Development of 4-Gsps 2-bit ADC with GaAs ICs for radio astronomy

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Abstract — **We developed two sets of the prototype of 4-Gsps 2-bit Analog to Digital converter (ADC) with GaAs IC for the realization of 4 GHz sampling in an ADC system of Atacama Large Millimeter / submillimeter Array (ALMA). This consists of three sets of 12-Gbps Decision Circuits and 12-Gbps Demulitiplexers, and has a capability of sampling in a bandwidth of 6 GHz. Toward the implementation of GaAs IC in the ADC system, we measured the sampling jitter of the ADC using the Ultra-Wide Band Correlator (UWBC) developed for the Nobeyama Millimeter Array (NMA). The measured Allan standard deviation of phase, corresponding to the stability of sampling timing is 2.3×10^{-15} at 10 seconds, and the Allan standard deviation due to the Flicker-frequency noise is 0.8×10^{-15}. It is shown that the coherence loss successfully becomes 0.95 at coherence time of 86400 seconds (24 hours). The Alan standard deviation of sampling timing and its long-time stability are acceptable for the application of radio astronomical ADC system.**

I. INTRODUCTION

The radio interferometer technique was developed toward the higher angular resolution to measure positions and angular size of astronomical objects with greater precision in radio astronomy. The synthesis telescope is the radio interferometer designed to fully exploit the earth rotation technique and to apply it to large numbers of radio sources. In a radio astronomy the white Gaussian noise from a celestial radio source is received by a radio telescope (this is called a "signal"). Toward the higher-sensitivity radio interferometer, it is essential to realize wideband observations.

In 1990's the Nobeyama Millimeter Array (NMA) was developed at Nobeyama Radio Observatory in National Astronomy Observatory (NAO), Japan, in which the bandwidth of 1024 MHz has been realized using the Ultra-Wide Band Correlator (UWBC) [1]. The Analog to Digital Converter (ADC) with the 1024-MHz bandwidth is now the world record in the operation of millimeter arrays. Toward the complete synthesis radio telescope at submillimeter and millimeter wavelengths, the design and development phase of Atacama Large Millimeter / submillimeter Array (ALMA) is now underway [2]. The realization of ADC with a sampling frequency of more than 4- or 4-Gsps and a quantization of more than 4- or 4-level (2 bit) is required from the ALMA Science group. Thus, we can obtain the spectroscopic imaging of redshifted lines from cosmologically-distant galaxies, and spectroscopic studies of galactic disks and spiral structure kinematics, and spectroscopic chemical analysis of protostars, protoplanetary systems and galactic nuclei.

The wideband ADC is necessary to break through the frontier of radio astronomy. The over 20-Gbps decision circuit using AlGaAs/GaAs heterojunction bipolar transistors is developed in the study of optical transmission systems [3]. Also, the 10-Gbps demultiplexer using an ECL-compatible low-power-consumption GaAs has been developed for high-speed optical communication systems [4]. Since these devices can be diverted to the sampling and quantization processes, it is possible to develop the wideband ADC system for a radio astronomy using such high-speed decision circuit and demultiplexer. In this paper, we present the results of the measurements of fundamental astronomical characteristic and phase stability of GaAs sampling IC in section II, and the contents of the design and structure of 4-Gsps 2-bit ADC with GaAs IC for a radio astronomy in section III. Finally, section IV provides the conclusions and the views on the future.

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II. Measurement of Astronomical Performance of GaAs Sampling IC

For the realization of a radio interferometer, it is necessary to realize the ADC with the sampling jitter of less than 10^{-12} [5]. We have to investigate the performance of the GaAs sampling IC before we implement that to the ADC. We present the test bench for the measurement of phase stability in subsection II-A, and the measurement results of sampling jitter in subsection II-B.

A. The test bench and results for measurement of astronomical performance

The test bench of the measurements of astronomical performance is shown in fig.1. First, wide-band Gaussian noise generated by a Noise Generator is distributed to two ports with IF distributor. Each distributed analog waveforms are limited to a bandwidth of 1 GHz to 2 GHz using analog filters that reduce the aliasing or foldover of noise from frequencies above the band edge due to the sampling process. Next, those analog waveforms are sampled, and digitally quantized with two sets of 1-bit 8-Gsps ADC (fig.2 and fig.3). Since the digital signal of 8 Gsps is reduced to 2 Gsps in digital transmission lines, the digital waveforms are converted to baseband in frequency range of 0 GHz to 1 GHz. Finally, these digital waveforms of 1-GHz bandwidth from two ADCs are correlated using the UWBC, which is the digital spectro-correlator for the NMA, with 128 lag [1].

