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An Integrated Sideband-Separating SIS mixer Based on Waveguide Split Block for 100 GHz Band

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Abstract

We have been developing an integrated sideband-separating SIS mixer at 100 GHz based on waveguide split block. The measured single-sideband (SSB) receiver noise temperatures with L-band IF (f_c = 1.5 GHz) are less than 60 K in the LO frequency range of 90–115 GHz, and minimum value of around 35 K is achieved at 100 GHz. The image rejection ratios are more than 11 dB in the frequency range of 90–110 GHz. We have installed the sideband-separating SIS mixer into an atmospheric ozone measuring system at Osaka Prefecture University and successfully observed an ozone spectrum at 110 GHz in SSB mode. This experimental result indicates that the sideband-separating SIS mixer is very useful for astronomical observation as well as atmospheric observation.

Keyword: sideband-separating mixer, SIS mixer, W-band, ozone spectrum

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I. 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. Some millimeter wave observatories use a mechanically tunable interferometer as an image rejection filter, but this is only beneficial if the temperature of the image termination is much lower than that of the atmosphere. In practice, however, it is quite difficult to achieve a good image termination at extremely low temperature. Furthermore, such an interferometric filter has only a limited instantaneous bandwidth. Therefore, wideband and tuner-less SSB receiver is requested for observations in radio astronomy and atmospheric radiometer. In earlier memos [1][2][3], the performance of double-sideband (DSB) and single-sideband (SSB) receiver have been compared for ALMA project, and it is suggested that 2SB mixer should be adopted for ALMA receivers for band 3 to band 7 [4].

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 Figure 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 have built a sideband-separating mixer employing two SIS mixers. In this report we have demonstrated performance and test observation result of a sideband-separating SIS mixer at W-band.

II. MIXER DESCRIPTION

Detailed structure of a split-block waveguide unit for our sideband-separating mixer is shown in Figure 2. We adopted W-Band waveguide (2.54×1.27 mm) for our waveguide unit. The basic design of the sideband-separating SIS mixer is similar to that described by *Claude et al.*[5]. The split-block waveguide unit contains an RF quadrature hybrid, two LO directional couplers, an 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 transformers. Note that no LO power is reflected back into another mixer in the case of ideal quadrature hybrid, since most of LO power reflected at a mixer is transmitted to the 4 K load and the feed horn through the RF quadrature hybrid.

