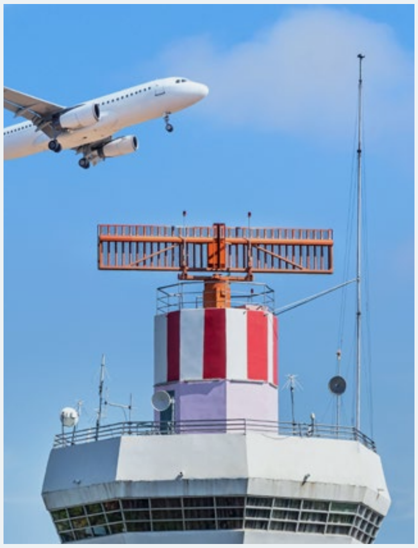
TECH BRIEF

Accurate Noise Figure Measurement in ERZIA K/Ka-Band Low Noise Amplifiers for Satcom Applications.

ERZIA

Contents

Introduction



The satellite communications industry is in constant evolution, always looking for new technologies and approaches to handle the exponentially increasing traffic demand. Driven by this continuous objective, higher RF and Microwave frequency bands have been gradually introduced, initially for networks in relatively low frequencies, such as L-Band, C-Band or X-Band, then for higher frequencies like Ku-Band which is widely used nowadays. The higher the frequency, the wider the channels, so bigger data capacity is required, thus the interest in exploiting the K/Ka-Bands and Q/V Bands.

Currently, Ka-Band is providing relief from the already crowded Ku-Band, and gaining momentum with a growing number of services available and many more coming in the following months and years.

Low noise amplifiers (LNAs) are key to the whole performance of satellite communication systems. The noise figure of these amplifiers is a critical value that fixes the system sensitivity. Their gain and input matching are also very important parameters for the rest of the system.

The electrical characterization of these parameters is critical to assess the system performance and provide system level engineers the right data to design their systems and link budgets. However, noise figure measurements at mm-Wave frequencies are not trivial and high uncertainties can be found during the process. This is especially critical in these modules, where every tenth of dB counts and the accuracy of the measurement itself must be minimized.

ERZIA is fully involved in the development and production of LNAs for K/Ka-Band Satcom applications and totally committed to the quality and performance of these amplifiers. The company has invested considerable resources and significant effort to determine the best way to accurately characterize these amplifiers. In this tech brief, we will present a noise figure measurement methodology that describes how ERZIA conducts measurement tests to accurately characterize these devices. According to the authors' best knowledge, the most accurate method to measure noise figure in Ka/K Bands has been applied to two state of the art ERZIA's LNAs with leading noise figure values, to accurately confirm their low noise figures.

Y-FACTOR VS COLD SOURCE MEASUREMENT

A discussion of noise figure measurements would include a wide number of options, instrumentation, and techniques each with their own advantages and limitations. In this tech brief, we have concentrated our efforts on non-cryogenic applications, with proven performance, that can be conducted with standard laboratory equipment and easily followed by trained personnel.

The Y-factor technique is one of the most popular methodologies used to measure the noise figure of a device. Its relative simplicity and fast calibration makes this a preferred technique and it is perfectly suited to measure the noise factor (NF) in systems with relatively high values, or where extreme accuracy is not really needed. However, the effect of DUT input matching (usually not consistent values in LNAs) and the low accuracy at mm-Waves are significant drawbacks for this technique.

The cold-source method is a good alternative. But, in order to maximize accuracy, the use of a power meter for the calibration step is preferred over the use of a noise source to minimize the mismatching between the calibration device and the DUT.

The cold-source method, using a power meter during calibration and a source-correction technique, provides the best possible accuracy, minimizes the impact of DUT input matching errors, and avoids a limitation in the measurement of bandwidth. However, calibration is slower and the equipment cost is significantly higher than the Y-factor method due to the higher sophistication required.

These noise figure measurement methods are compared in **Table 1**, pointing out their main advantages and disadvantages (Keysight [1] [2] [3]):

	Y-factor method using a noise source	Cold-source method using a noise source	Cold-source method using a power meter (with source correction)
Advantages	+ Large diversity of equipment using this method. ++ Fastest calibration.	++ Good accuracy. ++ Fast calibration (with noise BW: 24MHz).	+++ Best possible accuracy. No errors related to mismatch and noise-parameter effects. + Broadband power meters are easier to find.
Disadvantages	– Choice of appropriate noise source: lower ENR is associated with narrower bandwidth. ––– Higher effect of DUT mismatch and/or noise source match changes (ON/OFF states). –– Reference temperature must be 290 K. If not, correction must be applied to ENR. ––– Linearity of DUT and detector are required to avoid uncertainty. – Low accuracy above 45GHz due to jitter.	–– Choice of appropriate noise source: lower ENR is associated with narrower bandwidth. ––– Higher effect of noise source/DUT mismatching. – Low accuracy above 45GHz due to jitter. – Most equipment does not have this option available. –– Equipment cost.	– Slowest calibration (noise BW: 4MHz). – Most equipment does not have this option available. –– Equipment cost.

