SIMPLE FTS MEASUREMENT SYSTEM FOR SUBMILLIMETER SIS MIXER

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Abstract

We have constructed a simple Fourier Transform Spectroscopy system, and carried out performance measurement of our 640-GHz band SIS mixer devices. This system uses the identical quasi-optics to the one for heterodyne measurement, which allows a direct and quick comparison between FTS and heterodyne responses. With a room-temperature absorber for submillimeter source, instead of a high-temperature source such as Hg lamp, we successfully obtained interferogram with good signal-to-noise ratios. The frequency resolution is moderately coarse ($\Delta n \approx 17$ GHz) due to a limitation on the travel length of scanning mirror for the interferometer, but we found it is useful to investigate broad-band characteristics of SIS mixers.

Keywords: Fourier Transform Spectroscopy, SIS mixer, submillimeter

1. Introduction

It is desired to use Superconductor-Insulator-Superconductor (SIS) mixers for highly sensitive submillimeter observations, both for astronomical and atmospheric research purposes. The submillimeter performance of SIS mixers strongly depends on the characteristics of an RF tuning circuit that is integrated in the mixer device.

The design of a superconducting RF tuning circuit needs sufficient knowledge of values for critical parameters including junction capacitance and propagation constant of striplines. Unfortunately, those values usually have a high degree of uncertainty, especially at submillimeter wavelengths, because of limited accuracy in 1-μm-order junction patterning by available technology, and insufficient information on material parameters at high frequencies, etc. Thus, the characteristics of the RF tuning circuit will be often found only after tedious mixer measurements. Direct and quick measurement of the frequency response is important to investigate circuit characteristics of the mixer. Required frequency range for such measurements is usually broader than it is easily available with usual CW submillimeter sources.

Fourier Transform Spectroscopy (FTS) is a widely-used spectroscopic method, in which the spectrum is calculated by Fourier transformation with a profile of interferogram obtained with a two-beam interferometer. Since the FTS is a powerful tool for studying detector responses over a very broad bandwidth, several authors have developed FTS systems of high performance (high resolution, large throughput, etc.) for submillimeter analysis[1,2]. These systems, however, often require special components for FTS, such as a large mirror, long scanning length of interferometer, and high temperature submillimeter source. Sometimes this is too much sophisticated for the analysis of mixer response. An easy-to-use FTS measurement will be desirable even if its performance is moderate.

In this work, we designed and constructed a simple FTS system to study the performance of 640 GHz SIS mixers. We describe its system and some experimental results obtained with that.

2. SIS Mixer Device

The SIS mixer devices for our experiments were fabricated at the Nobeyama Radio Observatory (NRO), Japan. Fig. 1 shows a schematic view of the device that is designed for 620-660 GHz. We adopted the Nb/Al-AlOx/Nb technology with parallel-connected twin junctions (PCTJ)[3], which enable to achieve a broad RF impedance matching without mechanical tuning. Typical junction area is about 1.2×1.2 μm^2, current density is 7.5 kA/cm^2, and normal resistance is 20 Ω. The mixer circuits are constructed on a 65-μm-thick quartz substrate. Two identical junctions are connected by a superconducting microstrip with three choices of length, $L = 7.5$, 9.5, or 11.5 μm, to investigate the most suitable tuning length for 640 GHz application.

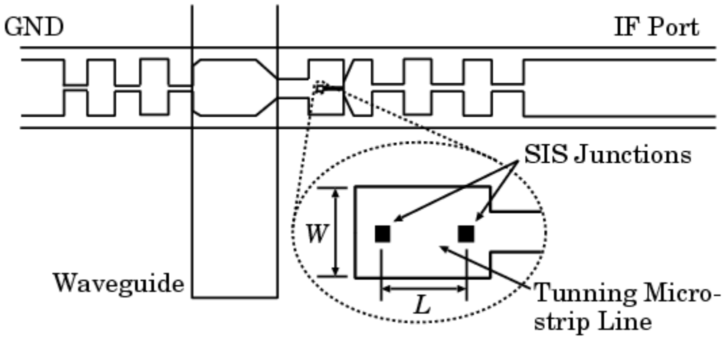

Fig. 1. Structure of SIS mixer device. The length of tuning microstrip is $L = 7.5$, 9.5, or 11.5 μm, with a width $W = 7$ μm.

3. System Description

We carried out both heterodyne and FTS measurements with almost identical quasi-optical system. In the following we shall discuss the details of our system.

3.1. Heterodyne Measurement

Schematic view of the heterodyne measurement system is shown in Fig. 2(a). Its more detail description is found in [4].

