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First Astronomical Observations with an ALMA Band 6 (211-275 GHz) Sideband-Separating SIS Mixer-Preamp

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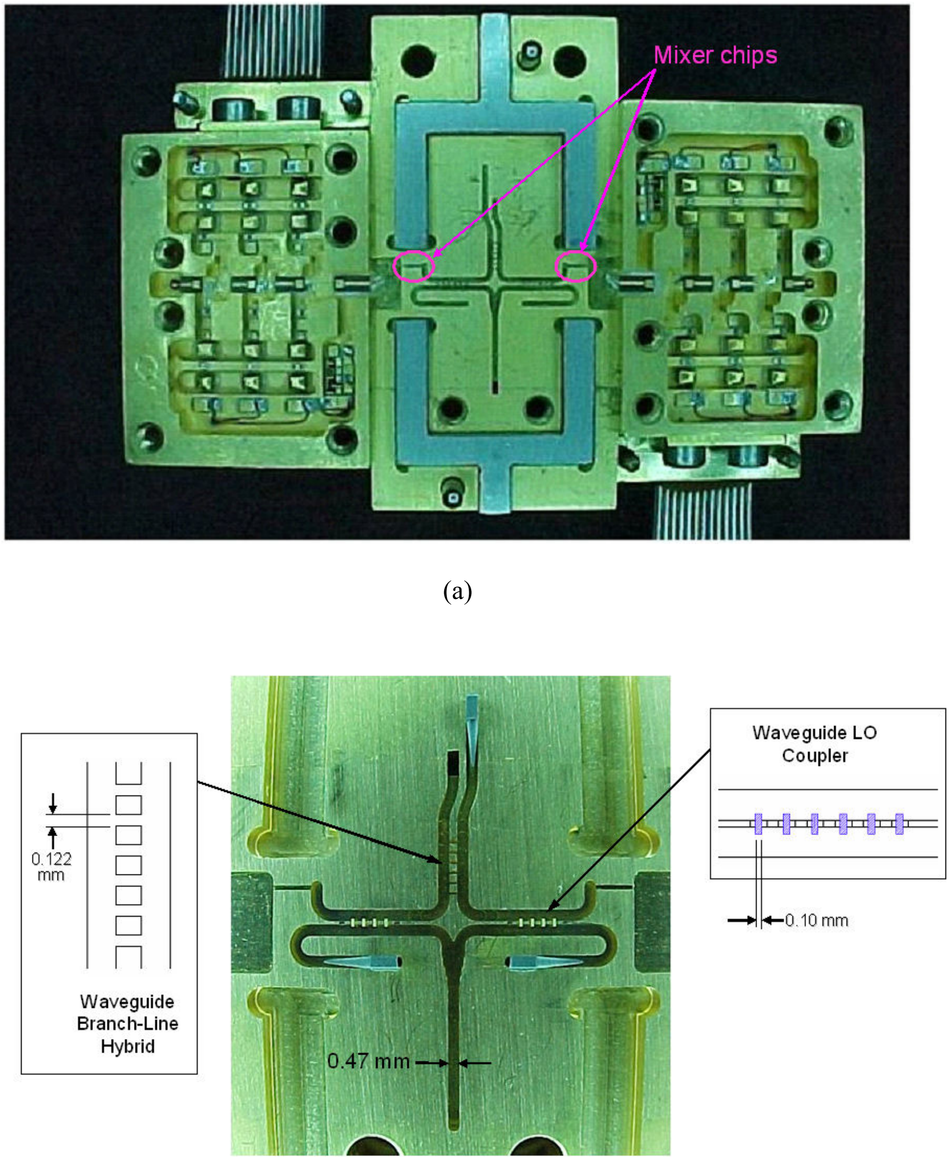
Abstract — A 211-275 GHz SIS receiver using an ALMA Band 6 sideband-separating mixer-preamp has been installed on the Submillimeter Telescope (SMT) on Mt. Graham, Arizona, a facility of the University of Arizona. Initial observations have yielded single-sideband system noise temperatures as low as 107 K referred to outside the atmosphere. The image rejection, measured on the sky, was > 12 dB (15 dB typical) for the upper sideband, and > 20 dB for the lower sideband. Excellent baseline stability was also observed: a 4° position offset in galactic latitude yielded a peak-to-peak baseline of only 10 mK. The receiver has separate 4-8 GHz IF outputs for the upper and lower sidebands, although in the present observations the instantaneous bandwidth was limited by the available spectrometers to 2 GHz in each sideband.

