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Noise Figure FAQ for Network Analyzers

KEYSIGHT TECHNOLOGIES

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PNA-X Noise Figure FAQ

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Measurements

Q. How does the PNA-X measure noise figure? Is a noise source required?
A. The PNA-X uses the cold-source method to measure noise figure. Unlike the Y-factor method (also called the hot/cold-source method), a noise source is not used during DUT measurements. Instead of measuring a DUT's output-noise power under two different input-noise conditions generated from a noise source, the cold-source method combines S-parameter measurements and (in its simplest form) a single measurement of the DUT's output-noise power. First, the DUT's S-parameters are measured using the internal sinusoidal source and the standard S-parameter receivers. From this data, the available gain of an amplifier or the conversion gain/loss of a frequency converter can be calculated. Then, the sinusoidal source is turned off, a nominal 50-ohm termination is presented to the input of the DUT, and a single output-noise-power measurement is made, either using the optional low-noise receiver or using one of the standard receivers. From the S-parameter and noise-power data, the DUT's noise figure is then calculated. Since only one input noise-power level is used, a noise source is not needed. The PNA-X also provides a unique variation of this method (called vector noise calibration) that eliminates measurement error due to imperfect system source match. For this method, several different, known source impedances are presented to the input of the DUT, and for each source impedance, an output-noise-power measurement is made. From the set of noise-power measurements, more accurate 50-ohm noise-power can be calculated, which then yields a more accurate 50-ohm noise figure measurement. Note that for calibration of the internal low-noise reciever, a noise source or power meter is required (see discussion below "How do I characterize the PNA-X low-noise receiver?")

Q. How are the different source impedances generated?
A. An impedance tuner is placed between the PNA-X's source and the test-port coupler. During S-parameter measurements, the tuner is set to its through state. During noise power measurements, the tuner's impedance is varied to present different source matches to the DUT. For 13.5 and 26.5

GHz models, an external N4690 Series ECal module is used as the impedance tuner. For the 43.5, 50, and 67 GHz models, an internal tuner is included with the noise option (Option 029). In both cases, the impedance tuner can be bypassed to optimize other measurements such as gain compression or intermodulation distortion (IMD). Block diagrams of PNA-X instruments with the noise figure option can be found in the PNA Family Microwave Network Analyzers Configuration Guide.

Q. Why is the PNA-X's measurement technique more accurate than the Y-factor method?
A. The PNA-X method eliminates two large sources of error: mismatch and noise-parameter effects. Mismatch errors are removed with standard VNA vector-error correction, and noise-parameter effects are removed by using an impedance tuner during the noise-power measurements to correct for imperfect system source match. Both techniques take advantage of the ability of the PNA-X to measure amplitude and phase with its S-parameter receivers, which cannot be done on scalar instruments like a spectrum analyzer (SA) or noise-figure analyzer (NFA).

Q. What is the minimum noise figure that can be measured with the PNA-X?
A. There is no theoretical or practical limit – noise figure measurements can be made down to zero dB. However, measurement accuracy does not scale with noise figure, but instead is usually dominated by the uncertainty of the calibration standard used to characterize the noise receiver (typically 0.2 to 0.3 dB). This uncertainty is the same whether the measured noise figure is 0.2 dB or 10 dB. Commercial noise sources and power sensors are generally calibrated in the factory using traceable, but secondary calibration standards. For a fee, lower measurement uncertainty can be achieved by sending the noise standard to a national metrology (or similar) lab for calibration using primary standards.

Q. Can the PNA-X measure high-gain LNAs?
A. Yes, the PNA-X can measure amplifiers with gain (dB) plus noise figure (dB) of around 60 dB. For higher values, it is recommended to simply add an attenuator to the output of the amplifier. An output attenuator will not affect the amplifier's or converter's noise figure, since the output signal-to-noise (SNR) ratio will not be changed, but it will affect its gain. The attenuator can be deembedded so the gain will be correctly measured.

Q. Can the PNA-X measure devices with pulsed bias, such as TWTAs?
A. Yes. The minimum pulse width in this case is 300 us, using the 24 MHz noise bandwidth. For applications requiring shorter pulses, please contact your local Keysight representative.

Q. Can the PNA-X measure lossy devices? What about low-gain-plus-noise-figure devices?
A. The cold-source method works well for measuring lossy devices (like an optical link for example). The technique also works well with low-gain, low-noise-figure devices. In these cases, it is recommended to use a relatively large number of noise averages to minimize noise figure trace noise and improve measurement accuracy. This capability can be demonstrated by measuring an attenuator and showing that the measured noise figure is about equal to the loss of the attenuator (exactly equal if the attenuator is at 290 K). This is difficult or impossible to do with the Y-factor

method (depending on the amount of attenuator loss), since the attenuator reduces or eliminates the difference in noise power coming from the noise source.

Q. Can the PNA-X accurately measure noise figure of devices with poor input or output match?
A. Yes. The combination of vector error correction for measuring S-parameters and source-match-correction using an impedance tuner for measuring noise power means that the match of the DUT has very little contribution to the overall measurement error.

Q. Does the PNA-X support noise figure measurements on mixers or converters?
A. Yes. For A models, converter noise figure requires either option 082 or 083. For B models, only S93029B is needed. The PNA-X can control one or two local oscillators (LOs), and one of the LOs can be swept for fixed-input or fixed-output measurements. Devices with embedded LOs that have no frequency reference can be measured with the addition of Option 084 or S93084B.

Q. Can the PNA-X measure noise figure of balanced/differential devices?
A. Yes. This requires the use of baluns or 0/180-degree hybrid couplers that are deembedded from the measurement. The differential performance of the balun or hybrid coupler can be measured by the PNA-X and saved as an s2p file.

Q. Can I measure the noise parameters of my device?
A. Yes. Using an external or internal ECal tuner, the intended use is for nominally matched devices. This is because the loss of the PNA-X’s test set plus external cable loss limits the range of impedances applied to the DUT to the center portion of a Smith chart, typically providing a cluster of impedances with a gamma of about 0.5 or less, depending on the frequency range of the measurement. This is sufficient for calculating accurate 50-ohm noise figure, or for providing the noise parameters of matched devices. This capability is very useful to show if Fmin and noise figure are close, which should be the case for a well-designed LNA. Unmatched devices such as bare transistors generally require high gammas for accurate noise parameter measurements. Also, many impedance states are required for low measurement scatter – more than the seven states provided by an ECal module or internal tuner. For unmatched devices up to 50 GHz, Keysight offers S93027B (mechanical tuner control), which allows the PNA-X to control an LXI-compatible electromechanical impedance tuner from Maury Microwave. This solution expands the gamma range and number of impedance states compared to using an ECal tuner. For higher frequencies, Keysight recommends a noise-parameter system from our solution partners Maury Microwave or Focus Microwaves.

Q. What value should I use for the ambient temperature setting?
A. The cold source method relies on knowledge of the temperature of the input termination used when measuring output-noise power. This value should represent the average temperature of all the components looking into test port one, including the test cable itself. This value might be a bit different depending on whether a scalar noise cal or vector noise cal is used (the default value is 297 K). For both methods, a good starting value is the ambient temperature outside of the PNA-X, which is typically 298 K. While the components inside the PNA-X are a bit hotter than ambient due to internal heating, any loss between the internal termination and the DUT will work to negate the temperature rise. This loss is often dominated by a test port cable, and it is generally frequency

dependent (more loss at higher frequencies). For a scalar noise cal with an ambient of 298 K, a better estimate at lower frequencies might be 300 K or 301 K. Note that the difference between using 298 and 300 K is only about 0.7%, which equates to a change in noise figure of only .03 dB. This amount of uncertainty is much smaller than other contributions. For vector noise cals, an ECal or internal tuner is used for the termination, and it is heated internally to 304 K. So, depending on the frequency of the measurement, somewhere between 299 K and 303 K might be a better estimate.

Q. Does it matter which noise bandwidth I use?
A. In general, the wider the noise bandwidth, the lower the jitter of the noise measurement for a given amount of measurement time (lower jitter is better, giving lower trace noise). However, the noise bandwidth of the instrument should always be narrower than the bandwidth of the DUT. For narrowband devices, it may be necessary to use one of the narrower noise bandwidth settings of the PNA-X.

