A 1MM SIS Receiver Utilizing Different Intermediate Frequency (IF) Configurations

D.Meledin[1], V. Desmaris[1], E.Sundin[1], A. Pavolotsky[1], M. Fredrixon[1], I.Lapkin[1,3], M.Strandberg[1], A. Ermakov[1,4], J-D, Gallego[2], I. Lopez-Fernandez[2], C. Diaz[2], and V.Belitsky[1]

Abstract **– We present experimental studies of the noise performance of a prototype heterodyne SIS receiver operating at wavelengths of about 1mm. The receiver employs different 4-12GHz intermediate frequency amplification chain configurations: a standalone low noise amplifier (LNA), the LNA cascading with a cryogenic isolator, and a low noise balanced amplifier.**

From our experiments and measurements, we could conclude that the latter configuration demonstrates the best broadband noise performance. In fact, the receiver equipped with the balanced LNA does not have noticeable noise degradation caused by the IF hybrids of the balanced LNA scheme. Moreover, our results indicate that even broader IF bandwidth of the receivers could be prospectively reached using balanced LNAs in the IF amplification chain.

I. INTRODUCTION

Mm-wave heterodyne receivers for radio astronomy progress towards a wider (8 GHz and larger) intermediate frequency (IF) band. Since the IF circuitry introduces additional loss and noise to the receiver system, the high performance IF chains (wideband, low loss, compact) are required when designing a receiver system. Moreover, in modern receiver employing the side-band separating architecture for more efficient and accurate observations [1], the IF chain becomes more complicated as it includes the IF hybrid combining the signals from the two SIS mixers and providing sideband separation.

The most widely employed IF circuit configuration comprises cryogenic isolators followed by a low noise amplifiers (LNA). The isolator reduces the standing waves in the IF band. However, it introduces insertion loss affecting potentially the overall receiver noise as well as the wideband isolator being bulky to cover the 4-12 GHz frequency band. In addition, cost per unit could play a role when designing a dual polarization or a multipixel receiver.

Therefore, employing balanced amplifiers for the receiver IF chain has the potential of improving noise performance of the receiver, accounting for the lower loss of quadrature hybrid, especially when employing superconducting materials, as compared to the isolator cascaded with the LNA. In addition, the receivers could be more compact, which is important for array receivers where tight pixel packaging is required, or for designs with severe geometrical constrains as in ALMA cartridge receivers.

In this work, we investigate the noise performance of a prototype SIS receiver operating at about 300 GHz, using different IF amplification chain configurations including a standalone commercial LNA, the LNA with the cryogenic isolator, and a low noise balanced amplifier.

II. RECEIVER DESCRIPTION

The receiver prototype used in the experiments, employs the side-band separating scheme (2SB) and is intended to be a part of SEPIA heterodyne receiver installed at APEX telescope [2]. The receiver is dual polarization with an operating frequency range of 272-376 GHz and wide (4-12 GHz) IF bandwidth per sideband, i.e. 32 GHz instantaneous IF bandwidth. As mixer elements, Nb-AlxO-Nb SIS mixers, fabricated in-house [3], are employed. The receiver topology features, inside the mixer block, an input 3dB waveguide 90 degrees RF hybrid, SIS mixers along with output 90 degrees 3dB IF hybrid with integrated broadband impedance transformers and bias-T. The local oscillator (LO) power is injected to the mixers by integrated -18 dB directional couplers.

The same mixer block is used with three different IF multiplication chains: a standalone 4-16 GHz LNF-LNC4_16B amplifier from Low Noise Factory (referred in this paper as the configuration A); a 4-12 GHz Quinstar isolator cascaded with the LNF-LNC4_16B amplifier (referred as the configuration B, Fig.1) and a 4-12GHz balanced amplifier (configuration C). The balanced amplifier is realized in a modular configuration with two wideband miniature 3dB 90 degrees hybrids and two identical cryogenic LNAs, Fig. 2.

