Comparison of Noise Temperature Measurements with Vector Network Analyzer (PNA-X) and Noise Figure Meter (NFA)

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Introduction

This report presents the comparison of the first noise temperature measurements obtained with the new Vector Network Analyzer recently installed in our laboratory[1] with previous measurements performed with the classical noise figure measuring instruments[2] used until now. The amplifiers used for this comparison cover the frequency range from 1 to 50 GHz. and the measurements were taken at ambient temperature. The goal is to show the differences which can be typically obtained but no attempt is made to analyze in depth the causes of the discrepancies observed.

Noise measurements with PNA-X

The PNA-X uses a novel approach for measuring noise which does not rely on Y factor measurements with input noise sources at different temperatures. The process is explained in detail in [1]. Basically it consists in measuring the noise power delivered to a carefully absolute calibrated receiver with the input of the DUT terminated with a load at ambient temperature. This method is usually referred in the literature as “cold source” (the term “cold” refers to “ambient” in opposition to the “hot” state of the noise diodes). For using this method is very important to determine with very good accuracy the gain of the DUT, but this is something that can be easily and reliably done with modern Vector Network Analyzers. One interesting feature of the method implemented in the Keysight PNA-X is the possibility to correct for the imperfections of the input impedance presented to the DUT. There is a built-in tuner which allows presenting several impedances at the input while measuring the output noise power to allow the determination of the noise parameters. In this way, noise measurements could be corrected and refereed to an ideal matched load, avoiding the “ripples” very often found in measurements of highly reflective DUTs.

In the noise measurement configuration, the calibration of the PNA-X for S parameters is performed in the usual way and some additional steps are introduced for the calibration of the noise receiver. The noise receiver calibration can be performed in two different ways: a) using a thermistor noise power meter or b) using a high ENR noise source. If a power meter is used is necessary to determine in addition the equivalent noise bandwidth of the receiver filter, but this is automatically done by the PNA-X calibration software. The two methods have been compared in the examples of this report, yielding quite similar results.

Note that the PNA-X used is equipped with Opt 029 (dedicated noise receiver) and all the measurements presented in this report were taken using this option. Noise measurements can also be performed with the standard receivers used for S parameter measurements, but then there are some important limitations of the system which should be carefully taken into account (see [1]).

Keysight provides a utility for determining the accuracy of the noise figure measurements performed with PNA-X [2]. This application must be run directly in the PNA-X since it needs access to all the data of the particular measurement being evaluated. Unfortunately it does not appear to be very reliable since it crash very often and provides quite limited information.

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[1] Keysight PNA-X model N5247A with option 029 (Noise Figure Aplication with dedicated receiver up to 50 GHz)

[2] Agilent 8970B (old model) Noise Figure Meter or Agilent N8975 A (new model)

The internal algorithms used by PNA-X for noise temperature and noise parameter calculation are proprietary and no information is available on them. The method is not intended for the determination of the noise parameters although they are used internally for obtaining a higher accuracy in the noise measurements and are available as additional results but without any commitment of their accuracy. The reason is that the number of impedance points and the Smith Chart coverage is limited. Keysight recommends a different third-party solution with a dedicated tuner for more accurate noise parameter measurement.

