Wideband SIS Receiver Development for the Submillimeter Array

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***Abstract*—We report on the development of wideband receivers for the Submillimeter Array (SMA). The current generation of SMA receiver offers an intermediate frequency (IF) of 4 – 14 GHz. We have further pushed the frontier of wideband SIS mixing, by developing a low noise receiver with an IF of 4 – 18 GHz.**

I. INTRODUCTION

THE sensitivity of submillimeter receivers can be improved by extending the instantaneous bandwidth, *B*, provided that any increase in receiver noise across the band is modest. If the receiver is used for the remote sensing of the temperature of a distant object, the radiometer equation states that the resultant uncertainty in the observation varies inversely as the square root of *B*. In the case of spectroscopy, a wider bandwidth allows multiple spectral lines to be observed simultaneously. In this paper, we report on the development of wideband superconductor-insulator-superconductor (SIS) receivers for the Submillimeter Array (SMA), a radio interferometer on Mauna Kea, Hawaii. The current generation of SMA receiver offers an IF of 4 – 14 GHz. The work describes here further extends the IF bandwidth.

II. METHODOLOGY

In order to increase the instantaneous bandwidth of the SIS mixer, we have employed a series connected SIS junction array with low output capacitance at the intermediate frequency (IF) [1]. We have also optimized the tuning circuit of the mixer circuitry to further reduce the parasitic capacitance associated with the tuning circuit. As the output bandwidth increases, the mixer also becomes more prone to saturation effects. The use of a series junction array increases the dynamic range of the mixer. The power handling capacity of an SIS mixer is generally proportional to N^2, where N is the number of series-connected junctions [2]. At the same time, the power level, at which the mixer experiences output compression, is expected to be a linear function of its instantaneous bandwidth. Therefore, the use of a series-connected SIS junction array is an effective and necessary means to extend the IF bandwidth of the SIS mixer.

In the current generation of receivers for the SMA, we place a 4-14 GHz cryogenic isolator [3] between the SIS mixer and the wideband low noise cryogenic IF amplifier. There are a number of reasons for doing that. First, the SIS mixer generally presents fairly high output impedance, and sometimes this impedance can be negative, when the mixer is highly inductively tuned. Besides, the input match of most wideband low noise amplifiers is not very good. The use of a wideband isolator provides a buffer between the SIS mixer and the low noise amplifier, and ensures unconditional stability for the receiver operation.

In order to increase the IF bandwidth, a cryogenic isolator with wider operating bandwidth is necessary. The 4-14 GHz isolator, that we are presently using, is a field displacement isolator, also known as edge mode isolator [4]. We have further refined the design of such an isolator. Recently, we have demonstrated an isolator, working at 4 K, which operates between 5 - 18 GHz [5]. This isolator offers an insertion loss of less than 2 dB, an input match of around -15 dB, and an isolation of greater than 20 dB over that frequency range.

III. RESULTS

We have performed experiments with both 3-junction and 4-junction series connected SIS mixer. In this work, we use a cryogenic low noise amplifier (LNA), which offers a noise temperature of below 10 K between 4 and 20 GHz [6].

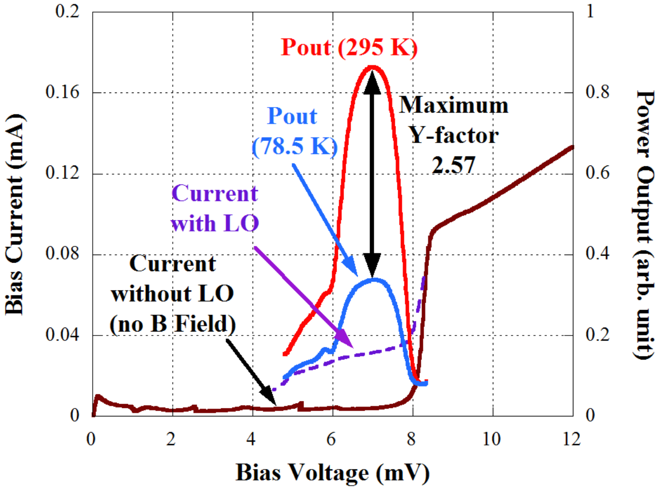

Fig. 1. Current-voltage (I-V) characteristics of wideband 3-junction array. A 3.3 mV wide photon assisted tunneling step is clearly seen when the mixer is optimally pumped by an LO of 270 GHz. Also shown is the P-V curve of the receiver for an IF of 16 GHz in response to ambient (295 K) and liquid nitrogen chilled (78.5 K) loads.

