arXiv:1106.4076v1 [astro-ph.IM] 21 Jun 2011

2010 Asia-Pacific Radio Science Conference
in Toyama, Japan on September 22-26, 2010
Commission J: Radio Astronomy
J2 Millimeter- and Sub-millimeter-wave Telescope and Array

Atacama Compact Array Correlator for Atacama Large Millimeter/submillimeter Array

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ABSTRACT

We have developed a FX-architecture digital spectro-correlator, Atacama Compact Array Correlator for the Atacama Large Millimeter/submillimeter Array. The ACA Correlator processes four pairs of dual polarization signals, whose bandwidth is 2 GHz, from up to sixteen antennas, and calculates auto- and cross-correlation spectra including cross-polarization in all combinations of sixteen antennas. We report the detailed design of the correlator and the verification results of the correlator hardware.

1. ALMA and ACA Correlator

ALMA (Atacama Large Millimeter/submillimeter Array) consists of fifty 12-m antennas and "Atacama Compact Array (ACA)" (Iguchi et al. 2009). The ACA antennas are composed of four 12-m antennas for total power observation and twelve 7-m antennas for short-baseline interferometer. The ACA Correlator proforms the processing of astronomical signals from all the ACA antennas.

2. Correlator Design and Requirements

Astronomical correlator calculates correlation coefficients between the signals from antennas, and it has a function to arbitrarily change the integration time and frequency resolution to get the data to be handled easily. It also provides information on frequency

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spectral profiles. The newly developed ACA Correlator adopts "FX" architecture, in which the Fourier transform is performed before a cross multiplication. ALMA is a general-purpose millimeter and submillimeter telescope which can observe all kinds of astronomical objects in the range of its angular resolution. There are many scientific goals, and sensitivity, frequency resolution, and frequency coverage are key factors to achieve the various scientific goals.

In ALMA, the quantization loss is required to be smaller than 12 %, which is the value of 2-bit quantization, by performing quantization with 3-bit 4Gsps. To achieve this requirement, ACA Correlator processes the digital signals of 3-bit 4Gsps without reducing the number of bits. In addition, the correlator is designed to achieve high spectral dynamic range of 10000 : 1. The ACA Correlator also supports wide variety of flexible spectral configurations (combinations of frequency resolution and coverage) for observations which span from wide continuum emission to high-resolution maser emissions. Major specifications of the ACA Correlator performance are listed in Table 1.

3. Correlator Hardware

The ACA Correlator was installed in the room of Array Operation Site Technical Building at an altitude of approximately 5000 meters (Figure 1). The correlator processes 8-baseband signals from 16 antennas with 8 racks. Each two racks perform all the necessary processes for one pair of dual polarization signals, and they are composed of three kinds of box-like modules. Also, module structure can be easily replaced by a few persons at the high site from the viewpoints of operability and maintainability.

4. Verification of the ACA Correlator

We have performed verification tests of design and implementation for the scientific function, stability, and performance of the ACA Correlator.

4.1. Function test using known signal data

The output of calculated results from the ACA Correlator were checked to be bit-accurately coincident with our developed simulator using known input data, for various sets of correlator configurations. Figure 2 demonstrates an example of verification tests of ACA Correlator using known data.

4.2. Long-term integration tests of analog noise

We conducted long-term integration test of analog noise in order to verify the performance of ACA Correlator. In this test, we verified the following two items by inputting 1-bit digitized thermal noise to the correlator and integrating the cross-correlation products for 8 hours:

- There is no harmful sporadic event caused by digital processing
- Noise level decrease in proportion to $1/\sqrt{\text{integration time}}$

Figure 3 shows this test results, which confirm the two verification items; The left plot clearly shows there is no artificial pattern caused by digital processing, and for the right plot it can be clearly seen that the noise level decreases in proportion to $1/\sqrt{\text{integration time}}$.

4.3. Signal receiving and data processing from ALMA antennas

We also conducted the test of receiving signals from ALMA antennas and data processing at Array Operation Site (AOS), and verified that the ACA Correlator successfully received the signals and processed the digitized data without any problems (Figure 4).

