The Performance of an Integrated Dual Polarization SIS Mixer at 350 GHz

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Abstract— **An integrated dual polarization (IDP) mixer at 350 GHz, which integrates a superconductor-insulator-superconductor (SIS) junction mixers with a planar orthomode transducer (OMT), has been designed and fabricated. The IDP mixer makes a receiver system with dual polarization observation capability more compact, which is significant factor for multi-pixel receiver. The orthogonal waveguide probes separate the incoming signals from a circular waveguide into two polarizations, and then the signals propagate to individual SIS mixer through the integrated transmission line which also behaves as an impedance match circuit. All circuits are implemented on a 2μm thick silicon nitride membrane which is suspended in a gap of 20 μm across the circular waveguide. The devices were fabricated by a standard Nb-based SIS junction technology and SiN/Si membrane process. We have measured the performance of fabricated IDP mixers. The double-side-band (DSB) receiver noise temperature (T_{rx}) of both polarizations, measured simultaneously in a 4K cryostat, is approximately 100K at between 332GHz and 372GHz. An Mylar beam-splitter and a linear polarization RF source are arranged as the measurement setup for the estimation about the dual polarization performance. The isolation of cross polarization is approximately 20dB.**

I. INTRODUCTION

For the application of radio astronomy in submillimeter-wave receivers, the ways to increase the observation speed and sensitivity of superconductor-insulator-superconductor (SIS) receivers are to use dual-polarized receiver and multi-pixel array [1-3]. An orthomode transducer (OMT) separates two orthogonal modes signals into its linear polarization components by a feed horn [4]. Either kinds of planar or waveguide OMTs have been proposed at millimetre and submillimeter wavelengths region [5-6]. Planar OMTs directly interfaces dual mode waveguide to mircrostrip input ports and have been integrated with transition-edge sensors (TES) in polarimeters [7-9]. The planar OMT which used in these polarization sensitive bolometric pixels consist of four probes suspended on a silicon-nitride membrane inside a waveguide. The waveguide is terminated in a backshort approximately one quarter wavelength behind the probes. Pairs of probes on opposite sides of the guide couple to a single incoming linear polarization. The signals from opposite probes are recombined by incoherently terminating power from both arms on the same TES prior to detection. To combine the signals of the same polarization from the 4-probe design, resorting to some high frequency power combining schemes is difficult. Simulations show that 2-probe and 4-probe design can have similar co-polarization coupling, but the 4-probe design has a substantially improved isolation of cross polarization. The membrane fabrication are wide

In this note, we describe the proposed planar OMT consists of two rectangular waveguide probes suspended on a 2 μm membrane within a circular waveguide [10]. Besides, the methods to measure the cross polarization performance of device is revealed. The appropriate use of the techniques lends a large-format detector array design as possible.

II. DESIGN AND FABRICATION

The IDP SIS mixers include a planar OMT, two SIS junctions, and RF chokes on a membrane chip. The planar OMT consists of two rectangular waveguide probes suspended on a 2 μm silicon nitride membrane inside a circular waveguide which is terminated in a back-short approximately one quarter wavelength behind the probes. Each probe couples radiation of orthogonal TE_{11} modes from the circular waveguide to junctions via the microstrip tuning circuit. The design of probes, RF chokes, and mixer block are optimized with the 3-D EM simulator (HFSS). The fabrication process of the membrane chip is described in [10]. For the membrane fabrication, the SIS mixers were fabricated on a 2-in silicon wafer, 200 μm-thick double-side polished, 2-in in diameter silicon wafer. The wafer front was deposited with a 2 μm-thick silicon nitride film as the membrane. An additional 0.3-μm-thick silicon oxide was deposited on the silicon nitride film as the etch stop for the etch process of junction definition on the front. The wafer back was covered with a 0.5-μm-thick silicon nitride film as a wet etching mask. Three-mask-level Nb/Al-Oxide/Nb junction fabrication with a 0.2-μm-thick niobium ground plane, 0.6-μm-thick niobium wiring layer, and a single layer of 0.25-μm-thick SiOx, which is used as the dielectric for the superconducting microstrip line [11]. For the backside process, IR was used as the light source from the bottom of the mask aligner for the membrane area definition on the backside. Before etching the silicon, reactive ion etching (RIE) was used to remove the silicon nitride of the membrane area with mixed gases of SF6 and Ar. Finally, an anisotropic wet chemical etching was carried out in KOH solution to etch away the thick silicon through the backside opening [12]. In so doing, a free-standing silicon nitride membrane containing planar OMTs and SIS mixers was created on the front side of the wafer [10]. Fig. 1 shows the picture of the device on the membrane. The circular part is the waveguide area of 655 μm in diameter.

