350 GHz Sideband Separating Receiver for ASTE

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***Abstract*— We have developed a 350 GHz Sideband Separating Receiver for ASTE (Atacama Submillimeter Telescope Experiment) . The RF frequency range is 330-360 GHz and the IF frequency range is 4-8 GHz. The receiver noise temperature was 150 – 200 K (SSB) and the image rejection ratio was typically 10 dB. This receiver was installed on the ASTE telescope in October 2007. The system noise temperature at the atmosphere condition of τ_{220} ~ 0.6 – 0.8 was 200 K (SSB). This is almost half of that of the previous DSB receiver.**

I. Introduction

In the 350 GHz band there are many high-J rotational transition lines of molecules, such as CO(J=3-2), CS(J=7-6) and HCN(J=4-3), which are useful for investigating dense parts of molecular gas.

In the 350 GHz band, double sideband (DSB) receivers have been used conventionally. However DSB receivers have several disadvantages. 1) It is difficult to calibrate the line intensity accurately because it is hard to know the image rejection ratio (IRR) precisely. 2) The Atmospheric noise from the image sideband is added and the system noise temperature increases. 3) If there were a line in the image sideband, signal line will be contaminated by it. Therefore single sideband receivers with a image-sideband rejection mechanism are needed to improve efficiency of the spectral line observations and are being developed at several institutes [1][2].

We have developed a 350 GHz sideband separating receiver CATS345 (Cartridge Type Sideband separating receiver at 345 ghz band) for ASTE (Atacama Submillimeter Telescope Experiment) which is a project to operate a 10-m submillimeter telescope in Atacama desert, northern Chile [3]. In our receiver, image band rejection is accomplished by the waveguide type 2SB mixer as shown in fig. 1 [4].

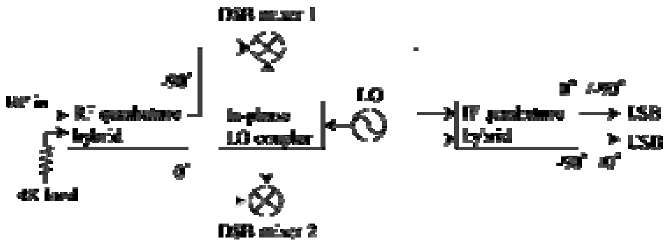

Fig.1 Block diagram of 2SB mixer.

After the evaluation in the laboratory, we installed our receiver on the ASTE telescope in October 2007. The system noise temperature, opacity and Allan variance were measured.

II. Instruments

The receiver is installed on the Cassegrain focus of the telescope. It is a 3-stage (4 K, 12 K, 50 K) cartridge type receiver (fig. 2, 3) .The RF signal (330-360 GHz) from the subreflector goes through a Kapton window and an IR filter and is reflected twice by a plane mirror and an ellipsoidal mirror. Then it is coupled with the 2SB mixer by the feed horn (fig. 4) .

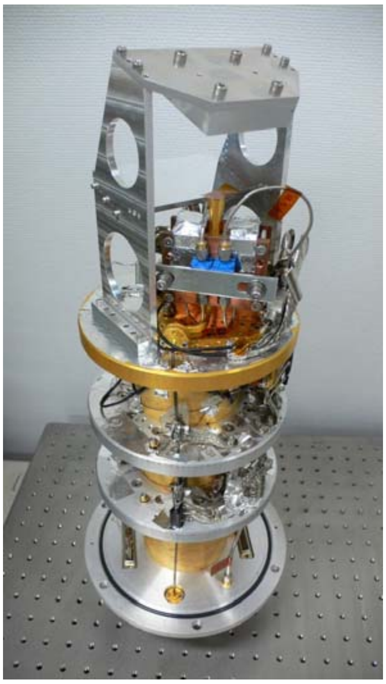

Fig.2 Whole image of CATS345. The height is about 400 mm. The diameter of the cartridge is 170 mm.

