ALMA Cycle-5 Study Project: Close-Out Report

Wideband Low-Noise Balanced IF Amplifiers for ALMA Band 6, with Future Application to ALMA Bands 3-10

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The goal of this project was to demonstrate a compact cryogenic 4-12 GHz balanced low-noise amplifier. Balanced amplifiers have noise characteristics similar to those of an amplifier preceded by an isolator [1]. The work was done over the period 10/1/2017-5/4/2021.

In collaboration with Low Noise Factory in Sweden, a compact balanced 4-12 GHz low-noise IF amplifier was designed for 4-K operation. Fig. 1 shows the configuration of the balanced amplifier, which contains DC bias circuits to enable an SIS mixer to be biased from the input of the amplifier.

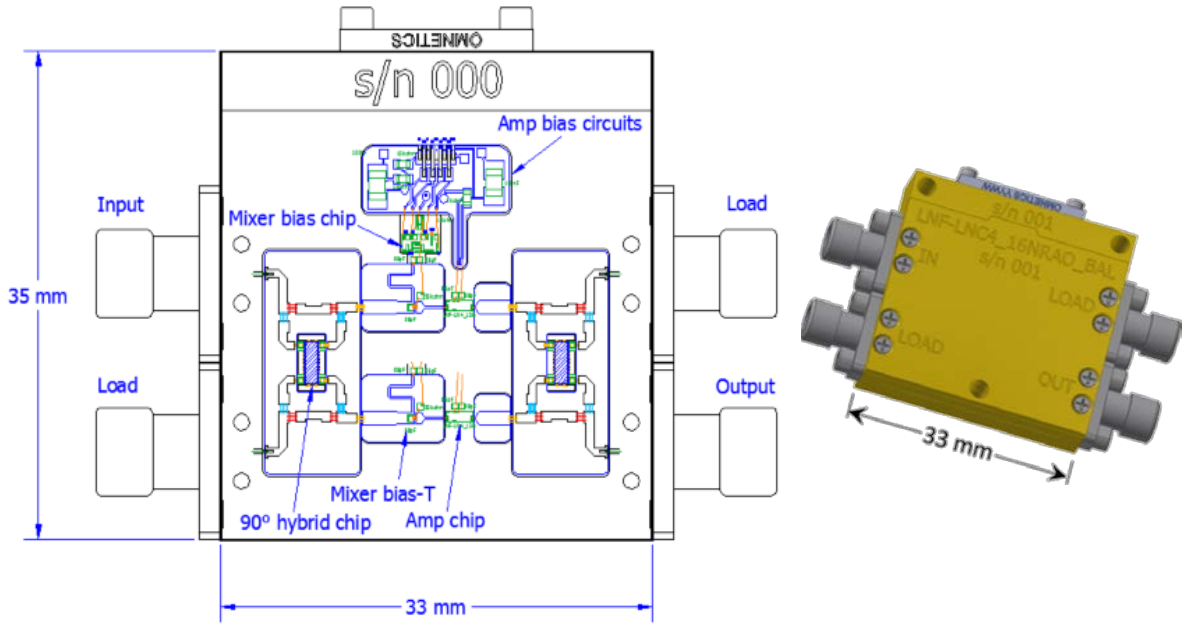

Fig. 1. Layout of the 4-12 GHz balanced amplifier employing the recently tested superconducting IF hybrids.

The balanced amplifier uses a pair of superconducting quadrature hybrids fabricated on small quartz chips 1 x 3 mm as shown in Fig. 2. The yield of the hybrids on the initial wafer was very low. The cause was found to be resistance in the vias interconnecting the first and third Nb layers. By the end of this study, attempts to eliminate this resistance had been unsuccessful, but a modified design with only two Nb layers is expected to solve the problem.

