A 530-GHz Balanced Mixer

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Abstract— **We report on the design and performance of a 530-GHz balanced SIS mixer, the first balanced mixer in this frequency range. This quasi-optical balanced mixer utilizes a cross-slot antenna on a hyperhemispherical substrate lens with eight superconductor–insulator–superconductor (SIS) junctions and a 180° lumped element IF hybrid circuit. The local oscillator (LO) and the radio frequency (RF) signal, orthogonal in polarization to each other, are coupled to the mixer using a wire-grid polarizer. The noise performance of the mixer is excellent, giving an uncorrected receiver noise temperature of 105 K (DSB) at 528 GHz.**

Index Terms— **Balanced mixer, low noise, superconductor–insulator–superconductor (SIS) junctions.**

I. INTRODUCTION

BALANCED mixers suppress local oscillator (LO) amplitude modulation (AM) noise, have better power handling capabilities, and reject certain spurious responses and spurious signals [1]. At millimeter and submillimeter wavelengths, single-ended mixers are almost always used, and LO injection is usually accomplished using an optical beamsplitter or a waveguide coupler. However, due to the low available LO power in this frequency range, the coupling often must be fairly large, −10 dB or greater. Since the LO is usually at room temperature, this results in 30 K or more of thermal noise being injected into the receiver along with the LO. This can be a rather significant contribution to the total receiver noise temperature; modern superconductor insulator superconductor (SIS) receivers can have noise temperatures well below 100 K. In contrast, balanced mixers are capable of rejecting the thermal noise incident at the LO port. In addition, balanced mixers make use of *all* of the available LO power, whereas single-ended mixers with beamsplitters or couplers waste ≥90% of the LO power. These advantages have also been noted by Kerr *et al.* [2]. However, no balanced mixer results have been reported to date at submillimeter wavelengths. Stephan *et al.* proposed the first quasioptical balanced mixer at 90 GHz [3], and Tong *et al.* proposed a magic tee balanced mixer which potentially could be used at millimeter wavelengths [4]. Kerr *et al.* reported the design of a waveguide balanced mixer for 200–300 GHz [2], but no experimental results were given.

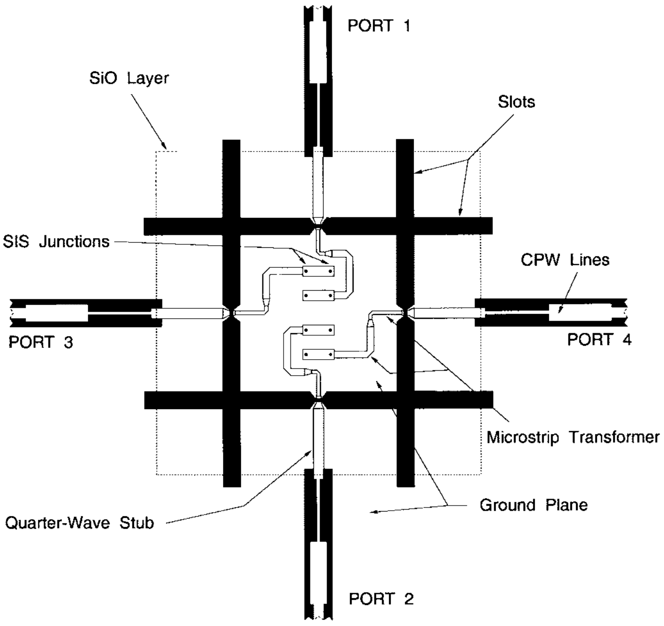

Fig. 1. Details of the mixer chip layout. CPW lines carry IF outputs which are combined to get the balanced output signal.

