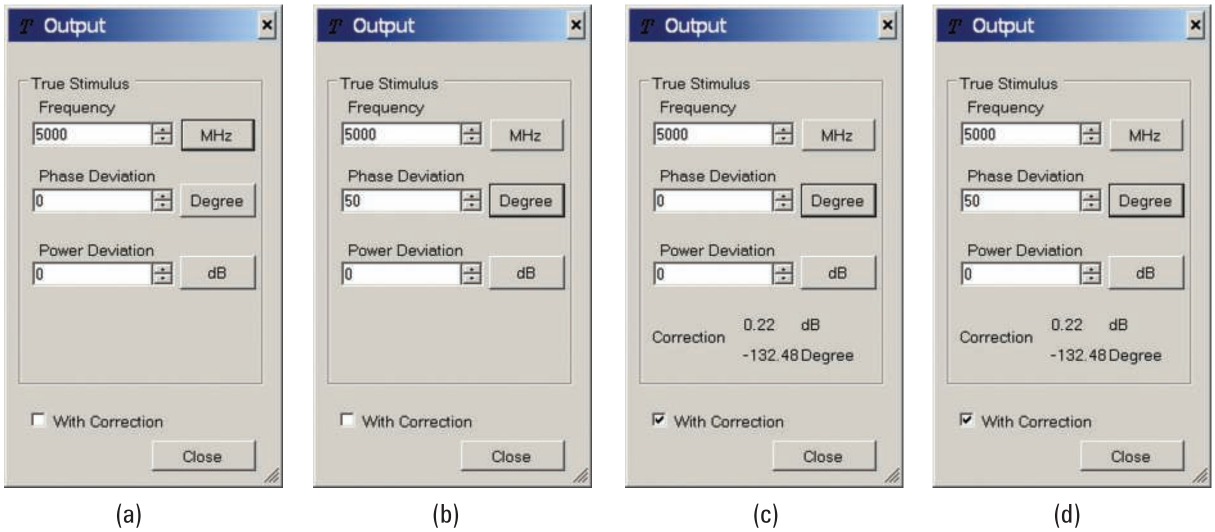


Figure 4. In a True Stimulus dialog box, the user can enter arbitrary values to control the phase and amplitude relationship of the two signals. Here are some examples: (a) no deviation and no correction applied, (b) 50 degrees phase deviation applied but no correction, (c) correction applied but no deviation, and (d) 50 degrees phase deviation and correction applied.

Measurement results

Figure 5 shows a measurement example of a 3-port filter with port 1 single-ended and port 2 balanced. This display has two traces, one memory and one active, for comparing measurement results between single-ended stimulus and true-mode stimulus. After performing a full 3-port calibration, single-ended stimulus, measurements were made and the trace Sds21 was put into memory. Next, TMSA was activated (hardkey [Macro], softkey [TMSA]) and Launch TMSA was selected. At this point, measurements were made using true-mode stimulus and upon completion, the trace was labeled as TM_Sds21. As can be seen in the plot, the two traces are identical to each other.