Table 1: *Comparison of Y-factor vs cold-source method for noise figure measurements.*

As described on page 4, the selection of the measurement instrument is also a key factor. Keysight, one of the world's main measurement equipment manufacturers, provides the PNA-X family of Network Analyzers which are some of the most sophisticated and accurate testing and measurement solutions available. Our analysis determined this instrument to be the perfect candidate for our high-accuracy noise figure measurements for several reasons including:

- PNA-X's source-corrected technique provides the best noise figure measurement accuracy.
- All power calibrations are fully match corrected.
- PNA-X's receiver is the most accurate thanks to its linearity.
- PNA-X's nominal specifications (at 1 GHz):
  - S21 parameter uncertainty: 0.05 dB
  - Instrument match: 1.02:1

In any case, for future tests, it would be interesting to compare the accuracy of test results using instruments from other manufacturers to determine the measurement technique that provides the highest accuracy.

Keysight has also conducted studies on the direction of this paper, with some interesting data published that confirms our preference for the cold-source method. **Figure 1** shows the measurement uncertainty of an LNA in an automated test environment, based on a Monte-Carlo calculation, performed by Keysight [1]. The cold-source using the PNA-X clearly improves the accuracy of the noise figure measurement with respect to Y-factor, improving the uncertainty from 0.75 dB down to 0.2 dB.

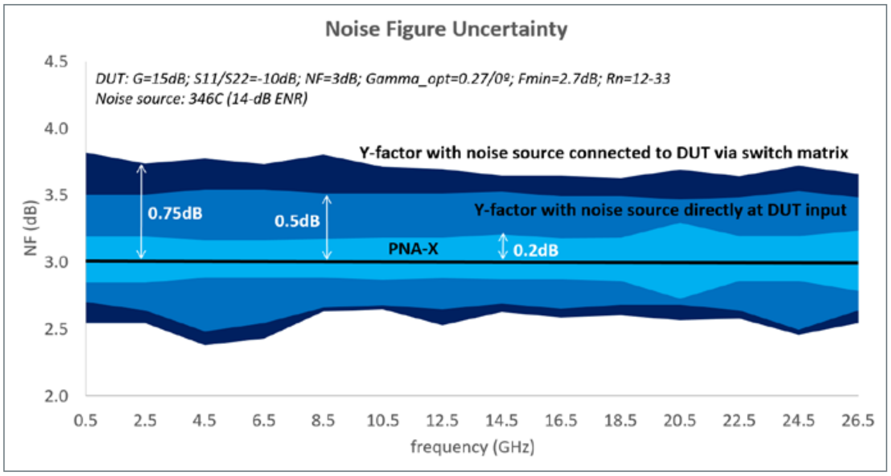
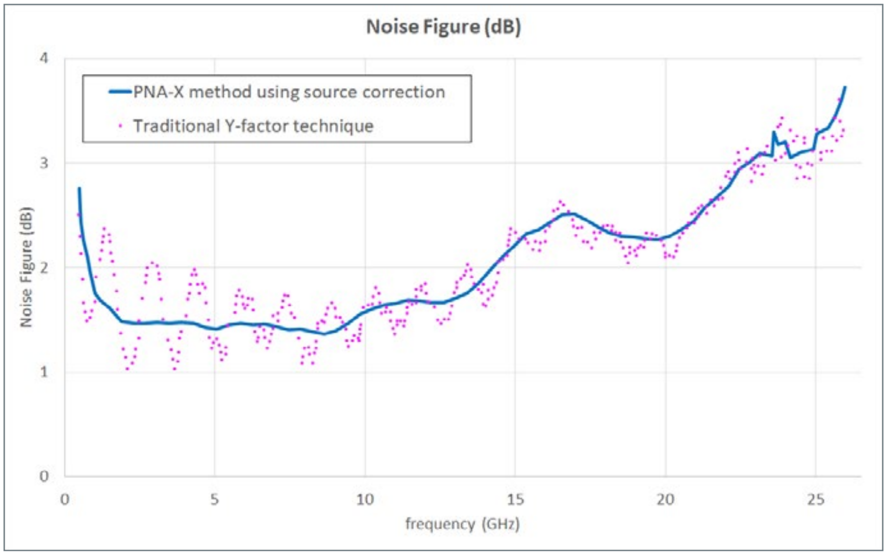


Figure 1: *Noise Figure uncertainty of Y-factor vs PNA-X method (Keysight [1])*

A different noise figure measurement example is shown in **Figure 2**, where it can be seen that the ripple tested with the PNA-X is much better than the one obtained using the Y-factor technique.