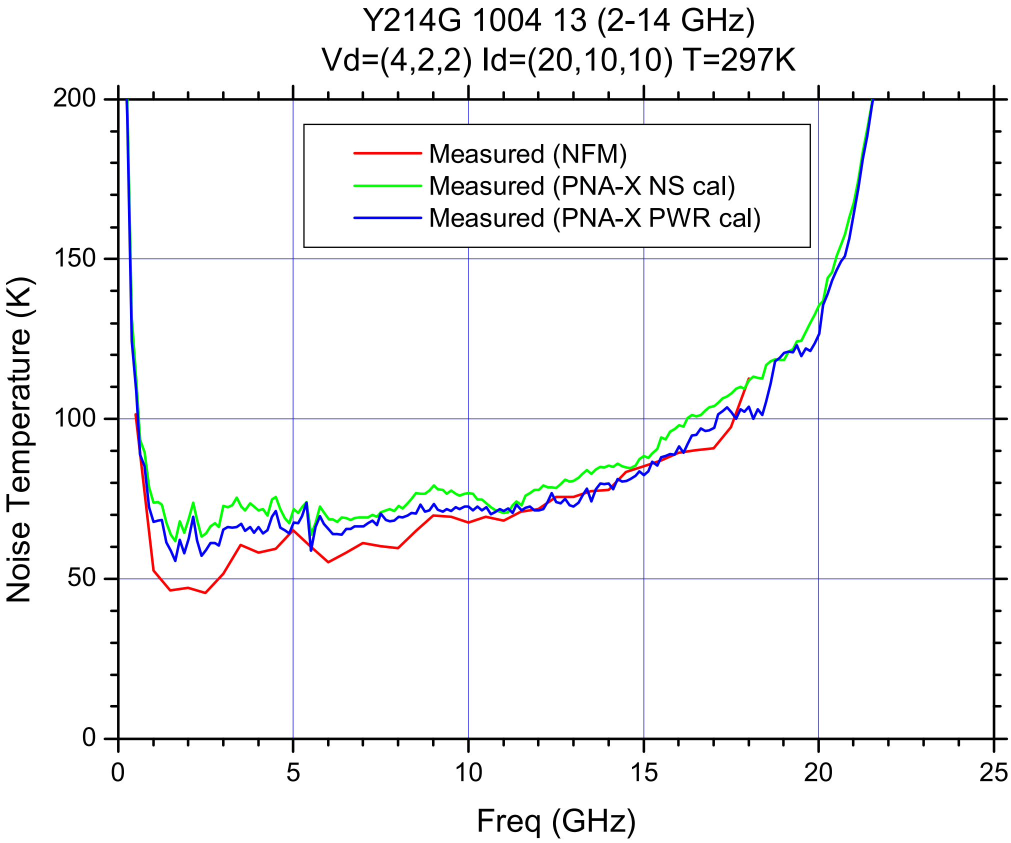
Amplifiers used in the experiment

Three different low noise amplifiers were used for this test:

- **2-14 GHz:** This is a VLBI 2010 design (non-balanced version) built in Yebes. The original measurement was taken with the newest noise figure meter and with a low ENR noise source (N8975A + N4000A). This amplifier is very wide band and the gain is quite flat (>30 dB) in all the range. The input reflection loss degrades considerably below ~4 GHz (<5 dB). Two sets of PNA-X measurements were taken; one calibrated with a power sensor (HP8485A) and the other with a noise source (HP346C). The data is shown in figure 1.

- **4-12 GHz:** This is an ALMA B9 design built in Yebes. The measurement system was the same as above (N8975A + N4000A). The input reflection loss is between 5 and 10 dB in the band and the gain is greater than 30 dB. Only PNA-X measurements calibrated with a noise source (HP346C) were taken. The data is shown in figure 2.

- **0.25-50 GHz**: This is a commercial amplifier built by Quinstar. The gain is larger than 30 dB and input reflection loss better than ~10 dB at frequencies less than 40 GHz and better than ~5 dB above 40 GHz. I/O connectors are 2.4 mm. The original measurement was taken with the old NFM (HP8970B) with a Q band downconverter built at Yebes and a 50 GHz diode noise source (HP346CK01) plus a calibrated 10dB precision attenuator. Due to the limitations of the downconverter that measurement could only cover the 27-50 GHz range. On the other hand, PNA-X measurements cover the whole 0.25-50 GHz in one single sweep. Two sets of PNA-X measurements were taken; one calibrated with a power sensor (HP8487A) and the other with a noise source (HP346CK01). The data is shown in figure 3. The manufacturer measured data is also presented is the same plot for comparison