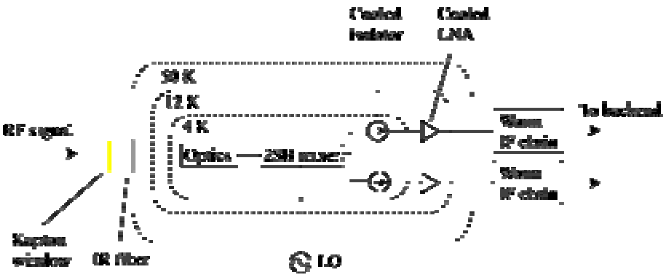

Fig.3 Block diagram of CATS345

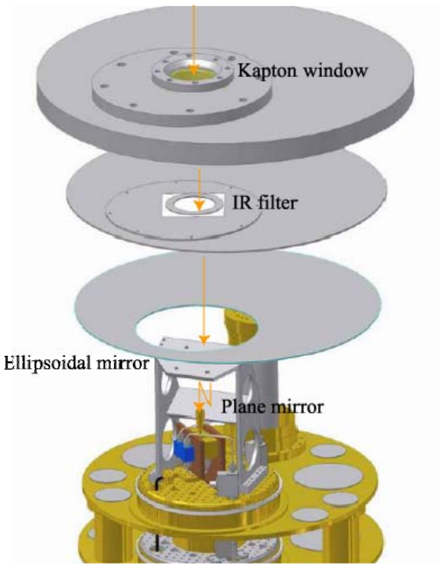

Fig.4 Optics. The diameter of the top shield is 460 mm.

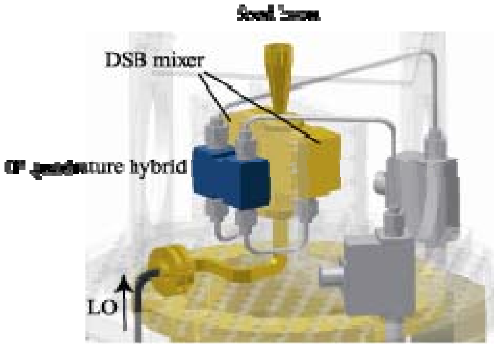

Fig.5 2SB mixer on 4 K stage. The size of the IF quadrature hybrid is 20 mm×40 mm×10 mm.

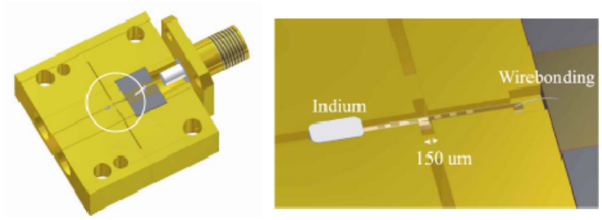

Fig.6 Mixer block and DSB mixer

The 2SB mixer mixes the RF signal with the LO signal and down-converts to the IF frequency (4-8 GHz). It consists of a RF quadrature hybrid, two DSB mixers and an IF quadrature hybrid. Our RF quadrature hybrid is a scale model of [4]. The DSB mixer is designed by S. C. Shi. The LO signal is generated by the synthesizer and multiplied 24 times. After the 2SB mixer, the signal is amplified by the IF chain, which is composed of cooled isolators, cooled amplifiers, isolators, room-temperature amplifiers and bandpass filters, and is sent to the backend.

TABLE I
SPECIFICATION OF CATS345

Observation frequency	330 – 360 GHz
Intermediate frequency	4 – 8 GHz
Pixel	1
Polarization	1
Receiver noise temperature	150 – 200 K
Image rejection ratio	10 dB

III. EVALUATION IN THE LABORATORY

It is required for a sideband separating mixer that there is neither amplitude nor phase imbalance in the 2SB mixer. So, first we investigated the imbalance of the RF quadrature hybrid, the DSB mixers and the IF quadrature hybrid.

The role of the RF quadrature hybrid is to divide the input signal equally and to add a 90 degree phase difference between the two output signals. The amplitude imbalance of the RF quadrature hybrid was measured by inputting power from the RF port and measuring the power from the output port. The other two ports were terminated with absorbers (fig. 7). The input signal is produced by the synthesizer and a 24 times multiplier. The result was that the amplitude imbalance was within 1 dB.

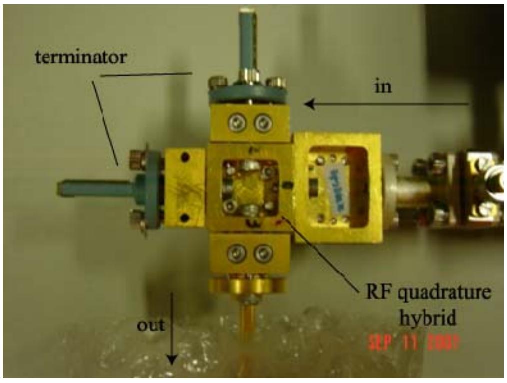

Fig.7 Measurement of imbalance of RF quadrature hybrid. The right port is RF port, the left port is LO port and the upper and lower ports are IF output ports to DSB mixers. The size of the RF quadrature hybrid is 20 mm×20 mm×20 mm.