Fig. 1 shows the current–voltage curve of a 3-junction SIS series distributed mixer. The design of the mixer circuitry has been described previously [1]. The normal state resistance, R_N, is 87 Ω, or 29 Ω per junction, and the area of the individual junction is about 0.85 μm^2. This translates into an R_NA product of ~24.5 Ω-μm^2. The junction array demonstrates very low leakage characteristics: the ratio of sub-gap resistance to R_N is in excess of 20. One advantage of the series junction array is the ease of application of magnetic field. The mixer exhibits a smooth power output versus bias voltage (P-V) curve over a wide range of magnetic field once the field is strong enough to suppress the zero-voltage critical current.

Referring to Fig. 1, when the mixer is pumped by a Local Oscillator (LO) of 270 GHz, a broad photon-assisted tunneling step 3.3 mV wide can be observed in the I-V curve. From the slope of the I-V curve on the step, we infer that the output resistance of the mixer is around 300 Ω. We estimate that the sum of capacitance of the junctions and the tuning network is about 0.15 pF, which represents a shunt reactance of ~60 Ω at an IF of 18 GHz. The role of the wideband isolator is to provide a broadband 50-ohm match to the SIS mixer. Using the equivalent circuit model given in [7], we conclude that the IF bandwidth of this mixer is in excess of 18 GHz since the shunt reactance at 18 GHz is less than the 50 Ω load offered by the isolator in parallel with the 300 Ω mixer output resistance.

We have measured the noise temperature of the mixer using the standard hot/cold load Y-factor method. In these measurements, the IF was swept between 4 and 19 GHz with a YIG-tuned bandpass filter, in steps of 100 MHz, with filter bandwidth of 40 MHz. The P-V curves given in Fig. 1 are obtained at an IF of 16 GHz. A maximum Y-factor of 2.57 is recorded at the center of the photon step, corresponding to a double-side-band (DSB) noise temperature of about 60 K. The DSB conversion loss of the mixer is estimated to be 2 dB. Using the SIS junction as a shot noise generator, the noise temperature of the isolator-LNA combination is measured to be ~13 K, which includes ~5 K of added noise from the insertion loss of the isolator. Thus the contribution of the IF chain is about 20 K. With an estimated contribution of 20 K from the input optics, the mixer noise temperature is therefore around 20 K.

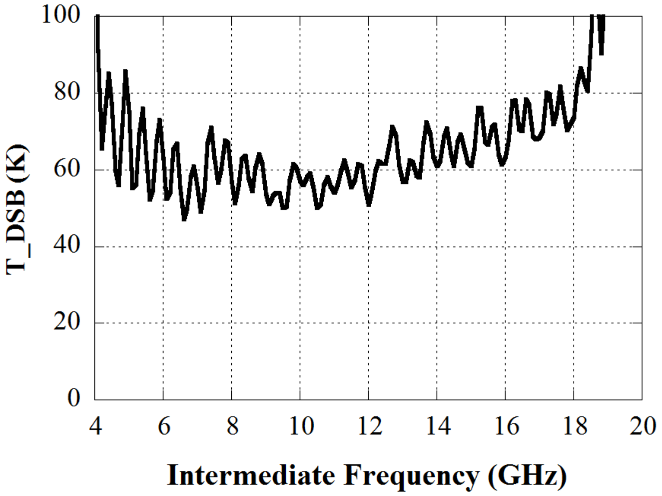

Fig. 2. Laboratory receiver noise temperature measured at an LO frequency of 258 GHz, with the IF sweeping from 4 to 19 GHz.

Fig. 2 gives the measured noise temperature as a function of IF. The observed ripples are the result of the input reflection of the isolator, which had an input return loss of between -12 and -15 dB. The ripple period corresponds well to the 20 cm cable length between the mixer and the isolator. The rise in the noise temperature towards higher IFs is also attributable to the finite insertion loss of the isolator, which increased from 1.5 dB at the low frequencies to above 2 dB at the high end of the IF band.

Further work is under way to improve the input match of the isolator as well as to reduce its insertion loss.

IV. CONCLUSION

A wideband low noise SIS receiver, based on series-connected distributed SIS junction array coupled to wideband isolator, has been developed. We have demonstrated that this receiver offers low noise operation over a wide IF range of 4 - 18 GHz. After further optimization, this receiver will be deployed at the Submillimeter Array for routine astronomical observations.

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