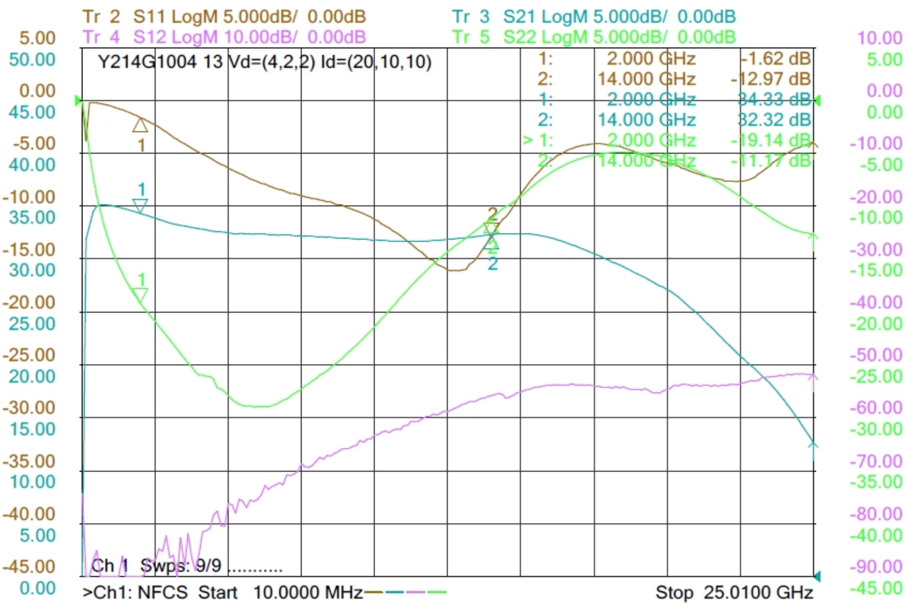
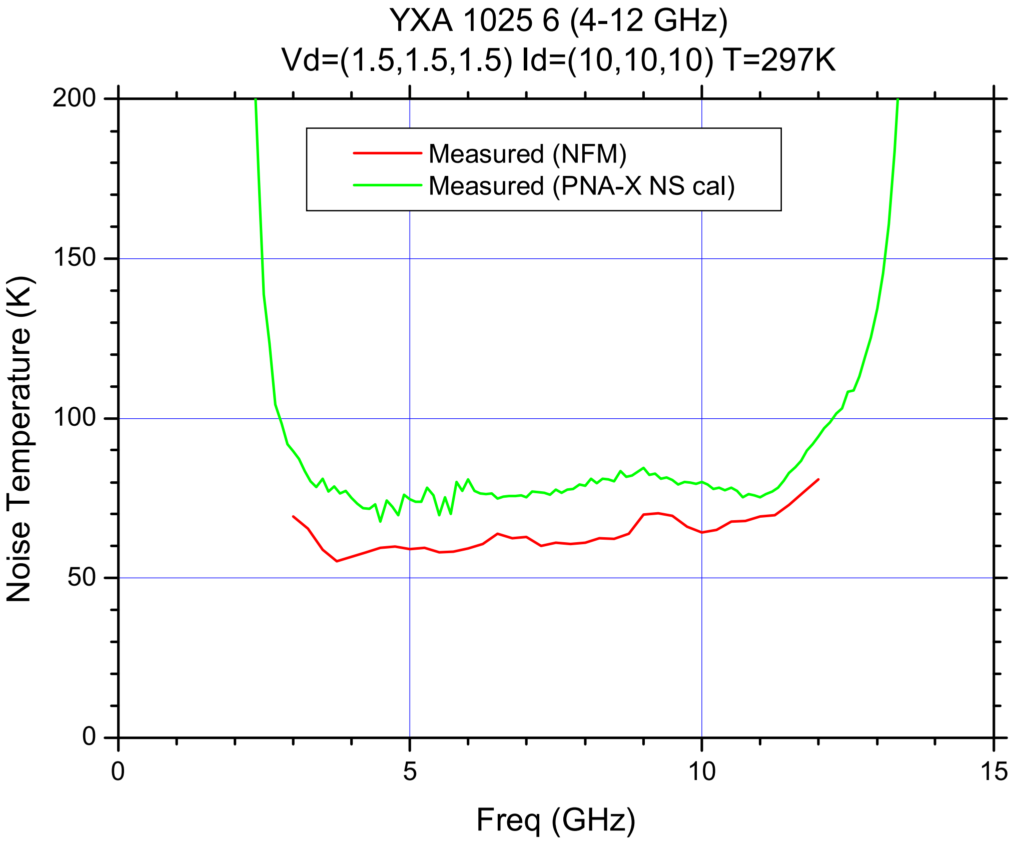


Figure 1: Comparison of Noise Temperature Measurements of a 2-14 GHz amplifier (Y2-14G 1004) at ambient temperature. The S parameters are shown in the bottom graph.



