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Preliminary Tests of Waveguide Type Sideband-Separating SIS Mixer for Astronomical Observation

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Abstract

We have developed an integrated sideband-separating SIS mixer at 100 GHz based on waveguide split block with 4.0–8.0 GHz IF. The measured receiver noise temperatures with 4.0–8.0 GHz IF are less than 60 K in the LO frequency range of 90–110 GHz, and minimum value of around 45 K is achieved at 100 GHz. The image rejection ratios are more than 10 dB in the LO frequency range of 90–110 GHz in the laboratory measurements. We have installed the sideband-separating SIS mixer into the cartridge-type receiver cryostat for Japanese prototype antenna and successfully observed a spectrum of ^{12}CO($J = 1 - 0$) from Orion KL and confirmed the image rejection ratio as large as 13 dB in the astronomical measurements. This result is the first astronomical observation with a waveguide type Sideband-Separating SIS mixer.

Keyword: Sideband-Separating mixer, SIS mixer, ^{12}CO($J = 1 - 0$) spectrum

1 INTRODUCTION

We developed an integrated sideband-separating SIS mixer (2SB mixer) at 100 GHz based on the waveguide split block. We installed the 2SB mixer into an atmospheric ozone measuring system at Osaka Prefecture University and successfully observed an ozone spectrum at 110 GHz at the lower sideband with an IF frequency of 1.5 GHz [1]. We have upgraded the mixer for the IF frequency to 4.0-8.0 GHz for ALMA receivers.

Recently we installed the sideband-separating SIS mixer into the Cartridge-type receiver system on the Japanese prototype antenna, which is a 12 m submillimeter telescope built as a prototype ALMA antenna. The prototype antenna was assembled at ALMA Test Facility (ATF) site and is currently being tested. The antenna is designed to meet ALMA specification requirements, high surface and pointing accuracy, and fast position switching capability. The 2SB mixer developed by our group will be used for radiometric observations to evaluate the prototype antenna. In particular, the character of 2SB mixer, separating upper-sideband from lower-sideband, enables us to measure the beam size and other radiometric performance without frequency ambiguity. In this report we present brief design, performance, and test observation results using our 2SB mixer on the Japanese prototype antenna.

2 Mixer performance

2.1 mixer description

The detailed structure of a split-block waveguide unit is shown in Figure 1. The detail of this waveguide unit is written in MEMO 453[1]. The DSB mixer adopted here was developed at Nobeyama Radio Observatory [2]. The measured DSB receiver noise temperature of the SIS mixer with 4.0–8.0 GHz IF is less than 25 K in the LO frequency range of 95–120 GHz, and a minimum value of around 19 K is achieved. To integrate this SIS mixer into the split-block waveguide unit, we changed the mixer chip layout from the E-plane-perpendicular substrate orientation to the E-plane-parallel substrate orientation. A photograph of the DSB mixer part and a magnified view of the mixer chip are shown in Figure 2. The SIS device is a parallel-connected twin-junction [3]. These SIS junctions are connected in parallel through the stripline inductor. A quarter-wavelength impedance transformer made of superconducting stripline was integrated with the SIS junctions on the mixer chip. To reduce the feed point impedance, a mirror symmetrical circuit pattern about the bisection plane in the center of the waveguide was introduced. One end of the RF choke filter is connected directly to a 50 Ω IF line by a 25μm-diameter Al wire to extract the IF output and to supply DC bias. The slot of the other port of the channel is filled with indium and electrically grounded. The signal and the LO are fed to the feed point through a linearly tapered waveguide impedance transformer (full height to 1/5 reduced height). The IF signals from the two DSB mixers are combined in a commercial quadrature hybrid (Anaren Microwave, Inc.).