The hybrids are fabricated on alumina and employ the three-sections planar design [4]. The central section of the hybrid with a Lange coupler is placed between two sections with coupled line couplers. The Lange coupler provides the highest coupling coefficient while the other two sections are loosely coupled. The hybrids are produced using thin-film microfabrication technology that combines photolithography and dry etching processes for the formation of galvanically plated gold transmission lines and air bridges to connect the coupler fingers in the middle section. The overall size of the miniature hybrid chip is limited only by the pitch required between the through and coupled ports, in order to conveniently interface with coaxial contacts. The hybrids demonstrate excellent performance in terms of insertion loss, return loss, as well as amplitude and phase imbalance [4]. In the balanced amplifier, at the input, we used a 4-12 GHz hybrid and at the output, a hybrid with slightly extended bandwidth of 4-16 GHz [5].

[1] Group for Advanced Receiver Development, Chalmers University of Technology, SE412 96, Gothenburg, Sweden.

[2] Observatorio de Yebes CDT (IGN), Guadalajara, Spain.

[3] Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS), N. Novgorod, Russia.

[4] Kotelnikov Institute of Radioengineering and Electronics (IRE), Moscow, Russia.

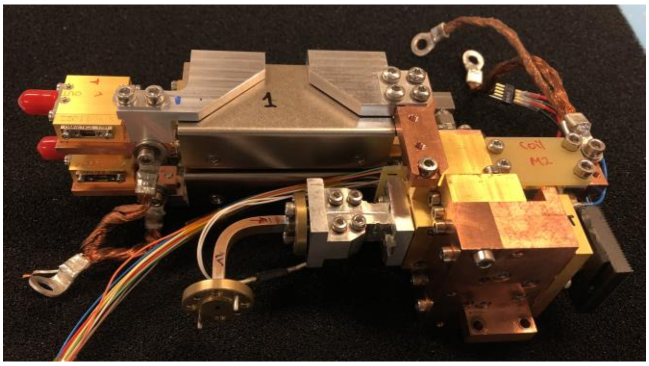

Fig. 1. Picture of 2SB mixer block used in the experiments including 4-12 GHz Quinstar isolator cascaded with the LNF-LNC4_16B amplifier (configuration B)

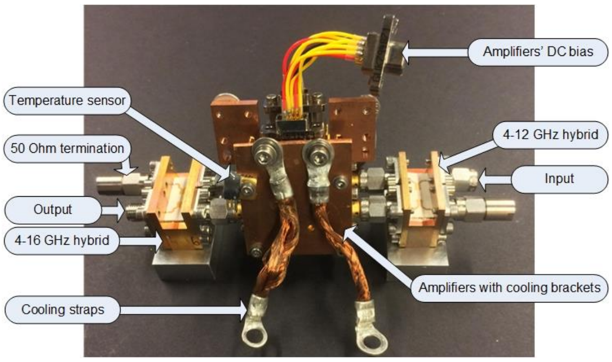

Fig. 2. Image of balanced modular amplifier.

The LNAs employed in the balanced amplifier were developed and fabricated at the Yebes Observatory. The amplifiers feature three stages with single 150 µm x 0.1 µm InP transistors in the first two stages and a GaAs commercial HEMT in the third. The design has been described in detail in [6].

The noise performance of the standalone Yebes LNAs and balanced amplifier were measured in a cryostat at about 4 K using a cold attenuator of about 20 dB. Later, the cold attenuator was removed and S-parameters measurements were conducted at the LNAs' optimum bias conditions for the best noise performance, thus requiring an additional cooling cycle. The amplifiers' characterization results are presented in Fig. 3a,b.

As could be seen from Fig.3, the noise and gain performance of the modular balanced LNA is similar to the single end amplifier. However, the input matching of the balanced amplifier is considerably improved as compared to the single end amplifier, and provides a return loss better than -13 dB over the 4-12 GHz frequency band.

In an earlier stage of the receiver development, we have designed and fabricated a mixer block where we could characterize the double side band (DSB) noise performance of the mixers. In this version, we have a single-end mixer arranged in the same manner as in a 2SB mixer block: with the same SIS mixer chip channel geometry, LO coupler, and IF transformer for the mixer to have a 50 Ohm output impedance.