Q. What does “Use Narrowband Compensation” do?
A. This feature is useful when the noise bandwidth of the noise receiver is a significant portion of the bandwidth of the DUT, for example, for devices with narrowband filters (2 to 20 MHz) after a broadband LNA. Under this condition, the NF trace is distorted near the band edges, with values that are too large. This condition is the result of measuring the gain at each trace point at a single frequency (i.e., normal S-parameter mode), while measuring the noise power at each point over the noise bandwidth of the noise receiver. When the DUT’s gain is constant over the noise bandwidth, the gain-bandwidth calculation is correct and there is no distortion of the noise figure measurement. When the gain is changing across the noise bandwidth, such as what happens at band edges of narrowband devices, then the measured noise power is not consistent with the gain measurement, resulting in inaccurate measured noise figure. Turning on narrowband compensation mathematically modifies the gain measurement at each point to account for the delta gain across the noise bandwidth, thus restoring the accuracy of the noise figure measurement. Because narrowband compensation post processes the measured data, it has almost no impact to overall measurement time. The on/off status of narrowband compensation does not affect calibration of a noise figure channel.

Q. Does the PNA-X indicate when my amplifier has too much gain?
A. Yes, there are two indications. One is when the low-noise receiver’s IF ADC over-ranges and the other is when the front-end detector in the noise receiver detects excessive RF power. These indicators will show on the screen during overload conditions. Temporary overload sometimes occurs when measuring unshielded amplifiers on printed-circuit boards, for example, when a wireless LAN or mobile phone signal is picked up and amplified by the DUT. To avoid this, it is recommended to make measurements in a shielded room. If an overload condition occurs on high-gain amplifiers while the noise-receiver gain is at the lowest setting (0 dB), then attenuation on the output of the amplifier is likely needed. Note that receiver overload can also occur due to out-of-

band amplifier oscillations or in the case of frequency converters and mixers, excessive LO feedthrough or other spurious output signals.

Q. If I get an overload indication, is the entire measurement bad?
A. If the overload indicator is on throughout the measurement, then the noise figure data is suspect and should not be trusted without further investigation. Since the filters in the low-noise receiver are well past the front-end amplifiers, an interfering signal can cause the front-end amplifiers to compress, which can distort the noise measurements. If the overload indicator only comes on briefly, then the data away from the interfering signal may be OK, but again, caution is urged. Often there will be interfering signals that cause spikes in the measured results, but do not trip the overload detectors. For example, signals from mobile phones and wireless LAN routers often sneak into unshielded power cables or onto PC boards. In these cases, it is likely that the data around or in-between the spikes is accurate.

Q. Can I measure noise figure and S-parameters at the same time without throwing a mechanical switch?
A. Yes. Noise figure measurement channels support S-parameters as well as noise figure, effective input temperature, noise-power parameters (DUT and system relative noise power [output power above kTB in dB] and DUT and system noise-power density [output power in dBm/Hz]), and noise parameters.

Q. Can I measure noise figure, S-parameters, gain compression, and IMD in one setup?
A. Yes, this can be done by setting up multiple measurement channels: one for S-parameters and noise figure, a second one for gain compression, and a third channel for IMD. The compression and IMD channel configurations are likely to have different switch or attenuator settings, so only one channel at a time can be measured to prevent excessive wear on the mechanical switches and attenuators. Additional measurement channels can be set up for other measurements like harmonics or phase-versus-drive. Multi-channel setups can be easily calibrated using the PNA-X's Cal All feature. All of the measurement channels and their associated calibrations can be saved in one instrument state.

Q. Is the low-noise receiver used for S-parameter measurements?
A. No, the low-noise receiver is only used for measuring noise power, which is then used to calculate noise figure, Teff, ENR, etc. When measuring S-parameters in a noise-figure channel, the standard measurement receivers are used, and the low-noise receivers are placed in a “protection” mode to prevent potential damage due to large CW signals.

Q. Can I measure the ENR of a noise source?
A. Yes. A power meter can be used to calibrate the low-noise receiver and the hot state of a noise source can be directly measured, with the results expressed as ENR. Because the power meter calibration method is very accurate, the PNA-X can be used to provide a calibrated ENR table for the noise source. ENR measurement uncertainty can be included in the ENR table by using the PNA-X Noise Figure Uncertainty Calculator, available at www.keysight.com/find/nfcalc. Note that

the uncertainty of the power sensor (typically 0.1 to 0.3 dB) will set the lower limit of measurement uncertainty for the ENR measurement.

Q. Can I de-embed a fixture or wafer probes while measuring noise figure?
A. Yes. Deembedding is available in all PNA-X measurement channels (noise figure, gain compression, IMD, etc.)

Q. Can I control the number of impedance states used when making a noise figure measurement?
A. Yes. The minimum number of impedance states is four, but the user can select up to seven states for increased accuracy. On 13.5 and 26.5 GHz units, the default is four. On 43.5, 50, and 67 GHz units, the default is five. When using a Maury Microwave impedance tuner with S93027B for measuring noise parameters, the default is 21 states per band (many tuners have a low-band and high-band probe to provide broadband frequency coverage).

Q. Can I manually control the noise measurement switches?
A. Yes, they can be controlled from the Path Configuration dialog box. For instruments with the noise-figure option, there is an additional tab for setting the noise hardware. This is useful when other, non-noise-figure channels are present in conjunction with a noise figure channel, and continuous triggering is desired for all channels (accomplished by setting the mechanical switches and attenuators to the same states). Note that if a vector noise calibration is used in the noise figure channel (requiring the use of an external ECal module or the internal tuner if available), then the impedance tuner will be in series at port one for all the measurement channels, and the tuner loss will lower the available port power by about 4.5 dB.

Q. Does the PNA-X compensate the port-power levels to correct for the internal loss of the Option 029 noise figure hardware?
A. Yes and no. On the port two side, the nominal delivered port power matches the value shown in the user interface. In other words, when in noise mode, the PNA-X adjusts the power level to compensate for the additional loss of the bridge (for 13.5/26.5 GHz units), switches, and cables associated with the noise receivers on port two. On the port one side, the nominal port power is correct only for the “internal” or “bypass” positions of the tuner switch. When an external ECal or the internal tuner (if available) is switched in, the PNA-X does not compensate the port one power value. Therefore, the delivered power at the test port is typically about 4.5 dB lower than what the user sets. There are several ways to compensate for this offset between the requested and actual port powers. For an open-loop correction, an offset value of -4.5 dB can be entered in the Offsets and Limits table (in the Power and Attenuators dialog). For calibrated power, one can either perform a source-power calibration (using a power meter), or use receiver leveling with a calibrated reference receiver. Note that when Cal All is used, source power cals will be applied to the noise figure channel.

Q. How many sweeps does it take to perform a noise figure measurement?
A. It depends. For vector noise calibrated noise figure measurements of amplifiers, the total number of sweeps is the sum of two (for the forward and reverse S-parameters) plus the number of sweeps corresponding to the selected number of different impedance states of the ECal module or internal

tuner. For example, on a 26.5 GHz unit, the default number of impedance states is four, so the default number of sweeps for a noise figure measurement is 2 + 4 = 6 sweeps. On a 50 GHz unit, the default number of impedance states is five, so it takes seven sweeps to measure an amplifier. For a scalar calibrated noise figure measurement of an amplifier, only 3 sweeps are required (two for S-parameters and one for noise power). For frequency converters, two additional sweeps are required for the gain and match portion of the noise figure measurements, since measurements must be made at both the input and output frequencies. For vector noise calibrated noise figure measurements, this corresponds to a default value of 8 sweeps for 26.5 GHz units or 9 sweeps for 50 GHz units. For a scalar calibrated noise figure measurement of a converter, 5 sweeps are required (four for gain/match and one for noise power).

Q. Why does my PNA-X show a higher noise figure than when I use a noise-source-based instrument?
A. If the difference is more than about 0.2 dB, it may be caused by setting the channel power too high and causing compression of the DUT or the PNA-X when the DUT's S-parameters are measured. For a given output-noise power, less gain due to compression makes the amplifier appear to have a worse output signal-to-noise ratio, which makes the noise figure look worse. This can be easily fixed by lowering the channel power. Sometimes the difference is due to the Y-factor method under-reporting noise figure due to cables, switches, adapters, or probes between the noise source and the DUT. The components can cause the source match of the noise source to degrade, resulting in shifts in the DUT's measured noise figure (dependent on the S-parameters and noise parameters of the DUT). Differences below about 0.2 dB are generally within the measurement uncertainties of the two instruments, and are often due to different noise-calibration standards used for the two instruments. This might be from using different noise sources with the same ENR, or from using one low ENR and one high ENR source, or from using a noise source for the NFA or SA and a power sensor for the PNA-X.