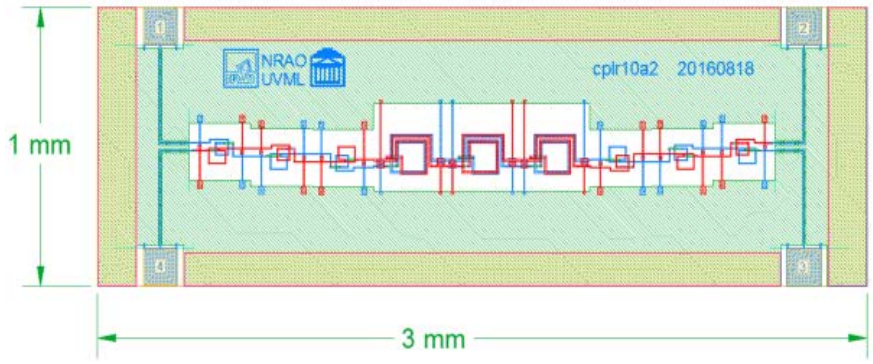

Fig. 2. The superconducting quasi-lumped element quadrature hybrid has three niobium layers separated by thin SiOx films.

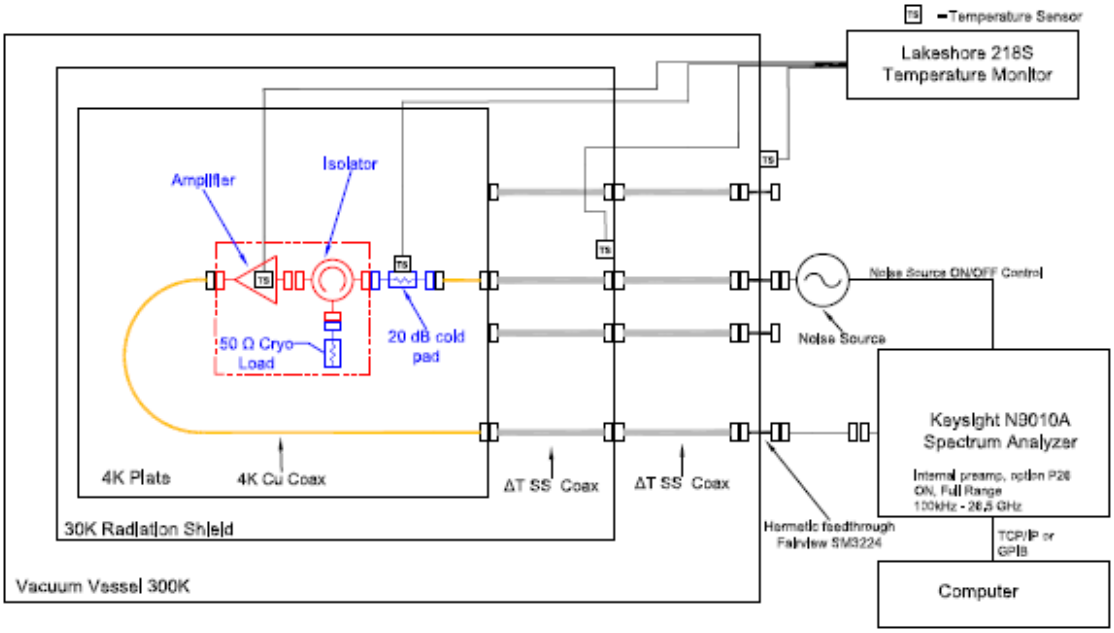

Fig. 3. The 4-K amplifier noise and gain test set.

A 4-K amplifier test set (Fig. 3) [2] was assembled to allow accurate measurement of cryogenic low-noise amplifiers. Typical data for an LNF LNC4-16B amplifier is shown in Fig. 4, which compares our measurements with LNF's own data for that amplifier.