INTRODUCTION

For terrestrial observations of millimeter-wave spectral lines in astronomical sources, a receiver using a sideband-separating mixer is more sensitive than a double-sideband receiver. This is because the atmospheric noise in the image band increases the noise temperature of the double-sideband system, while the sideband-separating receiver does not respond to signals or noise in the image band. For this reason, the Atacama Large Millimeter Array (ALMA) will use sideband-separating mixers in its lower frequency bands where the technology exists to build them. The ALMA receivers have no mechanical tuners and provide 8 GHz of instantaneous IF bandwidth per sideband per polarization.

As part of the development of receivers for ALMA, several approaches to wideband sideband-separating mixers were explored at the NRAO from 1993 to 2004 [1-8]. The designs being used for ALMA Bands 3, 6, and 7 are based on the split-block waveguide quadrature hybrid, which divides the power from the antenna between two component mixers with a 90° phase difference. The IF outputs of the component mixers are combined in a quadrature IF coupler which delivers the downconverted upper- and lower-sideband signals at its output ports. The fourth port of the RF input hybrid is terminated in a cold load which functions as the image termination for the mixer; RF power from this load is downconverted and appears at the IF output ports along with the desired upper- and lower-sideband signals. Because sufficient LO power is available in the lower ALMA bands, the LO is coupled into the two component mixers through ~20 dB waveguide couplers which are integral with the mixer block. In ALMA Band 6, the IF preamplifiers are mounted directly on the mixer block and isolators are not used; this permits the full 4-12 GHz bandwidth of the preamplifiers to be utilized. Bias for the mixer chips is provided by bias-tees built into the preamplifiers. The ALMA Band 6 mixer-preamp is shown in Fig. 1.



(a)

(b)

Fig. 1. The ALMA Band 6 mixer-preamp [8]. (a) Mixer (center) and preamps (left and right), shown with lids removed. (b) Mixer block details showing the waveguide branch-line hybrid and the LO couplers.

To verify the performance of the mixer-preamp in actual astronomical observations before continuing with the production of more than 120 units for ALMA, a prototype mixer-preamp was built into a receiver for operation on the Submillimeter Telescope (SMT), a 10-m reflector with an RMS surface accuracy of 15 μm. The SMT is a facility of the University of Arizona, Arizona Radio Observatory (ARO) and is located on Mt. Graham, AZ, at an elevation of 3,200 meters. After initial testing in the laboratory, the receiver was installed on the telescope in late February 2006.

FRONT-END CONFIGURATION

The 1-mm receiver cryostat on the SMT contains ports for up to six receivers. It is cooled by a Joule-Thompson valve mounted on a commercial two-stage Gifford-McMahon cooling engine. The GM refrigerator pre-cools the He gas heat-exchanger supplying the JT valve to ~10 K, and the JT stage has a cooling capacity of ~1.5 W at 4.2 K. The temperature of the JT stage is stable to within ± 1 mK over a period of several minutes. The inside of the receiver dewar is shown in Fig. 2.

The telescope beam is coupled at the Nasmyth focus to the receiver by three flat 45° mirrors at room temperature. It then passes through a polystyrene foam supported polypropylene film vacuum window [9] and through a Teflon lens to the scalar feed horn. The room temperature mirrors contribute ~6 K to the receiver noise temperature.

