Direct Integration of an SIS Mixer with a High-Impedance SiGe Low Noise Amplifier

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Abstract—We present the design and preliminary characterization of a cryogenic SiGe low noise amplifier optimized for direct integration with an SIS mixer. The LNA was designed to provide 25 dB gain over an IF frequency range of 4–8 GHz. The noise temperature of the LNA was simulated to be less than 6 K over the band at a power consumption of 720 µW. The LNA was directly connected to the SIS mixer block and measurement results yielded a minimum noise temperature of approximately 40 K at an LO frequency of 214 GHz.

Index Terms—Silicon germanium, cryogenic, superconductor-insulator-superconductor mixer, low noise amplifier, focal plane array

I. INTRODUCTION

The pumped output resistance of an SIS mixer is a function of both the LO frequency and the DC bias point. For broadband devices, this output resistance is typically well above the 50 Ω impedance level that is expected at the input of most cryogenic low noise amplifiers (LNAs). Thus, low noise amplifiers are usually matched to an SIS mixer either through an isolator [1], [2] or a matching network [3]–[6]. An alternative approach is to specifically design the amplifier to achieve nominal performance when its input is terminated by an SIS mixer. For large-scale focal plane arrays, a direct connection from an SIS mixer to the low noise amplifier is needed to increase scalability while maintaining a low-level of complexity. Silicon germanium (SiGe) cryogenic low noise amplifiers are an attractive option for the implementation of these large-scale systems, due to their increased yield and competitive low-GHz noise performance in comparison with HEMT based amplifiers [7], [8].

In this paper, we present the preliminary design, implementation, and characterization of a 4–8 GHz SiGe low-noise IF amplifier that is optimized for direct integration with an SIS mixer. The amplifier operates at a DC power consumption of just 720 µW and was designed to provide greater than 25 dB of power gain at a noise temperature ranging from 3–6 K over the frequency band.

II. DESIGN AND FABRICATION

An SIS mixer has an IF output impedance that can be modeled by a parallel RC circuit, where the resistive component is given by the slope of the pumped I-V curve and the capacitance is related to a combination of the parallel plate capacitance of the SIS junction(s) and the capacitances associated with the embedding circuit. For our initial experiments, we selected an SIS mixer with the pumped IV curves shown in Fig. 1. The device is a three junction series array SIS mixer and is described in [9].

To facilitate the design of an amplifier, the equivalent IF impedance of the SIS mixer was determined as follows. The conductance of the SIS junction was found using a linear regression. The resulting generator resistance is plotted in Fig. 1 as a function of bias voltage. Since the Y-factor is maximized near the center of the photon step, we have chosen a bias voltage of 7 mV as the operating point for our design. The corresponding output resistance of the mixer ranges from 100–200 Ω, depending on the local oscillator frequency. Rather than designing for a fixed LO frequency, we chose a generator impedance of 150 Ω, which is considerably higher than the 50 Ω impedance to which a typical LNA is matched. The intrinsic shunt capacitance of the SIS mixer is estimated to be 270 fF.

Designing a low-noise amplifier for a large generator impedance has pros and cons. For a given transistor technology, the optimum generator impedance is inversely proportional to the device periphery. As low-noise devices are typically biased at a fixed current density to realize the minimum noise, a smaller transistor periphery corresponds to a lower overall current, which translates to a decrease in power consumption. On the other hand, realizing a broadband matching network given a high generator impedance requires large reactances, which are not easy to realize using transmission line components.

As an initial demonstration, we have implemented a two-stage amplifier using discrete SiGe HBTs fabricated in the
is higher than 25 dB, with less than 3 dB of gain variation
intrinsic SIS mixer. From 4–8 GHz, the simulated power gain
simulation results have been referenced to the plane of the
transformation associated with the SIS IF filter network. All
intrinsic capacitance of the SIS mixer as well as the impedance
Fig. 3. Simulated performance of amplifier driven from 150
Ω generator impedance of 150
Ω and the results appear in Fig. 3. These simulations are for
amplifier were simulated using the models reported in [8]
consumption of 0.72 mW.

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at a current of
V
the gain and provide output matching. Finally, the circuit is
and second-stage transistors ensure unconditional stability.
Resistors at the output of the first-
and surface mount components. A close-up of the circuit board
across the band. The simulated input return loss is better than
7 dB over the entire band. For a generator impedance of
150 Ω, the simulated noise performance is below 6 K over the
entire frequency range. Moreover, as the generator impedance
is swept from 100–200 Ω, the noise performance is expected
to change by less than 1 K over the majority of the frequency
range.

III. EXPERIMENTAL RESULTS

The amplifier was assembled using a mixture of bondable
and surface mount components. A close-up of the circuit board
is shown in Fig. 4(a). The board measures just 12.7 mm
by 25.4 mm. A micro-D connector was incorporated into
the housing to provide DC bias to the amplifier and the
SIS mixer. The amplifier housing was designed to mate with
an existing SIS mixer block [9], and a direct connection
was made between the amplifier and the SIS mixer chip
using a 0.125 mm, 1 mm long wire. The hybrid mixer/LNA assembly is shown in Fig. 4(b).

A block diagram and photograph of the measurement setup
are shown in Figs. 5 and 6, respectively. The mixer/amplifier
assembly was cooled to 4.2 K in a liquid helium cryostat.
A 214 GHz local oscillator was quasi-optically coupled to
the SIS mixer. The output of the LNA was further amplified
by a second gain stage (LNF-LNC4-16A) before exiting the
cryostat. A third amplifier (Minicircuits ZV A-183,2-18 GHz)
at room temperature was used to further amplify the IF signal
before band-limiting and power detection.
Fig. 6. Photograph of the measurement setup

![Photograph of the measurement setup](image)

Fig. 7. (a) Output power measurement at 77 K and 295 K. (b) Double-sideband system noise temperature. These measurements are for an LO frequency of 214 GHz and an IF frequency of 6 GHz.

![Output Power and Noise Temperature Measurements](image)

A double-sideband Y-factor measurement was carried out using ambient (295 K) and liquid nitrogen cooled black bodies (77K) placed in the input beam of the receiver. For these measurements, the IF was centered at 6 GHz with a bandpass of 40 MHz. For a local oscillator frequency of 214 GHz, the corresponding sideband frequencies were 208 and 220 GHz. The results of the Y-factor measurement, taken with the amplifier operating at its nominal bias point of 0.72 mW, are plotted in Fig. 7(a). The corresponding double-sideband system noise temperature appears in Fig. 7(b). The system noise temperature was found to be better than 40 K over a wide range of bias voltages. As these data include optical losses, the intrinsic performance of the mixer/amplifier assembly is expected to be better than that reported in Fig. 7(b).

IV. Conclusions

The results presented in this paper demonstrate the feasibility of achieving excellent system performance using sub-milliwatt SiGe LNAs directly integrated with SIS mixers. Although, these initial results are narrow-band, future adoption of this technology will require broadening the IF bandwidth. A logical next step is to demonstrate the operation of the SIS/LNA assembly over both wide RF input bandwidths as well as over at least a 4–8 GHz IF bandwidth. If successful, the combination of ultra-low-power consumption and tight integration is expected to impact the scalability of SIS focal plane array systems.

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REFERENCES


