Sideband-Separating SIS Mixer at 100GHz Band for Astronomical Observation

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ABSTRACT

We have developed an integrated sideband-separating SIS mixer at 100GHz based on waveguide split block with 4-8GHz IF. The measured receiver noise temperatures with 4-8GHz IF are less than 60K in the LO frequency range of 90-110GHz, and minimum value of around 45K is achieved at 100GHz. The image rejection ratios are more than 10dB in the LO frequency range of 90-110GHz in the laboratory measurements. The sideband-separating SIS mixer was installed into the cartridge-type receiver system on the Japanese prototype antenna, which is a 12m submillimeter telescope built as a prototype ALMA antenna. This antenna is located on the ALMA Test Facility (ATF) site. We detected continuum signals from the moon and planets (Mars and Saturn) at 98GHz (LSB observation), and successfully obtained a spectrum of ^{12}CO (J =1-0) (rest frequency = 115.27GHz, USB observation) from Orion KL by using a spectrum analyzer as the spectrometer. We confirmed that the image rejection ratio is as large as 13dB in the spectrum of ^{12}CO (J =1-0). This image rejection ratio is consistent with the measurement value in laboratory. These results show that a sideband-separating mixer is very promising for ALMA project.

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

INTRODUCTION

There is a strong interest in the millimeter astronomical and atmospheric community to operate low noise quasi-particle mixers in SSB mode in order to eliminate atmospheric noise in the image band during spectral line observations. To meet these demands we have been developing a sideband-separating mixer. In the microwave range, sideband-separating mixers have been available commercially for many decades. The usual implementation is to divide the signal and LO power into two mixers using a quadrature hybrid in either the signal or LO path. Here, the former option as shown in Fig. 1 is used in our SSB mixer. The IF outputs from the two mixers are combined in an IF quadrature hybrid and in principle, all the downconverted power from the upper and lower sidebands appears separately at the two output ports of the IF hybrid. Following this manner We developed an integrated sideband-separating SIS mixer (2SB mixer) at 100 GHz based on the waveguide split block. We installed the sideband-separating SIS mixer into the Cartridgetype 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.

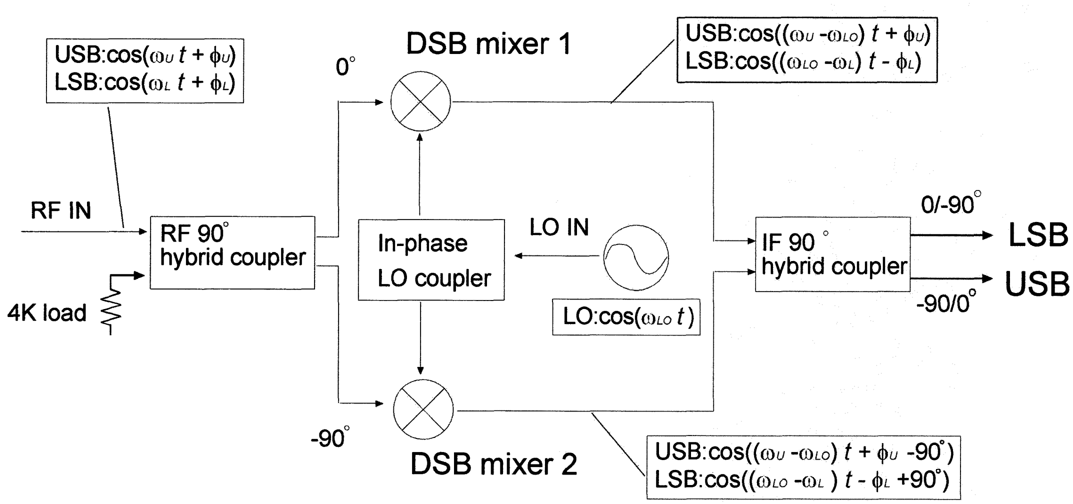

Fig. 1: Block diagram of the sideband-separating mixer

2. MIXER DESCRIPTION

Detailed structure of a split-block waveguide unit for our sideband-separating mixer is shown in Fig. 2. We adopted W-Band waveguide (2.54 x 1.27 mm) for our waveguide unit. The basic design of the sideband-separating SIS mixer is similar to that described by *Claude et al.* [1]. The split-block waveguide unit contains an RF quadrature hybrid, two LO directional couplers, a LO power divider, and 4 K cold image terminations. We also integrated two DSB mixers on the split-block waveguide unit through the waveguide taper transformer. The detail of this waveguide unit is written in MEMO 453 [2]. The DSB mixer adopted here was developed at Nobeyama Radio Observatory [3]. 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 19K is achieved. 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.).