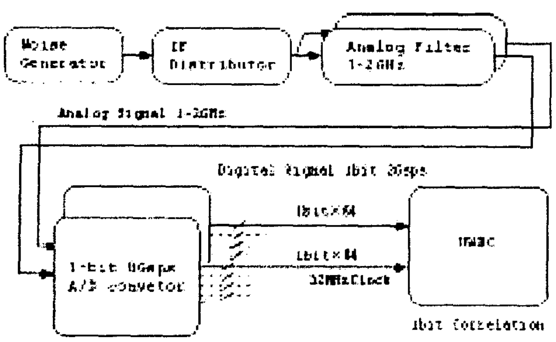

Fig. 1. The test bunch of the measurements of astronomical performance using the UWBC that was developed for the NMA. The ADCs quantize samplehold signals at 1bit only while UWBC correlates digital signals at 2bit. Thus, the max transmission rate is 4 Gbps with the 2 bit quantized 2 GHz sampling, but a low bit in the transmission line of 2bit has no signal.

We have measured some important parameters about the 1-bit 8-Gsps ADCs. The passband characteristics over the 1-GHz bandwidth have less than 10% variation as shown in fig.4. The linearity is confirmed to be good over one order of magnitude through the linearity measurement for CW signals. And the width of the indicision regions is estimated about 50 mV at 1-V full scale.

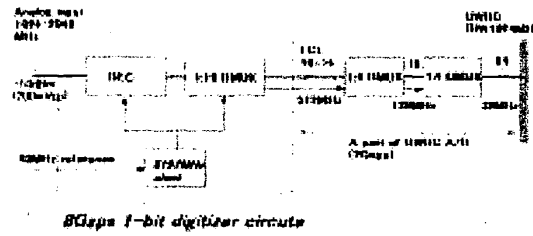

Fig. 2. Block diagram of 1-bit 8-Gsps ADC experiments. Fig.3 shows the circuit within the dotted square.

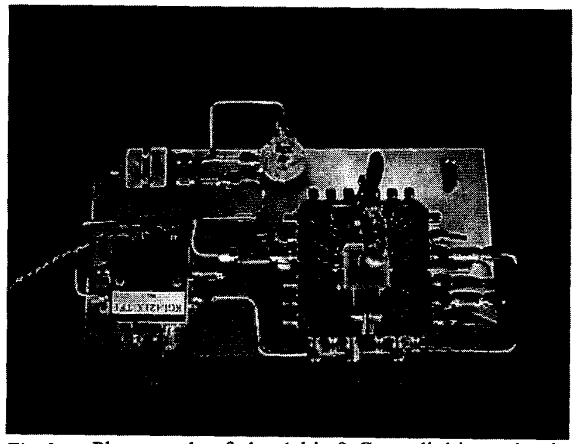

Fig. 3. Photograph of the 1-bit 8-Gsps digitizer circuit corresponding to the dotted square in Fig.2.

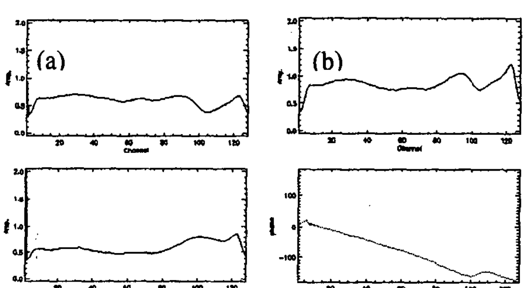

Fig. 4. (a) Amplitude spectra of the auto-correlation with 1-GHz bandwidth. Upper and lower spectra are for two AD Cs. (b) Spectra of the cross-correlation. The upper panel shows the amplitude spectrum, and the lower one shows the phase spectrum.

B. The measurement results of phase stability

We measured the Allan standard deviation with the phase of cross-correlation coefficient from UWBC. The results are shown in fig.5. The Allan standard deviation is 2.3×10^{-15} at 10 seconds, and the Allan standard deviation due to the Flicker-frequency noise is 0.8×10^{-15}. These results are including the sampling jitter due to the timing fluctuation of sampling intervals and the aperture jitter due to the time- and response-delay fluctuation of the samplehold keeping and the amplitude fluctuation of indecision region for two identical ADCs. We don't need to separate each jitter effects to estimate the coherence time for a radio interferometry. Assuming that the Random-Walk frequency noise is inexistent, we derive the coherence loss of 0.95 at coherence time of 86400 seconds (24 hours) using the IF frequency of 4 GHz from the measurement results of Allan standard deviation [5]. The measurement time of 1000 seconds x 10 sets might be short to estimate the Allan standard deviation due to the Random-Walk frequency noise. It is confirmed, however, that the developed ADCs successfully realize the requirement of the ALMA observation time for one sequence of an object (e.g. 1000 seconds). If the turnover to the Random-Walk frequency noise in the Allan standard deviation response starts at 1000 seconds, we estimate the coherence time of 28800 seconds (8 hours) with the loss of 0.95.

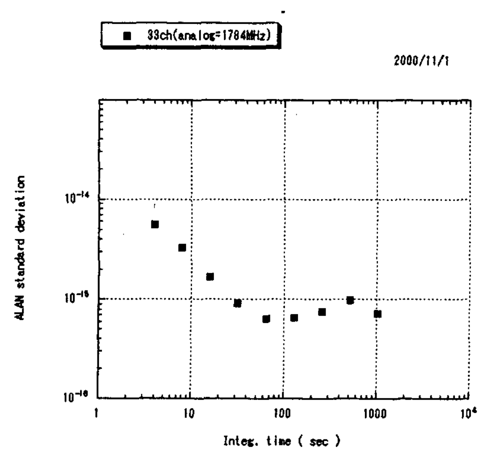

Fig. 5. Allan standard deviation of 1-bit 8-Gsps ADCs with a GaAs Decision Circuit and a GaAs Demultiplexer.

