Cryogenic IF Balanced LNAs Based on Superconducting Hybrids for Wideband 2SB THz receivers

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Abstract—Future heterodyne 2SB THz receivers for Radio astronomy shall require better sensitivity and higher IF bandwidth. This paper investigate, in a modular approach, the use of balanced amplifiers based on superconducting quadrature hybrids, as an option to realize wide band low noise amplifiers with improved input matching without compromising the noise performance. Measurements of the proposed wideband balanced amplifier shows very good agreement with the standalone amplifier in terms of gain and noise temperature. The input matching of the balanced amplifiers are limited by the input matching of the hybrids, still showing return loss better than 15 dB.

INTRODUCTION

Future heterodyne receivers operating at mm-wave or THz frequencies would require higher sensitivity and higher IF bandwidth [1]. A larger IF bandwidth of the receiver is however not possible without the availability of wideband IF low noise amplifiers (LNA). Unfortunately, no suitable amplifiers, even from specialized suppliers, are currently available with acceptable noise performance and adequate power consumption over a large bandwidth.

LNAs aimed for operation at cryogenic temperatures and used for radio astronomy are usually optimized for best noise performance and low power consumption at the cost of poor input matching. This forces the use of isolators between the mixers and amplifiers, adding potentially extra noise but certainly limiting the bandwidth over which amplification can be achieved because of the inherent small bandwidth of the circulators.

One approach to solve the bandwidth limitation without compromising the noise performances is to use a balanced scheme where two quadrature hybrids are used, one in front, and one after the LNAs [2].

In this paper we report on the noise performance and input reflection performances of balanced amplifiers fabricated using a modular approach and using available superconducting hybrids developed for ALMA Band 5 [3] and LNAs from the ALMA Band 5 pre-production [4]. The performance of the balanced amplifiers could then be compared with the performance of the standalone amplifiers.

BALANCED AMPLIFIER

The balanced amplifier were built by cascading a superconducting quadrature hybrid at the input followed by two amplifiers, and a superconducting quadrature hybrid at the output [2] as in Fig. 1.

In this experiment we tested two different sets of superconducting hybrids: a 4-8 GHz hybrid with built-in bias-T, currently used in ALMA band 5 [5], and a prototype 4-12 GHz hybrid. Both types of hybrids are fabricated in-house using Silicon substrate and superconducting transmission lines and air-bridging technology [6].

The 4-12 GHz units contains just the hybrid chip, while the 4-8 GHz units also have built in bias-T and have additional Si-chips to match the longer center-to-center pitch of the coaxial connectors needed in the mixer assembly where they are used. Clearly for this application, the built in bias-T are not needed, and are instead a parasitic, however, this are the units available for test with no modification required.

The cryogenic LNAs used in this study consists of 3-stage amplifiers, where the first stage is made of InP HEMT whereas the two others are realized using GaAs HEMTs.

MEASUREMENTS

The noise performance of the standalone LNAs and balanced amplifiers were measured in a cryostat at about 4 K using the cold attenuator method with an Agilent N4000A ENR noise diode and an Agilent MXA N9020A spectrum analyzer with Noise Figure Measurement option. In practice, as the main purpose of these initial measurements is to find the relative differences between the different configurations and not necessarily the correct absolute noise temperature, we carried out a simplified characterization of the cryostat losses and the temperature sensor to be used for the cold attenuator.

The optimum noise performances of the different LNAs (balanced and standalone) were determined by independently tuning the bias conditions of the different transistor stages.

The LNAs were later characterized by means of S-parameters measurements at their optimum noise bias conditions using an Agilent PNA E8364B vector network analyzer. Those measurements were performed without the cold attenuator in front of the amplifier, thus requiring additional cooling cycle.

The two balanced amplifier chain configurations used is the 4-8 GHz version shown in Fig. 1, and the 4-12 GHz shown in Fig. 2.