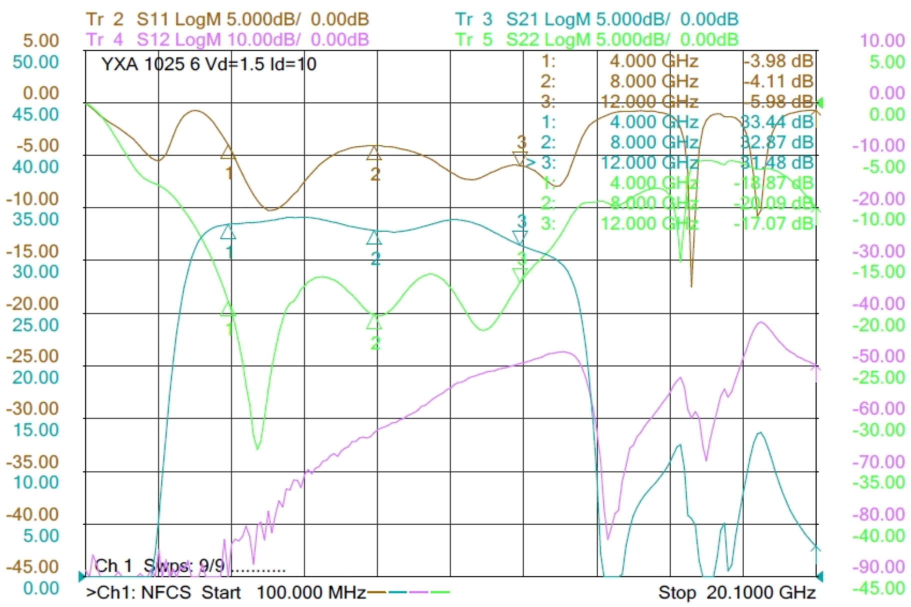


Figure 2: Comparison of Noise Temperature Measurements of a 4-12 GHz amplifier (YXA1025-6) at ambient temperature. The S parameters are shown in the bottom graph.