Noise performance is measured by the Y-factor method in a conventional setup with room-temperature (hot) and liquid-nitrogen-cooled (cold) absorbers. The submillimeter emission from each of the absorbers will couple to the SIS mixer after several reflections at 45°-off-axis flat and ellipsoidal mirrors. Each mirror covers the beam down to –40 dB. We adopted a Martin-Puplett type interferometer (MPI)[5], consisting fixed and movable rooftop mirrors and a 45° (projected angle) wire grid. The MPI acts as a single-sideband (SSB) filter in the heterodyne measurement. The local oscillator (LO) power, generated by a Gunn-diode and two cascaded multipliers, is injected into the SIS mixer via a dielectric beam-splitter. The cryostat receives the submillimeter signal from hot or cold load and LO power through a vacuum window, made of 500-μm-thick polytetrafluoroethylene (PTFE), and an infrared filter, Zitex G-108[6]. The SIS mixer is installed on 4-K stage of a Gifford-McMahon refrigerator. The IF signal (≈12 GHz) is intensified by cooled and ambient temperature amplifiers, then finally detected by a power meter and spectrum analyzer.

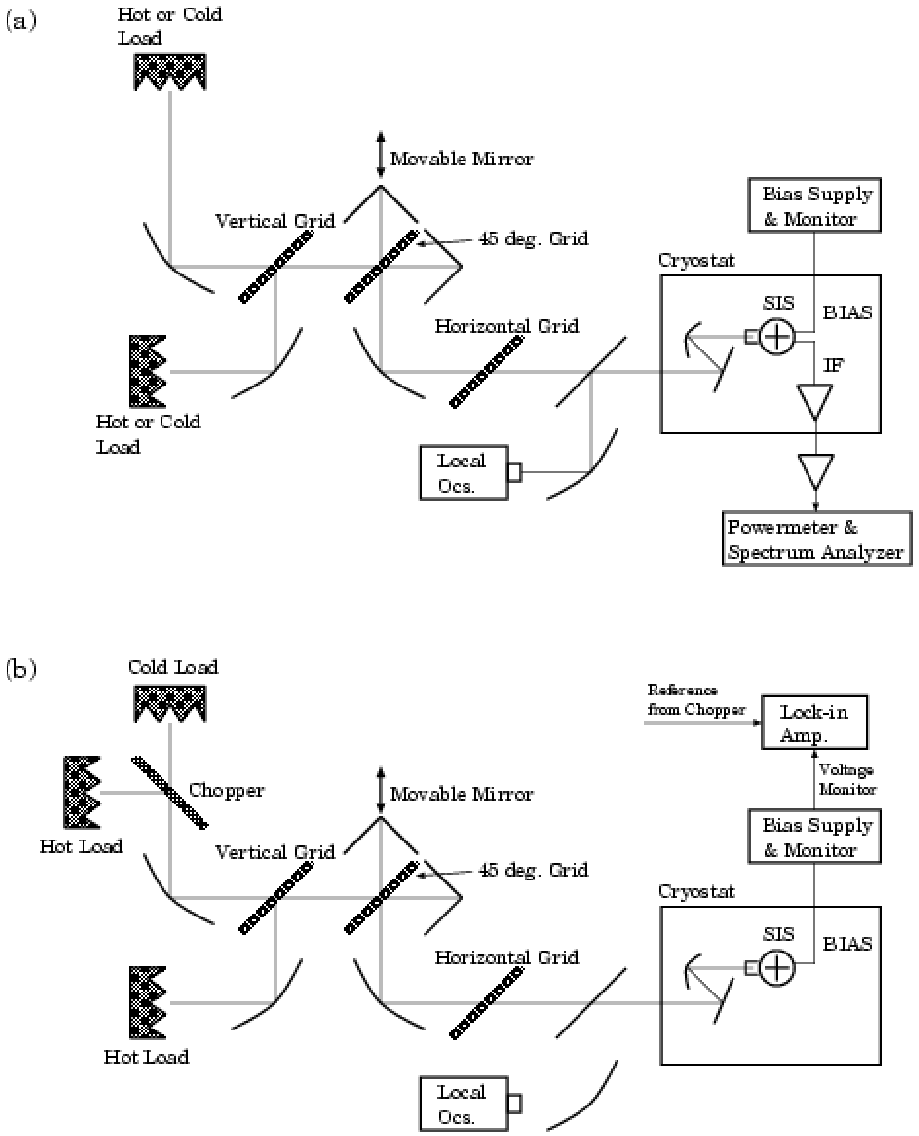

Fig. 2. Schematic view of the heterodyne (a) and FTS measurement system (b).

3.2. FTS Measurement

For the FTS measurement, almost identical quasi-optics to that of the heterodyne system is used (Fig. 2(b)) except for the following points:

1. An optical chopper blade enables alternate coupling to hot and cold load at a frequency around 100 Hz.
2. No LO power is generated.