In summary, the cold-source method using a power meter and a source-correction technique has several advantages, whereas the main drawbacks are the calibration time and the necessity of having more expensive equipment than the ones incorporating the Y-factor technique. But, it is worth investing in performance analysis equipment to achieve the best possible accuracy in critical noise figure measurements, especially for low-noise values and in a market that supports enough volume to justify the investment.

Figure 2: Noise Figure measurement example of Y-factor vs PNA-X method (Keysight [2])



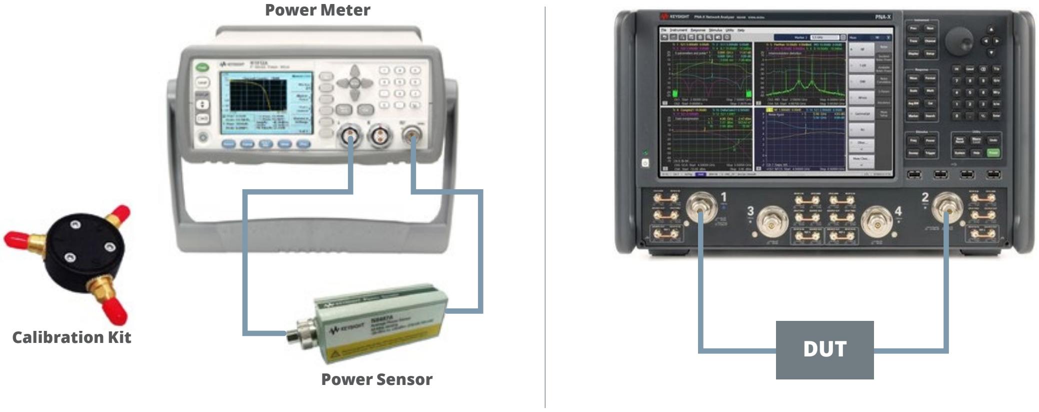
CALIBRATION AND INSTRUMENT SETUP

The setup required to measure the noise figure of a low noise amplifier using the PNA-X and the cold-source method with source correction is relatively simple, but several things must be considered for an accurate measurement.

Figure 3 presents the required equipment for calibration and **Figure 4** shows the test bench to measure the noise figure and the S parameters with the PNA-X.

Figure 3: (Left) Calibration equipment

Figure 4: (Right) Test equipment: PNA-X



In our case, we have used the following equipment:

- Keysight N5245B PNA-X
- Keysight N1912A P-series dual channel power meter
- Keysight N8487A thermocouple power sensor
- Keysight 3.5-mm calibration kit

The calibration process is very simple. First of all, the power sensor has to be connected to the power meter in order to calibrate its power level.

After that, the PNA-X has to be calibrated and configured. The setup chosen for the results included in this work is:

- Type of measurement: noise figure cold source.
- Vector noise calibration using the power meter. No additional equipment is needed since the N5245B PNA-X has an internal electronic calibration (Ecal) module. Noise receiver bandwidth: 4 MHz. IF bandwidth: 1kHz.
- Noise averaging factor: 50. This parameter reduces the calibration and measurement jitter.
- Low receiver gain since in our case Gain+NF>35 dB. Otherwise, the receiver would be in compression.
- Input power level for the tests: -40 dBm to ensure there is no compression from the DUT. If required, a source attenuator shall be fixed for the whole process of calibration and test. In this case, a 10-dB source attenuator is needed.

Once the PNA-X configuration was completed, the PNA-X wizard guide provided steps to adjust the cold-source noise figure calibration as follows:

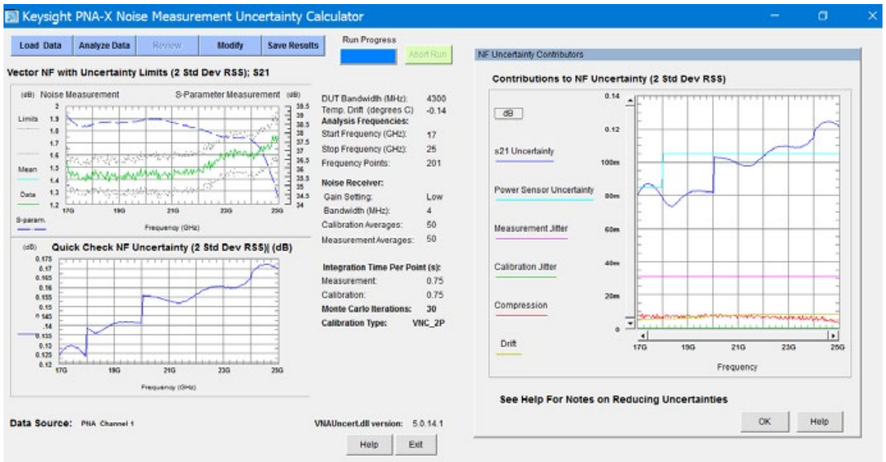
- The first step is to connect the power sensor to the input port. A higher power level is preferred during the calibration to reduce the S21 uncertainty. 0 dBm have been used.
- After that, the calibration kit is used at the input port and the output port to test the open, short and load terminations.
- Finally, a coaxial through is required to complete the calibration.

