Noisecom

Application Note

Cold Attenuator Noise Measurements on Cryogenic LNAs

Abstract

In the quest to produce Low Noise Amplifiers (LNAs) with the lowest possible noise figures it is common to employ cryogenic techniques to cool the LNA to 20° kelvins (-253° C) or even lower. This has multiple beneficial effects: the minimum noise figure and noise resistance of the low noise transistors in the LNA are both substantially reduced, but also any ohmic losses in the LNA contribute far less thermal noise and indeed the losses themselves are usually substantially reduced as the conductivity of metals generally increases considerably at these low temperatures.

Cold Attenuator Noise Measurements on Cryogenic LNAs

One of the challenges associated with cryogenic LNA development is that of devising a way to accurately measure the noise figure (or noise temperature) of the amplifier. It is fairly straightforward to measure the noise figure of a room temperature LNA; typically a noise diode (such as the Noisecom NC346B) or hot/cold noise source is connected directly to the input of the LNA and the LNA's output is connected to a suitable noise figure analyser or other power ratio measurement device. At room temperature the main accuracy concerns are the calibration of the noise source, the impedance match between the noise source and the LNA, and the accuracy with which the Y factor can be measured [see Noisecom Application Note 121]. In the case of cryogenic LNAs it is not possible to gain direct access to the LNA input to connect a noise source; the LNA (at -253° C) must be thermally isolated from the atmosphere and any items at room temperature. Normally the LNA is housed in a cryogenic Dewar, or Cryostat, in which there is a high level of vacuum in order to provide thermal isolation from the walls of the Dewar. All connections to the LNA, RF and power, also have to provide thermal isolation; RF connections normally take the form of thin wall waveguides made from low thermal conductivity material like stainless steel, or long coaxial cables, also fabricated from low thermal conductivity material.

Cryogenic LNAs are usually extremely low noise; there is little point in going to all the trouble of cooling to these extreme temperatures unless the benefits, in terms of noise figure, are substantial. Applications include radio astronomy and satellite ground station receivers, and cryogenic LNA noise figures can be as low as 0.03 dB (noise temperature of 2° K) at lower microwave frequencies. The users of these extremely sensitive amplifiers are very concerned to measure the performance accurately so they know that their required sensitivity is being achieved. At higher microwave frequencies, typically above 8 GHz, the measurement technique commonly involves mounting the LNA in a test Dewar with a very low loss input waveguide section (low loss is achieved by plating the inside of the waveguide with a high conductivity metal such as gold). Then accurate hot and cold terminations can be applied to the waveguide input in order to characterise the noise figure of the LNA; some uncertainty is introduced by the losses in the waveguide and its connection to the LNA, but these can be characterised and the overall accuracy can be good if the losses are low. At lower microwave frequencies the waveguide size starts to get impractically large and this is where the cold attenuator technique is particularly valuable.

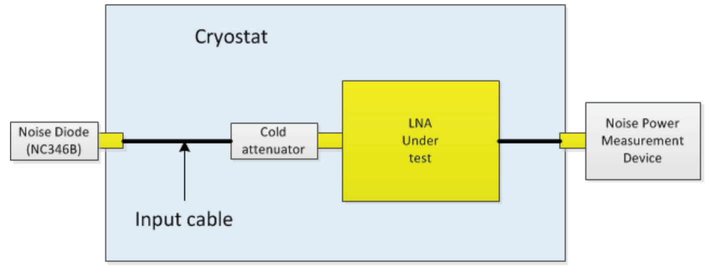

Figure 1: Diagram showing cold attenuator set up for measuring the noise figure of a coaxial LNA.

Figure 1 shows the cold attenuator set up for measuring the noise figure of a coaxial LNA. This technique exploits the availability of a low temperature reference point adjacent to the LNA input connector. With suitable thermal design the cold attenuator (typically 20 dB) connected to the LNA input can be held at the same temperature as the LNA, i.e. around 20° K (-253° C) or lower. With the noise diode in its 'off' state the noise input to the LNA is dominated by this attenuator (with small additional contributions from the noise diode and the input cable), which also presents a very good 50 Ω impedance match to the LNA. When the noise diode is turned 'on' the noise input to the LNA derives mostly from the noise diode, attenuated by the attenuator, with small contributions from the input cable and the attenuator itself.