Q. Why do noise figure measurements of my frequency converter change depending on what LO signal I use?
A. This is most likely due to broadband noise on the LO mixing to the IF of whatever mixer it is driving. This additional noise adds to the noise coming from the amplifiers in front of the mixer. The only way around this issue is to use a signal generator with lower broadband noise (for example, a PSG has lower broadband noise than the PNA-X's internal sources), or to place a band-pass filter in series with the LO signal to strip away broadband noise.

Q. Why do noise figure measurements of my frequency converter read several dB higher when measured on a PNA-X, compared to when I use a noise-source-based instrument?
A. This can happen when the converter being tested does not have any filtering prior to the first mixer, which is commonly called the double-sideband (DSB) case. Depending on how much gain there is ahead of the first mixer, the Y-factor method either measures the DUT's conversion gain incorrectly, or under-reports the DUT's noise contribution due to ratioing of the hot and cold noise-power measurements. This results in the Y-factor method typically reading between 0 and 3 dB better (lower) than the DSB converter's actual noise figure, although it is possible to see even larger

errors. The PNA-X's cold-source method measures the correct conversion gain (using a sinusoidal stimulus) and actual output noise power (using only the cold input-noise temperature), so the noise figure of DSB converters is correctly measured.

Q. When measuring mixers and low- or medium-gain frequency converters, why do I frequently get overload warnings, even at the low receiver-gain setting?
A. This is very common when there is no or insufficient filtering to remove LO feedthrough or other spurious output signals. These signals (particularly LO feedthrough) are often too large for the low-noise receiver, even in the 0 dB gain setting. This can be solved by using filters to remove out-of-band spurious signals.

Q. How do I get good noise figure measurements for converters with very high (> 70 dB) gain?
A. The key to getting good measurements for high gain devices is to set up the instrument to obtain calibrations and measurements with a minimum amount of noise. If the calibration is performed at the low power level needed for the DUT measurement, the resulting poor SNR can add considerable trace noise to the noise figure measurement results. Here are some tips for optimizing the setup:
1. Set the source attenuator to the smallest setting (lowest amount of attenuation) that will still get the low input power required during the measurement. Doing this will allow the source power in the noise figure channel to be raised as much as possible for the calibration, thereby improving the measurement SNR of the calibration standards.
2. For high gain converters, deembedding external attenuators after the calibration is very useful. For example, let's say -90 dBm input power is needed to measure a high gain converter. The source attenuator at the port connected to the DUT input can be set to 30 dB, which allows the calibration to be done at -20 dBm or so. For the measurement, the source power can be electronically reduced by 40 dB, and an external 30 dB attenuator can be added (and deembedded) to lower the source power by an additional 30 dB (for a total of 70 dB), allowing test of the DUT with -90 dBm input power. An output attenuator is only needed if the DUT's output noise overloads the low-noise receiver, even at the low-gain setting. High gain converters can be tested using the standard, S-parameter receivers, which are much less susceptible to overload. For the attenuator s2p files needed for deembedding, use the Cal Plane Manager feature to make the s2p files transmission only, by zeroing out the reflection terms. This will eliminate noise in S21 when trying to measure S11 and S22 of the DUT through the attenuators. When adding an external attenuator at the input of the DUT, scalar noise calibration (SNC) must be used, since the attenuator would cause the impedance states used for vector noise calibration (VNC) to be clustered too close to one another.
3. Use Cal All with the default settings. Cal All uses separate power and attenuator settings for the calibration that are independent of the noise figure channel settings, which results in S-parameter calibrations with low trace noise. Cal All performs the extra measurements needed to account for the difference between the source attenuator value used during the calibration and the value used during the measurement. You still need to set the underlying noise figure channel power as high as possible (as mentioned in the first comment), independent of the Cal All power setting. This is needed since the through step of the noise calibration uses the noise figure channel power setting, not the Cal All power setting.

4. Test port powers should be uncoupled, so that the port two power can be high (like -20 dBm), using 0 or 10 dB of source attenuation. This will give clean S22 measurements.
5. For the power-meter step, the source power should be set as close to 0 dBm as possible. This setting is independent from the noise figure channel power setting. The Port Attenuator Auto feature used for the power-meter measurement step (available when using the low-noise receiver) uses 0 dB source attenuation for the power measurement, and then takes extra measurements with the source attenuator at the higher setting as defined in the measurement channel.
6. When low input powers are required, it is usually advantageous to reverse the port one test coupler by reconfiguring the front-panel RF loops. This lowers the maximum-available port power (good for high gain converters), while increasing test receiver sensitivity for S11 measurements by 15 dB or more, depending on frequency.

Q. What formats are available for saving my measurement data from a noise figure channel?
A. The best way to save all traces in a noise figure channel is to use the CSV (comma-separated variable) format. This format supports log mag/angle, lin mag/angle, and real/imaginary. Alternately, CITI, or MDIF formats can be used. In addition, S-parameter and noise-parameter data (but not noise figure) can be saved in an s2p file.

Calibration

Q. What's the difference between scalar and vector noise calibration?
A. The scalar noise calibration method assumes the source match provided to the DUT during output noise-power measurements is exactly 50 ohms, so only one noise-power measurement is performed. The more the system source match deviates from this assumption, the higher the measurement error. The vector noise calibration method does not assume the source match is perfect. Instead, several different known source impedances are presented to the input of the DUT, and for each impedance, an output noise-power measurement is made. From the set of noise-power measurements, very accurate 50-ohm noise-power is calculated, which in turn yields a very accurate 50-ohm noise figure measurement. The noise-power data can also be used to calculate the DUT's noise parameters. The different impedance states are measured as part of the calibration process. Vector-noise calibrated noise-power measurements combined with vector error-corrected S-parameter measurements eliminate noise figure errors due to imperfect 50-ohm source match.

Q. When using a scalar noise calibration, can I add an attenuator to the end of my test cable to improve the system source match?
A. Yes, this is a good approach, if the attenuator is not too large. A good choice is 3 to 6 dB. Anything more than this causes the raw directivity of the system to degrade such that calibrations can become noisy and drifty. Scalar-noise-calibrated measurements are faster than vector-noise measurements (less noise-power measurements are performed) and the attenuator can make the accuracy almost as good or in some cases, equal to that obtained using vector-noise calibration. In cases where there is a lot of cable loss at port one (perhaps in an on-wafer setup at high

frequencies for example), scalar noise calibration is often the best choice, since the vector-noise algorithm can produce measurement spikes when the tuner impedance states do not have enough gamma spread (see next question).

Q. Why does vector-noise calibration produce spikes or ripple in my measurements that are not related to interference, especially between 45 and 50 GHz?
A. This typically occurs in an on-wafer test setup when excessive cable loss at port one causes the cluster of impedances presented to the DUT to get too close to one another for the vector-noise algorithm to properly solve for the noise parameters of the DUT. The algorithm needs enough spread in the impedances to give a good estimate of 50-ohm noise power. There are a few things that can help prevent this. One is to use as short and as low-loss cable at port one as possible. Increasing the amount of noise averaging also helps. Since cable loss is frequency dependent, broadband noise figure measurements can be split into two bands, where the lower band uses vector noise calibration, and the higher band uses scalar noise calibration. The best way to avoid this problem is to use an external ECal as a tuner, along with an external bias tee (if needed) and test-port coupler, placed as close to the wafer probe as possible. These components are connected to the PNA-X via its front-panel jumpers. This configuration puts the impedance tuner closer to the DUT, eliminating the effect of cable and test set loss.

Q. How do I characterize the PNA-X low-noise receiver?
A. Measured noise power is affected by the gain, bandwidth, and noise figure of the receiver. Gain and bandwidth can be measured separately or together as a single product. The most common way to characterize the noise receiver is to use a noise source and the Y-factor method. The gain-bandwidth product and noise figure are directly measured by applying a known amount of excess noise to the receiver. The PNA-X offers an alternative approach that uses a power meter and power sensor as a calibration standard in place of a noise source. This method relies on separate measurements of receiver gain and bandwidth. There are three steps to the process. First, the power meter and sensor are used to calibrate the PNA-X's RF source across the desired frequency range. The calibrated source is then used to calibrate the gain of the noise receiver. Next, the noise-bandwidth filter is swept with a sinusoidal stimulus to measure the receiver's IF response at every RF frequency point within the desired measurement span. Each IF response is integrated to calculate the receiver's equivalent noise bandwidth. The gain and noise-bandwidth values are combined point-by-point to characterize the receiver's gain-bandwidth product. Once this is known, a cold-source noise figure measurement can be done.