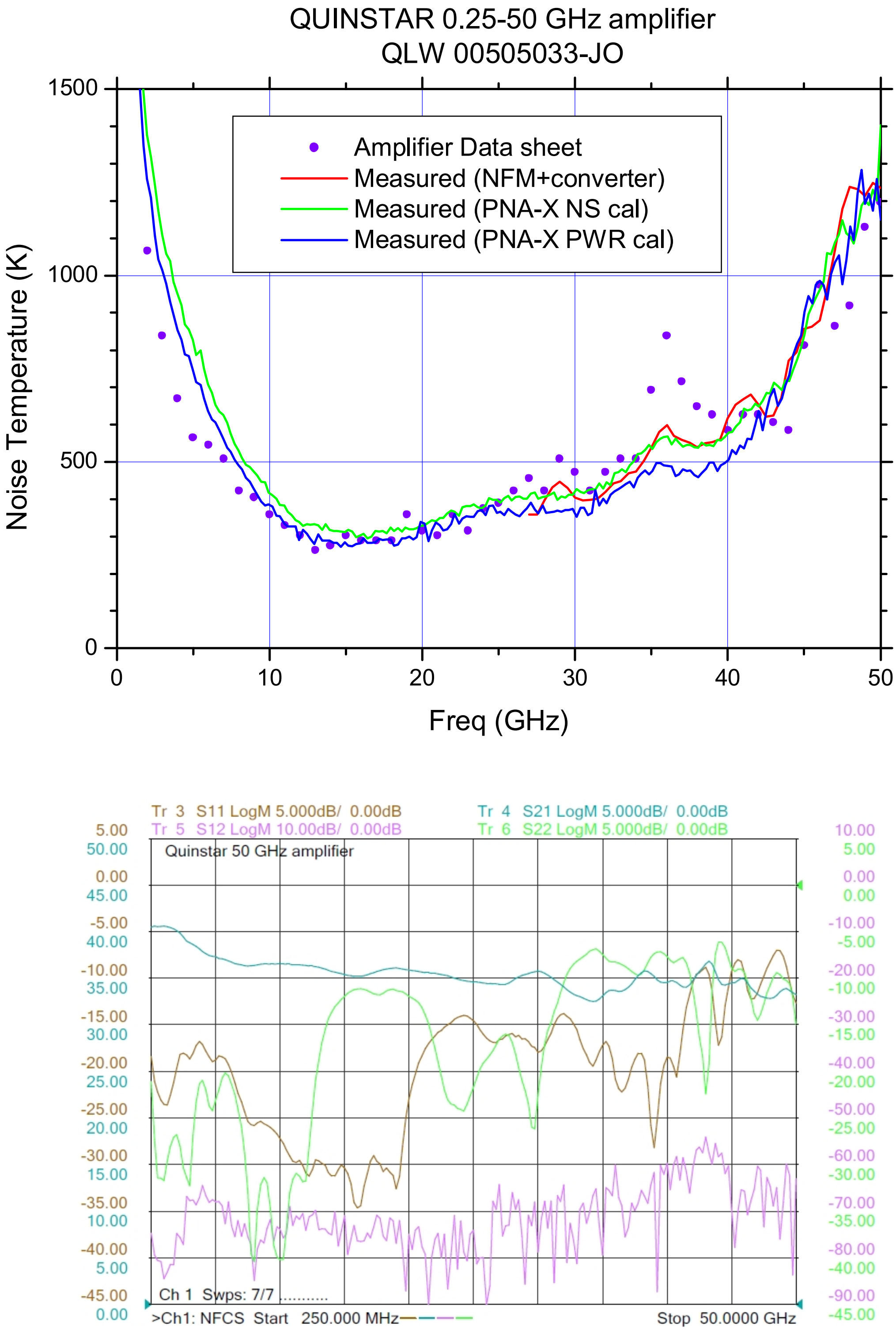


Figure 3: Comparison of Noise Temperature Measurements of a 0.25-50 GHz amplifier (Quinstar QLW 00505033 JO) at ambient temperature. The S parameters are shown in the bottom graph.

Measurements of noise parameters

In order to check if the noise parameters (Tmin, Zopt, Rn) obtained by PNA-X make some sense it was decided to compare the results with the predictions of the ADS model of the 2-14 GHz amplifier described in the previous section. The results of the comparison are presented in figure 4. The length of the input line of the amplifier model was adjusted to make the ripples fit in phase. Note that the accuracy of the model prediction is not known and depends strongly on the noise model used for the transistors.

The overall agreement is relatively good especially within the band. The most remarkable differences appear in Tmin at low frequencies (<5GHz) and some glitches in the convergence of the algorithm are clearly observed at ~2 GHz).