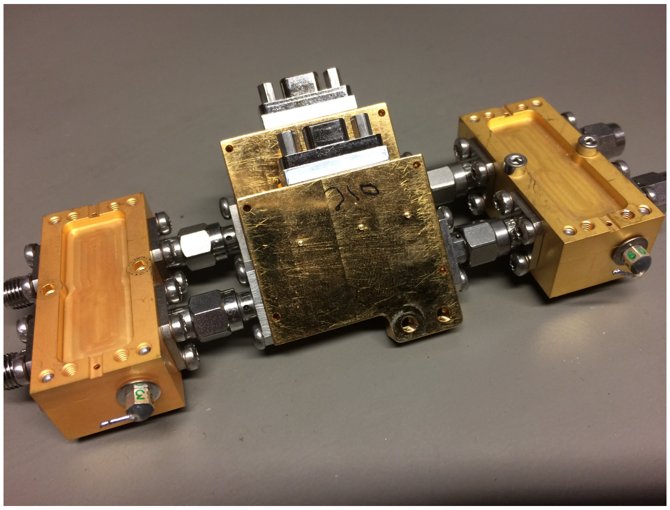

Fig. 1 Balanced amplifier assembly based on 4-8 GHz hybrids

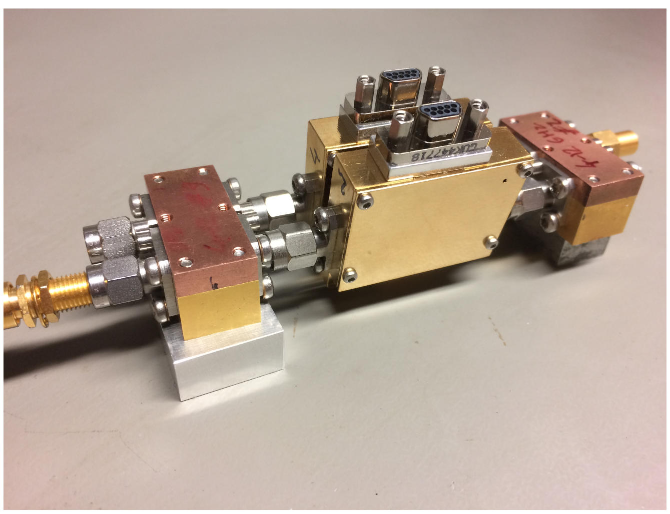

Fig. 2 Balanced amplifier based on the 4-12 GHz hybrids.

RESULTS AND DISCUSSION

The measured noise performances of the different LNAs are presented on Fig. 3. It clearly shows that using superconducting hybrids and a balanced mode does not increase significantly the noise performance compared to the standalone LNAs. In fact, the 4-12 GHz version result in an increase of about 0.2 K (from 5.49 K to 5.69 K) when used in the balanced configuration described. For the 4-8 GHz version, a noticeable increase is seen around the frequencies where the imbalance between the through and coupled signals of the hybrids was maximal (0.7 dB), which could not be compensated by a difference in biasing conditions of the two LNAs.

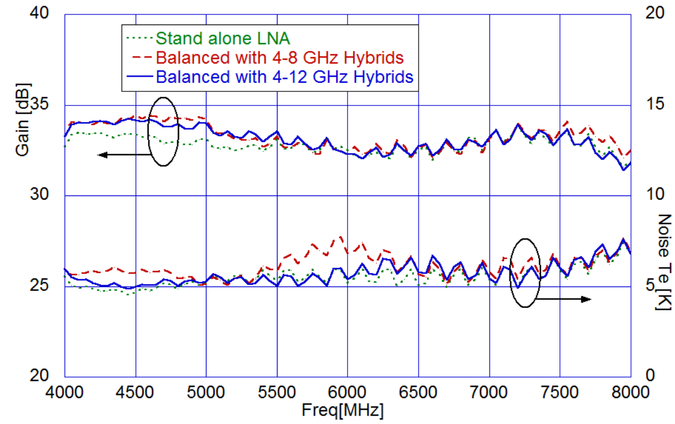

Fig. 3 Noise performance of the Balanced and standalone amplifiers

The Return loss of the different LNAs is presented in Fig. 4. The improvement of the input reflection using balanced amplifiers is clearly demonstrated and the difference between the two balanced configuration can be ascribed to the difference in input reflection of the hybrid versions. In addition, measurement results showed that the return loss of the wideband hybrid is the limiting factor for the return loss of the balanced amplifier. The obtained results shows that very good input matching can be achieved with such balanced amplifier at cryogenic temperatures. The receiver design can potentially be simplified by removing the need of the typically used isolator [7].

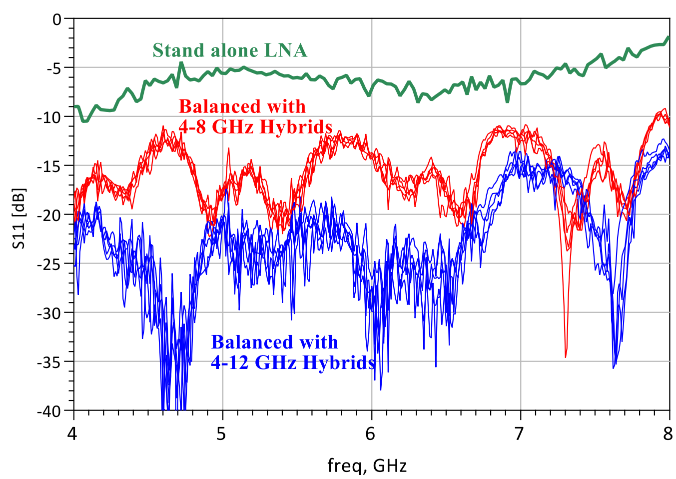

Fig. 4 Return loss performance of the Balanced and standalone amplifiers

CONCLUSION

The use of superconducting hybrids for the demonstration of cryogenic balanced LNAs in a modular approach is successfully demonstrated. The balanced LNAs showed negligible degradation of the noise performance of balanced amplifiers compared to the standalone versions. In addition, our results show that the improvements in terms of return loss are considerable (better than 15 dB over the whole frequency band) and that return loss of the hybrids sets the limits for the input matching of the balanced LNAs.

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