Q. What are the differences between using a noise source or power sensor during the noise calibration?
A. From an accuracy standpoint, power-meter-based measurement uncertainty is likely to be a bit better compared to using an off-the-shelf noise source, or comparable to using an NPL-calibrated noise source. Also, power sensors are more commonly available than noise sources, especially at 50 or 67 GHz. They also work better in cases where excessive loss at port two (due to a long cable for example) attenuates the excess noise coming from a noise source. The tradeoff to using a power meter is that calibrations and sometimes measurements are slower. The power-meter method only

works with noise bandwidths up to 4 MHz, whereas the noise-source method works with noise bandwidths up to 24 MHz, which usually results in faster sweeps. During calibration, the power-meter method sweeps out the IF response for each data point, which adds time to the calibration process. Depending on the number of data points, this additional time can be several seconds to several minutes.

Q: Why is the noise source left on when not used during calibration?
A: It was determined during development of the noise figure application that noise figure measurement results were more repeatable if the noise source was left on when not in use, to stabilize its temperature. There is a field in the “Configure Noise Source” calibration dialog where the user can enter the temperature of the noise source, which will be a few degrees K above room temperature. Its temperature can also be determined using some type of external thermometer.

Q. What power level should I use during the power-sensor portion of the calibration?
A. It is best to use as close to 0 dBm as possible, as this is the level used to calibrate most power sensors. The power used during this step is independent from the power used for the S-parameter portion of the calibration, which is determined from the channel-power value entered prior to starting the calibration. When the noise receiver is calibrated with a power sensor, the source attenuator is automatically set to whatever value is needed to provide the specified power during the power-sensor step. In most cases, this will be 0 dB of source attenuation. However, when a standard receiver is used, the source attenuator is fixed to the channel value, so it often isn’t possible to get to 0 dBm. In this case, set the power as high as possible without causing the source to unlevel, and make sure the power setting is at least 6 dB above the noise floor of the power sensor (a wide-dynamic-range, diode-based power sensor is helpful in this situation).

Q. Is it necessary to use noise averaging during calibration?
A. It is not required, but it is a good idea to use noise averaging during the calibration to produce a clean calibration. Noise that is present in the calibration cannot be removed in subsequent measurements. When using the low-noise receiver, a noise-average value of 10 or more is recommended during calibration. For the measurement, this value can be lowered if faster measurements are desired, at the expense of more trace noise and less accuracy. When using a standard receiver, 100 or more noise averages are needed. Note that noise averaging only affects the noise power measurements. During calibration, channel averaging affects S-parameter measurements only. In this way, the amount of averaging used for noise-power measurements and S-parameter measurements can be individually optimized.

Q. To avoid compressing my high-gain amplifier, I set the input power very low, but this makes for noisy calibration and measurements. Are there ways to overcome this?
A. Yes, there are several things you can do. Cal All is a good calibration choice as the setup used during the calibration can be optimized independently from the measurement setup, so higher powers can be used. For scalar-noise calibrations, the port one test coupler can be reversed (swapping the main and coupled arms) to provide more sensitivity for S11 measurements, which then makes the corrected S21 and noise figure measurements less noisy (this approach can’t be

used for vector-noise calibrations since the extra loss in the source path makes the impedance tuner states too close to one another). Channel averaging can also be used to lower S-parameter trace noise which in turns lowers the jitter on the noise figure trace.

Q. When doing an on-wafer TRL cal, why do I get an error that states that there are not enough standards for the cal?
A. This appears because at least five impedance states must be presented to the noise receiver to determine its noise parameters, requiring more standards to be defined than normal for a typical TRL impedance-standard-substrate (ISS) cal kit (this problem also occurs with coaxial TRL cal kits). To correct this situation, you must define additional standards using the Modify Cal Kit feature (see the Help file for more detail on how to do this). The extra impedance standards can be created by reusing the through and line standards (or multiple line standards) as reflection standards. This is done by probing one end of the transmission line and leaving the other end open, thereby creating a pair of offset opens. However, extra on-wafer impedance standards are not required when you use an ECal module to perform de-embedding of a noise-source adapter on port two. In this case, the ECal module is used to present five different impedance states to the noise receiver.

Q. Can the ECal module that is used as an impedance tuner also be used to perform the 2-port calibration?
A. No. A separate ECal module or mechanical cal kit must be used for the S-parameter portion of the calibration process.

Q. Which ECal modules are supported with the noise figure option?
A. Any ECal can be used for the S-parameter portion of the calibration. For use as an impedance tuner, only the N4690 Series of two-port ECal modules are supported.

Q. Which noise source do you recommend?
A. For 26.5 GHz units, we recommend the Keysight 346C noise source, which has 15 dB nominal ENR. The higher ENR is needed since the noise figure of the PNA-X's low-noise receiver is about 10 to 14 dB. The 346B is also a good choice for coverage up to 18 GHz. For measurements in the 1 to 50 GHz range, we recommend the 346C-K01. As an alternative to a noise source, a power sensor can be used for the noise-receiver calibration.

Q. Can the 346A noise source be used?
A. Yes, the calibration can be performed with a 346A noise source, but the lower ENR value (6 dB) will give a less precise measurement of the PNA-X's low-noise receiver compared to using a 346B or 346C source. When using a 346A, a lot more noise averaging should be used during calibration to help overcome the lower ENR.

Q. Does the PNA-X noise figure application support N4000A Series Smart Noise Sources (SNS) or the U1831C USB Smart Noise Source?
A. No.

Q. During calibration, is the match of the noise source measured in its hot and cold state?
A. Yes. This value helps get a more accurate measurement of noise power.

Q. After calibration, can I change the gain setting of the PNA-X's noise receiver without having to re-calibrate?
A. Yes. During calibration, all three gain stages (0, 15, 30 dB) are measured, so they can be changed after the calibration according to the gain and noise figure of the DUT.

Q. After calibration, can I change the noise bandwidth setting without having to re-calibrate?
A. The user interface allows you to do this, but it is not recommended. Changing the noise bandwidth changes the gain-bandwidth product of the noise receiver slightly, causing measurement error. It is recommended to use the same noise bandwidth for calibration and measurements.

Q. Can I view the error terms from a noise figure calibration in the Cal Set Viewer, including the gamma values of the impedance tuner?
A. Yes.

Q. Can I calibrate my system if the noise source or power sensor does not mate directly to the test port cable?
A. Yes. The calibration can remove the effect of an adapter used to connect a noise source or power meter during calibration. An extra 1-port calibration is required at the point where the noise source or power sensor is connected in order to align the noise cal plane with the 2-port cal plane. This feature is also very useful when using a noise source in 50 GHz on-wafer test systems, as the noise source can be connected directly to test port two with a short adapter, eliminating the adverse effect that cable loss would have on the receiver characterization.

Q. How do I calibrate on-wafer measurements when I can't connect a coaxial noise source or power sensor at the on-wafer calibration plane?
A. There are two approaches. One approach is to perform the noise calibration entirely with coaxial calibration standards and deembed the wafer probes. The other approach is to use the Cal Wizard to guide you through a mixed coaxial/on-wafer calibration. With this method, you can perform the characterization of the PNA-X's noise receiver at any point in the coaxial portion of the test setup. The calibration routine adds an extra 1-port calibration so that the noise-calibration plane can be extended to the on-wafer calibration plane. The calibration routine handles the cases when an adapter is needed to connect the noise source or power sensor and it is left in place for the on-wafer cal, or the adapter is removed after the 1-port cal, in order to connect the wafer probes to the test system.

Q. When measuring devices with two female connectors, I use an ECal module for the 2-port cal. However, when I try to do the 1-port cal on the adapter used to connect the noise source or power sensor to the test system, my ECal does not show up as a cal kit choice. Why not?
A. Only ECals with at least one connector that will mate to the adapter will show up. If you are using a female-female ECal module, you cannot use it to perform a 1-port cal on an adapter with a female

connector. Instead, you need an ECal with at least one male connector. The most flexible ECal module is one with both male and female connectors, which will handle all different combinations of DUT-connector gender. When using a male-female ECal for female-female devices, the calibration routine is broken into three steps instead of one. Step one uses the female connector of the ECal for port one, step two uses the female connector for port two, and step three requires an external through adapter.