Fig. 1 The IDP SIS mixer with a planar OMT on the membrane. The transparent part is free standing membrane without covered metal. Two rectangular probes, turning circuit, SIS junctions, and RFCs are suspended on the membrane.

III. Polarization Model

To measure the cross polarization performance of the IDP SIS mixer receiver, a Mylar beam splitter combines the LO and RF signals together, and then transmit the heterodyne signal to the mixer block. This method is different from the ALMA band 7. In ALMA band 7 receiver, two mixer block for dual polarization detection, couples the RF polarization signal from a wire grid, and then the LO signal is combined with a coupler. In our setup, only one mixer block sense the LO and dual polarization signals at the same optical path where is combined with a Mylar beam splitter. The Mylar beam splitter is polarizer material and the polarization of the two signal sources are discussed below.

A. LO Injection

To provide the similar LO pumping power to the both junctions at the polarizations, we chose the LO transmission of TM mode through the Mylar beam whose incident angle of 45 degree, and then to the mixer block. The detail calculation of oblique incidence at a dielectric interface can be found in [xx]. The polarization of the LO signal is orientated at the centre between the orthogonal probes. At frequency of 350GHz, the TM transmission of the 50 μm thick Mylar beam splitter is 0.971 at an incidence angle of 45 degree. This arrangement can support more power to the both SIS junction mixers than the setup of TE mode dominated which the transmission is only 0.792.

B. RF Input

Compared to the LO pumping power, the RF signal for the measurement of cross polarization is only differential source. We conduct the RF signal via the reflection from the Mylar beam splitter to the mixer block as the signal path and set a wire grid between the beam splitter and the source. The polarization is described in Fig. 2. The linear polarized source pass through the wire grid which make an angle, xxx, between the transmission axis of the wire grid and the source signal polarization. To handle the TE and TM reflection, the polarizations are separated into horizontal and vertical parts as E_x and E_y, respectively.

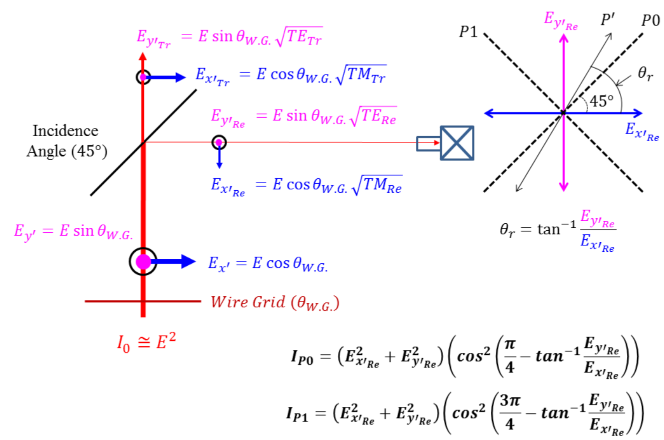

Fig. 2 The polarization model for the RF signal source passing to the mixer block via a wire grid and the reflection from the Mylar beam.