As indicated in Table 1, this process will require more time than a regular S-parameter calibration or a noise figure calibration using a noise source, but accuracy is a key parameter, especially in low noise figure measurements.

One of the main points of this work is to estimate the noise figure uncertainty of the measurements. For this purpose, the Keysight PNA-X noise measurement uncertainty calculator has been used. This software has been run directly on the PNA-X and all the required data have been transferred to the calculator, where the measurement uncertainty has been modeled with full traceability. The results depend on the calibration setup and the DUT performances.

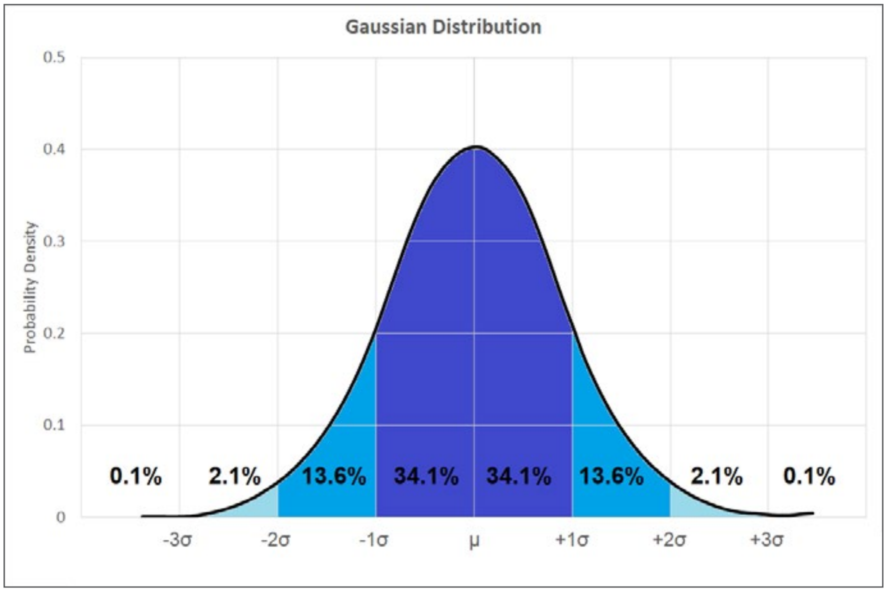
A screenshot of the data provided by this calculator is shown on the following page in **Figure 5**.

Figure 5: Keysight PNA-X Noise Measurement Uncertainty Calculator



The figure above shows the noise figure uncertainty within two standard deviations of the mean value, thus the 95.4% of the possible results is covered, as explained in **Figure 6**.

Figure 6: Gaussian Distribution



In our case, our production flow chart allows us to reduce this variation to one standard deviation. If one of the devices is not within the 68.2%, it will be measured again to check if all the requirements are fulfilled, and the first value was just far from the mean. If several tests provide a bad value, the device will be tuned or rejected.

MEASUREMENS

The cold-source method has been used to characterize two low noise amplifiers. All the measurements have been performed using a PNA-X calibrated and prepared as described before.

Two K/Ka-band Low Noise Amplifiers have been selected for the test. Both are designed to operate on the 17-22 GHz frequency range, having extremely low noise, so they are the ideal candidates to verify the accuracy of this methodology.

The first one is a catalogue item, the ERZ-LNA-1770-2200-40-1.5, while the second one is a preliminary version of a future catalogue item, the ERZ-LNA-2000-2250-45-1.3.