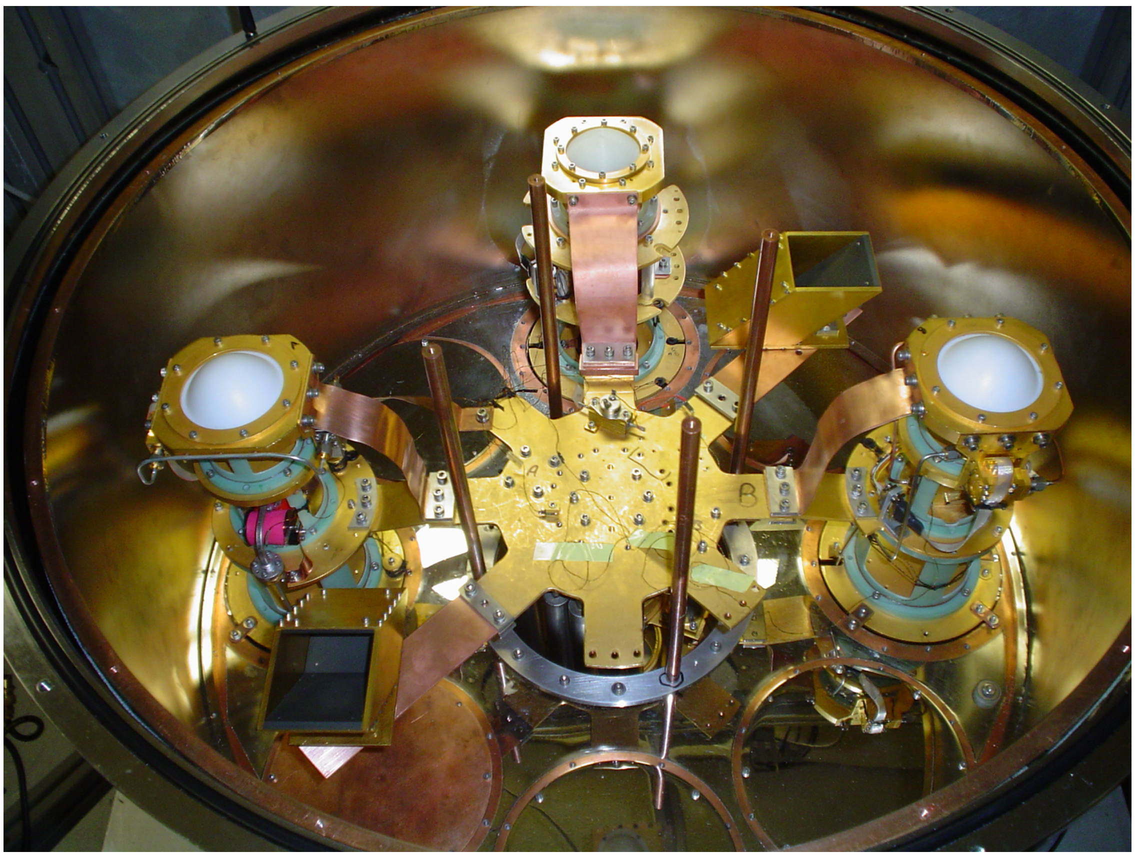


Fig. 2. The 230 GHz receiver at the SMT with the top covers removed, showing the 4-K stage with three receiver inserts surrounded by a nickel-plated copper 50-K radiation shield and the stainless-steel vacuum vessel. The two inserts at the left and right are part of the standard dual-polarization SSB receiver which uses a room temperature Martin-Puplett interferometer (not visible) for sideband separation. The insert at the top contains the ALMA Band 6 mixer-preamp.

BACK-END CONFIGURATION

At the SMT, the standard 4-6 GHz IF can be fed to various spectrometers. In the present observations, two filter banks were used, each with 1,024 1-MHz channels, and also two acousto-optic spectrometers (AOS), each with 1 GHz bandwidth. One IF output was connected to a pair of filter-banks in series, and the other was connected to a pair of AOS's in series, providing a total IF bandwidth of ~2 GHz for each sideband. (Additional IF processing between the mixer-preamp and the spectrometers permitted observations to be made with the first IF anywhere in the 4-8 GHz band.)

OBSERVATIONS

In early February, the atmospheric conditions were excellent for these observations, with opacity τ less than 0.025. A SSB system noise temperature of 107 K, referred to outside the atmosphere, was achieved at a sky frequency of 230 GHz. Relative to the old receiver, which uses a room temperature Martin-Puplett interferometer for sideband separation, T_{sys} was lower by a factor of 2-4, depending on the sky frequency. This corresponds to a decrease in integration time by as much as a factor of 16. Because of the lower receiver noise temperature, atmospheric ozone lines are now more prominent in the calibration scans used for determining the antenna temperature. The added noise from these lines can be significant; at certain sky frequencies they add more than 100 K to the system temperature calibrated above the atmosphere. This affects the RMS noise level, and can make it difficult to achieve flat baselines over the wider IF bandwidths now available from the receiver.