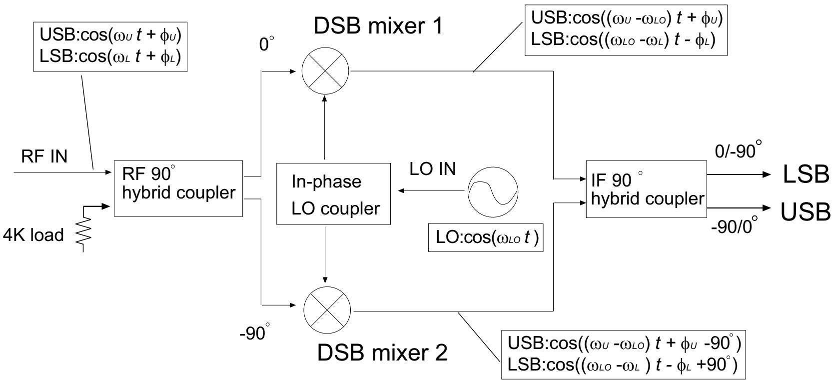


Figure 1: Block diagram of the sideband-separating mixer

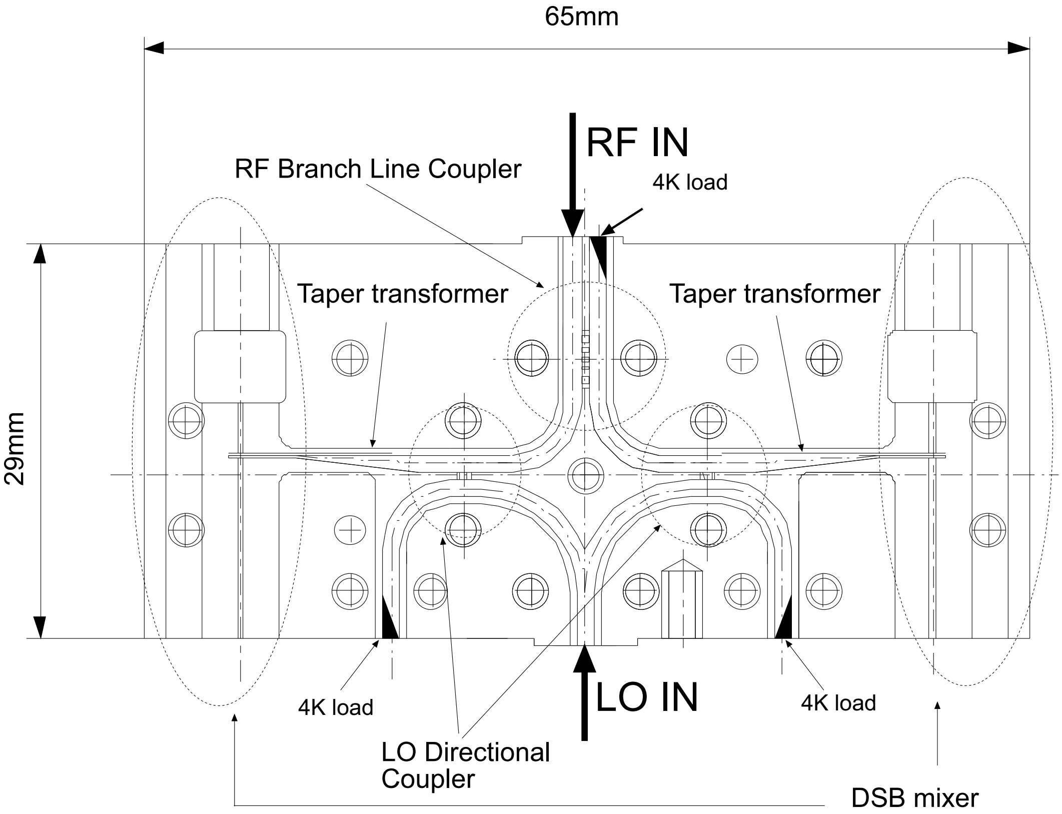


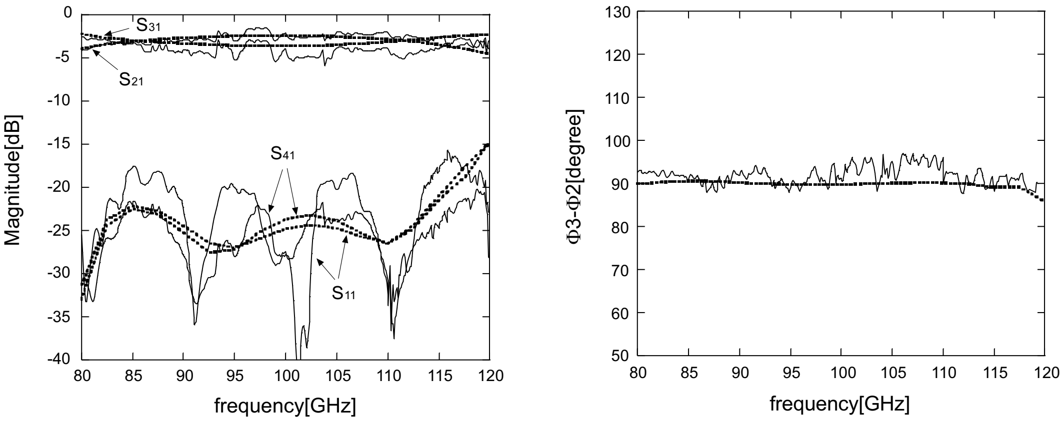
Figure 2: Configuration of the split-block waveguide unit. The split-block waveguide contains two DSB mixers, an RF quadrature hybrid, two LO directional couplers, an LO power divider, and 4 K cold image terminations.

A. SIS mixer

DSB SIS mixers adopted here are fabricated at Nobeyama Radio Observatory. SIS junction tuning circuitry is parallel-connected twin-junction (called PCTJ here for short)[6]. Measured DSB receiver noise temperature of these SIS mixers with 4.0–7.5 GHz IF is less than 25 K in the frequency range of 95–120 GHz and minimum value of around 19 K is achieved [7]. The mixer noise temperature is determined to be about 8.5 K, which is around twice the quantum limit (i.e., 2 $\hbar\omega/k$).

