A Wide-Band High-Gain Compact SIS Receiver utilizing a 300-μW SiGe IF LNA

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***Abstract*—Low-power low-noise amplifiers integrated with Superconductor-Insulator-Superconductor (SIS) mixers are required to enable implementation of large-scale focal plane arrays. In this work, a 220-GHz SIS mixer has been integrated with a high-gain broad-band low-power IF amplifier into a compact receiver module. The low noise amplifier (LNA) was specifically designed to match to the SIS output impedance and contributes less than 7 K to the system noise temperature over the 4-8 GHz IF frequency range. A receiver noise temperature of 30-45 K was measured for a local oscillator frequency of 220 GHz over an IF spanning 4-8 GHz. The LNA power dissipation was only 300 μW. To the best of the authors' knowledge, this is the lowest power consumption reported for a high-gain wide-band LNA directly integrated with an SIS mixer.**

***Index terms*—** Superconductor-Insulator-Superconductor (SIS) mixers, Heterodyne receivers, Cryogenic, Low noise amplifier (LNA), Focal plane arrays, Silicon-Germanium (SiGe)

I. Introduction

LARGE-SCALE heterodyne focal plane arrays (FPAs) are desired to enable wide-ranging sub-millimeter wave astronomical surveys, which will be used to study the stars, galaxies, and molecular clouds in the cosmos [1] In comparison to today's state-of-the-art single-pixel THz instruments, a focal plane array containing hundreds or even thousands of pixels promises to provide a reduction of several orders of magnitude in the time it takes to acquire an image of a given fidelity. This is particularly important for ground-based sub-millimeter wave astronomy, as high system noise temperatures create a need for long dwell times, making large-scale surveys difficult, if not impossible, to carry out using a single pixel telescope. However, despite the promising science that might be done with such a system, THz heterodyne FPAs of this magnitude have been slow to develop due to the various mechanical and thermal challenges associated with their implementation [1].

Practical kilopixel heterodyne arrays will require sub-milliwatt power consumption low-noise amplifiers (LNAs) to enable cooling to liquid helium temperatures using commercial closed-cycle refrigerators. Silicon germanium (SiGe) LNAs have been recently emerged as a popular alternative to the HEMT IF amplifiers and particularly attractive due to their ability to operate with very low power consumption. We have recently shown that SiGe HBTs can be used to implement high performance cryogenic LNAs operating with sub-milliwatt power consumption and leveraging the models developed in [2], we have designed and implemented a sub-milliwatt LNA directly integrated with an SIS mixer [3]–[5]. A brief description of the project and some results are presented here.

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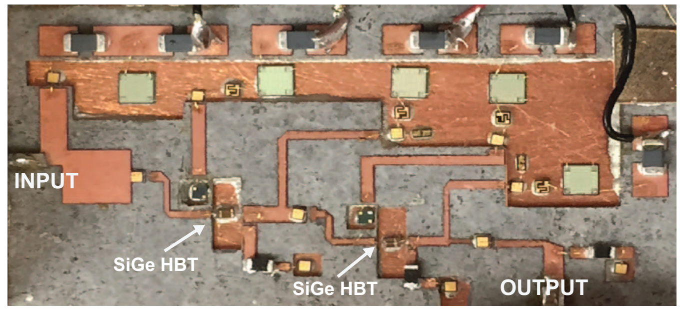

Fig. 1. A photograph of the assembled LNA circuit.

II. Project Description

A two-stage LNA was designed using the SiGe heterojunction bipolar transistor (HBT) models described in [2]. The amplifier was designed to provide 30 dB gain over the 4-8 GHz frequency range and less than 7 K noise temperature. The SIS mixer selected for this work was a distributed series array of three SIS junctions previously reported in [6]. The LNA was assembled in a housing that was designed to mate with the SIS mixer block. A photograph of the assembled LNA circuit is shown in Fig. 1. The amplifier was implemented using discrete transistors from the IBM BiCMOS8HP process together with the wire bondable and surface mount resistors and capacitors. The LNA module was bolted directly to an SIS mixer block. A photograph of the assembly appears in Fig. 2(a). The hybrid assembly was mounted in a liquid helium cryostat configured to facilitate Y-factor measurements (see Fig. 2).