Q. Are the noise-parameter effects of the PNA-X's noise receivers removed from measurements?
A. Yes. Knowing the receiver's noise parameters allows subtraction of the exact amount of receiver noise from a measurement, which is dependent on the output match (S22) of the DUT. When two ECal modules are present during calibration (one as the tuner, one for calibration), the one that is used for the 2-port calibration portion is also used to present a set of variable source impedances to the noise receivers to characterize their noise parameters. This is done because this ECal is closest to the noise receivers, and therefore provides a wider range of impedance values due to lower loss. This means that the ECal that will be used as an impedance tuner during measurements is not used as an impedance tuner during calibration if a second ECal module is available. When only the tuner ECal module is present during calibration, then it will be used in combination with the mechanical standards used during the 2-port calibration to provide the variable source impedances needed for a noise-parameter characterization.

Q. Is there a way to verify the absolute accuracy of a noise-figure measurement, using some type of verification kit?
A. At this time, there are not any commercial, off-the-shelf noise-verification kits. However, Keysight and NIST have published a paper showing how a mismatch transmission line (Beatty standard) and an amplifier can be used as a verification standard. See "Verification of Noise-Parameter Measurements and Uncertainties", IEEE Transactions on Instrumentation and Measurement, vol. 60, no. 11, November 2011, pp. 3685–3693 (James Randa, Joel Dunsmore, Dazhen Gu, Ken Wong, David K. Walker, and Roger D. Pollard). A more practical alternative to verify a noise figure calibration is to verify the two parts of the calibration independently. The S-parameter portion can be verified with a normal Keysight VNA verification kit (or more simply, by measuring a through and a high-reflect standard like a short or open). The noise receiver calibration can be verified by measuring the ENR of a trusted noise source that was not used for the noise-receiver characterization. If the measured ENR matches the ENR table (to within +/- 0.1 to 0.2 dB), then the noise calibration is likely good. Keysight also has a PNA-X noise figure uncertainty calculator, which can be used to calculate the accuracy of noise figure measurements.

Q. Is measuring a through connection or an attenuator a good way to verify noise figure accuracy?
A. No, these are poor verification devices for two reasons. Firstly, neither a through nor an attenuator produce excess noise, as would a device with gain. This means that the noise power measured with the through or attenuator is the same amount of noise power measured during the calibration process. When two sets of small and noisy data are subtracted, the result shows high levels of noise variation. This can be observed when measuring a through connection – while the trace is centered around 0 dB as expected, the trace shows large peak-to-peak variation of more

than a couple of dB. This amount of trace noise or jitter gets worse as frequency increases and the noise receiver's sensitivity degrades. Secondly, devices that don't produce any excess noise cannot verify that the noise receiver's gain-bandwidth product has been properly calibrated. See the previous question for better ways to verify noise figure accuracy.

Q. Does Keysight have a noise-figure uncertainty calculator that works for the PNA-X's source-corrected technique?
A. Yes. It is available at www.keysight.com/find/nfcalc. Keysight's PNA-X noise figure uncertainty calculator is the most comprehensive tool in the industry for estimating errors in noise figure measurements. Due to the PNA-X's advanced noise figure error-correction methods, and unlike other uncertainty calculators which ignore key contributions to error, Keysight's Monte-Carlo-based noise figure uncertainty calculator provides estimates of errors due to the following contributions:

· Mismatch error resulting from residual S-parameter uncertainty
· Noise-parameter-induced errors resulting from DUT input-noise interaction with imperfect system-source match, and source-pulling of the noise receiver due to the DUT's output match
· Noise-source ENR or power-meter/sensor uncertainty
· Noise-receiver linearity, compression, jitter, and temperature drift

The PNA-X noise figure uncertainty calculator runs on a PNA-X or an external Windows®-based PC. It is limited to amplifier measurements using the low-noise receiver provided with Option 029. Both vector and scalar noise calibrations are supported, as well as characterization of the noise receiver using a noise source or power meter. It requires Keysight's VEE Runtime application, which is factory-installed on PNA-X units, or available for external PCs here.

Hardware

Q. Do all PNA-X models offer a low-noise-receiver option?
A. Yes. Option 029 adds an internal low-noise receiver at port two. For N5241/42/44/45 models (13.5/26.5/43.5/50 GHz), the noise receiver works up to the stop frequency of the instrument. For the N5247 (67 GHz) model, the low-noise receiver works up to 50 GHz. However, noise figure measurements can be made in the 50 to 67 GHz band using one of the instrument's S-parameter receivers (see section Using S-parameter receivers). Note that for A-model PNA-Xs, Option 029 includes the noise figure measurement application. For B-models, the application must be purchased separately as S93029B. S93029B can be used without Option 029, but then only the standard S-parameter receivers are available for noise figure measurements.

Q. How do I measure noise figure above 67 GHz?
A. Keysight's N5290/91A broadband PNA millimeter-wave network analyzers can be used to measure noise figure above 67 GHz. For measuring down converters where the output is below 50 GHz, no external hardware is needed. For this case, the system can be configured with one millimeter-wave extender connected to the input of the DUT, while the output of the DUT can be connected directly to port 2 of the PNA-X (if using the low-noise receiver), or another port if there is

enough excess noise to use a standard S-parameter receiver. For applications where both the input and output signals are above 67 GHz, a switched, external, banded LNA/block downconverter must be used, since the noise figure of a millimeter-wave extender is too high to directly measure noise power. The downconverter is bypassed for the gain or conversion-gain measurement, and then switched in to measure the down-converted noise on one of the native PNA-X test ports. The block downconverter must be provided by the user, or from a third-party supplier such as Challenge RF. Maury Microwave also offers banded noise figure and noise parameter solutions from 50 to 75 GHz, 60 to 90 GHz, and 75 to 110 GHz.

Q. What is the noise figure of the PNA-X's noise receivers?
A. While the internal noise figure is quite good, the loss of the internal test-set components (cables, switches, couplers, etc.) degrades the noise figure somewhat, especially at higher frequencies. The noise figure at test port two is typically about 10 to 11 dB over approximately 90% of the instrument's frequency range. For the upper 10% of the range, the noise figure degrades typically to about 14 dB. Guaranteed specifications for the noise figure of the noise receiver can be found in the instrument data sheets.

Q. Which ports are available for noise figure measurements?
A. When using the low-noise receiver of Option 029 on an A-model PNA-X, measurements must be made between ports one and two. This was done originally because the tuner or tuner switch is only at port one, and the low-noise receiver is only at port two. For B-model PNA-Xs, the source port choice was relaxed, allowing use of ports one, three, or four. When using vector noise calibration with source port three or four, the user must make sure the ECAl impedance tuner is configured correctly. When making noise figure measurements using a standard S-parameter receiver as the noise receiver, then any combination of available test ports can be used as the source and receiver (see section Using S-parameter receivers).