B. RF Waveguide quadrature hybrid coupler

A waveguide quadrature hybrid coupler was designed to divide an RF power into the two SIS mixers with a phase difference of 90°. We have chosen to use a branch-line coupler because of its compatibility with the split-block type of construction and its simplicity of fabrication. Initially, the coupler was designed by a numerical analytical method by using matrices based on the circuit theory [8]. To optimize the design of the branch-line coupler, we used a commercial 3D electromagnetic simulation software (HFSS$^{\rm TM}$, Ansoft Corporation). We have adopted quadrature hybrid with six branch lines (see Figure 2). The simulated and the experimental result of the branch-line coupler are shown in Figure 3.

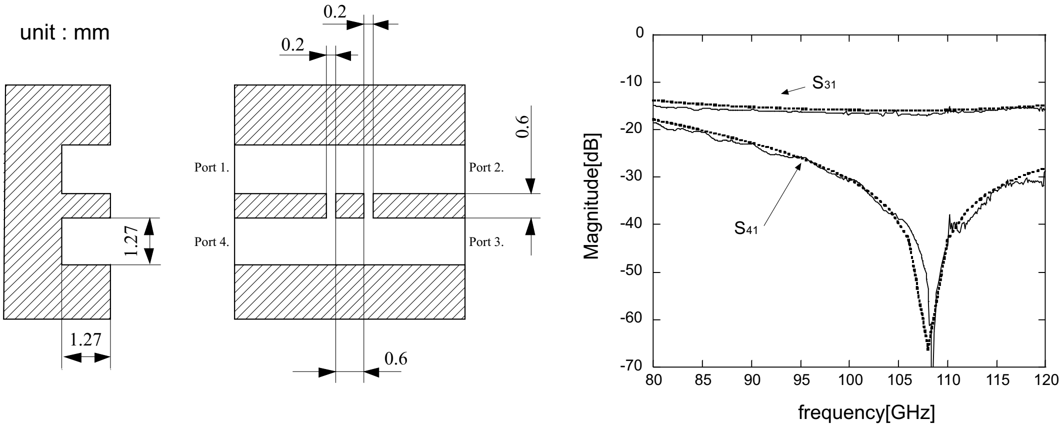


(a) (b)

Figure 3: The simulated (dashed lines) and the experimental result (thin solid lines) of the waveguide branch-line coupler. (a) input return loss (S11), isolation (S41), and coupling to the main and side waveguides (S21 and S31, respectively), and (b) phase as functions of frequency.

C. 2 slot LO Directional Coupler

LO power is usually coupled into a single-ended mixer using a directional coupler or beam splitter. If the signal loss through the LO coupler is to be kept small, the LO loss must be substantial, typically 15–20 dB. We have chosen to use simple 2 slot type directional coupler. Figure 4 (a) shows the cross-sectional view the 2 slot directional coupler. The experimental result and the result predicted by the HFSS$^{\mathrm{TM}}$ are shown in Figure 4 (b).



(a) (b)

Figure 4: (a) Diagram of the 2 slot LO Directional Coupler. (b) The simulated (dashed line) and the experimental result (line) of the 2 slot directional coupler showing coupling (S31) and directivity (S41), as functions of frequency.

D. In-Phase LO Power Divider

In the present application, there is no need for the special characteristics of a four-port hybrid junction, and a much simpler waveguide E-plane Y-junction can be used. We have adopted the Y-junction proposed by *Claude et al.*[5].

III. Mixer Assembly

The assembled mixer is shown in Figure 5. The RF signal is fed into the front of the mixer using a detachable corrugated feed horn. The local oscillator signal is introduced from the opposite side. The IF signals from the two DSB mixers are combined in a commercial quadrature hybrid (Anaren Microwave, Inc.). For the initial experiment, we have chosen an IF of 1.0–2.0 GHz suitable for the existing atmospheric ozone measuring system at Osaka Prefecture University. The DC biases for each of the DSB mixers are supplied independently using coaxial bias tees via IF hybrid coupler.