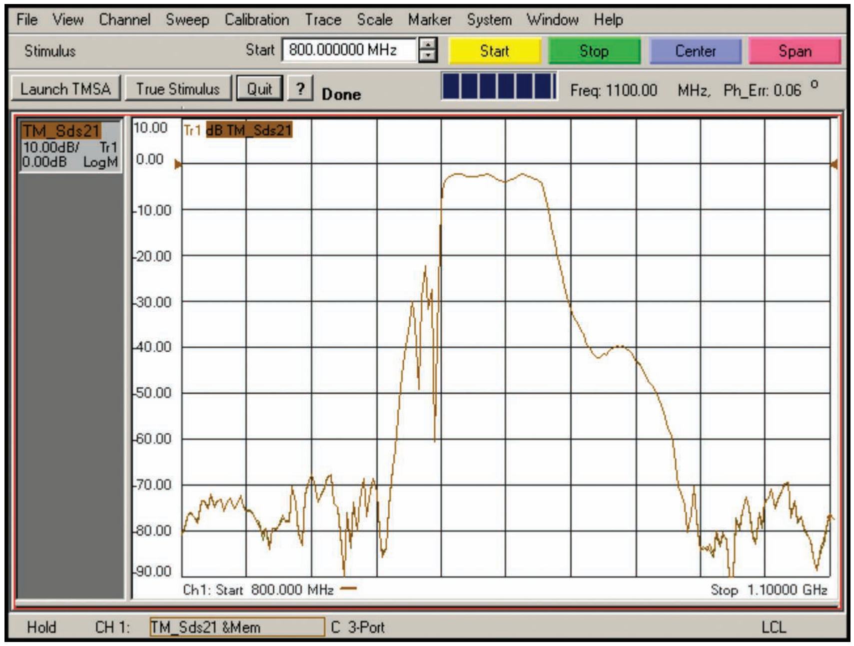


Figure 5. Measurement results of a passive device, a 3-port SE-BAL filter. Memory trace was measured using single-ended stimulus, while the active trace was measured using true-mode stimulus.

Phase error

Measurements can be impacted by two key factors: absolute phase error and residual phase error. Absolute phase error is important in true-mode stimulus. It describes how closely the phases of the two signals are aligned, and this can be affected by errors in calibration, phase setting and phase measurement. In general, small errors (less than 10 degrees) to a first order do not affect signal magnitude. Table 1 shows the typical values of absolute phase error on the N5230A Option 146 or 246.

Table 1. Absolute phase error on N5230A Option 146 or 246:

Frequency	Typicals (in degrees)
Up to 750 MHz	2
750 MHz to 3 GHz	1
3 to 6 GHz	3
6 to 10 GHz	4
10-20 GHz	9

Residual phase error is important in true-mode network analysis. This describes what we measure versus what it is. In other words, if we measure the phase setting error accurately, we can account for it in error correction. Residual phase error includes calibration error and phase measurement. In general, good residual phase error means clean measurements. Figure 6 shows a typical residual phase error trace of the N5230A Option 246, up to 20 GHz. As shown, the largest error is slightly more than 4 degrees. Depending on the type of device being tested, residual phase error can directly show up in cross-mode parameters, such as Scd21.