The image rejection was measured by injecting a calibration tone at the image frequency, generated by a microwave synthesizer and harmonic generator. The image rejection is the ratio of the strengths of the downconverted tone in the upper- and lower-sideband IF outputs, measured using a spectrum analyzer. Typical values of the image rejection were 15 dB for the upper sideband (12 dB worst case), and 20 dB for the lower sideband. Fig. 3 shows a typical ^{13}CO spectral line observation of the planetary nebula K4–47 measured with the old and new receivers under similar conditions.

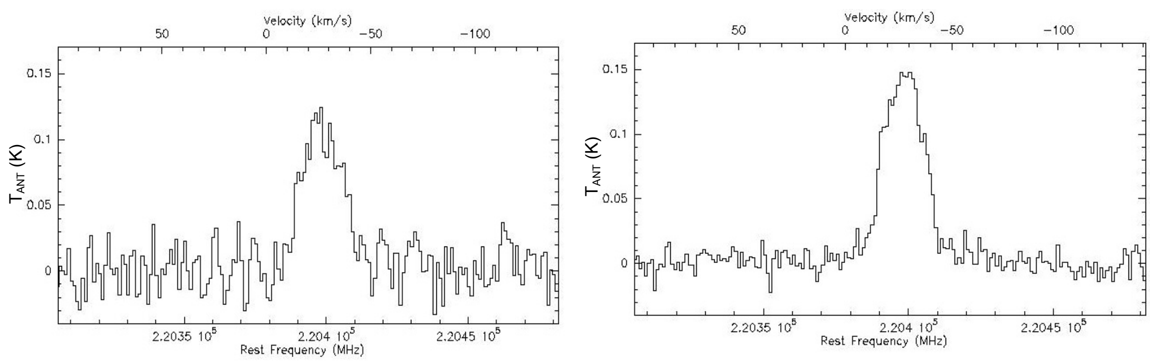


Fig. 3. ^{13}CO spectrum comparison from the planetary nebula K4–47 measured with (a) the SMT's old 1.3-mm SSB receiver with T_{sys} = 398 K, and (b) the 1.3-mm receiver using the ALMA Band 6 sideband-separating mixer-preamp with T_{sys} = 173 K. The source and integration time were the same for both. A comparison of the spectra shows the improved signal to noise ratio obtained with the receiver using the ALMA Band 6 mixer-preamp.

Figure 4 shows a lower sideband measurement of ^{13}CO in NGC7027 with a stronger 8 K ^{12}CO line present in the image band and demonstrates the ~20 dB image rejection of the receiver.

^{12}CO observations of the planetary nebula M3-55 were made with a 4° position switching offset in galactic latitude (which involved both azimuth and elevation motion). The baseline variation due to position switching was less than 10 mK – see Fig. 5. This offset was repeated later under less than ideal weather conditions and still yielded comparable baseline stability.

Figure 6 shows a scan of SgrB2(N) with 30 arc-minute position switching, using the two filter banks simultaneously to achieve a total of 2 GHz IF bandwidth.

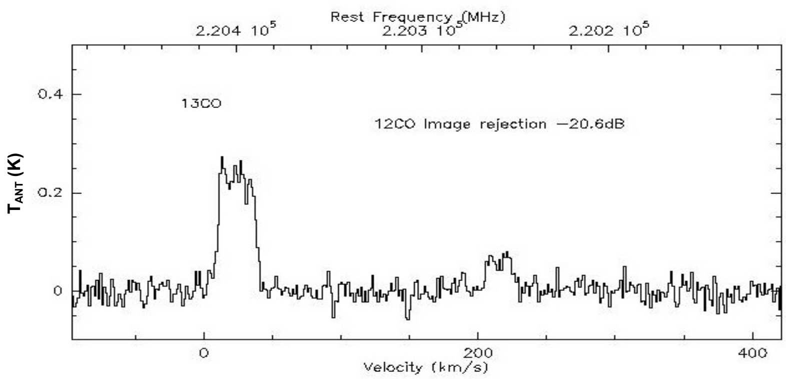


Fig. 4. A lower-sideband ^{13}CO observation of NGC7027 with a stronger ^{12}CO line present in the image band. The weak line visible just above 200 km/s is the ^{12}CO line from the image band, attenuated by the ~20 dB image rejection of the sideband-separating receiver.