III. MEASUREMENT RESULTS

In order to deduce the noise temperature of the IF circuitry embedded in the receiver, we used the standard Y-factor technique, where the SIS mixers were biased in the normal part of their IV-curve and thus behave as a calibrated noise source providing loads with known equivalent temperatures. This method has been widely used, for instance in [7, 8].Those bias voltages (for example, V_{cold}=4 mV and V_{hot}=7mV) correspond to hot and cold loads at the input of IF network while the equivalent temperatures of these loads could be determined accounting for a rate of ≈5.8 K/mV.

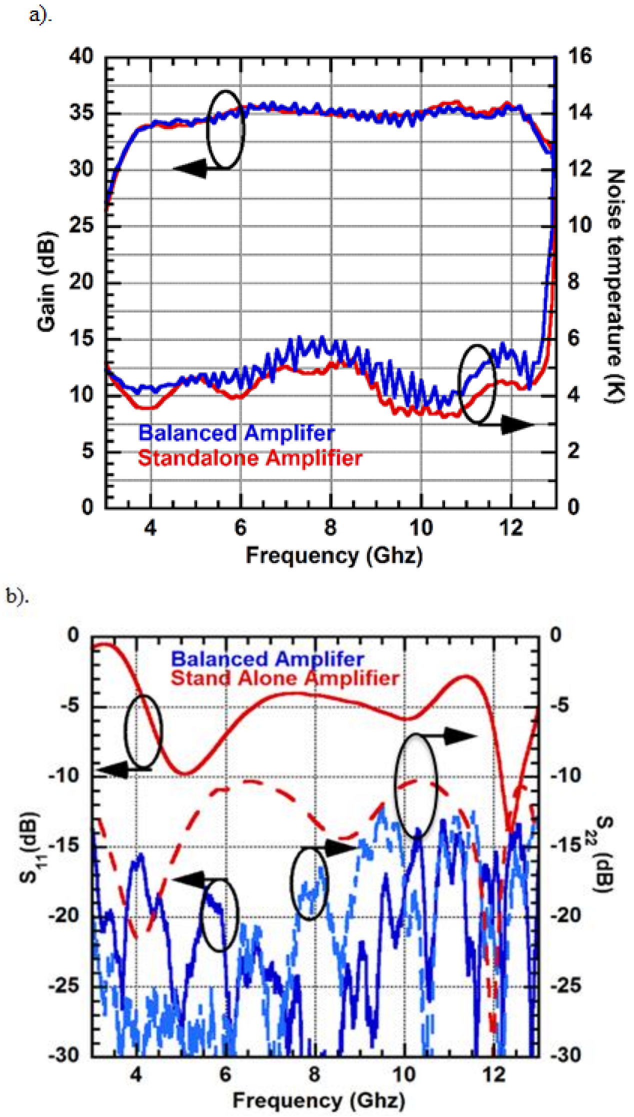

Fig. 3. Measured performance of YEBES standalone and balanced modular amplifiers as a function of frequency: a). noise temperature and gain values; b). S-parameters

The resulting noise temperatures of the whole IF-chain using DSB mixer block are plotted on Fig. 4. In Fig.5, the output IF power of the DSB receiver measured when SIS junctions are biased at V_{cold} is demonstrated. These results show that the chain consisting of the standalone LNF-LNC4_16B amplifier (configuration A) is in average less noisy over the 4-12 GHz frequency band. However, it exhibits large standing waves which manifest as IF power ripples, as shown in Fig. 5. Therefore, configuration A of the IF chain was withdrawn from further tests with the 2SB receiver. The chains consisting of the isolator with the LNF-LNC4_16B amplifier (configuration B) and the balanced amplifier (configuration C) are very similar from a noise contribution perspective. However, the isolator in the configuration B seems to limit the performance at the lower end of the IF band (below 5 GHz). An improved flatness of the output power is also observed in Fig. 5 for the IF chain with balanced amplifier (configuration C).