LNA1: ERZ-LNA-1770-2200-40-1.5

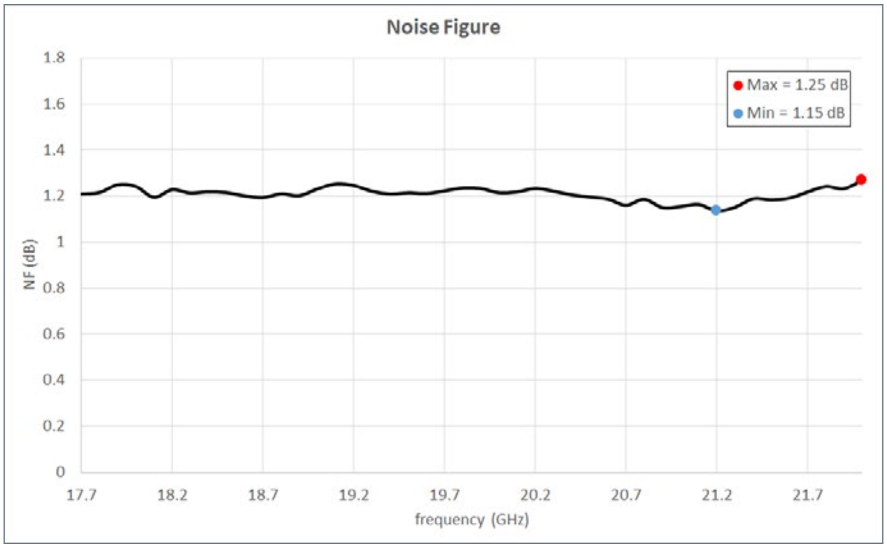
The first example is one LNA from ERZIA's catalogue: the ERZ-LNA-1770-2200-40-1.5, that presents unique characteristics, with 4.3 GHz of bandwidth and a 40-dB gain guarantees a noise figure lower than 1.4 dB at 25ºC all over its frequency range, making it unique on the industry, and one of the LNA's commercially available in the market with less noise figure in K/Ka Band.

Figure 7: *ERZ-LNA-1770-2200-40-1.5 Photo*

The input port is a WR-42 waveguide, with an input matching better than 2.0:1, while the output port is a female coaxial connector. A photo of the tested amplifier is shown in **Figure 7**.

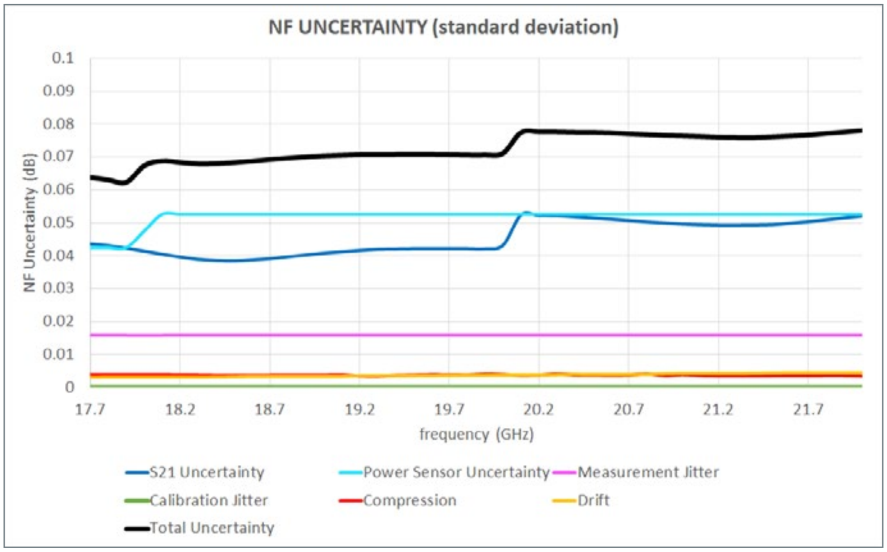
After a complete PNA-X calibration as described in section 3, the LNA is measured at 25ºC laboratory conditions. **Figure 8** presents the measured noise figure which is below 1.3 dB in the whole bandwidth 17.7-22 GHz with typical values on the 1.2 dB. This is an excellent noise for this band.

Figure 8: *ERA-LNA-1770-2200-40-1.5 Noise Figure*



This is the typical noise figure measurement that can be found in a general datasheet without further information, but to verify how accurate is this information, the uncertainty is calculated with the noise measurement uncertainty calculator, being the result presented on the following page in **Figure 9**.

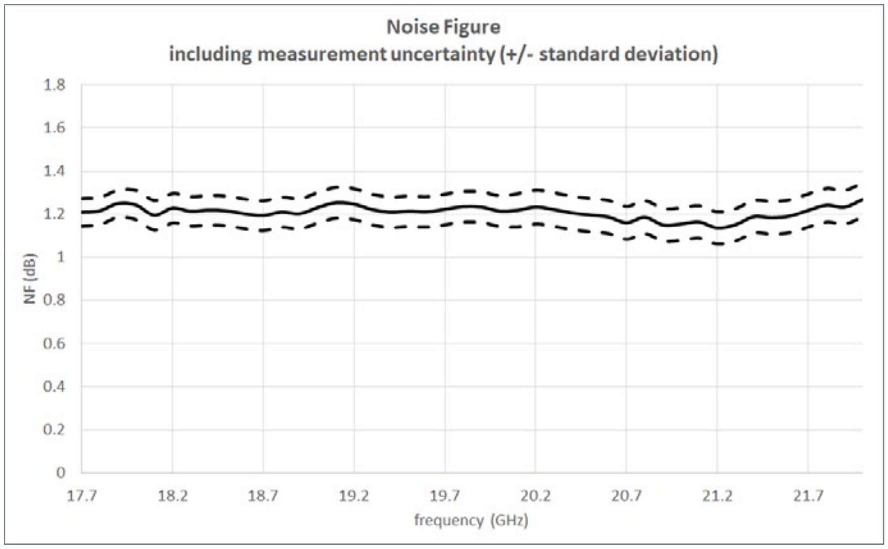
Figure 9: Noise Figure Uncertainty



Overall uncertainty for one standard deviation is less than 0.08 dB which is an excellent value for this frequency range and low noise values. The biggest contributors to the uncertainty are the power sensor itself and the S21, while the jitter stays below 0.02 dB.