This allows a direct comparison between heterodyne and FTS results without ambiguity due to different optics. We successfully obtained an interferogram with a good signal-to-noise ratio (Fig. 3) despite the fact that we used a room-temperature absorber for the hot load. This means no need to use any special submillimeter sources such as Hg lamp.

The MPI acts as a frequency moderator. A linear micro-stepping motor drives the movable rooftop mirror continuously during a scan. We set the step distance at 50 µm, corresponding to 100 µm in optical path difference, which gives the highest measurable frequency of 1500 GHz. Since the maximum travel length of the movable mirror is limited to $\Delta l \approx 9\,\mu$m, the frequency resolution is $\Delta n = c/2\Delta l \approx 17$ GHz. A typical SIS mixer of ours has a sensitivity bandwidth of ≈ 100 GHz, so this resolution is good enough to investigate mixer circuit performances. As shown in Fig. 3, the system takes a one-sided profile of interferogram. The one-sided measurement has some advantages in comparison with the two-sided; higher frequency resolution is attained for a given travel length of scanning mirror; scan and computation times could be reduced.

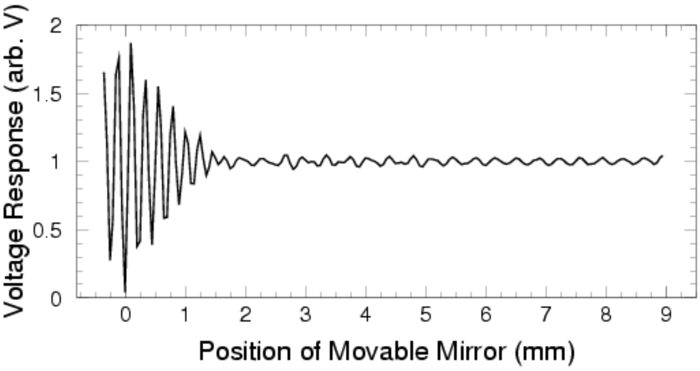

Fig. 3. Example of measured interferogram

Phase error is corrected by recording a short portion of the interferogram on the other side of the phase center (i.e. minus position of movable mirror in Fig. 3)[7].

A constant bias current is applied to the SIS device, and chopper-modulated voltage through the device is monitored. It is amplified and demodulated in a lock-in amplifier with a reference signal synchronized to the chopping. The integration time constant of the lock-in amplifier is set to 1 second to obtain a desirable signal-to-noise ratio. The interferogram is then recorded in synchronization to stepwise moving of the rooftop mirror of the MPI. The data acquisition time depends on a time constant of the lock-in amplifier and stepping frequency of the movable mirror. It took about 20 minutes to obtain a profile of interferogram such as represented in Fig. 3, whose number of data points is 187.

4. Measurement Results

4.1. Performance Verification with CW Signal

To verify the performance of our FTS system, we measured the frequency response for a monochromatic (CW) signal. For this measurement we replaced the cold (liquid-nitrogen temperature) load with a CW source that was the LO source for heterodyne measurements. Though the CW introduction slightly changes the quasi-optics in Fig. 2(b), it will not affect the submillimeter performance of the FTS. Now the optical chopper switches two incident beams of hot (room temperature) load and CW signal, while the interferogram is recorded in the same way as described in section 3. Since we simply uses a rectangular window function for Fourier transformation, the monochromatic signal should be convoluted by a sinc function. Fig. 4 shows a measured FTS spectrum with CW frequencies $f_{\mathrm{CW}} = 618$ and 654 GHz. The spectrum is fitted by a sinc function quite well, indicating the system is correctly working.

4.2. Frequency Response of SIS Mixers with Different Tuners

We have made FTS measurements of SIS mixers with different tuning lengths, $L = 7.5$, 9.5, and 11.5 μm. Fig. 5 represents the obtained Fourier transform spectra, superimposed on DSB noise temperatures measured with the heterodyne system. As we can see, the frequency

