Gain and noise analysis of HEMT amplifiers from room temperature to superfluid He.

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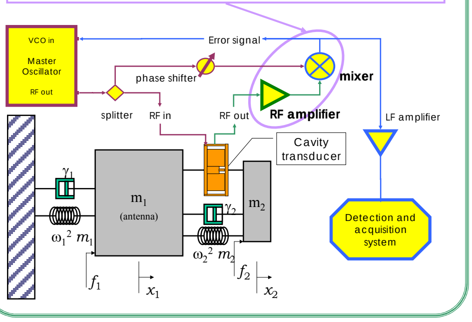
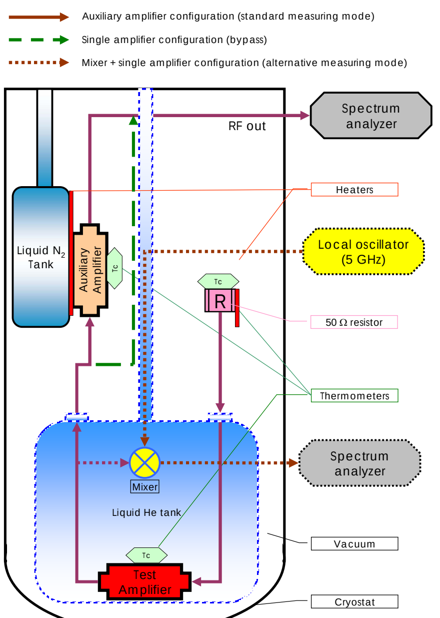
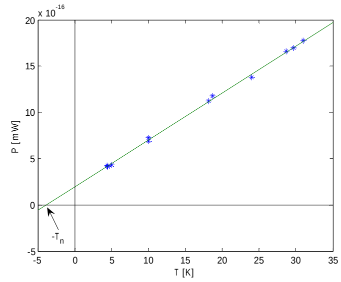
- We are developing a a microwave parametric transducer for massive gravity wave antennas, like bars and spheres, based on the high sensitivity of a superconducting RF cavity to the change of the appropriate geometrical dimension.
- To fully exploit the transducer sensitivity, a very low noise amplifier, at the operating frequency of few GHz, is required.
- We describe the experimental set-up and the test procedure that has been used to measure the noise temperature and the gain of the LNA at several temperatures, from 300 K to 1.5 K.
- The influence of an imperfect impedance matching with the temperature change is investigated. A commercial GaAs LNA in the frequency range 1 ÷ 3 GHz has shown a Noise Temperature $T_N \leq 4$ K at 4.2 K and below.

The most critical RF components in a typical detection scheme for a parametric transducer mounted on a gravitational wave antenna. Both are needed to work at low temperature.



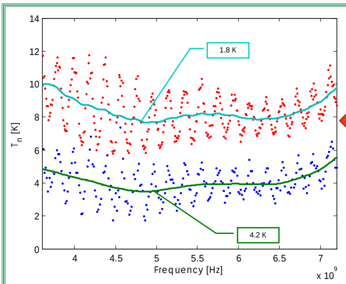
The experimental set-up





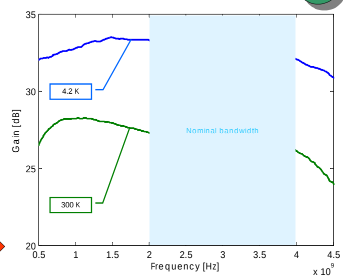
- Our experimental setup consists of a helium tank contained into a cryostat and a liquid nitrogen tank, which is used as heat reservoir for the auxiliary amplifier.
- The amplifier to be tested is sealed in the liquid He vessel, together with the mixer, when using the single amplifier/mixer configuration.
- The noise source is contained in the cryostat and is held into vacuum. The resistor is cooled through the RF cable that connects the resistor itself to the He vessel. We use an heater to provide different temperature of the noise source.
- An additional heater is positioned onto the auxiliary amplifier (JCA type only) to keep it at 120 K because it fails to operate at liquid nitrogen temperatures.
- The noise temperature T_n of the amplifier is calculated by least square fit of the power P over a given bandwidth Δf outputted by the system, versus the temperature T_R of the noise source. This methods is insensitive to parameters such as the amplifier gain G and the bandwidth.
- The noise source temperature is measured with a calibrated silicon diode thermometer (LakeShore DT-470-SD-11A). In the case of room temperature or liquid nitrogen measurements we fix the temperature by a cryogenic.
- The amplifier temperature is likewise precisely controlled with calibrated sensor.