II. MIXER CONFIGURATION AND DESIGN

We have designed and fabricated a quasi-optical balanced superconductor–insulator–superconductor (SIS) mixer at 530 GHz. The mixer utilizes a cross-slot antenna on a hyperhemispherical substrate lens which has symmetric E- and H-plane beams, low impedance, wide bandwidth, low cross polarization, and high coupling efficiency [5]. Instead of designing a new chip for this mixer, we used the dual-polarized SIS mixer chip described by Chattopadhyay *et al.* [6]. A layout of the mixer chip is shown in Fig. 1. This mixer chip has four antenna ports with a two junction SIS circuit connected to each of the ports. The radiation received by the cross-slot antenna is coupled into the SIS junctions with superconducting microstrip lines. The two-section quarter-wave microstrip transformer allows a good impedance match between the antenna (≈30 Ω) and the tunnel junctions ($R_n/2 \approx 7\ \Omega$). Balanced mixer operation is achieved by coupling the LO and the RF signals in two orthogonal polarizations using a wire-grid polarizer and combining the IF outputs using a 180° hybrid circuit.

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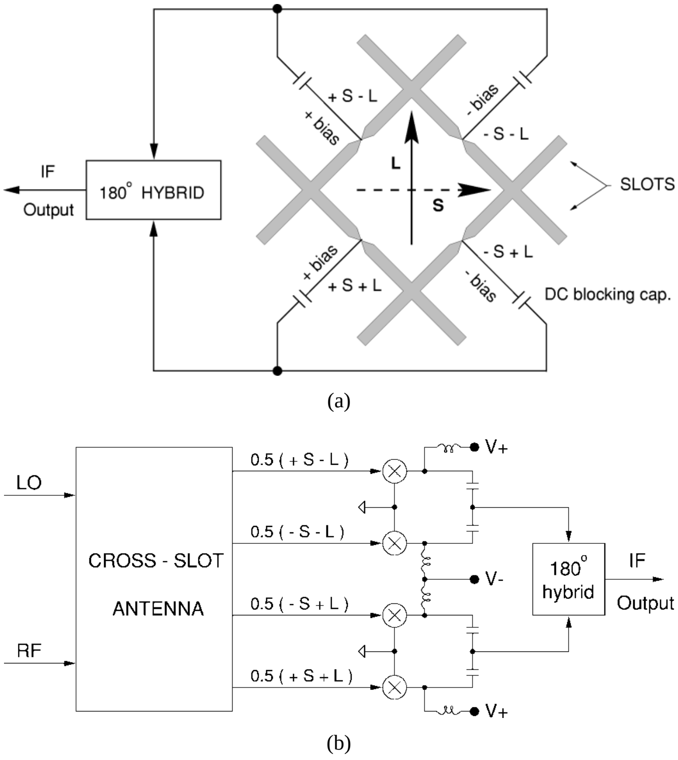

Fig. 2. Balanced mixer configuration using the dual-polarized mixer chip. (a) Cross-slot antenna with different signals and circuits. LO and RF signals (denoted as L and S, respectively) with the phases are shown at the four antenna ports. (b) Corresponding functional diagram.

Our implementation of a balanced mixer using the cross-slot antenna is shown in Fig. 2. In Fig. 2(a), the LO and RF signals are denoted by L and S, respectively, and have orthogonal polarizations, as shown. Also shown in the figure are the phases of the LO and RF signals at the four ports of the cross-slot antenna ($+S - L$, $+S + L$ etc.). The four IF outputs, as shown, are dc blocked and combined in a 180° hybrid circuit. Fig. 2(b) shows the corresponding functional diagram for the balanced mixer. It is to be noted that due to the mandatory series biasing of the mixers, the currents in the ports which are positively biased will be 180° out of phase compared to the currents in the mixers which are negatively biased [6]. This is taken into account in the functional diagram in Fig. 2(b).

The assembled balanced mixer circuit is shown in the Fig. 3(a). The bias for the SIS junctions come in through a connector from the right side and the IF output comes out of the mixer block on the left through a SMA connector as shown. The mixer chip is placed on an antireflection coated silicon hyperhemispherical lens, and the 180° IF hybrid circuit is realized using lumped capacitors and microstrip transmission lines as in [6]. The details of the IF and dc circuits are shown in Fig. 3(b).