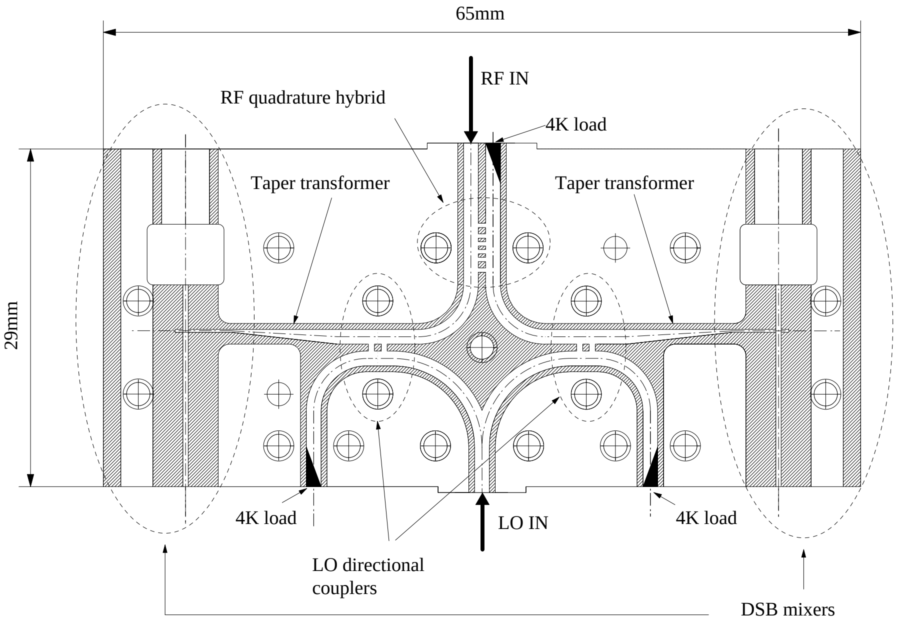

Figure 1: Configuration of the split-block waveguide unit. The split-block waveguide contains two DSB mixers, an RF quadrature hybrid, two LO directional couplers, an LO power divider, and 4 K cold image terminations.

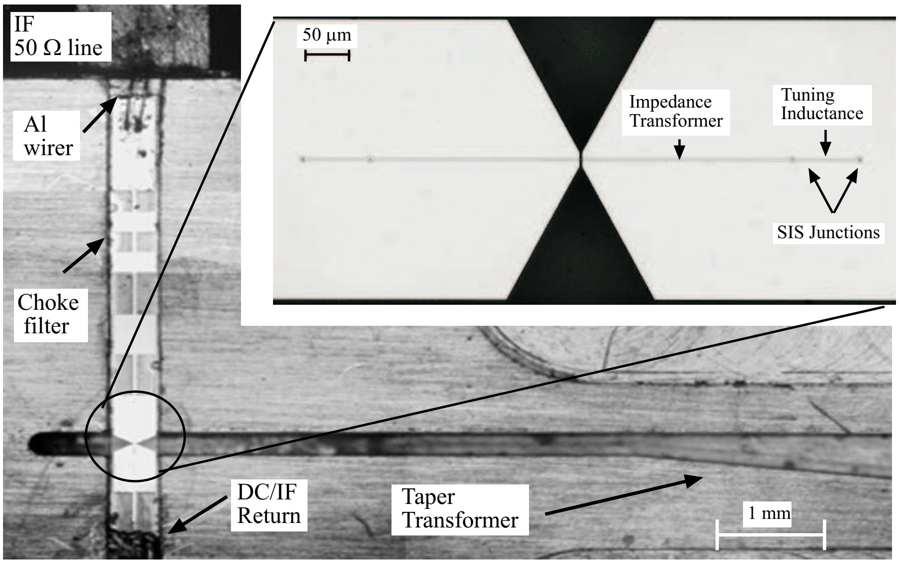

Figure 2: A photograph of the DSB mixer part and a magnified view of the SIS junction chip.

2.2 I-V curve, IF output, and Receiver noise temperature

The noise temperature of the sideband-separating mixer with 4–8 GHz IF was measured by a standard Y-factor method. The mixer was mounted on the 4K cold stage in a SIS receiver evaluation cryostat. A Teflon film with a thickness 1.0 mm was used as a vacuum window. The IF output from the mixer was first amplified by a cooled High Electron Mobility Transistor (HEMT) amplifier, and then further amplified at room temperature. The equivalent noise temperature and gain of the HEMT amplifier associated with the isolator were about 15 K and 30 dB, respectively. Typical DC I-V curves as a function of bias voltage are shown in Figure 3. Two DSB mixers are connected in parallel and the DC biases for the DSB mixers are supplied by one power supply. The IF output powers (LSB and USB port) with the 4.0–8.0 GHz system are presented in Figure 4. The overall receiver noise temperatures of the receiver (including the noise contribution of the vacuum window, feed horn, and IF amplifier chain), measured on the first photon step below the gap voltage, are plotted in Figure 5. The measured receiver noise temperatures are less than 60 K in the LO frequency range of 90–110 GHz, and a minimum value of around 45 K is achieved at 100 GHz.

