Cryogenic Amplifier Based Sideband Separating Receivers

Goutam Chattopadhyay[1], Theodore Reck[1], Erich Schlecht[1], William Deal[2], and Imran Mehdi[1]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109 USA
[2]Northrop Grumman Aerospace Systems, Redondo Beach, CA, 90277 USA

***Abstract*—We have developed HEMT-based sideband-separating receivers operating in the 180 to 270 GHz and 620 to 660 GHz bands. These receivers utilize 30nm InP HEMT MMICs for the front-end low-noise amplifiers and balanced mixers cryogenically cooled to 20K. This paper presents the room and cryogenic temperature characterization of the receiver front-end system.**

I. INTRODUCTION

MMIC-based radiometers are very attractive for radio astronomy and Earth science applications since their limited cooling requirements and front-end gain simplifies instrument design compared to superconductor-insulator-superconductor (SIS) mixers. Moreover, they provide the opportunity to integrate the entire receiver front-end components on a single MMIC chip which can be used for multi-pixel focal plane arrays. Additionally, for space-borne instruments 20 K cooling is much lower risk because 4 K closed-cycle coolers have limited flight heritage. And finally, the MMIC's sensitivity to physical temperature is much less than SIS, and hence the amplifier sensitivity degrades gracefully as temperature increases whereas SIS receivers do not operate at all above their critical temperature, generally around 10 K or lower.

Traditionally, where highly sensitive measurements are the prime requirement, SIS mixer based receivers cooled to 4 K temperature were used at the front-end of the submillimeter-wave radiometer and spectrometers. When cryogenic cooling is not an option, Schottky diode based receivers operating at room temperature were the obvious choice for these applications as there were no amplifiers available at the submillimeter wavelengths. The emergence of the Northrop Grumman's 25 nm gate InP high electron mobility transistor (HEMT) process has enabled MMIC technology above 300 GHz. They have f_{MAX} > 1.5 THz, enabling amplifiers up to 1 THz [1], [2]. These devices (both with 25 nm and 30 nm gate length) also offer higher performance at lower frequencies, such as the amplifier used in this work, which offers 40% bandwidth centered at 230 GHz. This paper presents the development and measured results of cryogenically cooled MMIC-based single-sideband receivers operating in the 180 to 270 GHz and 620 to 660 GHz bands.

II. RECEIVER DESIGN AND RESULTS

A schematic block diagram for the MMIC based sideband separating receiver front-end is shown in Fig. 1. The RF signal is first amplified by InP HEMT low-noise amplifiers working in the 180-270 GHz and 620-660 GHz bands. The amplified signal is split to two equal parts using a 90° quadrature hybrid. A 3-dB Y-junction splitter splits the phase coherent local oscillator (LO) signal to pump two HEMT based balanced mixers as shown in Fig. 1. The local oscillator signal is generated using HEMT based frequency multipliers and amplifiers driven by a Ka-band frequency synthesizer.

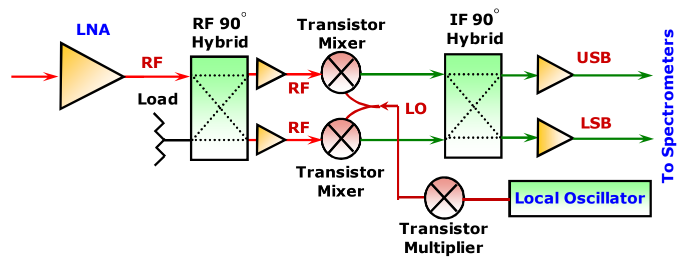

Fig. 1: Schematic block diagram of a MMIC based sideband separating receiver working in the 180-270 GHz and 620-660 GHz bands.

The low-noise amplifiers (LNAs) were designed and fabricated at Northrop Grumman Aerospace Systems in their 30 nm InP HEMT process. One of the amplifiers covers 180 to 270 GHz with a noise temperature below 150 K and a gain of 16 dB when operated at 27 K ambient. Fig. 2 shows the performance of the 230 GHz LNA when cooled to 27 K. To the best of our knowledge, this is the lowest noise temperature of an MMIC operating over such a wide bandwidth.

Of the several LNAs covering the 620 to 660 GHz band that we measured in our laboratory, one of them had a noise temperature better than 700 K across the band and 12 dB of gain when operated at 20K ambient [3]. The performance of the majority of the 620-660 GHz amplifiers was not as good. They measured noise temperatures in the 800-1000 K range over the 620-660 GHz band when cooled to 20 K. Fig. 3 shows the performance of the best measured results for the 620-660 GHz amplifier when cooled to 20 K ambient. The room temperature performance of this amplifier was 4000-4500 K over the 620-660 GHz frequency band.

The 90° quadrature hybrid and Y-junction splitters, shown in Fig. 1, are traditional designs optimized with HFSS. For overall ease of testing and development, the sideband

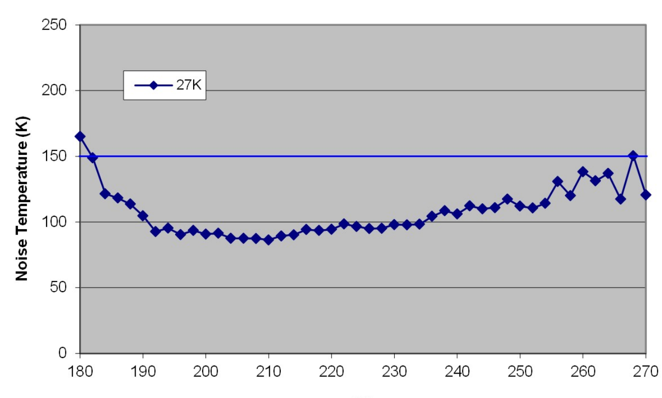

Fig. 2: Performance of the 180-270 GHz InP HEMT low-noise amplifier cooled to 27 K. Gain of the 5-stage amplifier was measured to be 16 dB.