III. MEASUREMENT AND RESULTS

The receiver response as a function of frequency was measured with an fourier transform spectroscopy (FTS) system using the mixer as a direct detector. Fig. 4 shows the FTS response for the mixer chip along with the simulation results obtained from the "Pcircuit" program [7]. The FTS response agrees reasonably well with the simulation results, and the peak response was found at 528 GHz. Since the RF junction impedances in heterodyne and in direct detection operation typically differ by less than 10%, the direct FTS measurements can be expected to give relatively accurate indication of the device frequency dependence in heterodyne mode [8], [9], which means that the noise temperature for this mixer will follow the FTS curve and the best noise temperature would be around 528 GHz. As can be seen in Fig. 4, the measured FTS response has a narrower bandwidth than predicted by our design simulation. We believe that this discrepancy can largely be attributed to differences in the device parameters assumed for the design versus those actually achieved in fabrication, particularly the properties of the microstrip dielectric layer.

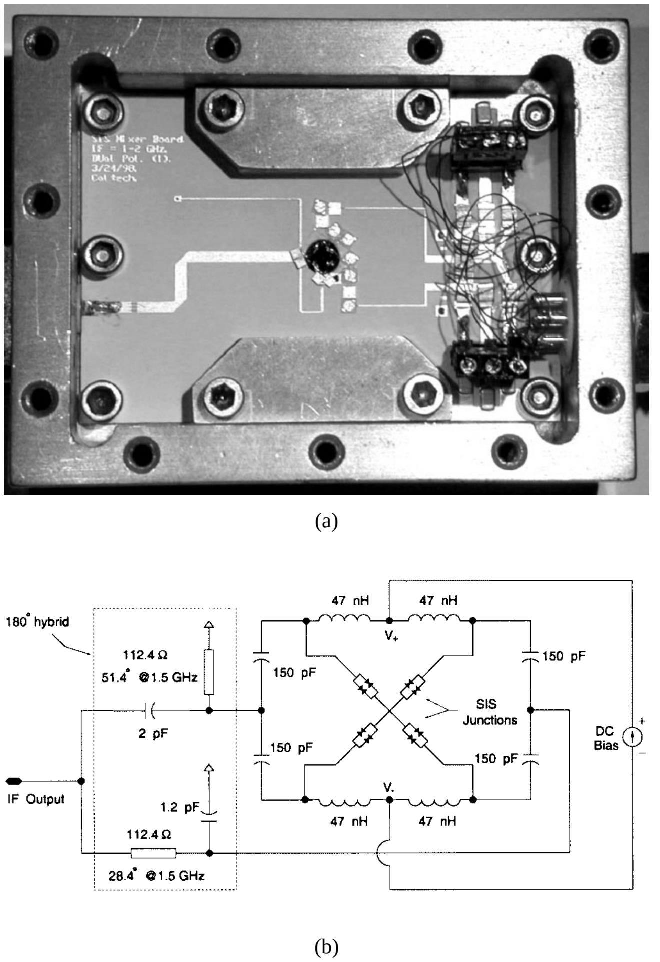

Fig. 3. Biasing and IF circuit details. (a) Mixer block with IF circuit board. The IF output is taken out through the SMA connector shown on the left and the bias comes in through the connector on the right. (b) Details of the IF and dc bias circuits.

The noise temperature measurement setup for the balanced mixer is shown in Fig. 5. The wire-grid polarizer reflects the vertically polarized LO signal and passes the horizontally polarized RF signal. The combined LO and RF signals, after passing through the optics, is incident on to the mixer inside the cryostat. The cross-slot antenna is oriented as shown in Fig. 2(a). The IF output is amplified by a 1.0–2.0 GHz cooled HEMT low-noise amplifier (LNA) with a measured

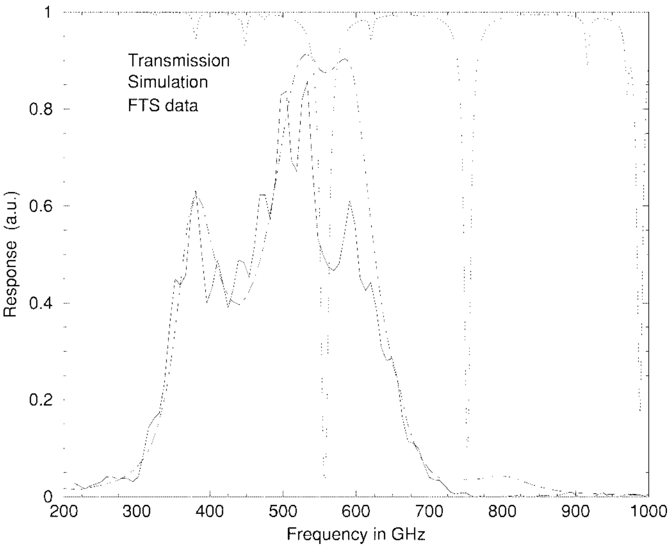

Fig. 4. FTS response. Solid line is the measured response, and the dashed line is the simulation result. The dotted line shows the transmission for the instrument.