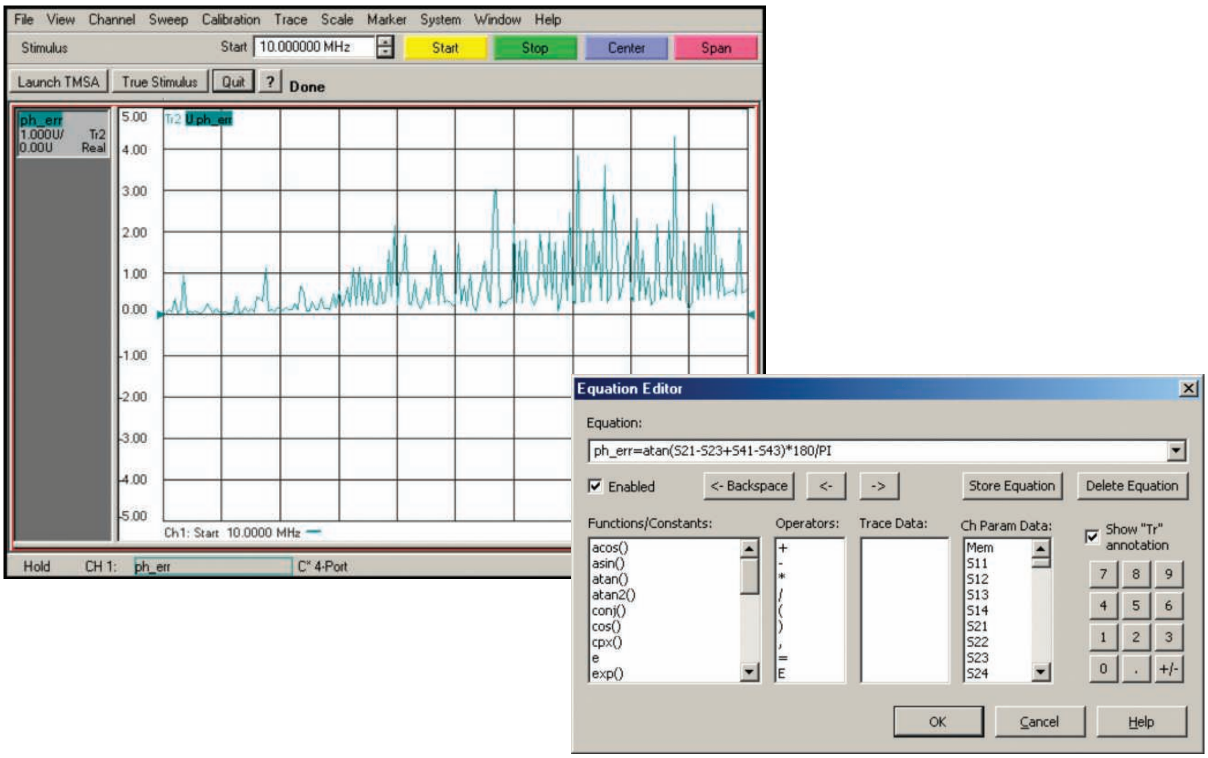


Figure 6. Using Equation Editor (right), a typical residual phase error trace of the N5230A Option 246, up to 20 GHz, is displayed.

Table 2. Applying the right mode.

	True-mode stimulus	Single-ended stimulus
Brief description	Apply true-differential or true-common-mode drive to a balanced device in both forward and reverse direction, measure the true-mode responses from a balanced device and combine the results mathematically to obtain the differential or balanced response.	Apply single-ended stimulus, measure single-ended responses from a balanced device and combine the results mathematically to obtain the differential or balanced response.
Equipment	Dual-source 4-port network analyzer: PNA-L or PNA-X N5230A Option 146 or 246 N5242A Option 400, 419 or 423	Any 4-port network analyzer, integrated or with a test set.
Arbitrary phase and amplitude deviation	Yes	n/a
Passive devices	Same results as single-ended.	Sufficient
Active devices (linear region)	Same results as single-ended.	Sufficient
Active devices (non-linear region)	Reveals true characteristics of device under true-mode operation.	n/a

TMSA is compatible with the following Network Analyzers:

N5230A, PNA-L Network Analyzer
- Option 146, 300 kHz to 13.5 GHz, 4-port, built-in second source[1]
- Option 246, 300 kHz to 20 GHz, 4-port, built-in second source[1]

N5242A, PNA-X Network Analyzer, 10 MHz to 26.5 GHz
- Option 400, 4-port, built-in second source
- Option 419, 4-port, built-in second source, extended power range & bias-tees
- Option 423, 4-port, built-in second source, extended power range, bias-tees, internal combiner and mechanical switches

How to obtain a copy of TMSA

TMSA is compatible with any Keysight dual-source 4-port network analyzers. A copy of the application will be shipped with each of these instruments. If your dual-source 4-port network analyzer currently does not have this application, you can download the installation file from www.keysight.com/find/balanced. After executing the .msi file, the TMSA button will automatically appear on the Macro menu. To run the application, you can press the hardkey [Macro], then the softkey [TMSA].

If your 4-port network analyzer currently does not have a built-in second source, depending on the model number, your unit may be upgraded to add a second source. The following upgrades are currently available:

N5230A, PNA-L Network Analyzers
- N5230AU-928, upgrades an N5230A-145 to N5230A-146
- N5230AU-927, upgrades an N5230A-245 to N5230A-246

1.Requires firmware version A.07.10.03 or later.

Accessories

Electronic Calibration (ECal) Modules

- N4432A, 300 kHz to 20 GHz, 4-port, Type-N connectors
- N4433A, 300 kHz to 20 GHz, 4-port, 3.5 mm connectors
- N4691B, 300 kHz to 26.5 GHz, 2-port, 3.5 mm connectors

Other resources:

5989-4518EN White Paper: *Advanced Measurements and Modeling of Differential Devices*

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