IV. Measurement Setup

The measurement system of cross-polarization is shown in Fig. 3. The LO used is a tunable Gunn oscillator which frequency is between 105GHz and 118 GHz and a triple multiplier. On the other side, another Gunn oscillator, which frequency is at between 80GHz and 95GHz and a quadruple multiplier as the RF signal source. The RF and LO signals pass through a 50-μm-thick mylar beamsplitter and the combined signals travel into the cryostat through a 50-μm-thick window at room temperature, followed by a 0.1mm-thick-Zitex IR filter at 77K. Inside the cryostat, the beam pass through a Teflon lens, and then through the corrugated horn to the mixer block which is mounted at 45-degree angle with respect to the horizontal plane. The detail design of the mixer block can refer [10].

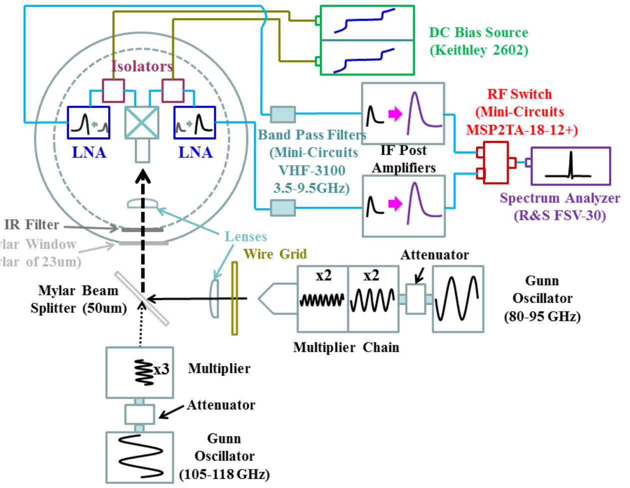

Fig. 3 The measurement setup of testing cross-polarization performance. LO and RF signals are combined at the Mylar beam splitter, and then after the SIS mixer, LNA, and, IF amplifier, the heterodyne signal can be sensed with a spectrum analyser.

V. Result

A. Junction I-V Curves

The I-V and P-V characteristics of a junction on the membrane chip are shown in Fig. 4. The normal state resistance (R_n) of the junction is 25.4 Ω with 1 to 2 Ω series resistance, J_c is approximately 7.2 kA/cm^2, and the quality factor (R_{sg}/R_n) is better than 10 where R_{sg} is the sub-gap junction resistance.

B. Receiver Noise Temperature

The receiver noise measurement setup and hot/cold load experiment can refer to [5]. Fig. 5 shows the noise performances of two IDP SIS mixer receivers. The double-side-band (DSB) receiver noise temperature was measured at approximately 120 K between 332 GHz and 360 GHz.

C. Cross Polarization

A cross polarization measurements of IDP SIS mixer has performed at a single frequency of 348 GHz. The linear polarization source is switched at 25 degree and 155 degree for co-polarization at P0 and P1 probes. The transmission axis of wire grid is rotated at between 10 degree and 40 degree for the P1 co-polarization and at between 140 degree and 170 degree for P0 co-polarization. The measurement results are presented in Fig. 6 and Fig. 7. The peak cross-polar signal of approximately -30dB relative to the input signal power is observed. The performance is dependent with a wire grid angle which cross-polarization power is minimized.