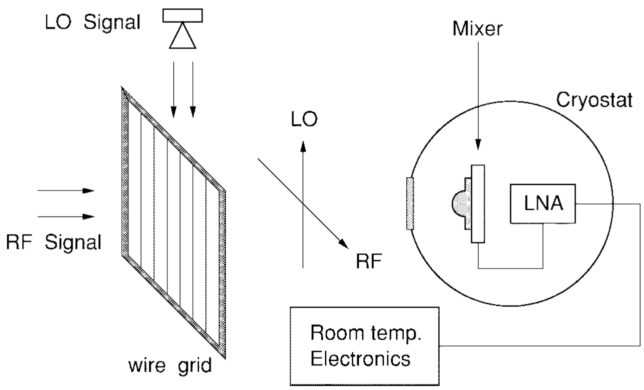

Fig. 5. Measurement setup for the balanced mixer. The LO frequency was 528 GHz and the cryostat temperature was 4.2 K.

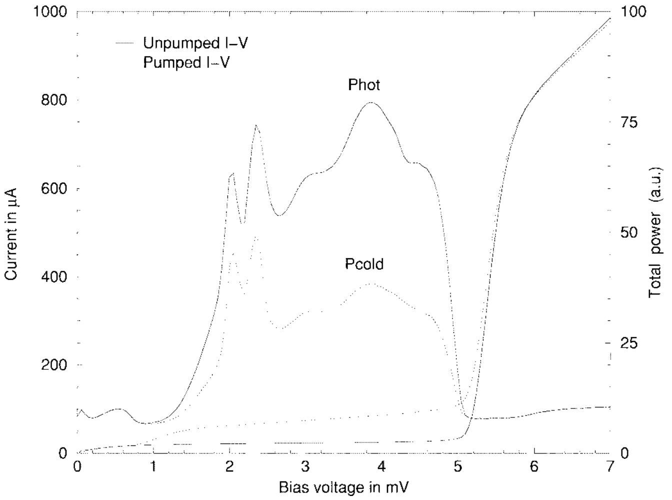

Fig. 6. Measured bias current and IF output power versus bias voltage at 4.2 K. The gap voltage is at 5.8 mV because two SIS junctions are connected in series. LO frequency for this measurement was 528 GHz and the measured DSB noise temperature was 105 K.

noise temperature of 5 K. The LNA output is sent to room temperature amplifiers and diode detectors which measure the total power in a 500-MHz IF bandwidth.

The noise temperature of the receiver was measured by the Y-factor method, using room temperature hot load and 80-K cold load. The cryostat temperature was 4.2 K for the measurements. The noise temperature reported here is referred to the input of the wire-grid; *no corrections have been made for the wire-grid or any other optical losses*. We adjusted the LO and the magnet current (which suppresses Josephson oscillations) to get a smooth IF output and then measured the noise temperature. Fig. 6 shows the pumped and unpumped I–V curves along with the IF outputs in a 500-MHz bandwidth at 528-GHz LO frequency when hot and cold loads are placed at the receiver input. At 528 GHz, the best noise temperature was measured to be 105 K. As mentioned earlier, for this device, the FTS measurement shows peak response at 528 GHz, which means that the best noise temperature should be near this frequency.

IV. CONCLUSION

We have designed, fabricated and measured a quasi-optical balanced SIS mixer at 530 GHz using a cross-slot antenna. This is the first balanced mixer at this frequency range, and has excellent noise performance (105 K DSB). The RF optics and the IF circuits were not optimized, and we think that the performance could be improved further. Wider IF bandwidth is also possible through the use of a more sophisticated 180° hybrid design, perhaps integrated on-chip.

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