The noise figure measurement with the overlapped uncertainty is presented in **Figure 10**, meaning that it can be guaranteed that the LNA is well below the limit NF specification of 1.4 dB including the measurement uncertainty.

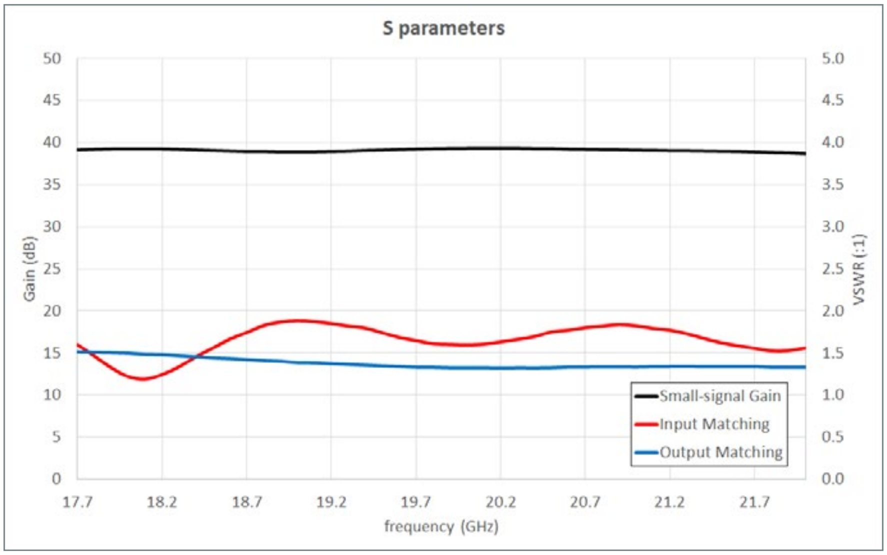
Figure 10: ERA-LNA-1770-2200-40-1.5 Noise Figure with Uncertainty Limits



This obtained data gives the absolute confidence that the measured unit is inside the indicated range, while measurements in similar bands using Y-Factor or other methods, can lead to uncertainties as high as +0.5 dB/-0.4 dB as shown in Figure 1. If this uncertainty were applied to this measurement, it would give a range between 0.7 and 1.8 dB; therefore, the obtained data would be completely distorted.

Small-signal gain and input/output VSWR can be observed in **Figure 11**, having values in the range defined on the item's datasheet. Results are summarized in **Table 2**.

Figure 11: *ERZ-LNA-1770-2200-40-1.5 S parameters*



ERZ-LNA-1770-2200-40-1.5							
Parameter	Specification Value @ 25ºC			Measured Value @ 25ºC			Check
	min	typ	max	min	typ	max	
Frequency (GHz)	17.7	-	22	17.7	-	22	✓
Small-signal Gain (dB)	38	39	41	38.7	39.1	39.4	✓
Gain Flatness (dB)	-	+/- 0.5	-	-	+/- 0.3	-	✓
Noise Figure (dB)	1.0	1.2	1.4	1.1	1.2	1.3	✓
Input VSWR	1.0:1	1.6:1	2.0:1	1.2:1	1.7:1	1.9:1	✓
Output VSWR	1.0:1	1.6:1	1.8:1	1.3:1	1.3:1	1.5:1	✓

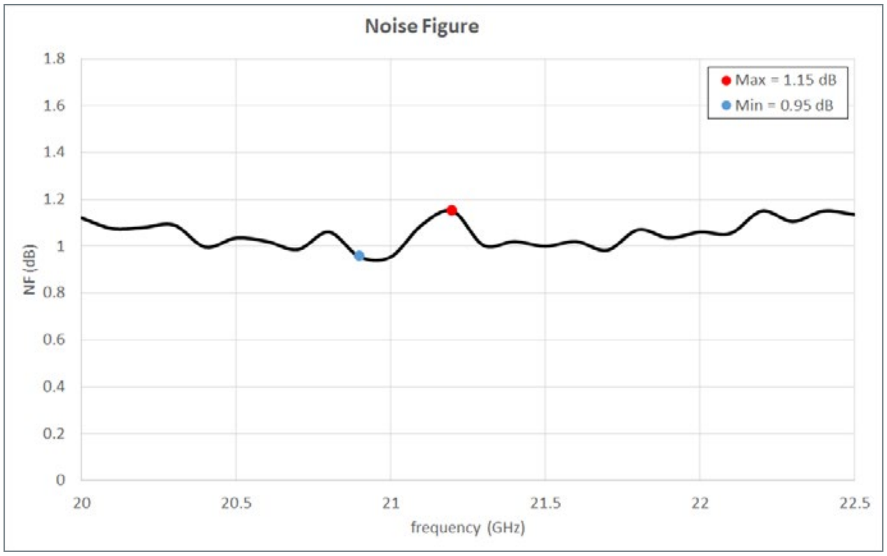
Table 2: *ERZ-LNA-1770-2200-40-1.5 Specifications Summary*

