A Simple Technique For Measuring Noise Figure

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1 Introduction

This report describes a simple technique for measuring the noise figure (or eqivalently, the noise temperature) of an RF amplifier using only a spectrum analyzer and a matched load at ambient temperature. This technique is demonstrated to have a raw accuracy of better than 1 dB (80°K) for a few low-noises amplifiers (LNAs). Most of this error appears to be due to unaccounted losses, which always positively bias the error. Thus, this method is useful for upper-bounding the noise figure.

2 Technique

The measurement setup is as follows: The input to the device under test (DUT) is terminated using a matched load at ambient temperature, T_{amb}. The output of the DUT is amplified by a preamp before input to the the spectrum analyzer. In order to overcome the relatively high equivalent noise figure of the spectrum analyzer, the preamp should have relatively low noise figure F_P and high gain G_P. In the examples to follow, an Avantek Model ABG-2015M GaAsFET amplifier with low (but unknown) F_P and $G_P \sim 40$ dB was used. The spectrum analyzer used was an Agilent Model E4407B.

The theory of the measurement is as follows: The power spectral density (PSD) of the noise presented to the input of the DUT is kT_{amb} W/Hz, where $k = 1.38 \times$

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10^{-23} J/K. Assuming $G_{DUT} > 10$ dB or so, the noise contribution of the preamp is relatively small and the spectrum analyzer measures a PSD of $kT_{amb}F_{DUT}G_{DUT}G_P$. Therefore, one can solve for F_{DUT} given the PSD measured by the spectrum analyzer, G_{DUT}, and G_P. T_{amb} can be assumed to be 290°K, since the error bars for this method are likely to be greater than the ±5° error associated with this assumption.

3 Example

The above technique was used to measure the noise figure of three amplifiers:

- A Mini-Circuits ZLJ-3G, specified $G_{DUT} = 19$ dB and $F_{DUT} = 3.8$ dB.
- An LNA from Radio Astronomy Supplies, Inc., specified $G_{DUT} = 28$ dB and $F_{DUT} = 0.4$ dB.
- ESL's Argus LNA + Line Amplifier combination, predicted $G_{DUT} = 35$ dB and $F_{DUT} = 1.8$ dB.

Here's the suggested step-by-step procedure used, based on the equipment specified above:

1. Measure G_{DUT} and G_P as accurately as possible. Our E4407B has a tracking generator which is ideal for this. This is done at three frequencies: 1400 MHz, 1420 MHz, and 1440 MHz.
2. Measure PSD using the spectrum analyzer at the same 3 frequencies. Some care is required in configuring the spectrum analyzer. Here are the settings used for our E4407B: Preamp: ON, Input Attenuation: 5 dB, Resolution Bandwidth: 1 MHz, Video Bandwidth: 3 MHz, Averaging: ON (100 sweeps), Averaging type: Power (RMS), Detector: Sample. Since the resolution bandwidth is 1 MHz, the PSD is the display reading minus $10\log_{10}(10^6)$ dBm/Hz.
3. Note $kT_{amb} = -173.98$ dBm/Hz.
4. F_{DUT} at each frequency is the result from (2) $-$ G_{DUT} (dB) $-$ G_P (dB) -173.98 dB.

For the ZLJ-3G, the results were F_{DUT} = 4.20 dB, 4.24 dB, and 4.11 dB at 1400 MHz, 1420 MHz, and 1440 MHz, respectively. This is about 0.4 dB higher than the specified "typical" value of 3.8 dB, and so seems reasonable. In terms of equivalent noise temperature, the difference between 4.2 dB (473°K) and 3.8 dB (406°K) is 67°K. Some portion of this is due to losses due to attenuation in connectors, impedence mismatches, and the neglected preamp noise contribution; none of which were accounted for in the measurement model.

For the Radio Astronomy Supplies LNA, the results were F_{DUT} = 1.21 dB, 1.57 dB, and 1.45 dB, respectively. This is about 1 dB higher than the specified value of 0.4 dB. The mean of the measured equivalent noise temperatures is 111.5°K; thus the error with respect to the specified value is 83°K. Again, we expect that some part of this is due to the systematic errors listed above.

For the Argus LNA + Line Amplifier, the results were F_{DUT} = 2.54 dB, 1.89 dB, and 1.52 dB, respectively. The mean of the measured equivalent noise temperatures is 170°K; thus the error with respect to the predicted value (150°K) is 20°K. We find again that the measurement error is positive, although somewhat smaller.

Taking into account all three experiments, it appears that the excess temperature introduced through measurement model ommissions is somewhere between 20°K and 83°K; in other words, it is likely that measurements will always be positively biased by at about this much. The remaining measurement error is probably unbiased and somewhere on the order of ±10°K.

As long as these limitations are kept in mind, this method seems quite useful as a simple technique to get rough estimates of the noise figure (or equivalent noise temperature) of RF amplifiers. The systematic errors cause the estimates to be consistently high; thus, this method is useful for upper-bounding the noise figure.