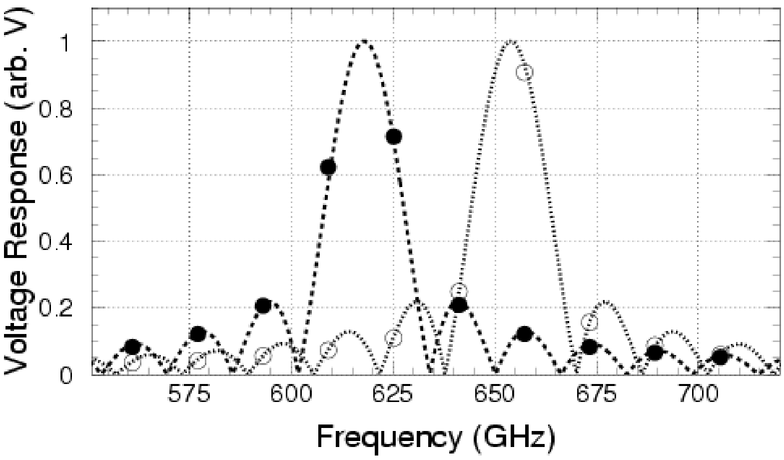

Fig. 4. Measured FTS spectrum with CW signals of $f_{CW} = 618$ GHz (filled circles) and 654 GHz (open circles). Dashed and dotted lines are fitting results with a sinc function $y = \left| A\sin[2p\Delta l(f_{CW} - x)/c] \ / \ [2p\Delta l(f_{CW} - x)/c] \right|$, where A is a fitting parameter.

dependence of the direct detection and that of the heterodyne response correlates very well. It is also clearly seen that the center frequency, which is defined by the maximum RF response, shifts lower as the tuning length becomes longer. By simple assumption, the resonance frequency of the tuning circuit is expected to be proportional to $1/\sqrt{L}$. Although the center frequency is not only determined by the resonance of course, we successfully controlled it by changing tuning length almost as expected.

This work has been conducted as part of developmental activities for an atmospheric observation mission, Superconducting Submillimeter-wave Limb-emission Sounder (SMILES), which is under joint auspices of NASDA and CRL in Japan[8]. Authors acknowledge Dr. H. Ozeki for his useful comments and discussions. K. K. acknowledges the support from the Japan Science and Technology Corporation (JST).

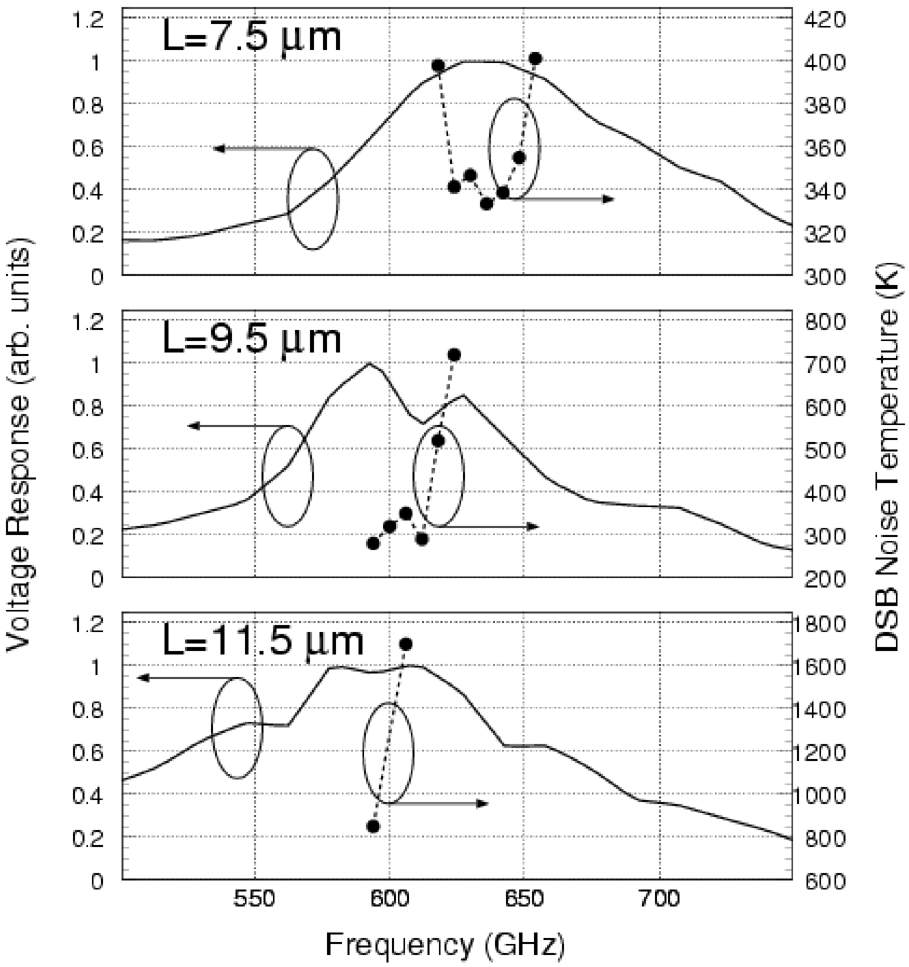

Fig. 5. Comparison of FTS data (solid line) and receiver noise temperatures (dashed) for three mixers with different tuning lengths, $L = 7.5$ (upper panel), 9.5 (middle) and 11.5 μm (lower).

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