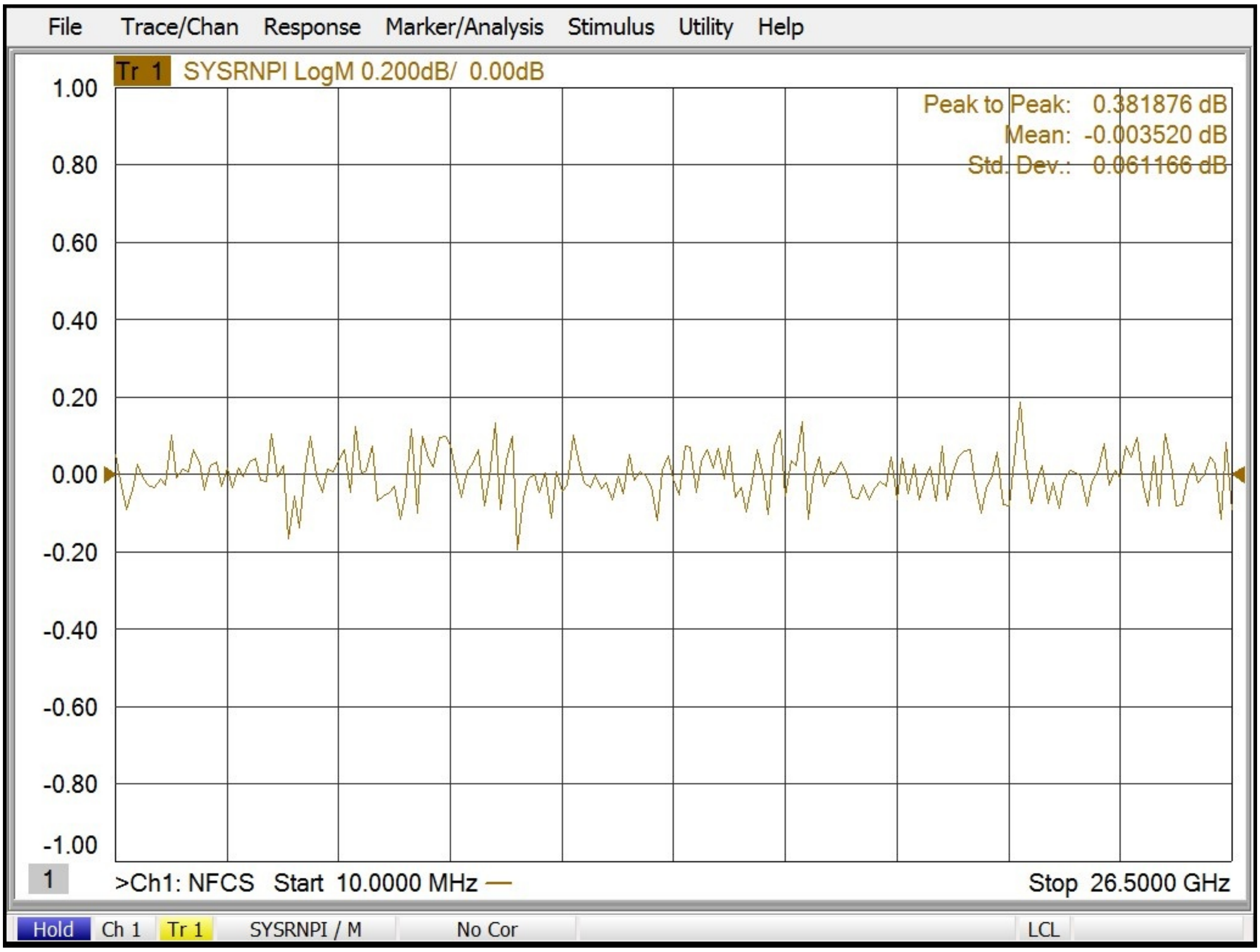
Q. Can I use a PNA-X with Option 029 with a multiport test set?
A. Yes, with some caveats. Only the standard (S-parameter) measurement class has a "multiport mode" where a user can select an S-parameter Sxy where x and y can be larger than four (for example, S95), and that automatically controls the switches in the multiport test set. For applications like noise figure, the port selection is referenced to the PNA-X itself, so the user may not specify a noise figure measurement directly between ports of the test set. The different path settings of the multiport test set must be set with SCPI commands unique to the test set. This can be accomplished with an external program, or by including the path commands in the Interface Control dialog. In the latter case, each test-set path setting (which selects the test-set ports used for the measurement) would require a separate noise figure channel with the appropriate SCPI commands for that path. So from the DUT's standpoint, the noise figure measurement might be between say, ports five and sixteen, but the noise figure setup dialog would show the native PNA-X ports (typically ports one and two). Another consideration when using a multiport test set is the amount of loss between the test-set ports and ports one and two of the PNA-X. Loss is due primarily to switch loss (especially for solid-state switches), and internal-cable loss, and it usually increases as frequency increases. For paths connected to port one, if the test-set loss is too large,

then vector noise calibration cannot be used. The alternatives are to use an external ECal placed on the test set and switched in such a way as to minimize loss between the tuner and the DUT, or to use scalar noise calibration. Since loss is generally frequency dependent, a noise figure measurement may be split into two bands, using vector noise calibration for the low band, and scalar noise calibration for the high band. For paths connected to port two, test-set loss degrades the sensitivity of the PNA-X's low-noise receiver, which increases the amount of trace noise for noise figure measurements. This effect can be mitigated by increasing the number of noise averages.

Q. What noise bandwidths are available in the noise receivers?
A. For the low-noise receiver: 800 kHz, 2 MHz, 4 MHz, 8 MHz, and 24 MHz (the default noise bandwidth is 4 MHz). When using a standard S-parameter receiver as a noise receiver, only 720 kHz and 1.2 MHz noise bandwidths are available (see section Using S-parameter receivers).

Q. How do I check if my low-noise receiver is working properly?
A. There are three recommended things to do. The first is to run the Operator's Check (under Utility, System, Service, Verification). If everything passes, there are two other tests than can help verify proper performance.

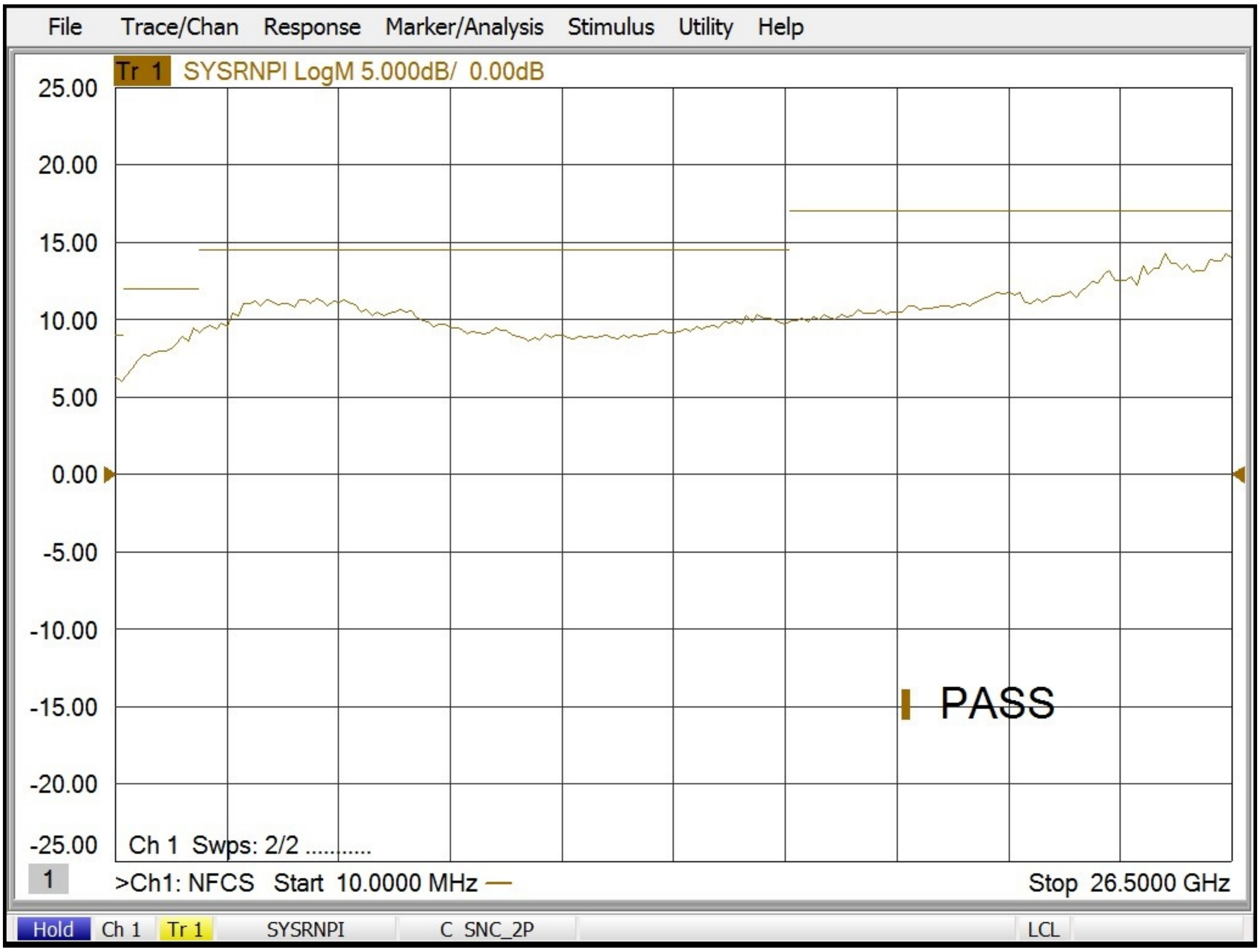
Test 1: Raw noise-receiver jitter
1. Connect a 50-ohm load to port two (a cal kit load can be used for this purpose or any other 50-ohm termination).
2. Create a noise figure measurement class (Response, Measure, Measurement Class..., Noise Figure Cold Source).
3. Change the measurement to incident system relative-noise power (Response, Measure, SYSRNPI).
4. Set noise averages to 10, and turn on noise averaging (Response, Measure, Noise Setup..., or Instrument, Setup, NF Setup...; set Average Number to 10, select Average ON checkbox).
5. Normalize the trace (Marker/Analysis, Memory, Normalize, or Response, Math, Normalize).
6. Turn off noise averages (Response, Measure, Noise Setup..., or Instrument, Setup, NF Setup...; unselect Average ON checkbox).
7. Change scale per division to 0.2 dB (Response, Scale, Scale...).
8. Turn on trace statistics (Marker/Analysis, Analysis, Trace Statistics, or Response, Math, Statistics; select checkbox for Statistics).
9. The value for Std. Dev. should be < 0.1 dB to meet the published specification for the N5241/42A/B, or < 0.11 dB for the N5244/45/47A/B. A typical value is 0.07 dB, as shown below:



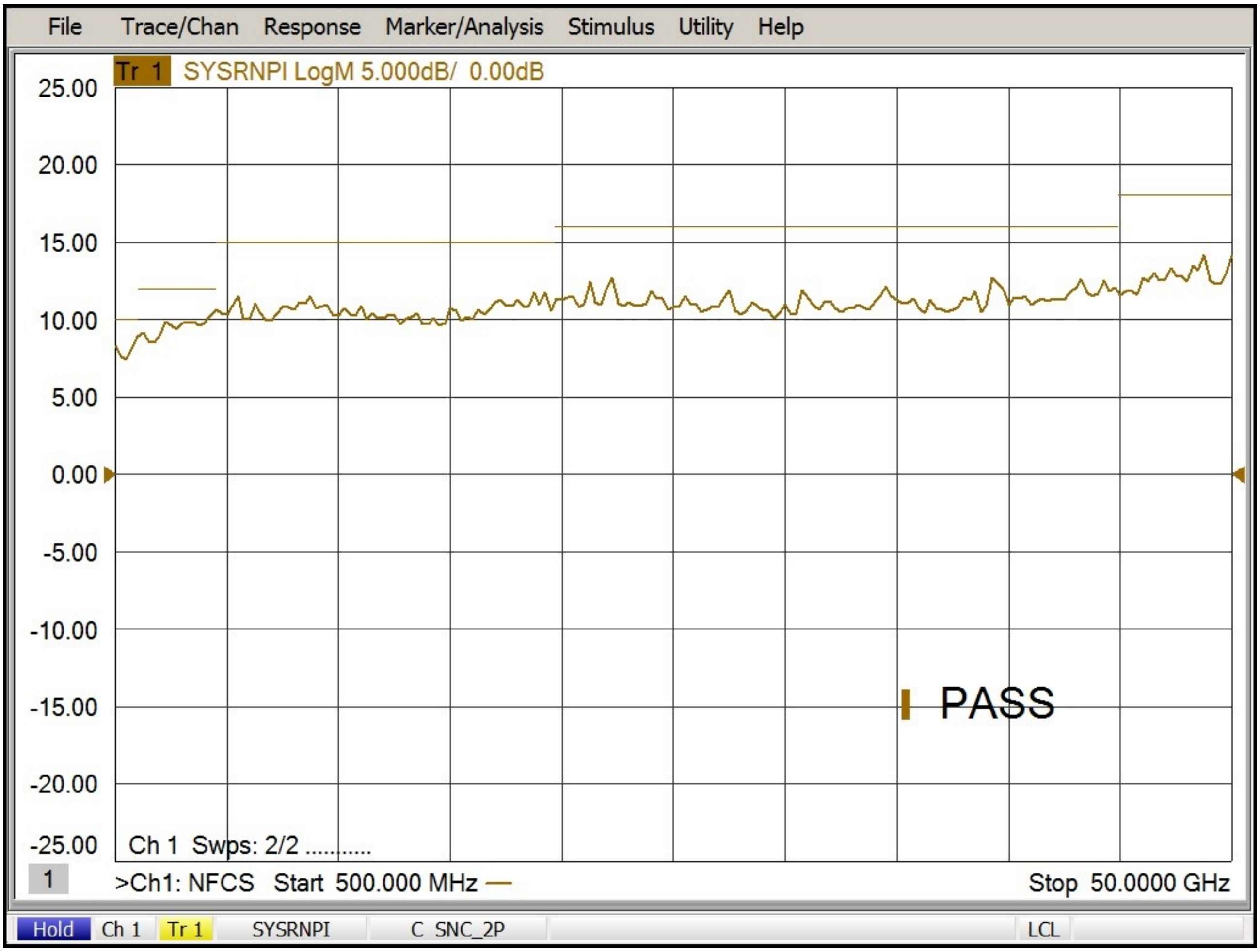
Test 2: Corrected noise-receiver noise figure

1. Use the setup from test 1 or create a new noise figure measurement class (Response, Measure, Measurement Class..., Noise Figure Cold Source). For N5241/42A/B units, use the default values for the measurement class. For N5244/45/47A/B units, set the start frequency to 500 MHz (this will allow use of a 50 GHz noise source, which although is only specified down to 1 GHz, works down to this start frequency).
2. Perform a scalar noise calibration of the noise figure channel. Use one test cable connected to port one and an adapter directly on port two (the reference plane for port two should be at the front-panel connector. This will prevent port two cable loss from contributing to the receiver's noise figure). You may use a power meter or a noise source for the calibration. Performing a vector noise calibration is okay but not necessary to test the noise receiver's noise figure.
3. Connect a 50-ohm load to port two (a cal kit load can be used for this purpose).
4. Change the NF measurement to incident system relative-noise power (Response, Measure, SYSRNPI).
5. Change the scale to division to 5 dB (Response, Scale, Scale...).
6. Connect a 50-ohm load to port two (a cal kit load can be used for this purpose or any other 50-ohm termination).

7. Read the noise receiver's noise figure directly from the trace. It will be between approximately 10 and 15 dB. Here is an example from an N5242A/B, with limit lines set to the published specifications:



Here is an example from an N5247A/B, with limit lines set to the published specifications:



Using S-parameter receivers

Q. What is Option 028?
A. Option 028 is a noise-figure option for the PNA-X A-models that uses the standard S-parameter receivers for noise-power measurements. It does not include a low-noise receiver or a tuner-bypass switch or built-in impedance tuner. It uses the same measurement algorithms and calibration techniques as those used in Option 029. For B-models, the equivalent to Option 028 is using S93029B without Option 029.

Q. Can an impedance tuner be used in conjunction with a standard S-parameter receiver?
A. Yes. The choice of using scalar or vector noise calibration is independent from the choice of noise receiver. With Option 028, the tuner is placed in the same loop as when using Option 029 (SOURCE OUT-CPLR THRU), but with Option 028, the tuner will always be in series with the coupler at port one, and it cannot be bypassed for other measurement channels, and the tuner loss will lower the available port power for all measurement channels by about 4.5 dB.

Q. Is Option 028 less accurate than 029?
A. To a first order, the accuracy of the two options is the same, since they share the same calibration techniques (scalar and vector noise calibration). However, in practice, Option 028 has more sources of potential error such as jitter due to higher receiver noise figure, and when using external LNAs to improve receiver sensitivity, LNA drift and compression. If the DUT or test system does not have a filter to remove out-of-band noise, then accuracy is degraded. Option 029 has built-in filters to eliminate this problem (see question below "Why are external filters often required when using a standard receiver for measuring noise figure?")

Q. Why would I buy the more expensive Option 029 instead of Option 028?
A. Simply put, Option 029 is much more convenient and general purpose (for B-models, the combination of S93029B and Option 029). It is a broadband solution that doesn't require any external components like LNAs or filters. It can measure any combination of gain and noise figure, and it works well with other measurements such as gain compression and IMD to provide a single-connection, multiple-measurement test solution. Calibration is also much easier without external components. Using a standard S-parameter receiver often requires an external LNA to improve receiver sensitivity, and due to the need for external filters to reject out-of-band noise, it is not a broadband measurement solution. Plus, the external components cannot be switched out, so they interfere with measurements of gain compression and IMD. And finally, since external LNAs result in high test-system gain, it is much more critical to set power levels properly for both calibration and measurements to ensure good signal-to-noise ratios, while not compressing the LNA, the internal S-parameter receiver, or the DUT.

Q. Are there devices where Option 028 is as good as Option 029?
A. Yes. Frequency converters that have high gain (> 40 dB) and output filtering that removes spurious signals and out-of-band noise can be measured quite well with Option 028, since no external components are required.