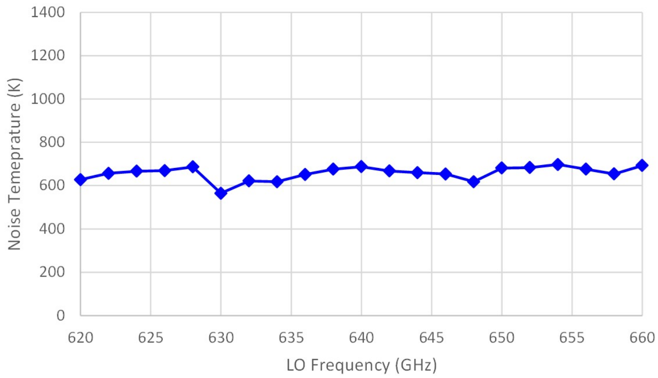

Fig. 3: Performance of the 620-660 GHz InP HEMT low-noise amplifier cooled to 20K. Gain of the 5-stage amplifier was measured to be 12 dB.

separating system was designed with discrete waveguide blocks. Each of the individual components was measured for their performance at room temperature. All the measured results for the passive components were found to match well with predicted performance. The overall amplitude and phase imbalance from these components for both the frequency bands was found to be less than 2 dB and 5°, respectively, setting an upper limit on the sideband rejection ratio of 20 dB.

The 230 GHz channel also has an orthmode transducer (OMT) to have dual polarization operation. The measured OMT has better than 20 dB of return loss across the 180-270 GHz band for both polarizations and better than 40 dB of polarization isolation. The detailed design and performance of the OMT has been reported in [4].

In anticipation of eventual integrated monolithic fabrication of the mixer with the LNA, the mixers designed for this system is also fabricated in the InP MMIC process. It is fabricated as a discrete component to allow for individual testing of the device. The balanced mixer pumps two transistors out of phase with a transmission line length difference of 180° at 230 and 640 GHz, respectively.

Fig. 4 shows the assembled dual-polarized sideband separating receiver for the 180-270 GHz band. Fig. 5 shows the measurement set up where both room temperature and cryogenic measurements for the sideband separating receivers were carried out.

At room temperature the 230 GHz mixer provides 10 dB conversion loss and 3000-6000 K DSB noise temperature.

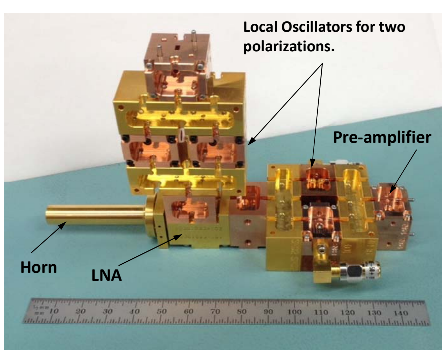

Fig. 4: Photograph of the assembled 230 GHz HEMT low noise amplifier based sideband separating receiver system.

When cooled to 20 K the DSB noise temperature drops to 2000-3000 K. For the 620-660 GHz band, at room temperature the mixer measured 15 dB conversion loss and 10000-12000K DSB noise temperature.

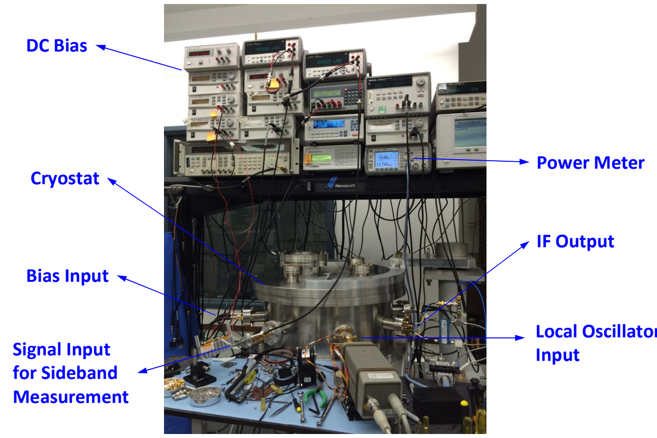

Fig. 5: Photograph of the cryogenic measurement set up where both the 240 and 640 GHz sideband separating receivers are tested.

The passive components and the mixers were put together in sideband separating receivers with the front-end LNAs for the 230 GHz and 640 GHz bands. We measured better than 200 K single sideband (SSB) noise temperature over the 180-270 GHz when cooled to 20K. We also measured 10-16 dB of sideband rejection over the same band. For the 620-660 GHz band, SSB noise temperature of less than 1100 K when cooled to 20 K was measured.

III. SUMMARY

The paper presents the application of new HEMT MMIC technology to the development of cryogenically cooled single-sideband receivers working in the 180-270 GHz and 620-660 GHz bands.

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