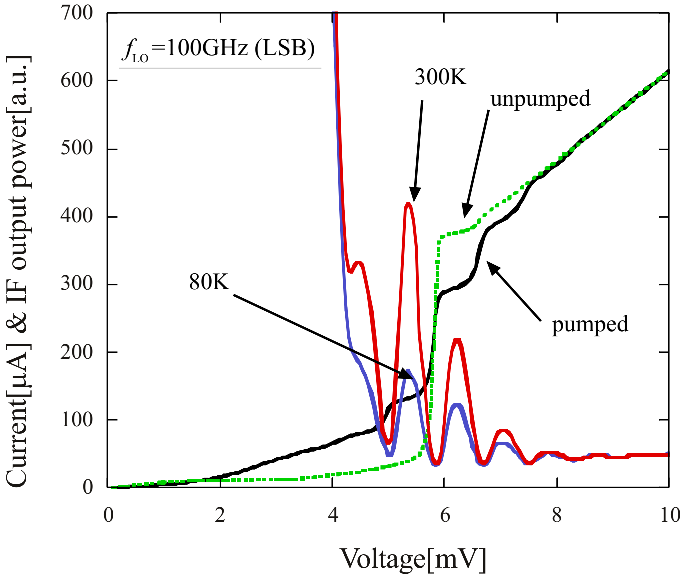

Figure 3: Typical I-V curves and IF-output-power curves (LSB) correspond to 100GHz LO pumping. The voltage was applied to two DSB mixers by one power supply. Two IF-output-power curves correspond to hot (300 K) and cold (80 K) input, respectively.

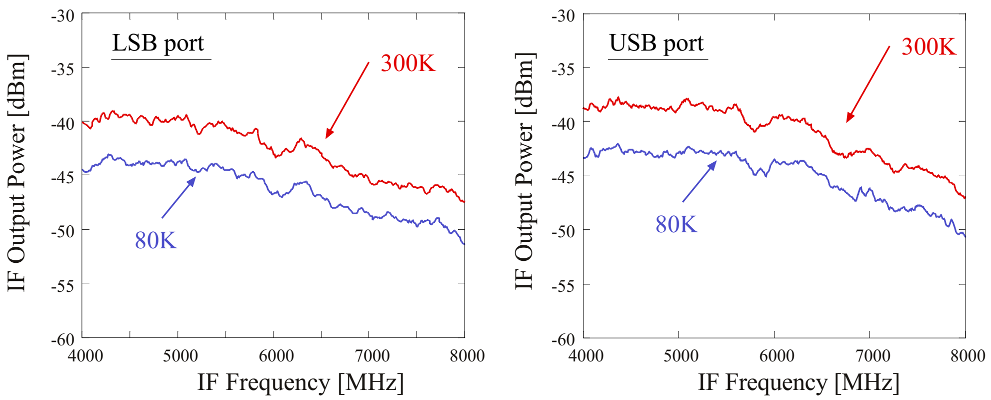

Figure 4: IF response from 4.0 to 8.0 GHz with LO frequency of 100 GHz. Two IF-output-power correspond to hot (300 K) and cold (80 K) input, respectively.

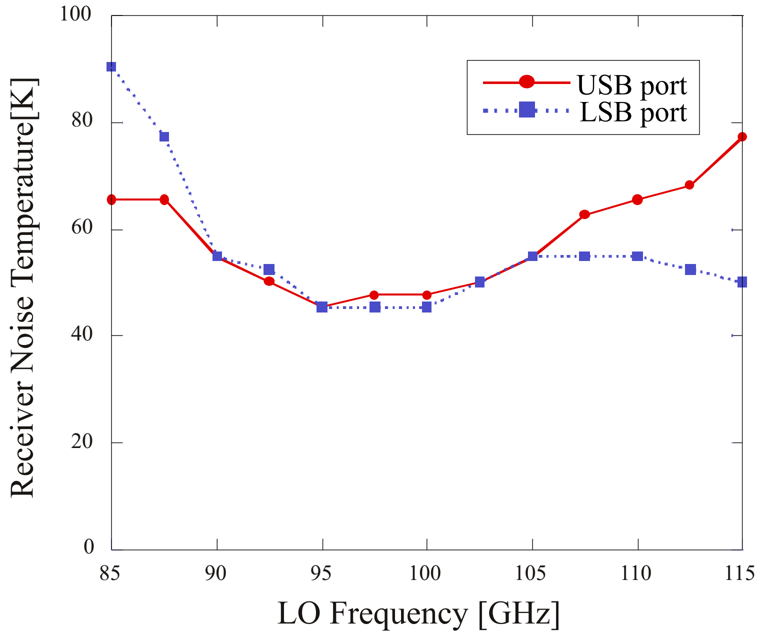

Figure 5: Receiver noise temperature as a function of frequency.