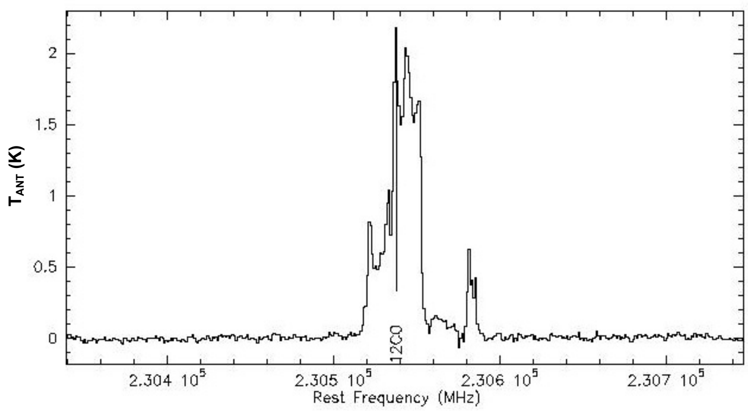


Fig. 5. ^{12}CO spectrum of planetary nebula M3-55 showing the baseline stability with a 4° position switching offset in galactic coordinates from the galactic plane. The integration time was 12 minutes with a SSB T_{sys} of 111 K.

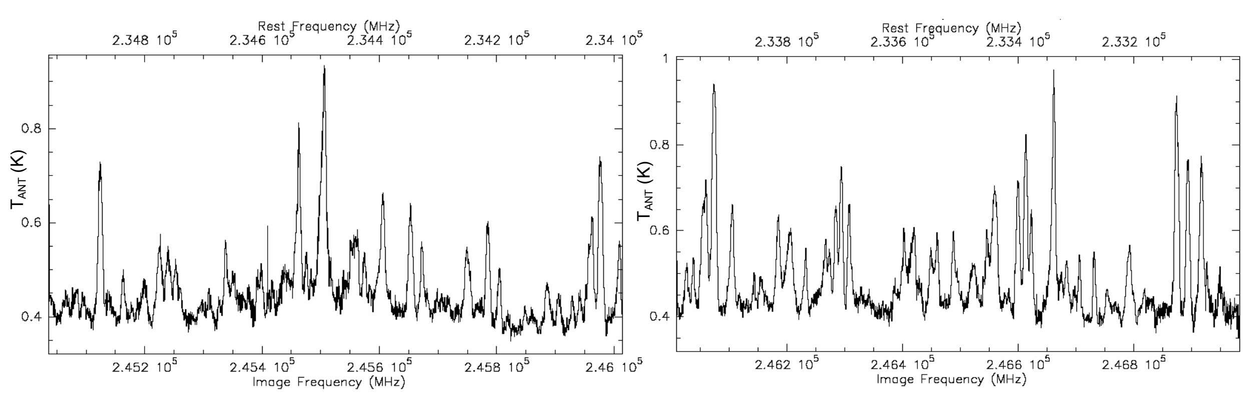


Fig. 6. Illustration of the 2 GHz wide IF bandwidth achievable using both filter banks. These data are part of one continuous 30 minute scan of the SgB2(N) region.

CONCLUSION

The first astronomical observations have been made using an ALMA Band 6 sideband-separating mixer-preamplifier on the SMT. Unprecedented single-sideband system noise temperatures and baseline stability were obtained. This single polarization receiver far outperformed the existing dual polarization, single-sideband receiver in both sensitivity and baseline stability. The amount of science that was done with this mixer during its three days on the telescope would have taken at least nine days with the old receiver (*i.e.*, a factor of three of improvement). These observations have confirmed the state-of-the-art performance predicted from laboratory measurements on the receiver, and demonstrate the value of the ALMA's investment in the new receiver technology.

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