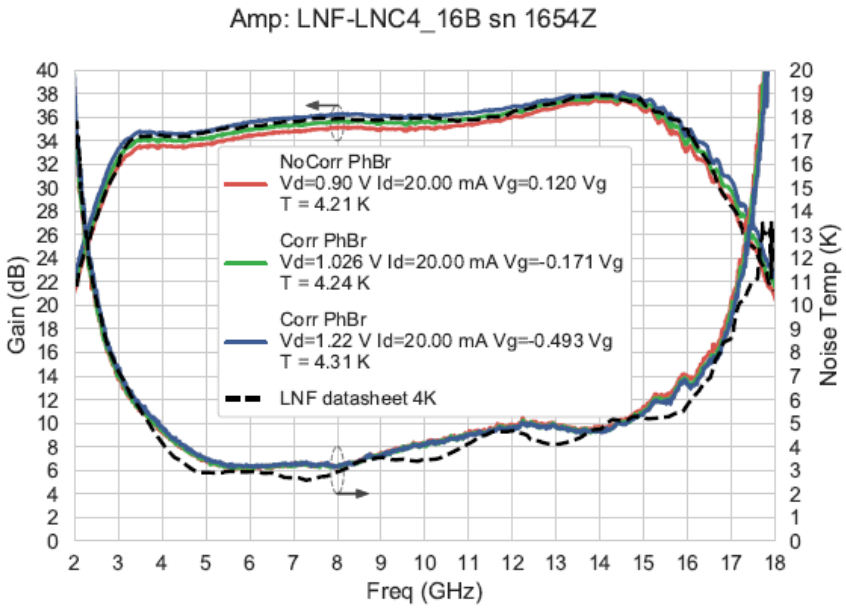

Fig. 4. Measurements of noise temperature and gain for an LNF LNC4-16B amplifier with three different bias settings, at 4 K. As indicated in the legend, two of the bias settings were adjusted to compensate for the voltage drop in the phosphor bronze bias wiring. Data from the manufacturer's data sheet are indicated by the dashed black lines.

Prior to connecting the hybrids in the balanced amplifier, straight-through 50-ohm connections were made to the amplifier chips from the four 2.92-mm connectors to allow the amplifier chips to be tested individually. The measured gain and input return loss are shown in Fig. 5.

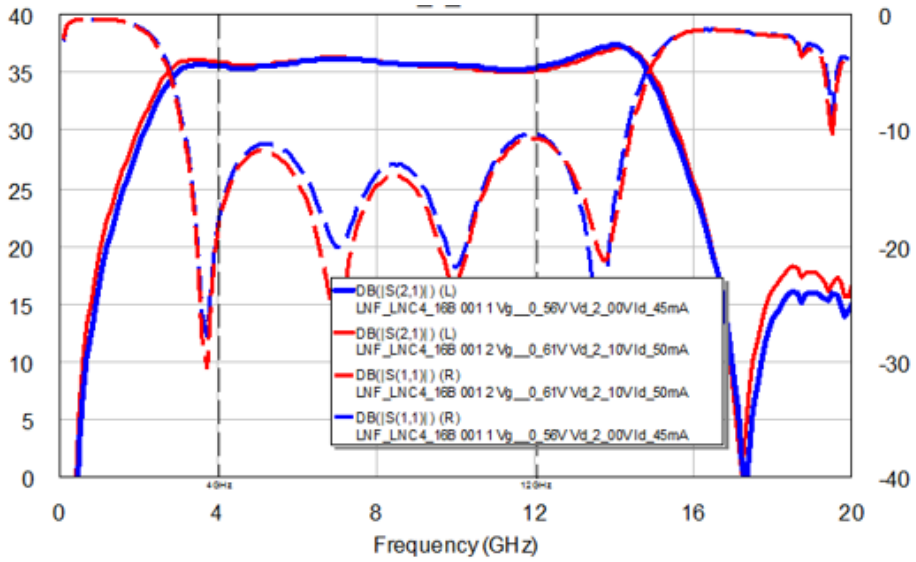

Fig. 5. Gain and input reflection coefficient of a 4-12 GHz NRAO-LNF balanced amplifier prior to installation of the two quadrature hybrids,

Two of the few successful hybrids were mounted in a balanced amplifier and tested at 4 K. The Noise temperature and gain are shown in Fig. 6. The cause of the rise in noise temperature and the decline in gain above ~13 GHz is not yet known. cool