2.3 Image rejection Ratio

In principle, the image rejection ratio of a receiver can be measured by injecting CW signals of known relative amplitudes into the upper and lower sidebands and measuring each IF response. At millimeter wavelengths, however, it is difficult to determine with sufficient accuracy the relative amplitudes of two RF signals separated in frequency by twice the IF frequency. In case of a sideband-separating mixer, the image rejection ratio can be measured accurately injecting CW test signals in the upper and lower sidebands, even when the relative power level of the test signals are not known [4]. In a ideal sideband-separating mixer, CW signals into the upper sideband and lower sideband appears separately at the two output ports. Since the image rejection ratio of an actual mixer is not perfect, a CW signal into one sideband appears at both IF output ports. In this case, the image rejection ratio can be determined by measuring the difference in the peak value referred to the noise revel at the corresponding output.

The block diagram of the image rejection ratio measurement is shown in Figure. 6. Considering stability and repeatability, we adopted a cross guide coupler (CGC) for CW signal injection. The coupling efficiency of the CGC is -25 dB. The corresponding IF signals at both ports with a CW signal are shown in Figure 7. The measured image rejection ratios are plotted in Figure 8. The image rejection ratios are more than 10 dB in the LO frequency range of 85–110 GHz.

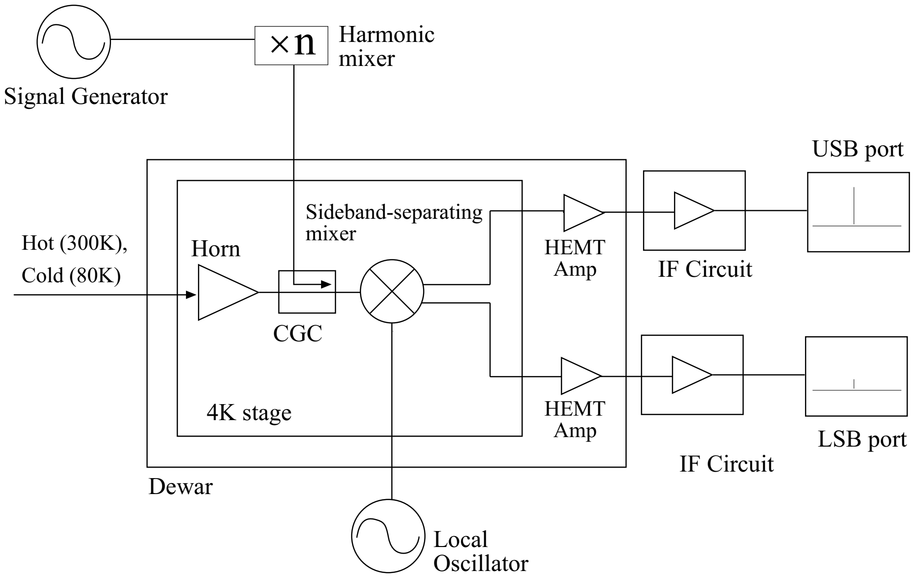

Figure 6: Block diagram of the image rejection ratio measurement set-up.