Q. When is an external LNA required to use a standard receiver for measuring noise figure?
A. As a rule-of-thumb, an external preamplifier is required for devices with < 30 dB of excess noise (gain plus noise figure in dB) up to 20 GHz, < 40 dB up to 50 GHz, or < 45 dB up to 67 GHz. If the amount of excess noise is a little below these values, the measurement can still be made, but the trace jitter will be higher. This can be mitigated by increasing the number of noise averages.

Q. Why are external filters often required when using a standard receiver for measuring noise figure?
A. The PNA-X S-parameter receivers are not preselected (i.e., there are no filters ahead of the mixer), and they use fundamental and 3rd-harmonic mixing to cover the full frequency range of the instrument. Up to 26.5 GHz, the PNA-X uses fundamental mixing. However, noise conversion can also occur at the 3rd (and 5th) harmonic of the LO, resulting in significant out-of-band noise contribution to the desired noise-power measurement if a filter is not used. A low-pass or band-pass filter placed right before the receiver (using the front-panel jumpers) removes out-of-band noise from entering the receiver, thereby eliminating that source of measurement error. For

frequencies above 26.5 GHz, 3rd-harmonic mixing is used, which causes a much bigger problem if a filter is not used. In this case, noise conversion also occurs at the fundamental frequency of the LO, where the conversion efficiency is about 9 dB higher than that at the 3rd harmonic. This results in a very large out-of-band noise contribution if a filter is not used. In this case, a high-pass or band-pass filter should be used to prevent out-of-band noise from entering the receiver. For the 50 to 67 GHz band, two Keysight V281A (WR-15) waveguide-to-coax adapters connected in series make an excellent high-pass filter that rejects signals below about 44 GHz.

Q. If I have Option 029 in a 67 GHz N5247A, but want to make noise figure measurements to 67 GHz, do I need to also have Option 028?
A. No. Option 029 for A-models (or S93029B for B-models) includes the choice of using the low-noise receiver or an S-parameter receiver. The low-noise receiver can be used to 50 GHz, and the S-parameter receiver can be used between 50 and 67 GHz.

Q. Why am I forced to use a power meter when calibrating a standard receiver for noise figure measurements?
A. Because the noise figure of a standard receiver is very high (30 to 45 dB, depending on frequency), the ENR value of standard noise sources are not high enough to overcome the internal noise of the receiver. The power-meter approach avoids this issue since the gain and bandwidth of the receiver are measured with comparatively large sinusoidal signals.

Q. When I calibrate my PNA-X using a standard receiver and a power meter for the first time, it does a measurement of the noise bandwidths across the full range of the PNA-X. For later calibrations, this step is skipped. Why is that?
A. Measuring the noise bandwidth of the standard receiver across the full range of the instrument is necessary to calculate its gain-bandwidth product versus frequency. However, since digital filters are used in the standard S-parameter receivers, the bandwidths are very stable and the measurement does not have to be repeated after having been done once, which saves calibration time. After the first calibration, the data for the noise bandwidth used with a particular test receiver is stored in a human-readable file on the instrument's hard drive (noiseBW.xml). Using another noise bandwidth or another test receiver requires another bandwidth calibration, so you may see this step reappear when you use a different port to measure the DUT or a different noise bandwidth on a previously used port. The new data will be appended to the xml file. Note that it is very important to not have any band-limiting components in place (such as waveguide adapters or filters) when this bandwidth calibration occurs, since it will be performed for the full frequency range of the instrument. If there is any doubt about the integrity of the stored noise-bandwidth calibration data, the xml file can be deleted and it will be regenerated the next time a calibration on a standard receiver is done. On instruments running Windows XP®, the noiseBW.xml file is located under C:\Program Files\Keysight\Network Analyzer\Noise. For instruments running Windows 7®, it is located under C:\ProgramData\Keysight\Network Analyzer\Noise. For B-models, the file is located under C:\ProgramData\Keysight\Network Analyzer\Noise (you must enable viewing of hidden files and folders to find the ProgramData folder).

Configuration

Q. Did noise figure ordering change between A-model and B-model PNA-Xs?
A. Yes. With the A-models, Option 029 included both hardware (low-noise receiver and tuner switch or built-in tuner), and the application software. Option 028 provided the software only, for measurements with the standard S-parameter receivers only. For the B-models, the hardware remains Option 029, but the application software is separate and ordered as S93029B. This allows more licensing flexibility. For example, for a pool of instruments where noise figure is not used very often, a single licensed copy of the application can be shared among the instruments, some or all of which might contain the hardware Option 029. S93029B can be used without hardware Option 029, but noise figure measurements can only be made with the standard S-parameter receivers in that case (equivalent to Option 028 for the A-models).

Q. Can I upgrade my existing PNA-X to add noise figure capability?
A. Yes. For a 2-port A-model, order N524xAU-924, and for a 4-port A-model, order N524xAU-929. In most cases, the upgrade can be done at your local service center. Upgrading N5244A units with noise figure hardware requires serial-number prefixes of 5204 or higher, and upgrading N5245A units requires serial-number prefixes of 5205 or higher. For these two models, units with lower serial-number prefixes can be traded in for credit towards a new unit with the noise figure hardware. For a 2-port B-model, order N524xBU-229, and for a 4-port B-model, order N524xBU-429. Upgrades from A-models to B-models are also available, and more information can be found here.

Q. Can I use an ECal module I already own?
A. Yes, you can use any existing ECal module for the S-parameter calibration, or any existing N4690 Series ECal for the impedance tuner (but one ECal cannot serve both functions). If the ECal module used for the impedance tuner is female-female, consult the PNA Family Configuration Guide (5990-7745EN for A-models or 5992-1465EN for B-models) to see which male-male adapter is needed to connect the ECal to the front panel of the PNA-X.

Q. Does Option 029 for 13.5 and 26.5 GHz units include the built-in tuner?
A. No. The internal tuner is only available for 43.5, 50, and 67 GHz units. For 67 GHz units, the tuner (and noise receiver) only work up to 50 GHz.

Q. Keysight used to offer N5244/45AS Option H29 which added a 26.5 GHz noise receiver to a 50 GHz PNA-X. Is that option still available?
A. No. That option was discontinued when the 50 GHz noise hardware was introduced.

Q. Which power meters and sensors are supported with the PNA-X?
A. The online PNA Help contains the most up-to-date information. This list of Supported Power Meters and Sensors can be found under the Power Calibration topic.

Solution partners

Q. Does Cascade Microtech's WinCal calibration software for on-wafer measurements include noise figure calibration?
A. Not directly, as WinCal only performs S-parameter VNA calibrations and cannot execute a noise-channel calibration. However, WinCal S-parameter calibrations can be combined with PNA-X noise calibrations for the most accurate on-wafer noise figure and S-parameter measurements. The PNA-X provides a Cal Plane Manager feature that can combine any S-parameter calset with a noise-channel calset to either produce a new composite noise-channel calset, or to provide s2p files for deembedding an adapter, fixture, or wafer probes. This feature allows a user to combine an on-wafer LRRM (or any other) calibration using WinCal with a coaxial noise-channel calibration done on the PNA-X.

Q. Are there any commercial noise-parameter systems that use the PNA-X?
A. Yes, both Maury Microwave and Focus Microwaves provide noise-parameter solutions based on the PNA-X. The same impedance tuners used in noise parameter systems can also be used in PNA-X-based load-pull systems. With recent changes to their noise-parameter software, Maury has achieved over two orders of magnitude improvement in measurement speeds, while at the same time improving the accuracy of the noise-parameter measurements.

Miscellaneous

Q. Does Keysight's IC-CAP Device Modeling software include the ability to measure noise figure?
A. No, not at this time.

Q. What noise figure application notes are available for the PNA-X?
A. There are two application notes specifically about PNA-X noise figure measurements:
· 1408-20 High-Accuracy Noise Figure Measurements Using the PNA-X Series Network Analyzer (5990-5800EN)
· Optimizing On-Wafer Noise Figure Measurements to 67 GHz, (5991-2524EN)

Q: What information should I provide when asking for help with noise figure measurements?
A: When requesting help from Keysight, be sure to always include the model number of your instrument, the installed options, and the firmware revision. If you can include an instrument state, which is very helpful, place all of the measurement channels in hold mode, which will preserve their data when a recall is performed. If you can't include an instrument state, send an image showing the problem. This eliminates problems due to imprecise or ill-defined terms. One example is the confusion between ripple and noise on measurement traces. Lastly, describe your test setup and the calibration steps used (such as connector type, cal kit, cal method...) as clearly as possible, since that information is not contained in the instrument state.