CALTECH SIS RECEIVERS

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ABSTRACT

This paper describes the superconductor-insulator-superconductor (SIS) receivers which are being used in the Owens Valley Radio Observatory Millimeter Interferometer These receivers operate over the frequency range from 85 to 115 GHz using a simple circular waveguide mixer block design and have achieved double sideband noise temperatures as low as 70 K. They have been in use since 1981 and have proven to be reliable and easy to operate.

INTRODUCTION

The initial tests of SIS rceivers [1] and mixers [2] indicated that they would make excellent millimeter wave heterodyne detectors for radio astronomy. The quantum mechanical theory of mixing in tunnel junctions which was developed by Tucker to describe the operation of these devices predicted that the mixer temperature should approach the quantum limit [3], which is hf/k=4.8 K at 100 GHz, and also have large available conversion gain [4]. The design approach we took was that with such great potential it should be easy to build a good receiver system using the simplest of mixer designs and a minimum of development effort. The design and performance of the resulting system is described below.

RECEIVER DESCRIPTION

The OVRO Millimeter Interferometer consists of three moveable 10.4 meter diameter antennas. The telescopes are in a Nasmith configuration with beamguide optics to transport the signal along the elevation axis to a sidecab where the receivers are mounted. The sidecab moves with the telescope in azimuth and the receivers are mounted on a 1.5 X 2.0 meter plate which is attached to the elevation axis and moves with the primary. The optics are designed to illuminate the primary surface with a gaussian beam with a -13 db taper at the edge. The included angle at the -13 db point in the receiver feed pattern is 30 degrees.

The major components of the receiver are the scalar feedhorn, circular waveguide mixer block, adjustable backshort, and GaAs IF amplifier all of which are cooled to 4.5 K in a commercial closed cycle refrigerator (Cryosystems model LTS-3C-4.5). The LO requirements for the SIS mixers is only a few nW and is provided by a varactor tuned Gunn oscillator doubled in a crossguide multiplier (Custom Microwave model MU-19-10) and coupled to the mixer via a -26 db mylar beamsplitter. The LO is phase-locked to the ~25th harmonic of an ~4 GHz reference. The reference is derived by tripling a phase stabilized 600 MHz signal provided at each dish, adding a synthesized frequency in the range from 50 to 160 MHz, and then doubling to get a clean reference in the range from 3.7 to 3.9 GHz.

A cutaway drawing of the mixer block is shown in figure 1. The circular waveguide is 2.4 mm in diameter and has a cutoff frequency of 74 GHz. The backshort has a two section noncontacting choke. The SIS tunnel junction is mounted between two posts which extend into the waveguide from opposite sides. One of the posts is grounded to the block while the other is the center conductor of a coaxial line formed from an insulated wire inserted through a close fit hole in the block. This line carries the dc bias and IF signal. A 1/4 wavelength wide slot 1/4 wavelength from the waveguide wall acts as a high impedence section in this coaxial line and serves as an RF choke. The .25 X 1.78 mm quartz chip containing the SIS junction is attached to the posts using silver paint for mechanical support and electrical contact. The propagation distance in the waveguide is kept to a minimum by having the scalar feedhorn starts less than 1/4 wavelength from the junction. This type of circular mixer block is very easy to fabricate directly from copper and a scaled version has been made and operated in the fequency range from 200 to 300 GHz [5]. The disadvantage of circular waveguide is that it is single moded (ignoring the orthogonal polarization) only over ~30% bandwidth. Although the mount symmetry should couple predominantly to the TE11 mode, there may be significant coupling to the other modes. This can be important in determining the embedding network and degrade the pattern produced by the feedhorn.

The most critical element in our SIS receivers is the SIS tunnel junction. R. Miller of ATandT Bell Labs provides us with the junctions we use. These are small area Pb alloy junctions which have good I vs. V characteristics even at 4.5 K [6]. Both PbBi and PbInAu alloy junctions have been used successfully. They are fabricated using a photolithographic bridge structure technique which allows junctions as small as 1/2 X 1/2 micron to be made. We use junctions with normal state resistances in the range from 30 to 100 ohm although the junctions can be made with a much larger range of resistances. The RC rolloff frequencies are close to 100 GHz. The I vs. V characteristic at 4.5 K of a