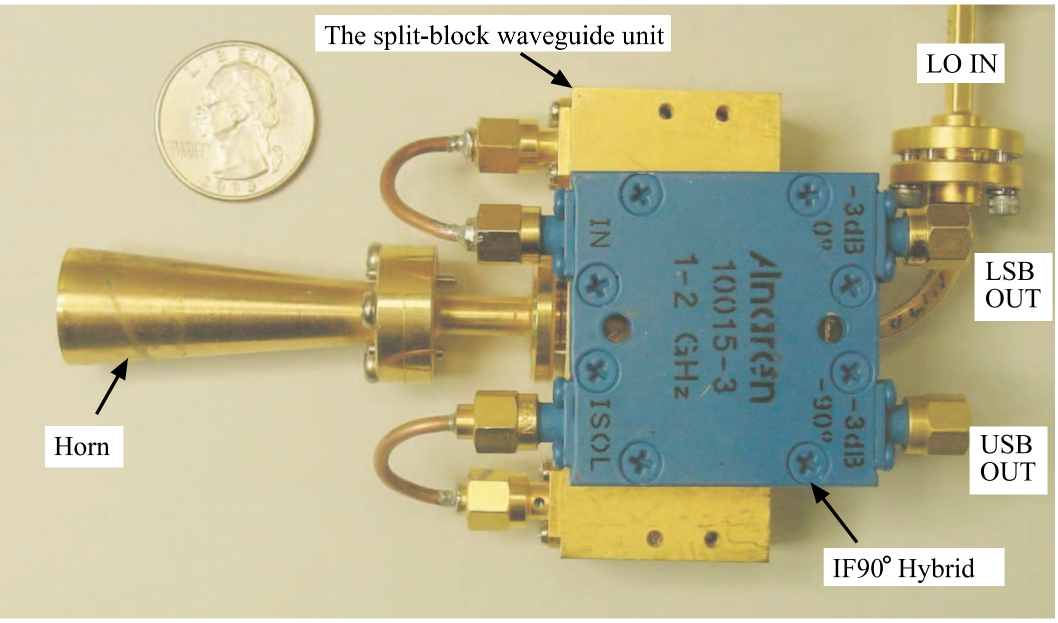
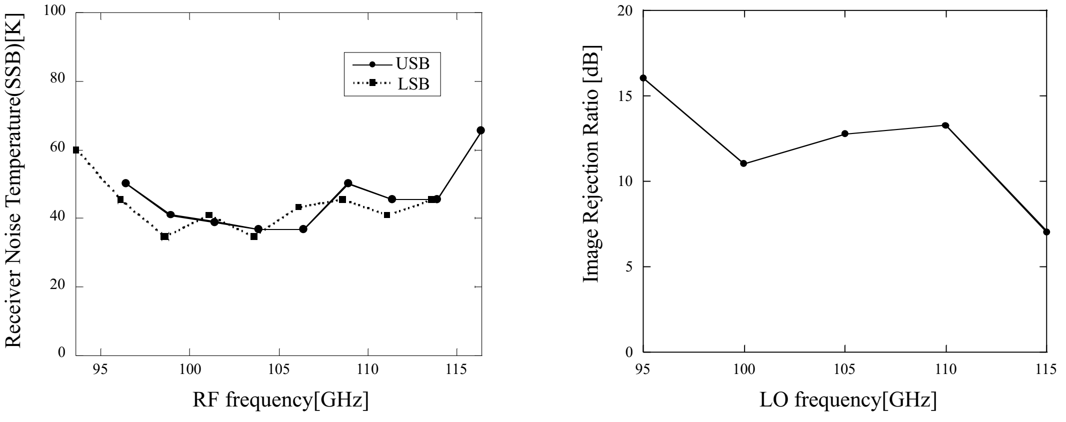


Figure 5: Photograph of the assembled mixer.

IV. Result and Discussion

A. Receiver Performance

Noise temperature of the SIS receiver was measured by a standard Y-factor method. The mixer was mounted on the 4 K cold stage of a dewar. A Teflon film with a thickness of 1.0 mm was used as a vacuum window. The IF output from the mixer was first amplified by a cooled HEMT amplifier at L-band (f_c=1.5 GHz) and further amplification was made at room temperature. The equivalent noise temperature and the gain of this HEMT amplifier associated with an isolator were about 2 K and 30 dB, respectively.



(a)

(b)

Figure 6: (a) SSB receiver noise temperature and (b) Image rejection ratio as functions of frequency.