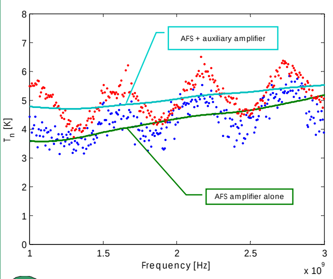
$$P = 4k_B R\,\Delta f\; G(T_R + T_n)$$



Noise temperature performance of a MiteQ AFS3-04000800-09-CR4 cryogenic amplifier specified for 4-8 GHz. Note that the 1.8 K performances are worse than those taken at 4.2 K. This may be due to a possible condensation of the gas sealed into the amplifier box, which condenses on the walls and reduces the heat exchange rate inside the amplifier. Another hypothesis may be the superconducting transition of a component inside the box. Both measure were taken with the aid of an auxiliary amplifier. The minimum T_n is ~ 3.5 K @ 4.8 GHz, which amounts to ~15 $\hbar$.

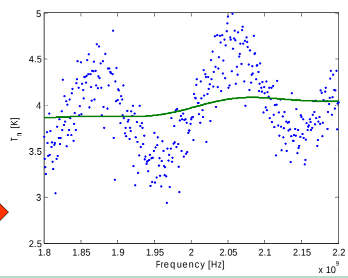
Gain versus frequency for the MiteQ AFS3-02000400-08-CR4 cryog. amplifier designed for 2-4 GHz, measured @ 4.2 K and 300 K. As expected, the gain performances at low temperature are higher than those at room temperature, while the noise figure decreases.



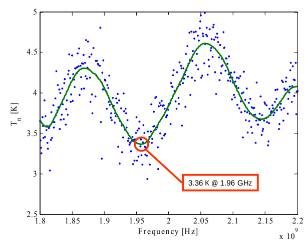


Noise temperature performance of a MiteQ AFS3-02000400-08-CR4 cryogenic amplifier @ 4.2K, designed for 2-4 GHz. The upper curve shows that using an auxiliary amplifier increases the effective noise temperature. Although in theory both measure should give the same results, this difference means that the contribution of the auxiliary amplifier cannot be neglected.

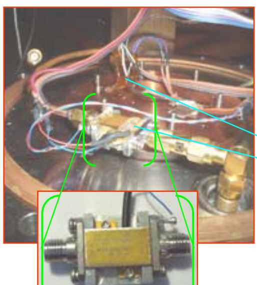
Noise temperature performance of a MiteQ AFS3-02000400-08-CR4 cryogenic amplifier in the single amplifier configuration. The amplifier external temperature is 1.8 K. This amplifier does not show any worsening of the noise temperature from 4.2K to 1.8 K.



Can we improve the current figure?



- The temperature curves show a periodic oscillation of approx. 200 MHz. This effect is not simply an experimental artifacts but it is due to the RF standing waves in connectors and cables, and it is indeed reproducible. The standing waves are originated by a non perfect impedance matching between the noise source and the amplifier under test.
- The noise temperature can therefore be quite different, depending on the frequency. It is though reasonable to set the working point next to a minimum of the curve, because the band that is required for the experiment is very small with respect to the oscillating period, and the absolute frequency is not an issue.
- In the measures shown here, we generally smooth out these oscillation in order to better estimate the average behavior of the RF components. Let us underline again though, that these are not experimental fluctuations (which are nevertheless superimposed onto the measure) but real noise temperatures.



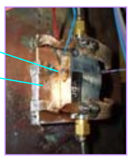
Amplifier under test in the liquid He vessel.

Cryogenic RF mixer Eclipse-Microwave J4080NB

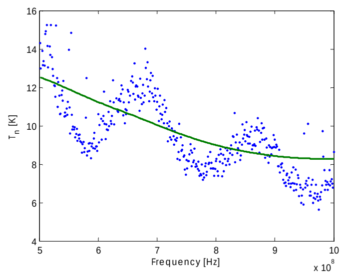
Noise temperature of the AFS3-04000800-09-CR4 in the "single-amplifier + mixer" configuration.

The mixer contribution to the performance is comparable to the amplifier one. This mixer, or at least its use in this configuration, is not advisable, and we are looking for other cryogenic compatible, low noise mixers.

Alternatively, a more complex configuration such as the use of 2 cascade amplifiers and a mixer can be tested.



Auxiliary Amplifier attached to the heater and the Liquid nitrogen reservoir.



Conclusion

- The RF amplifier is one of the most critical device for designing a high frequency parametric transducer.
- We have shown that a careful implementation of commercially available components can lead to a noise temperature as low as 3.5 K, which corresponds to ~15 $\hbar$ @ 5 GHz.
- Since the parametric conversion does not introduce additional noise in the system, the signal detection at very high frequency has the advantage of a readily available critical components, which works near their quantum limit.
- The implementation of other critical components such as mixers, circulators, attenuators, phase shifters and low-noise cables are under scrutiny.