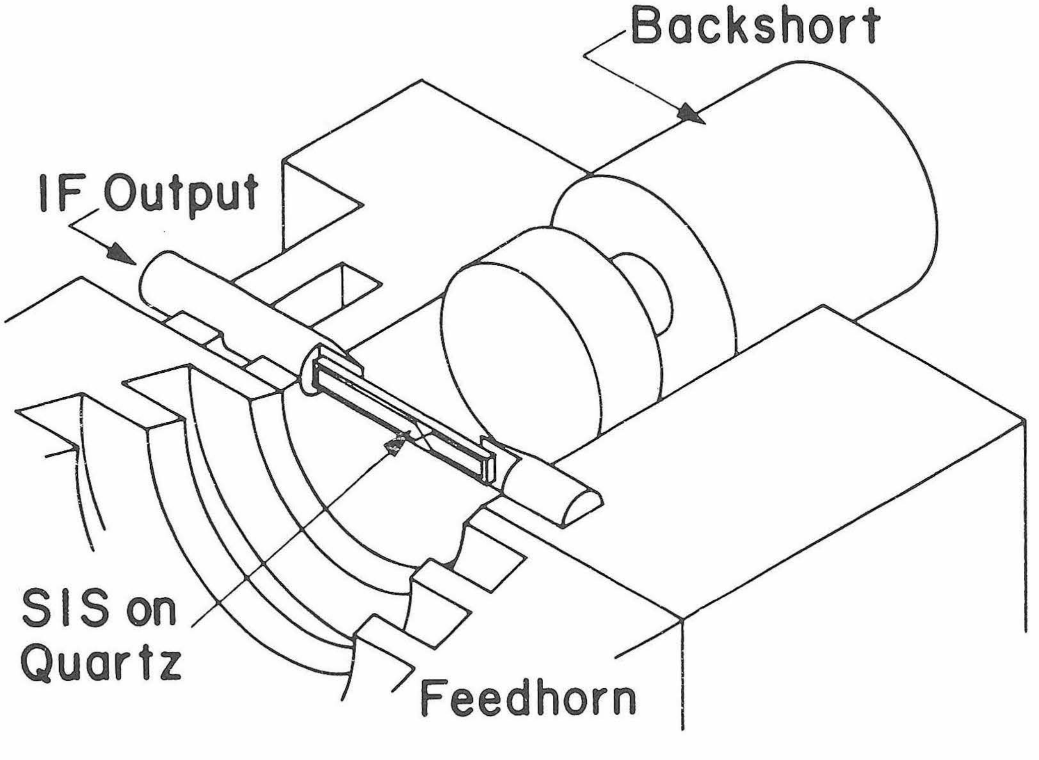

Figure 1. Cutaway drawing of 2.4 mm diameter circular waveguide mixer block.

typical junction is shown in figure 2. The I vs. V characteristic with LO power applied is also shown. One of the principle tradeoffs made in this system is operating at 4.5 K where commercial refrigerators are available instead of at lower temperatures where the Pb alloy junctions have better I vs. V characteristics. This allows us to operate continuously year round without dealing with the inconvience and cost of liquid helium at our remote site.

RECEIVER PERFORMANCE

The performance of the receivers is evaluated using hot and cold loads placed in front of the LO beamsplitter. The IF power out for hot and cold loads as a function of bias voltage is also plotted in figure 2. The vertical scale is calibrated in units of temperature referred to the input to the first IF amplifier. This calibration is obtained by using the linear dependence of the shot noise on the tunnelling current above 3 mV and gives it in terms of the equivalent temperature of a resistor whose value is equal to that of the normal state resistance of the junction. This calibration is used to deduce the IF amplifier noise temperature and to calculate the conversion efficiency and mixer noise temperature after correcting for the difference between the impedence at the operating point and the normal state resistance.

Four different receiver systems have been built for the OVRO Millimeter Interferometer with double sideband noise temperatures ranging from 70 to 200 K over the frequency range from 85 to 115 GHz for a 250 MHz IF bandwidth. Typical values are 100 to 150 K. The tuning of the receivers has proven to be simple and repeatable. Often the receivers can be tuned so that the conversion efficiency of one sideband is many times larger than the other sideband, in which case the single sideband noise temperature is often only slightly larger than the double sideband temperature. The IF amplifier noise temperatures range from 9 to 12 K while the double sideband conversion efficiencies are typically between -5 and -8 db with mixer temperatures of $<$60 K.

The 200 GHz system built by E. Sutton has a single sideband reciver noise temperature of 300 K at 230 GHz with a 500 MHz IF bandwidth. It has been operated at frequencies as high as 380 GHz but at significantly degraded performance.