III. DEVELOPMENT OF 4-GSPS 2-BIT ADC SYSTEM

In the previous section, we have measured the important astronomical performances of 1-bit 8-Gsps ADC with GaAs ICs. They are passband characteristics over the GHz bandwidth, size of the indicision region, and Alan standard deviation of sampling phase and its long-time stability, are all acceptable for the application of astronomical ADC system. Therefore we have started the developments of 4-Gsps 2-bit ADC system for the astronomical signal processing with the GaAs sampling ICs.

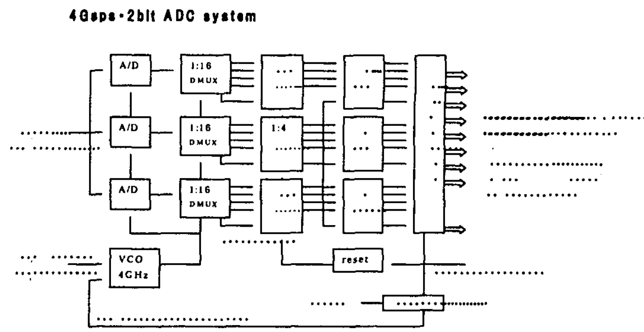

Fig. 6. Block diagram of 4-Gsps 2-bit ADC system using GaAs ICs. Shaded blocks are GaAs Decision and 1:16 DMUX chips, which have been confirmed their astronomical performances. Actually the encoder part is the separate frame from the other ADC part and they are connected with SCSI cables.

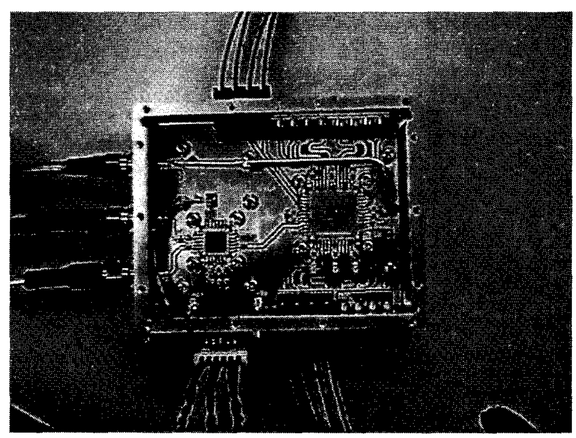

Fig. 7. Photograph of one set of GaAs Decision IC and 1:16 DMUX ICs. Left small IC is the Decision and right large one is the 1:16 DMUX IC. In the left side of the frame, sampling clock and analog signal are put into the printed board. Upper and lower blue cables are de-multiplexed digital signal and lower colored twisted cables are the power and ground lines.

Fig.6 shows the block diagram of 4-Gsps 2-bit ADC system. Input analog signal is sampled with 4096MHz clock using GaAs Decision (sample-hold) chips, and the digital signal is de-multiplexed with 1:16 and 1:4. Three sets of GaAs Decision and 1:16 DMUX chips are installed to make 2-bit resolution (see Fig. 7). They have been already confirmed the astronomical performances.

The encoding of 2-bit is proceeded after the de-multiplication of 1:4 at 64-MHz clock stage. The output signal is 2-bit 64 parallel ECL data with 64 MHz clock. Goals of the development of this ADC system are to establish a few GHz sampling technology for radio astronomy and to measure multi-bits 2GHz-bandwidth spectral performance with the combination of 2-GHz bandwidth FX-type spectro-correlator [6].

Now we have made two sets of the ADC system and are measuring the precise distribution of high and low bits for wide-band noise signal in order to make singal-to-noise ratio maximum in the case of astronomical observations (e.g., [7]).

IV. Conclusion and Future View

We are developing 4-Gsps 2-bit ADC system with GaAs sampling ICs for the application of radio astronomical observations. Before starting the development of the ADC system, we made the measurements of astronomical performances of the high-speed GaAs samplimg ICs : passband characteristics over the GHz bandwidth, size of the indicision region, and Alan standard deviation of cross-correlation phase and its long-time stability. They are all good enough for the application of astronomical ADC system. Then we started the development of the 4-Gsps 2- bit ADC system. Now we are preparing the 2-GHz wideband sub-millimeter (0.8-micron wavelength) observations using the two sets of the ADC system and 2-GHz bandwidth FX-type spectro-correlator with Nobeyama Millimeter Array.

After finishing the analysis of overall sensitivity for the astronomical observations, we plan to start the development of the sampling LSI, whose sampling speed is 4 – 8 GHz with 2 or 3 bits. It is an important key to success high-sensitive wide-band observations with millimeter and sub-millimeter radio astronomy.

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