The RF performance of the system was then measured by applying a 220 GHz LO pump power to the SIS junctions while the IF LNA was biased at a DC power consumption of 300 μW. The double-sideband (DSB) receiver noise temperature was computed from Y-factor data for IF frequencies from 3 to 9 GHz and results are shown in Fig. 3(a). The noise temperature was found to be between 30 and 40 K for the most of 4–8 GHz IF frequency range while consuming only 300μW DC power.

The impact of IF amplifier power consumption on system performance was evaluated later. The DC power consumption of the LNA was swept from 660 μW down to 230 μW. As shown in Fig. 3(a), a marginal increase in the system noise

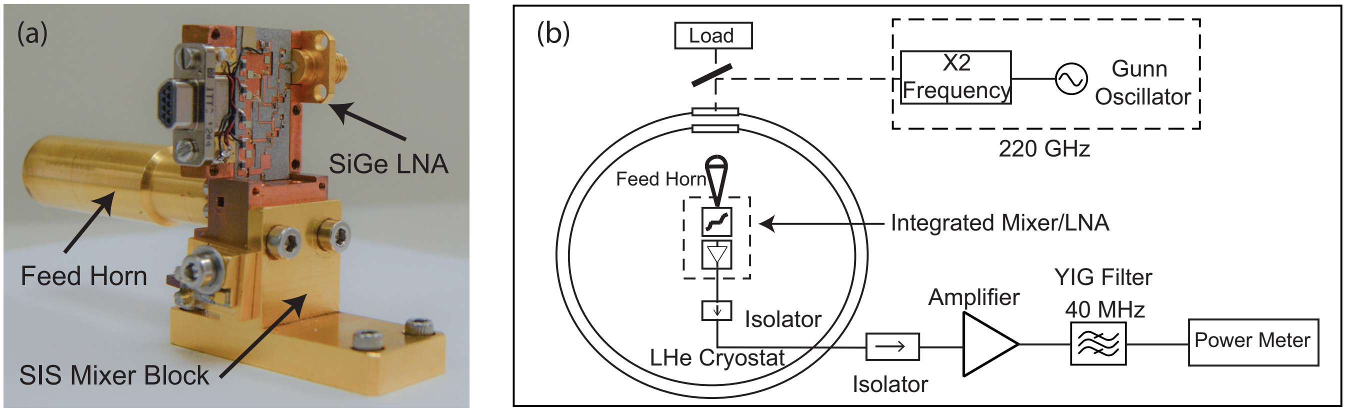

Fig. 2. (a) A photo of the LNA block directly connected to the Mixer block. (b) A block diagram of the measurement setup.