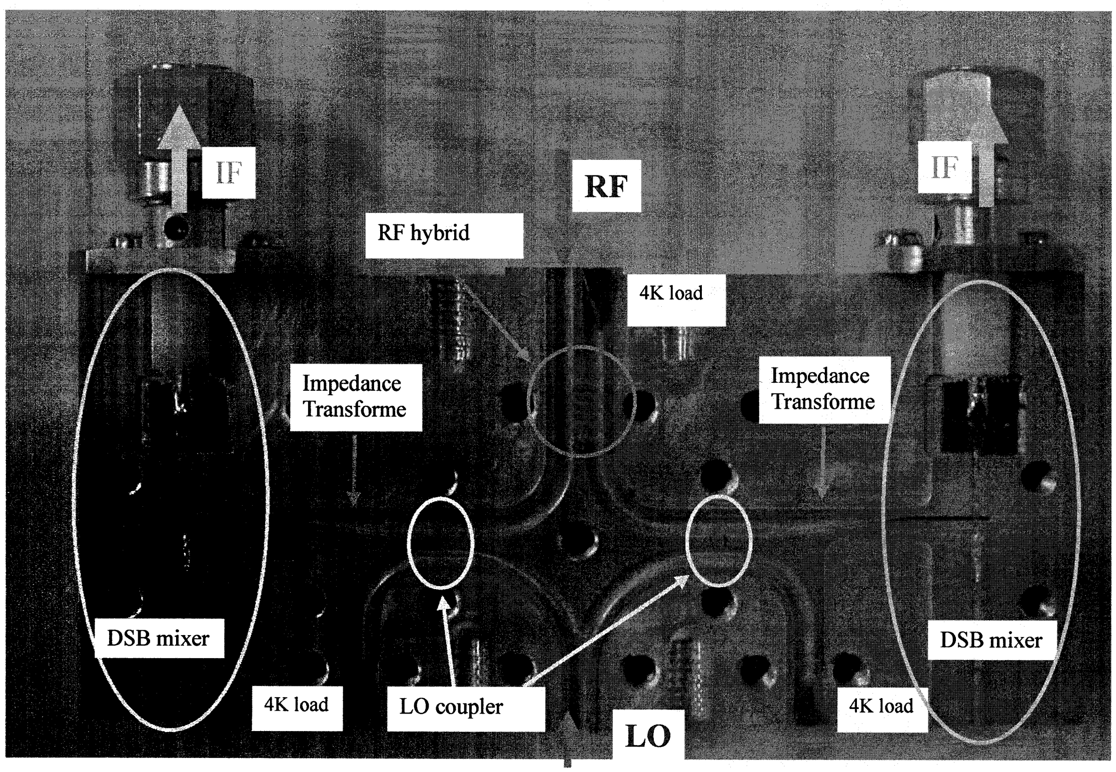

Fig. 2: A photograph of the split-block waveguide unit

3. MIXER PERFORMANCE

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. 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 Fig. 3. 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.

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]. 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 measured image rejection ratios are plotted in Fig. 4. The image rejection ratios are more than 10 dB in the LO frequency range of 85–110 GHz.