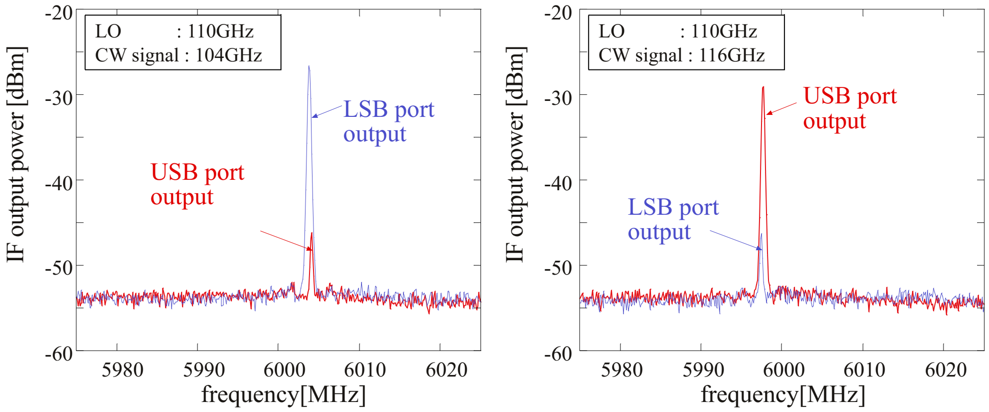

Figure 7: (a) IF signal outputs at USB and LSB port with a CW signal injected into the lower sideband. (b) IF signal outputs at both ports with a CW signal injected into the upper sideband.

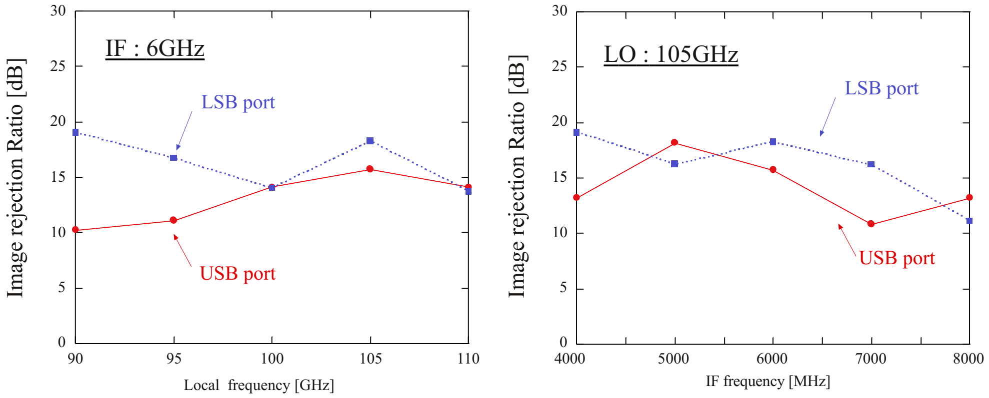

Figure 8: (a)Image rejection ratio at IF=6 GHz as a function of Local frequency. (b) Image rejection ratio at LO=105 GHz as a function of IF frequency.

3 Cartridge-type receiver for Japanese prototype antenna

The cartridge-type receiver cryostat for the Japanese prototype antenna is almost same as the cryostat tested on the Atacama Submillimeter Telescope Experiment (ASTE). The cryostat on ASTE was preliminary evaluated at Pampa la Bola (alt. 4800 m) in the northern Chile since November 2002[5]. The detail of the cryostat was described by Yokogawa et al.[6]. We developed Band 3 (100 GHz) and Band 6 (200 GHz) cartridge-type receivers for the Japanese prototype antenna. The picture of the cryostat, in which 2 cartridge-type receivers were installed, is shown in Figure 9 (a). The cylindrical cryostat can accommodate two cartridges of 170 mm diameter and one cartridge of 140 mm diameter. It takes about 12 hours from the room temperature to 4K. The lowest temperatures were 4.1 K on the 4 K stage of the cartridge, 14.5 K on the 12 K stage, and 46.1 K on the 80 K stage. The detail structure of cryogenic system and the performance of Band 6 receiver will be reported in the following papers.

The ϕ140 mm cartridge for Band 3 has been designed and developed by Osaka Prefecture University/Nagoya University[7]. The closeup of 4 K stage of the band 3 cartridge is shown in Figure 9 (b). We confirmed that cartridge-type receiver performances (noise temperature, image rejection ratio) were almost same as that measured with the SIS receiver evaluation cryostat.