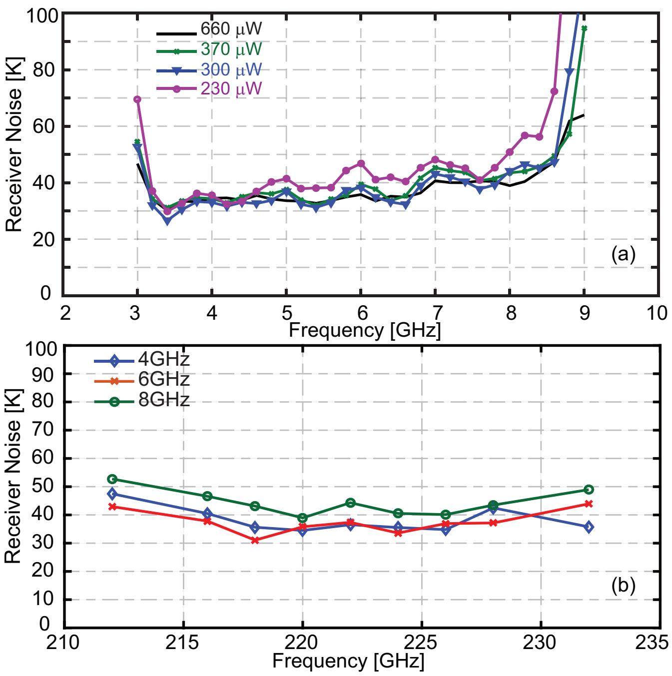

Fig. 3. Receiver performance when LNA was biased at Ic_1=1.2 mA, Ic_2=0.8 mA, and Vcc=150 mV which corresponds to 300 μW DC power. (a) Double side-band system noise temperature of the low power SiGe-LNA/Mixer at f_{LO}= 220 GHz at different power levels for the LNA. (b) Receiver noise temerature over the range of 212-232 GHz local oscillator frequency and IF spot frequencies of 4, 6, and 8 GHz.

temperature was observed for power levels as low as 230 μW. The performance of the hybrid SIS-mixer/SiGe-LNA assembly was also characterized as a function of LO frequency and results are shown in Fig.3(b).

The results achieved in this work demonstrate a broadband compact SIS receiver, with the lowest DC power dissipation reported to date. This is an important step towards scaling THz focal plane arrays to the kilopixel level. Future work should include the development of MMIC based ultra-low-power cryogenic LNAs designed to interface with SIS mixers.

III. Impact of the MTT-S Fellowship

I have been extremely honored and grateful to be a recipient of the 2016 IEEE MTT-S graduate fellowship award. It has been greatly encouraging for me that my research achievements have been recognized by the MTT-S society. This fellowship provided the opportunity for me to attend the IMS2016 which was a great environment for networking with other researchers and learning from their experiences and sharing ideas. I also had the opportunity to attended the Women in Microwave panel session at the IMS2016 which was greatly inspiring for young female engineers in this field.

IV. Future Work and Career Plans

I am planning to continue my research in the field of RF and microwave engineering and I am considering doing research in both industrial environment as well as academia. My goal is to learn more everyday and develop my skills in different aspects of the field to be able to come up with new ideas that would benefit the scientific society.

References

[1] C. Groppi, C. Wheeler, H. Mani, S. Weinreb, D. Russell, J. Kooi, A. Lichtenberger, and C. Walker, "The kilopixel array pathfinder project (KAPPa): A 16 pixel 660 GHz pathfinder instrument with an integrated heterodyne focal plane detector," in *Proc. 22nd Int. Symp. Space THz Techn*, 2011, pp. 164–170.

[2] S. Montazeri, W.-T. Wong, A. Coskun, and J. Bardin, "Ultra-low-power cryogenic SiGe low-noise amplifiers: Theory and demonstration," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 64, no. 1, pp. 178–187, Jan 2016.

[3] S. Montazeri, P. Grimes, C.-Y. Tong, and J. Bardin, "A 220-GHz SIS mixer tightly integrated with a sub-hundred-microwatt SiGe IF amplifier," *Terahertz Science and Technology, IEEE Transactions on*, vol. 6, no. 1, pp. 133–140, Jan 2016.

[4] S. Montazeri, P. K. Grimes, C. Y. E. Tong, and J. C. Bardin, "A wide-band high-gain compact sis receiver utilizing a 300- muw sige if lna," *IEEE Transactions on Applied Superconductivity*, vol. 27, no. 4, pp. 1–5, June 2017.

[5] S. Montazeri, P. K. Grimes, C.-Y. E. Tong, W.-T. Wong, and J. C. Bardin, "Direct integration of an sis mixer with a high-impedance sige low noise amplifier," in *Proc. 26th Int. Symp. Space THZ Technol.*, 2015, p. 30.

[6] C. Tong, P. Grimes, R. Blundell, M.-J. Wang, and T. Noguchi, "Wideband SIS receivers using series distributed SIS junction array," *Terahertz Science and Technology, IEEE Transactions on*, vol. 3, no. 4, pp. 428–432, July 2013.