ALMA Band 1 Receiver Status and its next Generation Development

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The Atacama Large Millimeter/submillimeter Array(ALMA) Band 1 receiver covers the 35-50 GHz frequency band, is with the largest relative bandwidth among the 10 allocated ALMA bands. At ASIAA the Band 1 receiver front-end cartridges are now in preproduction stage. We are presenting the receiver performance for five receivers. Here we also present the work has been done towards new generation of receivers. The study is focused on the wider RF bandwidth (28GHz to 52GHz) sideband separating receiver. The goal is achieve flat and low noise temperature and flatter gain variation across the IF bands. In addition, we are studying the down-conversion method involving digital sideband separation. Currently, we have successfully deployed digital sideband separation system to covering the 1.6GHz bandwidth at each sideband. The studies to achieve eventual goal for wider bandwidth will be presented.

ALMA Band 1

The Band 1 project is the East Asian ALMA contribution. The Project development and management is executed by ASIAA and deliver to NAOJ as ALMA-EA contribution (under the NAOJ-ASIAA ALMA Agreement).
The Band 1 receivers cover a range of frequencies from 35 to 52 GHz. When installed the observatory will be able to see twice further into the universe - detecting distant objects with higher redshifts because of the sensitivity to twice longer wavelengths. The detectable universe by ALMA is therefore increased in volume by a factor of 8. It will become possible for ALMA to detect the most distant and earliest star-forming gas reservoirs in the Universe, and to see dust grains grow to cm-sized pebbles around nearby stars: the first steps of planet formation.

Band 1 Block Diagram

The block diagram of the Band 1 receiver is shown in Fig. 3. The RF signal is split into two orthogonal polarizations by using OMT. The cryogenically cooled amplifier is used in the first receiver stage to amplified the signal. To minimize the impact of mixer noise, a room temperature Q-band amplifier is used prior to the mixer. The upper sideband configuration is realized by using high-pass filter. The mixer is chosen to provide high reliability and to simplify maintenance. The IF amplifier is chosen to meet the IF power level specification.

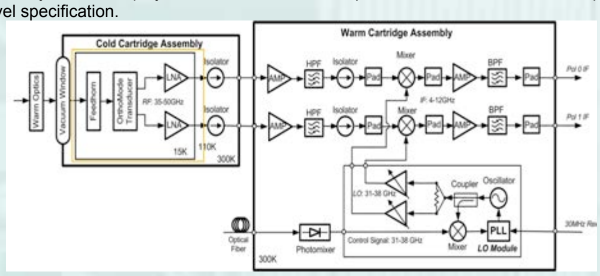

Fig. 1: Block Diagram of the Band 1 cartridge assembly

System Specification

Parameter	Specification	Parameter	Specification
RF Port Freq.	35 – 50 GHz	LO Port Freq.	31 – 40 GHz
IF Port Freq.	4 – 12 GHz	SSB Noise Temperature	≤25 K over 80% of band ≤32 K over entire band
Image Band Suppression and Sideband Mismatch	≥10 dB over 90% of IF Freq. >7 dB over entire IF Freq.	Large Signal Gain Compression	5% @ load exchange between 77K and 373K
IF Power Variation	4dB p-p over any 2GHz window 7dB p-p full band	The Total Power within the IF Band	> -32 dBm to -22 dBm
Amplitude Stability: Allan variance	4×10^{-7} (0.05s≤ T ≤100s) 3×10^{-6} for T=300s	Signal Path Phase Stability	22fs over 300s
Aperture Efficiency	>80%		

System Performance

We have integrated and fully characterized five ALMA band 1 receiver that exhibits good sensitivity and wide bandwidth coverage without performance degradation. The Band 1 receiver is compliant with ALMA specification. The ALMA specification of aperture efficiency is 80%. The measured aperture efficiency of optic is shown in Fig. 2. Amount of five receivers, there is a frequency points below 80% which is out of specifications. This is mostly due to effects associated with truncation at cryostat apertures, and reflection and impedance coupling in cryostat IR filters.