The overall receiver noise temperatures (SSB) of the receiver (including 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 6 (a). The measured SSB receiver noise temperatures are less than 60 K in the LO frequency range of 90–115 GHz, and minimum value of around 35 K is achieved at 100 GHz.

The measured image rejection ratios are plotted in Figure 6 (b). The image rejection ratios are more than 11 dB in the frequency range of 90–110 GHz. Above 110 GHz, the image rejection ratio is rapidly deteriorated. This deterioration seems to be caused by the excitation of higher order mode in the waveguide, because only the TE$_{10}$ mode can propagate in the W-Band waveguide below 110 GHz.

B. Observation

Since 1999, the Department of Earth and Life Sciences, College of Integrated Arts and Sciences, Osaka Prefecture University has been carrying out frequency switching observations of $J = 6_{1,5}$–$6_{0,6}$ (110.836 GHz) line of atmospheric ozone. We have installed the sideband-separating SIS mixer into the atmospheric ozone measuring system at Osaka Prefecture University. The output IF signal is adjusted to appropriate frequency and level for acousto-optical spectrometer (AOS) by the IF circuits. The center frequency of the AOS is 95MHz. The AOS covers a 60 MHz bandwidth with 2048 pixels on the CCD. The frequency resolution of the spectrometer is 35 kHz. The method to correct for tropospheric absorption is, in principle, same as the chopper wheel method. The atmospheric ozone spectra obtained with DSB and SSB (USB) receiver system are shown in Figure 7 . It is noted here that the brightness temperature of the ozone spectrum observed in SSB mode is just twice of that observed in DSB mode as expected.

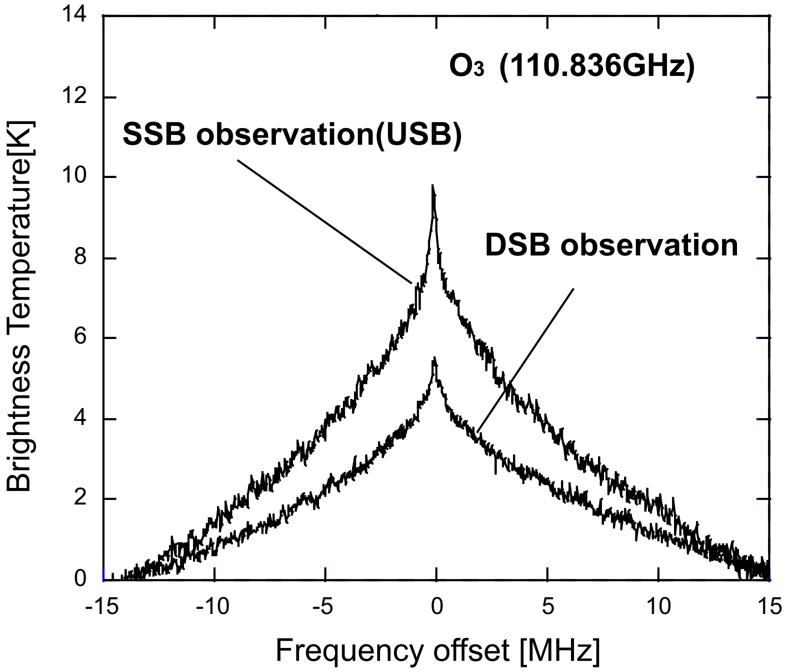


Figure 7: Atmospheric ozone spectra obtained with DSB and SSB receiver system.

V. CONCLUSION

We have demonstrated performance and test observation result of a sideband-separating SIS mixer at W-band. We integrated all mixer components on the split-block waveguide unit, which contains an RF quadrature hybrid, two LO directional couplers, an LO power divider, 4 K cold image terminations, and two DSB SIS mixers. The measured single-sideband (SSB) receiver noise temperatures with L-band IF (f_c= 1.5 GHz) are less than 60 K in the LO frequency range of 90–115 GHz, and minimum value of around 35 K is achieved at 100 GHz. The image rejection ratios are more than 11 dB in the frequency range of 90–110 GHz. We have installed the sideband-separating SIS mixer into an atmospheric ozone measuring system and successfully observed an ozone spectrum at 110 GHz in SSB mode. This experimental result indicates that the sideband separating SIS mixer is very useful for astronomical observation as well as atmospheric observation. Now we are upgrading the IF frequency to 4–8 GHz for ALMA receivers.

Acknowledgments

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