REFERENCES

[1] Iguchi, S. et al. 2009, PASJ, Vol. 61, pp. 1-12

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Table 1: Major specifications of the ACA Correlator

Function	Specification
Number of antennas	16
Number of inputs per antenna	4 baseband × 2 polarizations = 8 baseband
Processing bandwidth per input	2 GHz
Number of bits per sample	3 bits
Maximum delay compensation	> 18.5 km
Maximum number of processed correlations per input	120 cross-correlations + 16 auto-correlations
Highest frequency resolution	3.8 kHz
Integration in the time domain	1 or 16 msec (for auto-correlations), 16 msec (for cross-correlations)
Maximum correlator output rate	8192 frequency channels per baseband

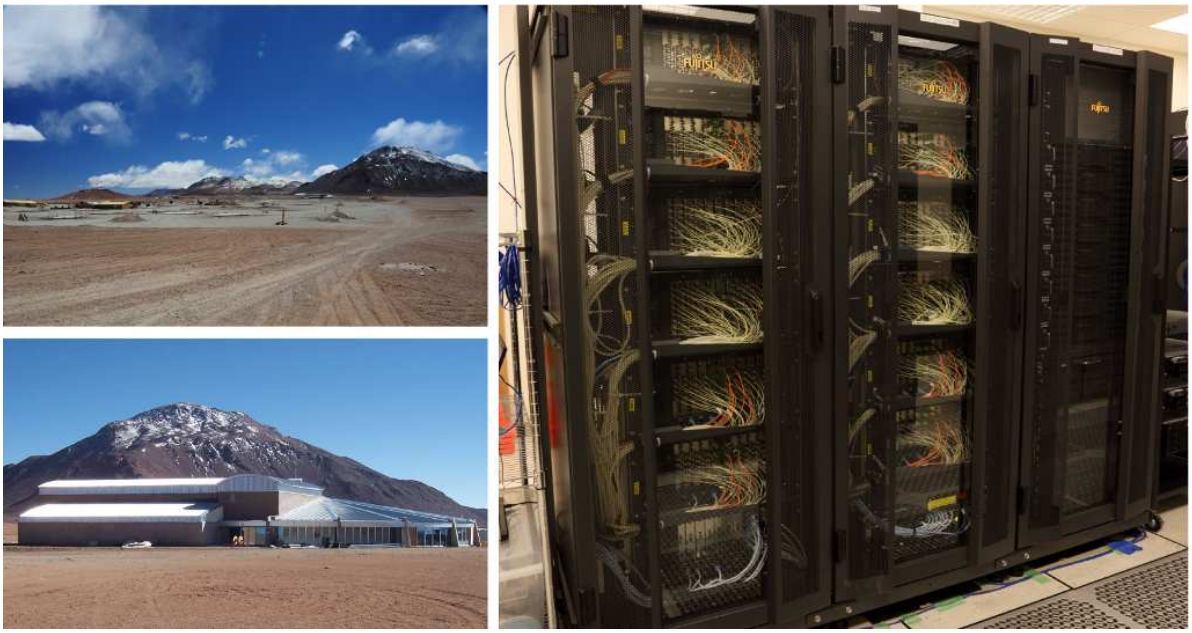


Fig. 1.— **Upper-Left:** A photo of Array Operations Site (AOS) (September 2009). **Lower-Left:** The AOS (Array Operations Site) Technical Building. **Right:** ACA Correlator racks.