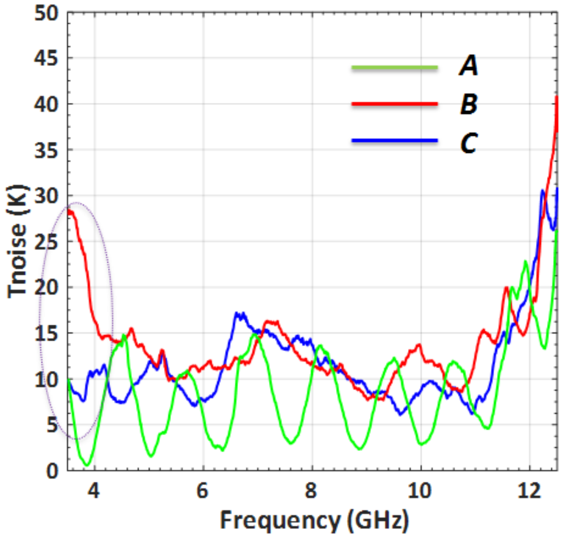

Fig. 4. Noise temperature of the IF chain of the receiver with DSB mixer block using different IF amplification chain: A, B and C (as described earlier).

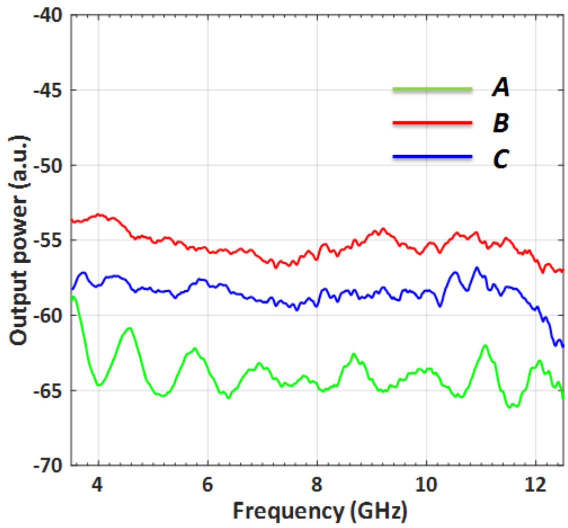

Fig. 5. Output power at V_{cold} bias of the SIS junction with DSB mixer block using different IF amplification chain: A, B and C (described earlier).

The obtained results clearly indicated the advantage of a balanced scheme for the IF amplifier chain due to its superior wideband input matching.

The results shown in Fig.5 were completely consistent with the measurements of the IF chain noise temperature as a function of frequency using the 2SB receiver prototype with IF configuration B and C. Both configurations demonstrated the same performance except at frequencies below 5GHz where the configuration B showed an increase of the noise temperature that is still to be ascribed to the isolator.

The receiver noise temperature at the lower side band (LSB) averaged over 4-12 GHz as a function of the LO frequency is presented in Fig.6 with the IF chain configurations B and C. Both chains show very similar noise performances over the presented LO frequency range with the exception of the LO frequencies around 300 GHz, where receiver equipped with balanced amplifier has slightly lower noise. Since we have only one available balanced amplifier, switching of the side bands was conducted by bias reversing of one of the SIS junctions.

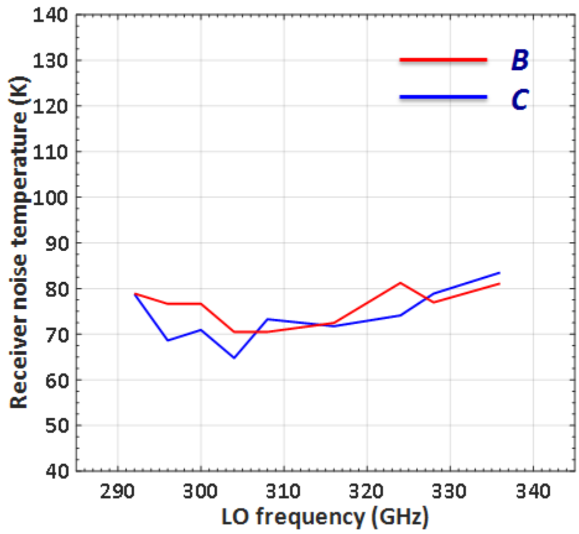

Fig. 6. Noise temperature of 2SB receiver at LSB with two IF configuration B and C (described earlier).