The role of the DSB mixer is to down-convert the RF frequency to the IF frequency. Its performance is dependent on its IV curve [5]. So, first we measured IV curves of 350 DSB mixers and selected 2 mixers which satisfy J_c~4 kA cm^2 and a quality factor ($R_{2\ \mathrm{mV}}/R_{4\ \mathrm{mV}}$) > 20 and resembles each other (fig.8) .Then, their DSB receiver noise temperatures of those were measured and it was confirmed that their frequency dependence resembles each other.

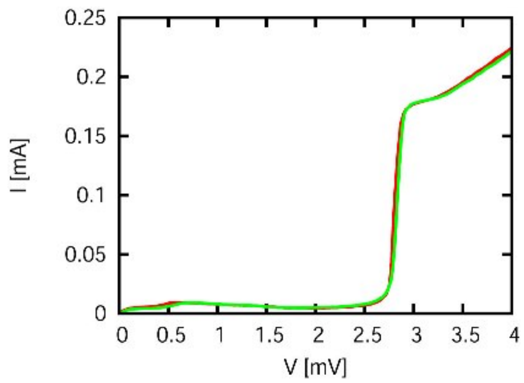

Fig. 8. IV curves of DSB mixers.

The role of the IF quadrature is to divide the input signal equally and to put a 90 degree phase difference between the two output signals like the RF quadrature hybrid. Its S parameters were measured with a network analyser. It was measured that its amplitude imbalance was within 1 dB and the phase imbalance was within 5 degree.

The total imbalance of the 2SB mixer is summarized in table II. In the ideal case that 2 DSB mixers are completely balanced, the total amplitude imbalance is about 2 dB and the phase imbalance is 5 degree. So according to [6], the expected image rejection ratio is 15 ~ 20 dB.

TABLE II
IMBALANCE OF 2SB MIXER

	Amplitude	**Phase**
RF quadrature hybrid	1 dB	?
DSB mixer	variable	?
IF quadrature hybrid	1 dB	5 degree
total	~ 2 dB	~ 5 degree

These components were assembled to the 2SB receiver. The receiver noise temperature was about 150-200 K (SSB) across the band (fig. 9).

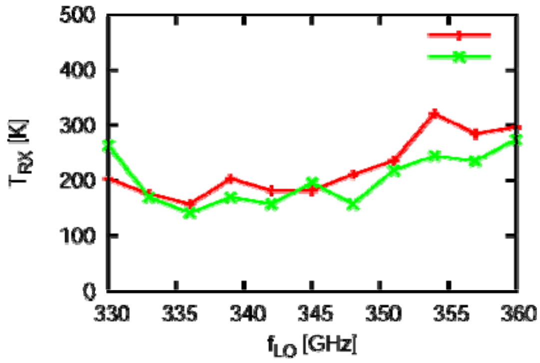

Fig.9. The receiver noise temperature of the 2SB receiver. The red plots are USB and the green plots are LSB.

The image rejection ratio was measured by the method of [7] and was typically 10 dB across the band (fig. 10).

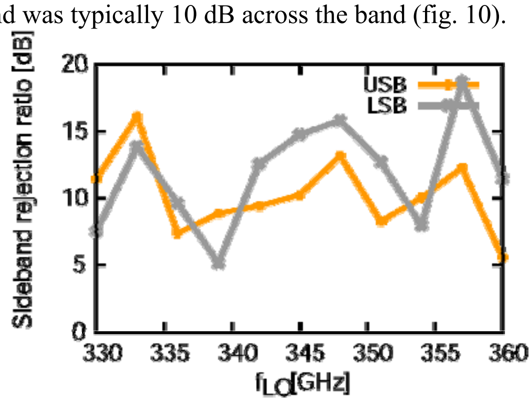

Fig.10. The image rejection ratio of the 2SB receiver.

IV. EVALUATION AT THE ASTE SITE

Our receiver was installed on the ASTE telescope in October 2007. At that time a new backend with a total bandwidth of 8 GHz was also installed [8].

Figure 12 shows the system noise temperature, receiver noise temperature and the opacity measured by the R-sky method and the secZ method. At that time the opacity at 220 GHz was about 0.06 ~ 0.08. The system noise temperature was about 300 K (SSB). This is almost half of that of the previous DSB receiver [9], which means that the integration time needed decreases to 1/4. The receiver noise temperature was about 150 ~ 200 K and was consistent with the performance in the laboratory. The opacity at 345 GHz was about 0.2 ~ 0.3 and this was almost the same as one predicted by the atmosphere model, τ_{345}=0.05+2.5×τ_{225} [10].

To know the stability of the receiver, the Allan variance at the outputs of the receiver was measured with a power meter. The Allan time was about 10 sec (fig. 11).