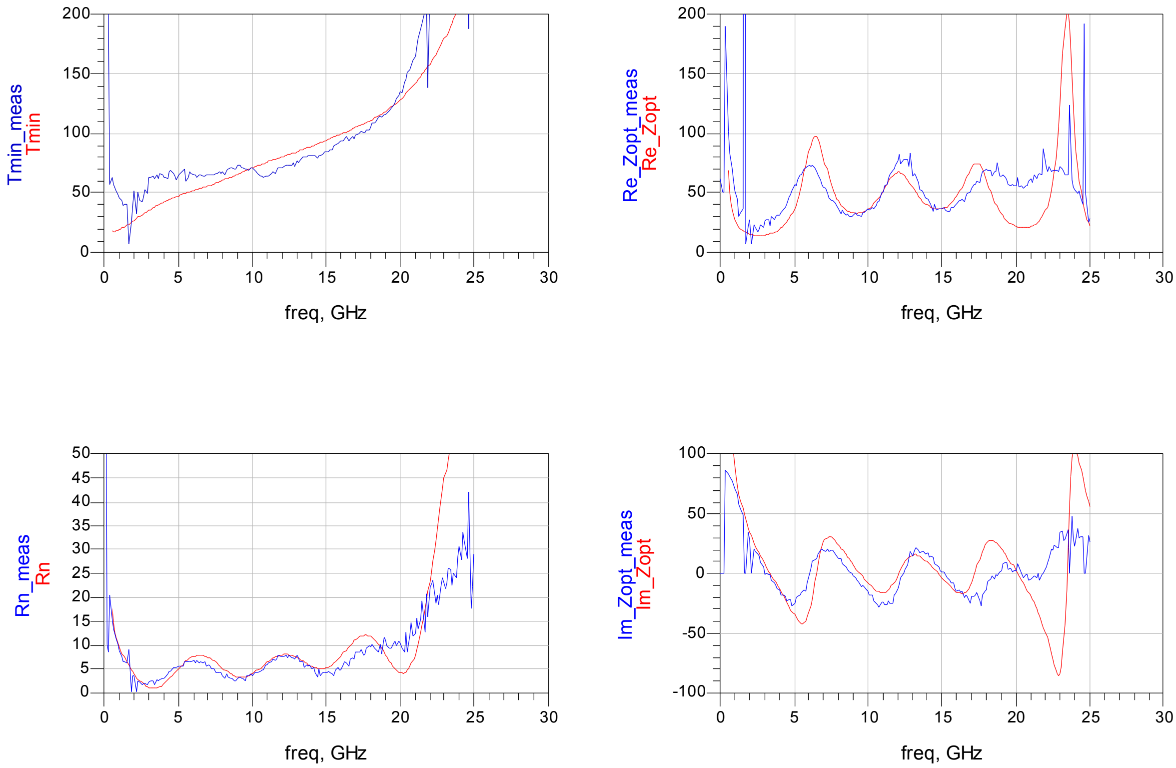


Figure 4: Comparison of noise parameter measurements of a 2-14 GHz amplifier (Y2-14G 1004) at ambient temperature with theoretical model prediction from ADS.

Conclusions:

The noise temperature measurements performed with PNA-X yield more pessimistic results in very low noise amplifiers for frequencies below ~10 GHz than those previously obtained with the newest noise figure meter (N8975A + N4000A). However, the accuracy of the NFM measurement is limited by the calibration of the noise source (±0.2 dB) and just taking that into account and neglecting other contributions to the error we could estimate an accuracy no better than ±15K. This will be sufficient to explain the differences even in the case of the 4-12 GHz amplifier of figure 2. Besides, which such low values of noise temperature, any error in the physical temperature of the input ambient termination will have an important impact in the noise measured. In the case of the PNA-X the value used for the ambient temperature was measured with an infrared thermometer in the front panel of the instrument, but it may happen that the real temperature of the inner parts could be much higher (10-15 K). Each K of increment of the input termination temperature should be subtracted from the measured noise temperature to obtain the real value. To complicate things even more, the cable from the PNA-X to the amplifier will also have some effect in the input termination temperature due to its loss (which changes with frequency). That makes the accurate calculation of the temperature quite difficult and more complex than in the noise source used for Y factor measurement.

In the high frequency region (>20 GHz) the agreement obtained shown in figure 3 is good. However, it should be noted that in this case the noise source used for NFM measurement and PNA-X calibration is the same. Nevertheless, the agreement with the calibration performed with the power sensor is still relatively good. In this case the contribution of the possible error in the physical temperature of the input termination is not quite relevant since the noise temperature of the amplifier is much higher.

Respect to the validation of the noise parameter measurement, it appears that the overall picture is consistent with the results expected from the simulations. Since the accuracy of the model is not well known it is risky to extract conclusions, but it appears that in the example presented in figure 4 there are some problems to measure accurately the expected low value of Tmin when the optimum source impedance is far from 50 Ohms in the low frequency region (<5 GHz).

References:

[1] Keysight Technologies, High-Accuracy Noise Figure Measurements Using the PNA-X Series Network Analyzer, Application Note AN1408-20, 2014.

[2] PNA-X Noise Figure Uncertainty Calculator, VEE application, Keysight 2015. www.keysight.com/find/nfu .