IV. CONCLUSION

In this work, we have demonstrated the noise performance of the 1mm SIS receiver employing different configurations of the IF chains. We have shown that the cryogenic balanced IF amplifiers can be a very promising alternative to the conventional IF amplification chain comprising a cryogenic isolator cascaded with the LNA.

Our measurements indicate that both configurations (B and C) are very similar in terms of the receiver noise performance. However, currently available isolators with a passband wider than 4-12 GHz exhibit higher insertion losses above 10.5 GHz, whereas balanced amplifiers are likely to demonstrate even more broadband performance as the hybrids with the bandwidth 4-16 GHz have already done, and even wider bands are possible.

A more compact solution for a balanced amplifier instead of a modular architecture has been demonstrated [9]. Moreover, further reducing the number of interfaces and optimizing the amplifier design would allow us to further improve the input and output matching of the balanced amplifier. A broader band solution for compact hybrids would open the possibility to reach larger IF bands by employing balanced LNAs.

ACKNOWLEGEMENTS

Part of the research leading to these results has received funding from the European Commission Seventh Framework Programme (FP/2007-2013) under grant agreement No 283393 (RadioNet3).

REFERENCES

[1] V. Belitsky et al., "ALMA Band 5 receiver cartridge. Design, performance, and commissioning", *Astron. Astrophys.*, vol. 611, A98, 2018.

[2] V. Belitsky et al., "SEPIA - a new single pixel receiver at the APEX Telescope", *Astron. Astrophys.*, vol. 612, A23, 2018.

[3] A. B. Pavolotsky, D. Dochev, and V. Belitsky, "Aging- and annealing-induced variations in Nb/Al- AlOx/Nb tunnel junction properties," *J. Appl. Phys.*, vol. 109, no. 2, p. 024502, 2011.

[4] H. Rashid et al., "Wideband Passive Circuits for Sideband Separating Receivers", *Proceedings of the 29th*

International Symposium on Space Terahertz Technology, Pasadena, USA, 2018.

[5] H. Rashid, V. Desmaris, and V. Belitsky, "Wideband Passive Circuits for Sideband Separating Receivers", *Proceedings of the 29th International Symposium on Space Terahertz Technology*, Pasadena, USA, 2018.

[6] I. Lopez-Fernandez, J. D. Gallego Puyol, C. D. Gonzalez and A. B. Cancio, "Development of Cryogenic IF Low-Noise 4-12 GHz Amplifiers for ALMA Radio Astronomy Receivers" *IEEE MTT-S International Microwave Symposium Digest*, San Francisco, CA, pp. 1907-1910, 2006.

[7] V. Belitsky,, V. P. Koshelets, I.L Serpuchenko, M.A. Tarasov, L.V. Filippenko. , S.V. Shitov "Superconducting Tunnel Junction Noise Generator and SIS Mixer Noise Measurements", *20th European Microwave Conference 90, Budapest, Sept. 10-13, 1990, Conf. Proc*.- Tunbridge Wells, 1990, pp. 816 -820.

[8] D. P. Woody "Measurement of the noise contributions to SIS heterodyne receivers", *IEEE transactions on Applied Superconductivity*, vol. 5, No. 2, 1995.

[9] R. I. Amils, I. López-Fernández, J. D. Gallego et. al., "Compact Cryogenic Wide-Band Balanced Amplifiers with Superconducting 90° Hybrids for the IF of Submillimeter-Wave SIS Mixers", *Proceedings of the 30th International Symposium on Space Terahertz Technology*, Gothenburg, Sweden, 2019.