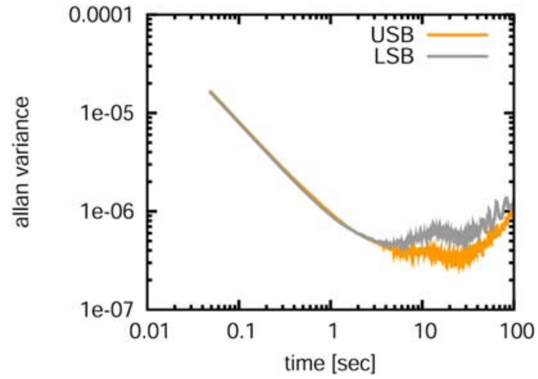

Fig.11. Allan variance

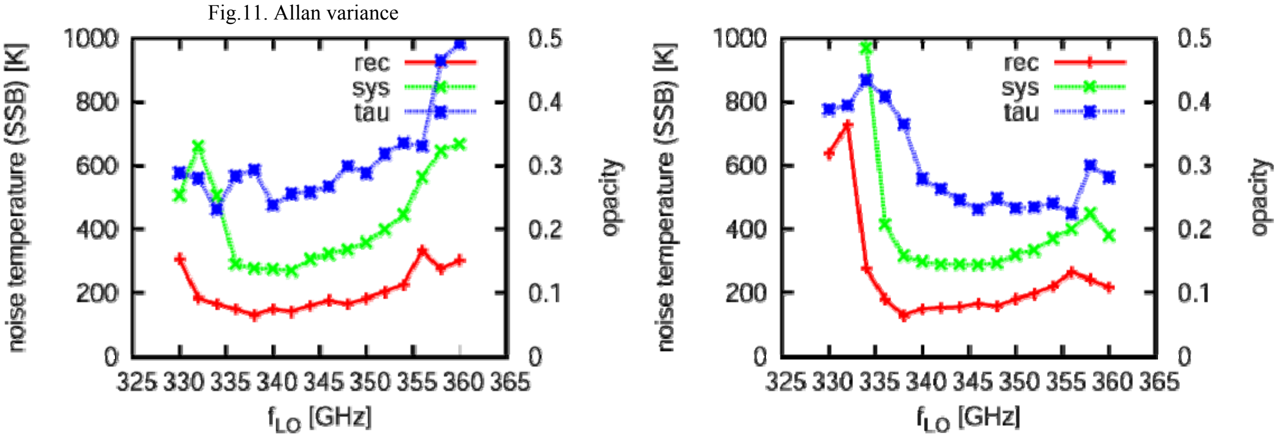

Fig. 12. The system noise temperature (green), the receiver noise temperature (red) and opacity (blue) at the atmospheric condition of τ_{220}=0.06 – 0.08. The left plots are USB and the right plot s LSB.

V. Test observation

IRC10216, a Carbon rich late type star, was observed with the new 8 GHz backend. At this observation the opacity at 220 GHz was 0.06 – 0.08, which was typical atmospheric condition of ASTE site in winter. Figure 13 shows the spectrum of IRC10216 and was obtained within a few minutes observation. The image rejection ratio was measured to be over 10 dB in these frequencies.

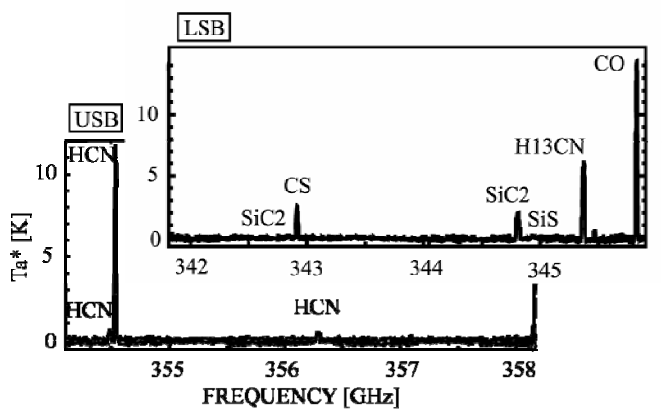

Fig. 13.Spectrum of IRC10216

CONCLUSIONS

We have developed a waveguide type sideband separating SIS receiver at 350 GHz band for ASTE. After the evaluation in the laboratory, it was installed on the ASTE telescope together with a new backend with a 4 GHz bandwidth in October 2007. The system noise temperature was typically 200 K (SSB), which is half of that of the receiver previously installed on ASTE. So the integration time needed to achieve a certain sensitivity decreases to 1/4. The image rejection ratio was measured with the lines from astronomical objects and was over 10 dB.

ACKNOWLEDGMENT

We are grateful to the ASTE team and ALMA Band 4 group for supporting our research. This study was financially supported by the MEXT Grant-in-Aid for Scientific Research on Priority Areas No. ~15071202.

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