LNA2: ERZ-LNA-2000-2250-45-1.3

The second example is a new amplifier design, the ERZ-LNA-2000-2250-45-1.3. This model is focused on the 20 to 22.5 GHz frequency range, with even better noise figure than the first example, but narrower bandwidth and slightly higher input matching. The external mechanical interfaces are the same: a WR-42 waveguide at the input and a female coaxial connector at the output.

The LNA is measured at 25ºC laboratory conditions. **Figure 12** on the following page presents the measured noise figure which is below 1.2 dB in the whole bandwidth with typical values on the 1 to 1.1 dB. This is also an excellent noise for this band.

__Figure 12:__ ERZ-LNA-2000-2250-45-1.3 Noise Figure



As in the previous example, the noise figure uncertainty has been calculated with the Keysight PNA-X noise measurement uncertainty calculator, presenting the result in **Figure 13**. The noise figure with uncertainty limits is presented in **Figure 14**.

__Figure 13:__ Noise Figure Uncertainty

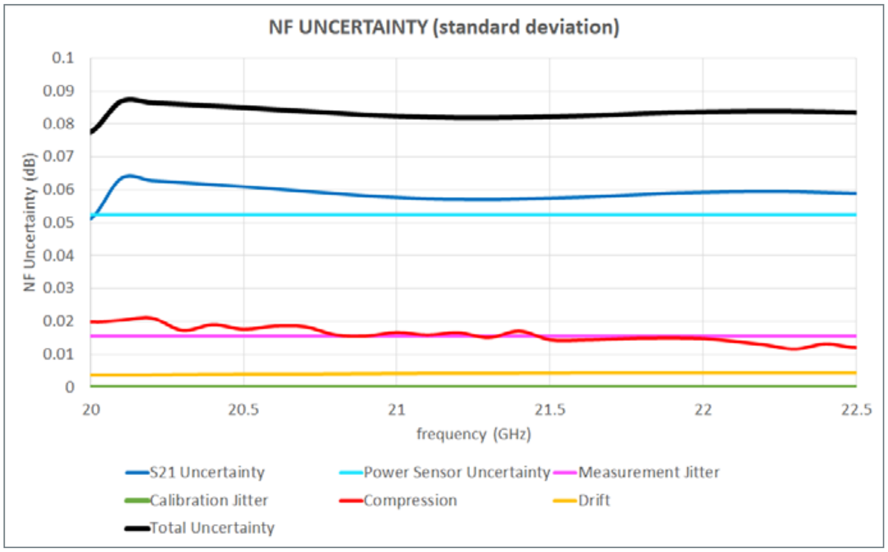
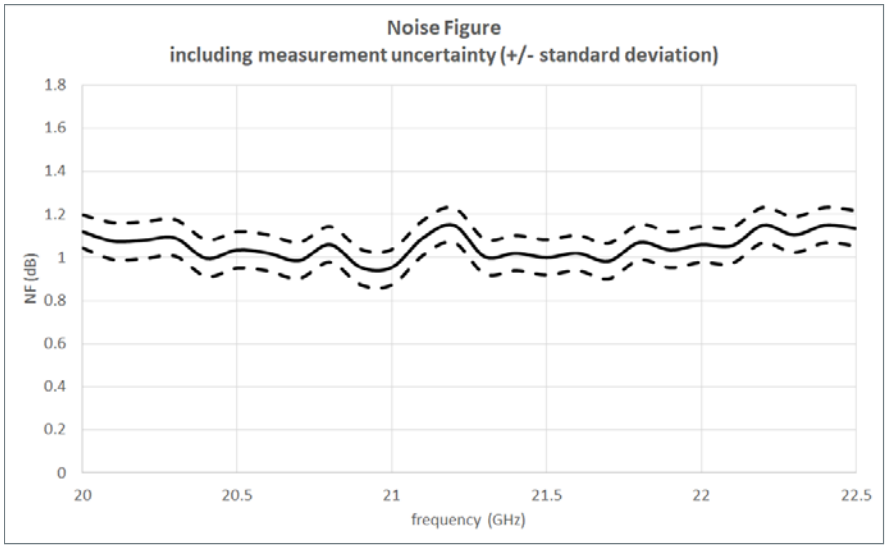