This arrangement provides a well-defined hot/cold noise source at the LNA input connector. In the 'hot' state (noise diode 'on') the noise power output from the noise diode is equivalent to that from a 50 Ω load at a physical temperature T_{Dhot} given by

$$T_{Dhot} = 290 \quad (10^{\frac{ENR}{10}} + 1)$$

For example, an NC346B noise diode with an ENR value of 15.2 dB would produce a 'hot temperature' of 9893° K at the diode output connector. In the off (or 'cold') state the same diode produces noise power equivalent to a 50 Ω load at its current physical temperature, typically around 295° K in a laboratory environment.

$$T_{Dcold} = \text{diode physical temperature} = T_{phys}$$

In order to make an accurate measurement of the LNA noise figure (noise temperature) it is necessary to determine the effective noise powers delivered to the input of the LNA (i.e. at the output of the cold attenuator) for the two states: noise diode 'on' and noise diode 'off'. In addition to the noise power from the noise diode itself, there are two other significant noise contributions: from the cold attenuator and from the input cable. Furthermore, the noise output from the noise diode, in either state, is attenuated by both the cable and the cold attenuator.

In order to calibrate the measurement system it is necessary to accurately measure the loss of the input cable and the cold attenuator, at their operating temperatures. A strictly rigorous approach would also involve measurement of VSWRs of all components to take account of errors due to mismatch, but in practice it is possible to get very accurate results without this complication provided good quality components are used.

A further simplification concerns the physical temperature of the input cable: in addition to providing a low-loss connection to the cold attenuator this cable also serves to thermally isolate the cold attenuator and LNA from the warm exterior of the cryostat. Its noise contribution at the input of the LNA depends on its physical temperature; we assume an effective temperature for the cable that is mid-way between the outside ambient temperature, Tamb, and the cold attenuator temperature Tatten.

The hot/cold load calculations are carried out as follows.

1.) Loss factors are calculated from the measured losses, in dB, of the input cable and the attenuator, L_{cab}dB and L_{atten}dB.

$$L_{cab} = 10^{\frac{L_{atten}dB}{10}}$$

$$L_{atten} = 10^{\frac{L_{atten}dB}{10}}$$

$$L_{total} = L_{cab} \times L_{atten}$$

2.) These loss factors are used with the values of hot and cold noise diode equivalent output temperature, discussed above, the measured temperature of the cold attenuator, Tatten, and the ambient Temperature outside the Cryostat, Tamb, to calculate the effective input temperatures to the LNA in the noise diode 'on' and 'off' states. We call these Th and Tc.

$$T_h = \frac{T_{Dhot}}{L_{total}} + \frac{(T_{amb} + T_{atten})}{2L_{atten}} \left(1- \frac{1}{L_{cab}}\right) + T_{atten}$$

$$T_c = \frac{T_{amb}}{L_{total}} + \frac{(T_{amb} + T_{atten})}{2L_{atten}} \left(1+ \frac{1}{L_{cab}}\right) + T_{atten}$$

3.) Measurements are made of the Y factor, i.e. the ratio of LNA output powers for the two noise diode states, usually at multiple frequency points. A purpose-built noise receiver can be used for this, but it is also possible to get good results using a good quality spectrum analyser or a power meter preceded by a band limiting filter. (Note that measurement of this ratio may require calibration of the noise measurement device, depending on its noise figure and the gain of the LNA under test). Then the noise temperature of the LNA can be calculated from the well-known formula

$$T_{LNA} = \frac{T_h + YT_c}{Y-1}, \text{ where } Y = \frac{\text{output power (noise diode on)}}{\text{output power (noise diode off)}}$$

4.) Noise temperature is exactly translated into noise figure using the relationship

$$NF_{LNA} = 10\mathit{log}\left(1+ \frac{T_{LNA}}{290}\right)$$

Typical values are as follows.

T_{Dhot}	9900° K (NC346B)
T_{Dcold} and T_{amb}	296° K (23 deg C)
L_{cab}	1.259 (1 dB)
L_{atten}	100 (20 dB)
L_{total}	125.9
T_{atten}	15° K

These result in the following input temperatures to the LNA.

$T_h = 95.4^{\circ}$ K and $T_c = 19.1^{\circ}$ K

For a cryogenic LNA with noise figure 0.1 dB (noise temperature 7^{o} K) the resulting Y factor will be 3.922 (5.93 dB).

References:

[1] NBS-Series Cryogenic Primary Noise Standards Product Page
http://noisecom.com/products/standards/nbs-series-cryogenic-primary-noise-standards

[2] NBS-Series Cryogenic Datasheet http://noisecom.com/~/media/Noisecom/Datasheets/PrimNoiseNBS4pages.ashx

[3] Application Notes http://noisecom.com/resource-library?brand=Noisecom&go=application_notes

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