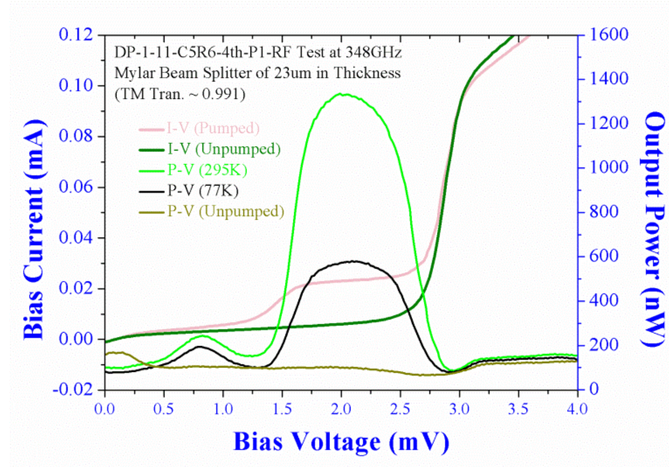

Fig. 4 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

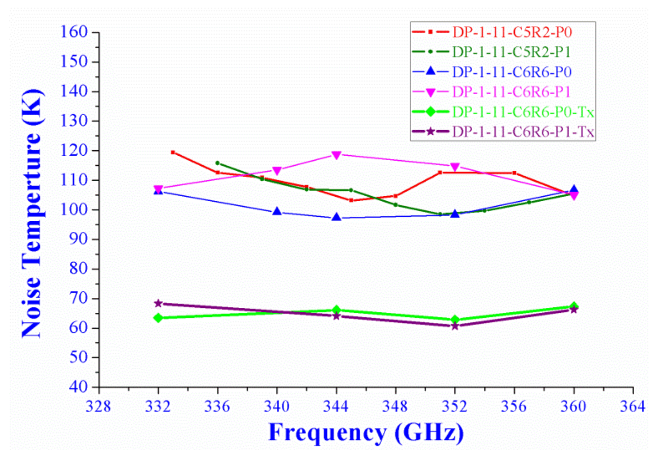

Fig. 5 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

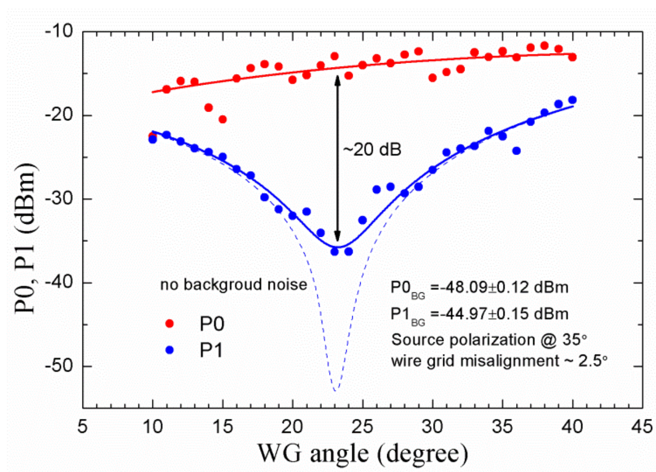

Fig. 6 A sample line graph using color which contrast well both on screen and on a black-and-white hardcopy

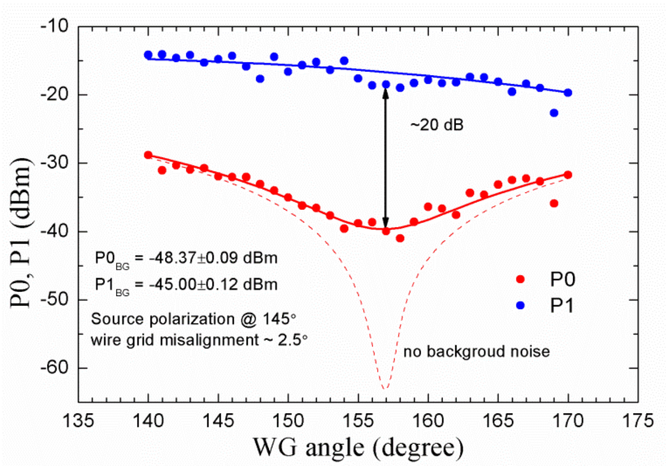

Fig. 7 A sample line graph using color which contrast well both on screen and on a black-and-white hardcopy

Fig. 2 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

VI. Conclusions

This study presents the performance of dual-polarization SIS junction mixers integrated with planar OMTs at 350 GHz band. This study also designs a method to estimate the cross-polarization performance via coupling simultaneously the LO pumping and RF signals by a Mylar beam-splitter. The isolation of cross-polarization is approximately 20 dB at frequency between 340GHz and 350GHz.

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