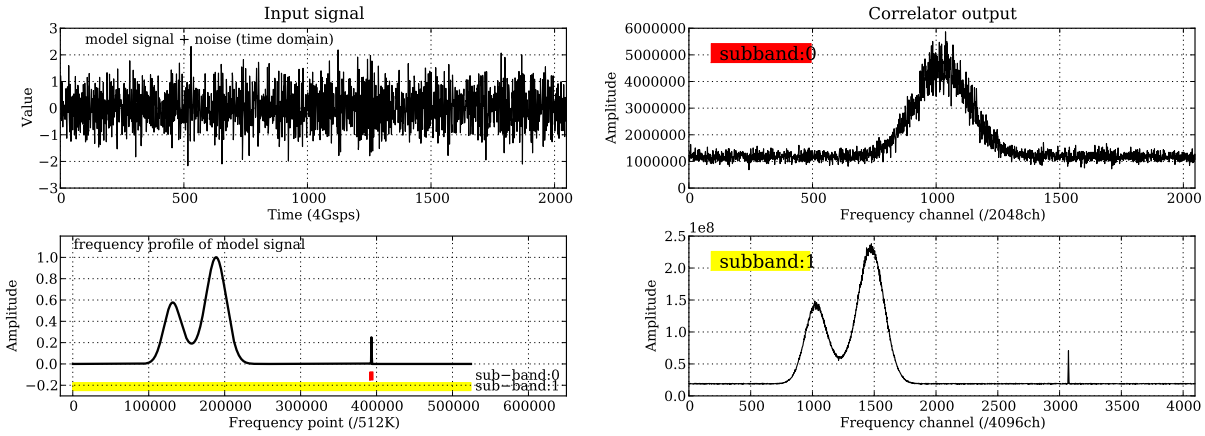


Fig. 2.— **Left:** An example of input data. For this input, the ACA Correlator was configured to have two sub-bands within the 2GHz baseband; one has a bandwidth of 15.625MHz with a frequency resolution of 7.629kHz (Red), and the other has a bandwidth of 2GHz with a frequency resolution of 488.28kHz (Yellow). **Right:** Correlator output (autocorrelation) for the sub-band 0 and 1, which show the autocorrelation spectra of a part of 2GHz bandwidth with high-resolution and overall profile within the 2GHz baseband.

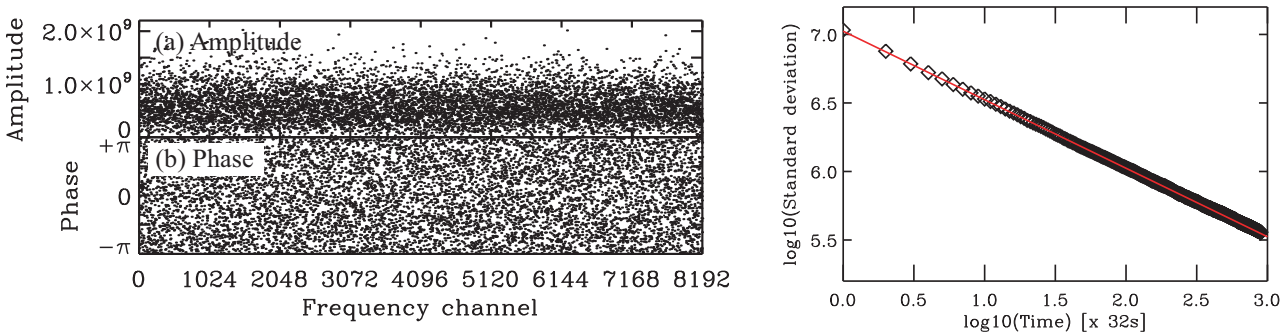


Fig. 3.— **Left:** Amplitude and phase of cross-correlation spectra integrated over eight hours. Its spectral bandwidth and resolution are 31.25 MHz and 3.815 kHz, respectively. **Right:** Amplitude root-mean-square of cross-correlation spectra as a function of the total integration time. It is overlaid by a red line with inclination of $1/\sqrt{\text{integration time}}$.

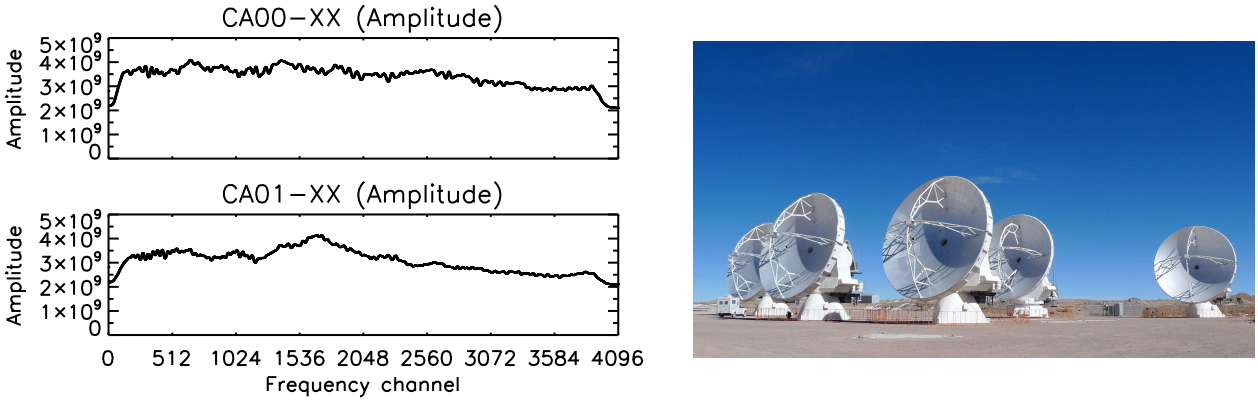


Fig. 4.— **Left:** ACA Correlator output for antenna input CA00 and CA01: amplitude of auto-correlation spectra for the signal from two ALMA antennas (Quadrant-1, bandwidth:2GHz, resolution:488kHz, 4096 frequency channels/polarization, polarization:XX, integration:4s). **Right:** ALMA 12-m antennas at AOS.