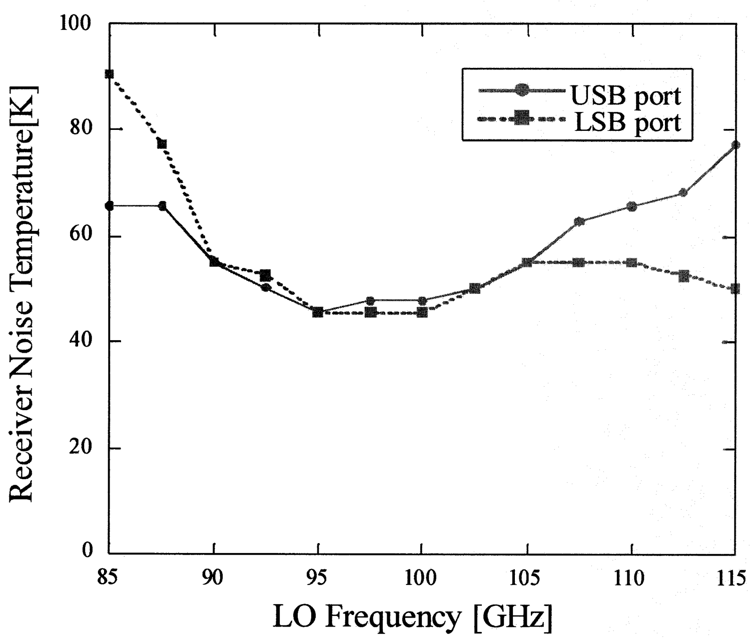

Fig.3: Receiver noise temperature as a function of frequency

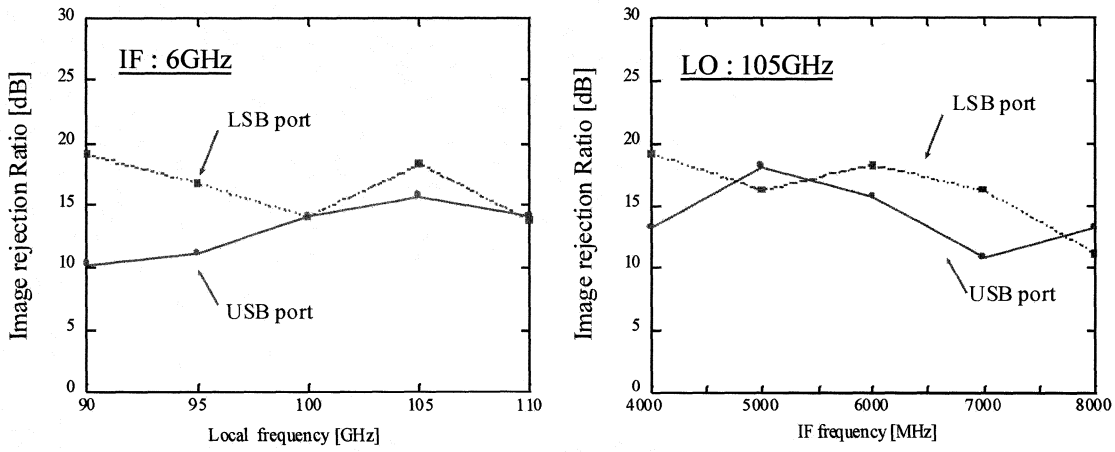

Fig.4: (a)Image rejection ratio at IF=6 GHz as a function of Local frequency. (b) Image rejection ratio at LO=105 GHz as a function of IF frequency.

3. FIRSTRIGHTS WITH SIDEBAND-SEPARATING SIS MIXER

The cartridge-type receiver cryostat for the Japanese prototype antenna is almost same as the cryostat tested on the Atacama Submillimeter Telescope Experiment (ASTE) [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 Fig. 9 (a). The cylindrical cryostat can accommodate two cartridges of 170 mm diameter and one cartridge of 140 mm diameter. 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 Fig. 9 (b).

In September 2003, the cartridge-type receiver cryostat was installed onto the Japanese prototype antenna. The 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 =115.27GHz, 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 these observations, Doppler corrections were not applied. The Doppler frequency shift is less than 40 kHz in ten minutes. This frequency shift is almost negligible because the resolution bandwidth of these 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.

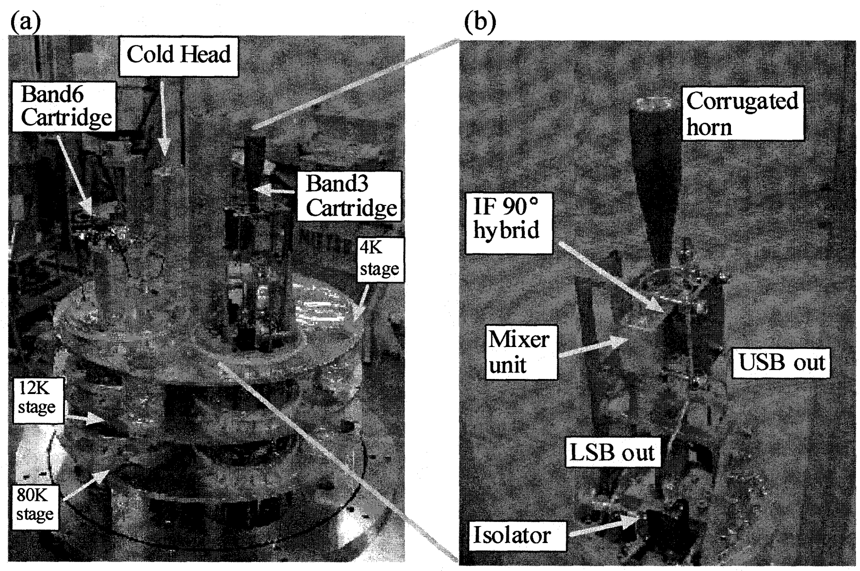

Fig. 5: (a) A photograph of the cryogenic system, in which 2 cartridge-type receivers were installed. The cryostat is composed of 3 stages (from up to down 4 K, 12 K, and 80 K stage). (b)The closeup of 4 K stage of the band 3 cartridge.

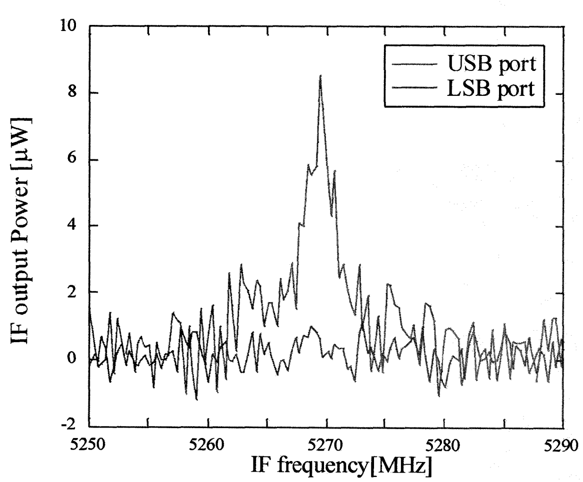

Fig. 6: Spectrum of ^{12}CO (J = 1- 0) from Orion KL by using a spectrum analyzer as the spectrometer. The Local frequency was 110 GHz (USB observation). The resolution and video bandwidth were 300 kHz and 3kHz, respectively. Average counts was 90 times.

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