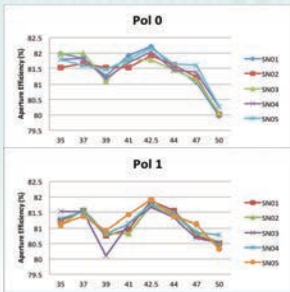

Fig. 2: : Aperture efficiencies for pol 0 and 1

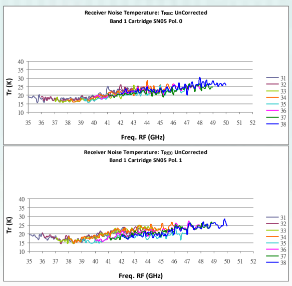

Fig.3::Band 1 SN05 Noise Temperature performance

Next Generation Receiver

The radio astronomy instruments is pursuing achievable sensitivity, dynamic range, and field of view. Here, we are presenting the development of wider frequency coverage in order to gains in sensitivity. The study is focused on the wider RF bandwidth (28GHz to 52GHz) sideband separating receiver. Currently, we are achieving the RF bandwidth of 30GHz to 50GHz. Please refer to the poster: 30-50 GHz Wideband Receiver for Nobeyama 45-m Telescope with Capability to Observe Three Zeeman Lines Simultaneously.

However, broadband sideband-separating down-converters are difficult to build because they require the construction of two hybrids and two parallel mixer/amplifier chains with excellent amplitude and phase balance over the entire bandwidth. The gain and phase imbalances of analog components in the two parallel signal paths limit the sideband rejection ratio (SRR) to approximately 10– 20 dB. An increase in the speed of digital hardware has made it feasible to implement an IF hybrid by using digital signal processing (DSP).

Digital sideband separating down-conversion

Sideband separating (2SB) down-conversion has been widely used in ALMA receivers to observe two sidebands simultaneously while avoiding spectral confusion and suppressing noise from the other sideband. However, due to the phase errors or amplitude imbalances of analog components over broad bandwidths, the sideband rejection ratios (SRRs) have been limited to 10 to 20 dB. The digital sideband separating scheme we propose here is to use wideband ADCs with bandwidths more than 4 GHz together with digital signal processing modules to implement the IF hybrid to produce 2 sidebands, each with a bandwidth of 4 GHz. After calibrating the amplitude imbalances and phase errors SRRs above 30 dB can be expected.

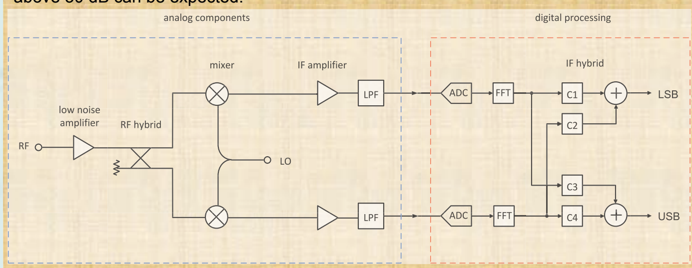

Fig.4:Block diagram of a digital sideband separating receiver. The RF signal is amplified and divided with an RF hybrid into two signals of equal amplitude but with 90° phase difference. The two signals are then down converted with mixers. The IF signals are amplified and fed into the digital portion. The IF signals are digitized using wideband analog-to-digital converters (ADCs). The IF hybrid is digitally implemented within digital signal processing (DSP) modules to produce two sidebands.

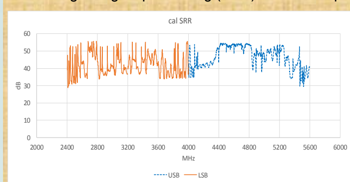

Fig.5::Calibrated SRRs

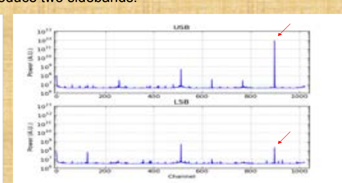

Fig.6::Calibrated spectra with a test tone in the USB. The image signal in the LSB is further suppressed

Discussion

The laboratory tests demonstrate that with calibration, the digital sideband-separating down-conversion technique can process a 2 x 1.6 GHz bandwidth with SRRs greater than 30 dB. The bandwidth is currently limited by timing within FPGAs. Another demux by 2 in the ADC interface block will be implemented to resolve this issue.