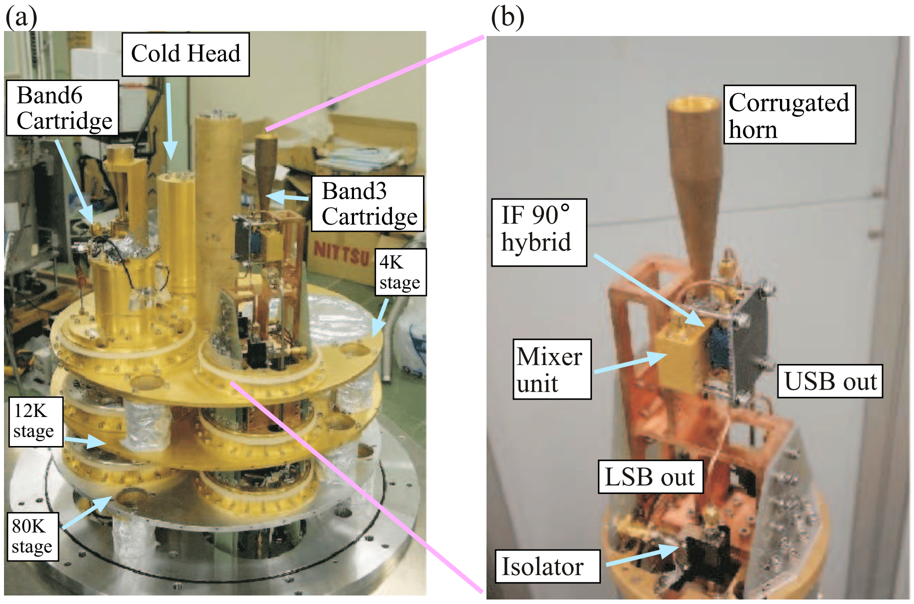

Figure 9: (a)A photograph of the cryogenic system, in which 2 cartridge-type receivers were installed. The cryostat is composed of 3 stages (from up to down 4 K, 12 K, and 80 K stage). (b)The closeup of 4 K stage of the band 3 cartridge.

4 First lights with sideband separating mixer

In September 2003, two cartridge-type receivers of band 3 and 6 were installed onto the Japanese prototype antenna. The cooling time of the system mounted on the telescope is almost same as that measured at the laboratory. The Japanese prototype antenna is equipped with RF Power Meter (Agilent E4419B dual channel powermeter with E9300A power sensors) and Agilent 8562EC Spectrum Analyzers in the receiver cabin. The beginning of October 2003, we detected continuum signals from the moon and planets (Mars and Saturn) at 98 GHz (LSB observation) with the Band 3 receiver.

On 18 October 2003, we successfully obtained a spectrum of ^{12}CO($J = 1-0$) (rest frequency = 115.27 GHz, USB observation) from Orion KL by using a spectrum analyzer as the spectrometer (Figure 10). USB and LSB spectra were not observed at the same time, and the interval of those observations was less than ten minutes. In this observations, Doppler corrections were not applied. The Doppler frequency shift is less than 40kHz in ten minutes. This frequency shift is almost negligible because the resolution bandwidth of this observations was 300 kHz.

We can estimate that the image rejection ration of LSB port is more than 13 dB because the rms noise level of those observations is 0.4 μW. This image rejection ratio is consistent with the measurement value in laboratory. Those results are the first astronomical observation with the waveguide type Sideband-Separating SIS mixer. We have confirmed that a sideband-separating mixer is very promising for ALMA.

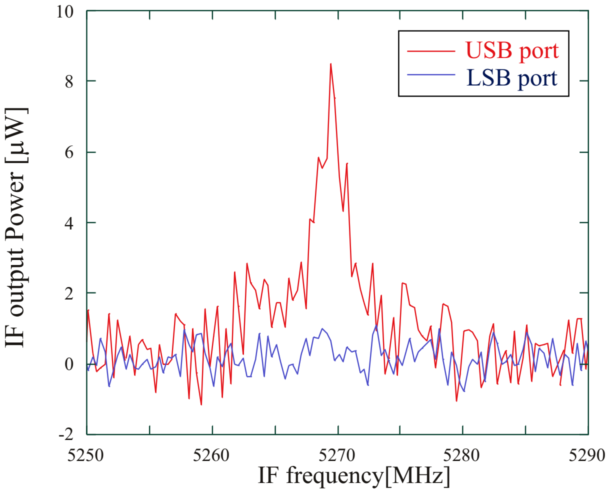

Figure 10: Spectrum of ^{12}CO($J = 1 - 0$) from Orion KL by using a spectrum analyzer as the spectrometer. The Local frequency was 110 GHz (USB observation). The resolution and video bandwidth are 300 kHz and 3 kHz, respectively. Average counts is 90 times.

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