The reliablity of the junctions has been excellent. They usually survive more than 10 temperature cycles and can be stored at room temperature for as long as one year. We put part of each good batch in liquid nitrogen for long term storage. There have been very few cases of failure of

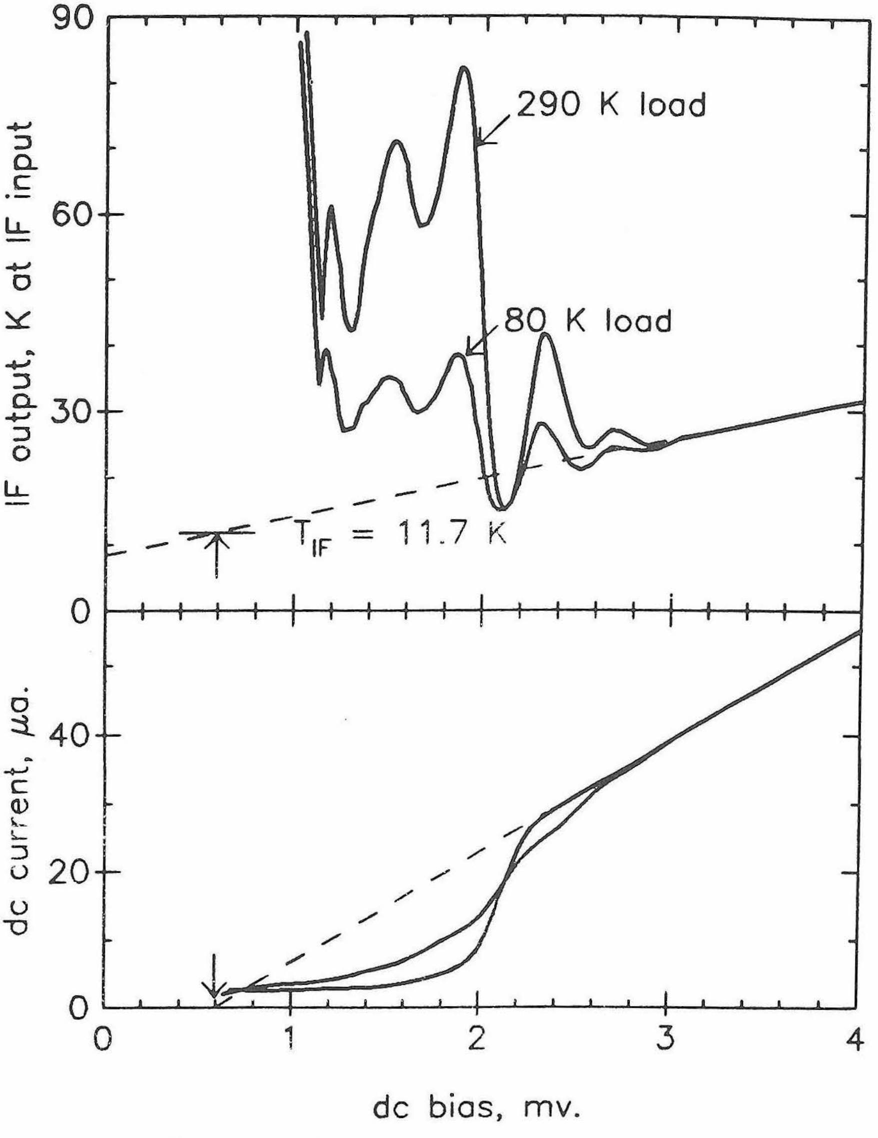

Figure 2. I vs. V characteristic for a typical SIS junction at 4.5 K with and without LO applied. The IF power as a function of the bias voltage for hot and cold loads in front of the receiver is also plotted.

junctions from handling or electrical transients, although we do lose a fair number because we can't find the little buggers. They even survive nearby lightning strikes which knockout the power lines and blowup the cumputers.

FUTURE DEVELOPMENTS

It is clear that although these receivers are quite good they can be greatly improved. We have undertaken an in depth analysis of what the optimum source and load impedence is for our SIS junctions using Tucker's theory [3],[7]. This analysis is being combined with a network analysis of scale models of various mixer blocks to arrive at a design for the next generation of 85 to 115 GHz SIS receivers for the OVRO Millimeter Interferometer. Preliminary results indicate that mixers with only backshort tuning can be fabricated which have single sideband conversion efficiencies of unity and noise temperatures less than 20 K over an instantaneous bandwidth of several GHz. A set of mixers scaled for operation above 200 GHz will also be built for use in the interferometer.

SUMMARY

In summary, a set of SIS receivers has been built and are in routine use on the OVRO Millimeter Interferometer over the frequency range from 85 to 115 GHz. Their typical double sideband noise temperature is 100 to 150 K measured over a 250 MHz IF bandwidth. This first generation of mixers is fairly primative and an improved second generation is expected to yeild substantially better performance.

ACKNOWLEDGEMENTS

The successfull operation of the SIS receivers used in the millimeter interferometer has required the efforts of many people. I would particularly like to acknowledge the work of R. E. Miller of ATandT Bell Labs in providing the SIS tunnel junctions, M. J. Wengler for his theoretical calculations and performance measurements, and C. L. Spencer for his effort in constructing and maintaining the receivers and their cryogenic systems.

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