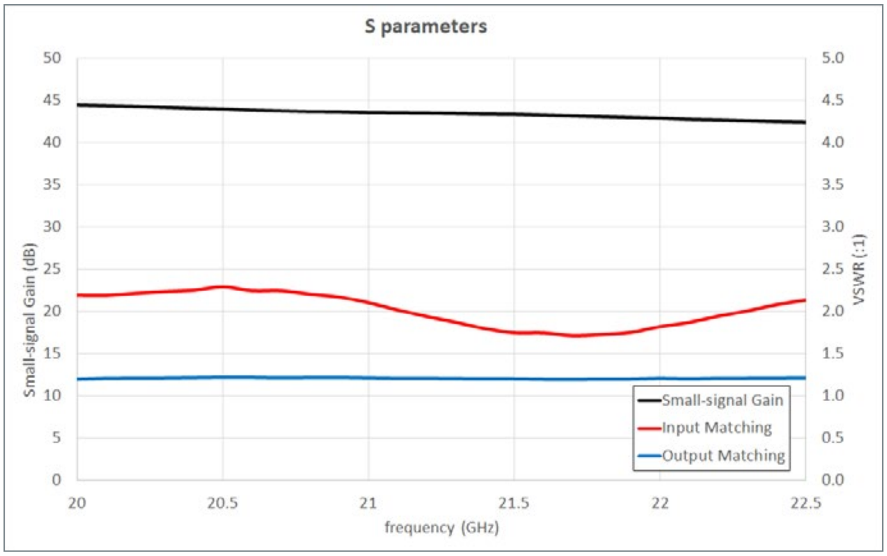
__Figure 14:__ ERZ-LNA-2000-2250-45-1.3 Noise Figure with Uncertainty Limits



In this second LNA, a noise figure lower than 1.3 dB is guaranteed, with an uncertainty similar to the first case. It can also be observed how the higher uncertainty contribution of S21 and compression makes a final uncertainty 0.01dB higher than the first case, being a reference of how sensitive this calculation is, even with similar LNAs. In any case, this is a negligible difference.

Small-signal gain and input/output VSWR can be observed in **Figure 15**, having values in the range defined on the item's datasheet. Results are summarized in **Table 3**.

Figure 15: *ERZ-LNA-2000-2250-45-1.3 S parameters*



ERZ-LNA-2000-2250-45-1.3							
Parameter	Specification Value @ 25°C			Measured Value @ 25°C			Check
	min	typ	max	min	typ	max	
Frequency (GHz)	20	-	22.5	20	-	22.5	✓
Small-signal Gain (dB)	41	43	45	42.4	43.4	44.4	✓
Gain Flatness (dB)	-	+/- 1	-	-	+/- 1	-	✓
Noise Figure (dB)	0.9	1.1	1.3	0.95	1.05	1.15	✓
Input VSWR	1.5:1	2.0:1	2.5:1	1.7:1	2.0:1	2.3:1	✓
Output VSWR	1.1:1	1.2:1	1.8:1	1.2:1	1.2:1	1.2:1	✓

Table 3: *ERZ-LNA-2000-2250-45-1.3 Specifications Summary*

Conclusion

The low noise figures needed at K/Ka Band Satcom receivers means that the accuracy obtained with traditional measurement methods like Y-factor could completely distort the noise data, leading to wrong decisions when selecting or implementing the right LNAs for Satcom systems.

The importance of accurate noise measurements has been presented in this tech brief, proposing the use of the cold-source method with source correction to characterize K/Ka-Band LNAs for Satcom applications.

The method has been described and applied to ERZIA amplifiers for LNA Ka-Band Satcom, confirming industry leading noise figures of 1.4 dB and 1.3 dB as maximum and typical values of 1.2 dB and 1.05 dB respectively. The accuracy of the measured values using the proposed method has also been confirmed with very low uncertainties, resulting less than 0.1 dB in both cases.

NEXT STEPS

Download the datasheets of the LNAs in this tech brief:

- ERZ-LNA-1770-2200-40-1.5 Ka Band Low Noise Amplifier
- ERZ-LNA-2000-2250-45-1.3 Ka Band Low Noise Amplifier

ERZIA catalogue LNAs:

- Low Noise Amplifiers | Compact Solid State Low Noise Amplifier RF/Microwave

ERZIA is under constant review of the state of the art to design new reliable and performant amplifiers. If you do not find what you are looking for at the catalogue, please ask us at sales@erzia.com.

For more information about the cold-source method, check the bibliography on page 15.

BIBLIOGRAPHY

[1] Keysight Application Note "High-Accuracy Noise Figure Measurements Using the PNA-X Series Network Analyzer".

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