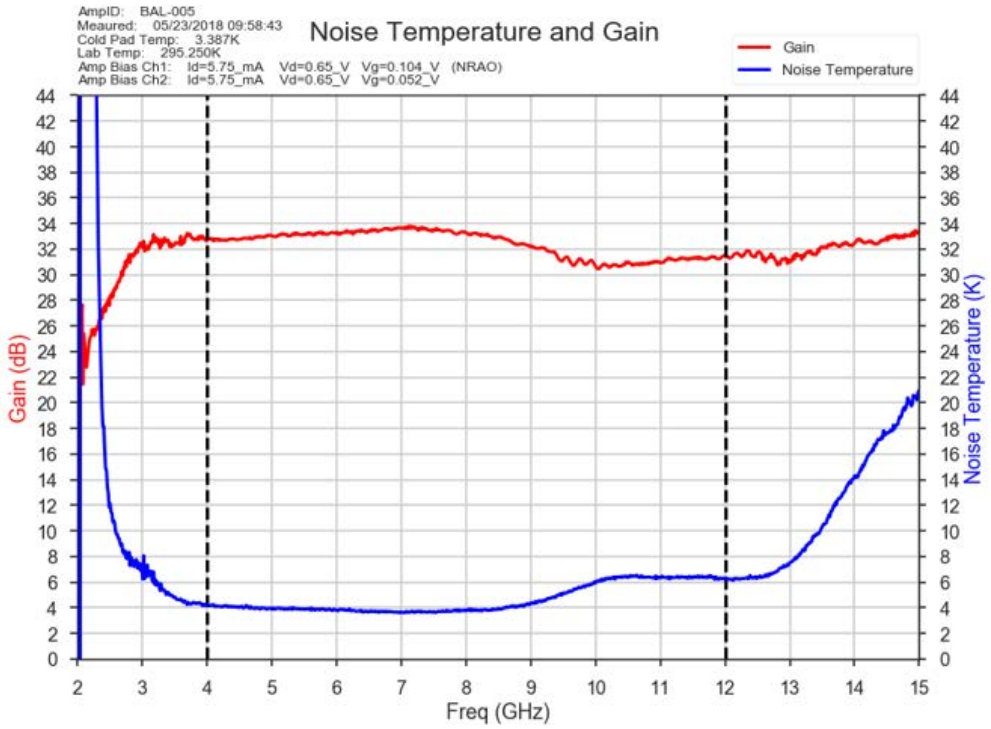

Fig. 5. Noise temperature (left axis) and gain (right axis) of the prototype balanced amplifier.

Conclusion

A balanced 4-12 GHz amplifier using small quasi-lumped element superconducting hybrids has been assembled and tested. Above 9 GHz the noise temperature increases step-wise by about 2 K, and the gain falls about 2 dB. The cause of this behavior remains to be understood, and will be explored in the follow-on study.

Excess via resistance between Nb layers in most of the hybrids was not eliminated despite several modifications of the fabrication procedure. However, a modified design with only two Nb layers should not have the same problem and will be explored in a follow-on study.

Goals:

1. Measure 4-12 GHz superconducting quadrature hybrid chips.
2. Construct a 4-K amplifier noise and gain test system.
3. Install hybrids in LNF balanced amplifiers & test.
4. Improve the low yield of hybrids.

Results:

1. Excess via resistance between Nb layers in most of the hybrids was not eliminated despite several modifications of the fabrication procedure. See 4.
2. The amplifier test system was constructed and gives results very close to those of Low Noise Factory.
3. A balanced 4-12 GHz amplifier using small quasi-lumped element superconducting hybrids has been assembled and tested. Above 9 GHz the noise temperature increases step-wise by about 2 K, and the gain falls about 2 dB. The cause of this behavior remains to be understood, and will be explored in the follow-on study.
4. A modified IF hybrid design with only two Nb layers should not have the same problem and will be explored in the follow-on study.

References

[1] A. R. Kerr, "On the Noise Properties of Balanced Amplifiers," *IEEE Microwave and Guided Wave Letters*, vol. 8, no. 11, pp. 390-392, Nov. 1998.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=736255

[2] J. Lambert "4-K Noise Measurements of LNF 4-16 GHz Amplifier with SAO Edge-Mode Isolator," Electronics Division Technical Note No. 225,, National Radio Astronomy Observatory, Charlottesville, VA 22903, Dec. 2019. http://library.nrao.edu/public/memos/edtn/EDTN_225.pdf