ALMA SECOND GENERATION CORRELAOTR – AN FX CASE

Sachiko K. Okumura [1], Yoshihiro Chikada[2], Munetake Momose[3], and Satoru Iguchi[4]

[1] Nobeyama Radio Observatory, National Astronomical Observatory, Nobeyama, Minamimaki, Minamisaku, Nagano, 384-1305, Japan
sokumura@nro.nao.ac.jp

[2] National Astronomical Observatory, Osawa, Mitaka, Tokyo, 181-8588, Japan
CHIKADA.Yoshihiro@nao.ac.jp

[3] Institute of Astrophysics and planetary science, Ibaraki University, Mito, Ibaraki, 310-8512, Japan
momose@mito.ipc.ibaraki.ac.jp

[4] As (2) above, but E-mail:iguchi@nro.nao.ac.jp

ABSTRACT

We report the feasibility study of a high-dispersion FX correlator for ALMA second-generation correlator. This FX correlator always realizes both super-high spectral-resolution (< 0.1km/s at 40GHz) and wideband (> 700km/s at 850GHz) observations simultaneously up to 850GHz for each 2GHz baseband of ALMA. It consists of 1 Mega - point FFT parts, 4-bit cross-correlation parts, and control parts. Re-quantization before cross-correlation and flexible frequency-channel smoothing are new features which were not implemented in conventional FXs. Realization of this correlator will allow us to make breakthrough in both sub-millimeter line and continuum observations with ALMA.

HIGH-DISPERSION FX CORREALTOR PROPOSED BY JAPAN

As the ALMA second-generation correlator, **we propose a high-dispersion FX correlator** in order to realize wideband and high-resolution observations simultaniously. The specifications of the FX correlator are summarized in Table 1. This FX correlator is characterized by the following performances: wideband(2048 MHz), super-high frequency resolution by 1024 x 1024 point FFT, and very large integration(max. 3160 correlations / baseband). This system should support the full polarization observations(RR, RL, LR, and LL correlations) and some kinds of single-dish mode observations.

The processing bandwidth per one baseband is 2048MHz assuming eight basebands per antenna. The total bandwidth does not depend on the highest frequency resolution. Spectral resolving points of the FFT parts at one baseband of one antenna is 1024 x 1024, and this number is also fixed for each antenna and baseband. The highest spectral resolution is 4 kHz. We plan 3-bit sampling and 4-bit correlation. Just after the calculation of correlation, ***flexible frequency-channel smoothing*** is performed according to the request of observers. It reduces the output frequency bins from 524288(=512 x 1024) to at most 8192 per baseband. Typical (maximum) data rate is estimated to be 4Byte x complex x 8 x 1024channel x 2016correlations / 0.1(0.016)sec = 1.3(8.3) GB/sec/baseband. This method realizes the reduction of cost with maintaining the total bandwidth of 16GHz and the highest frequency resolution of 4 kHz simultaneously. Total maximum correlation number is 8 times 3160.

We show the block diagram of the FX correlator in Fig. 1. The digital data from one baseband of one antenna are sent to the F-part of the FX correlator with 128MHz clock. In the F-part, delay compensation up to 50 km and 1024 x 1024 - point FFT are performed for the 32 parallel data(Fig. 1 left) and 524288 - channel spectral data are obtained. Functions of phase switching and delta W correction (residual fringe rotation) are also supported in the F-part. After the ***re-quantization*** and the arrangement of data-order, the correlations of the 524288 - channel spectral data from different antennas are calculated and the ***frequency-channel smoothing*** is performed in the X-part. Then the number of frequency bins is reduced to 8192 or less and the smoothing spectral data are integrated (Fig. 1 right).

We install a new function, ***re-quantization***, in the F-part. After 1024 x 1024 - point FFT, the spectral data are normalized using auto-correlation data, and we can decrease the number of bits of the complex data sent to X-part from 9 bits to 4 bits. This function resolve the previous cabling problem of FX compared with XF, pointed out by Escoffier et al[1]. We have estimated the signal-to-noise ratio of the re-quantization of Gaussian noise with simulational study. It is about 0.988 with 4-bit re-quantization for a 512-channel spectrum with complex 9-bit expression.

Table 1. Specifications of the high-dispersion FX correlator system

Number of antenna	64(max. 80)
Number of baseband inputs per antenna	8
Digitizing format	3 bit, 8 levels
Clock	128MHz*
Processing bandwidth per baseband	2048MHz
Maximum baseline delay range	50km (unit of 2.3m)
Number of FFT points	**1024 x 1024**
Phase SW demodulation	YES (90deg. and 180deg. with 256 μ sec unit) *# Offset fringing is also possible.*
Delta W correction	YES (max. 2.3m)
Re-quantization	***YES(9bit=>4bit)***
Wave-front clock application	*YES*
Window function	YES
Correlation format	**4 bit, 16 levels**
Number of correlation	**2016 (max. 3160 for 80 antennas)**
Output cross-correlation frequency bins	**8192, 4096, 2048, 1024, 512***
Auto-correlation per antenna	YES(output frequency bins are the same as above.)
Fastest dump times	16msec, 1msec*
Product pairs possible for polarization	RR, LL, RL, LR (for orthogonal R and L)**
Number of sub-array	*No limitation****

**Total processing bandwidth of analog signal is reduced from 16 to 8 GHz due to the calculations of RL and LR correlations.
***In the case of more than 4 sub-arraying, the same frequency-smoothing parameters have to be recommended.

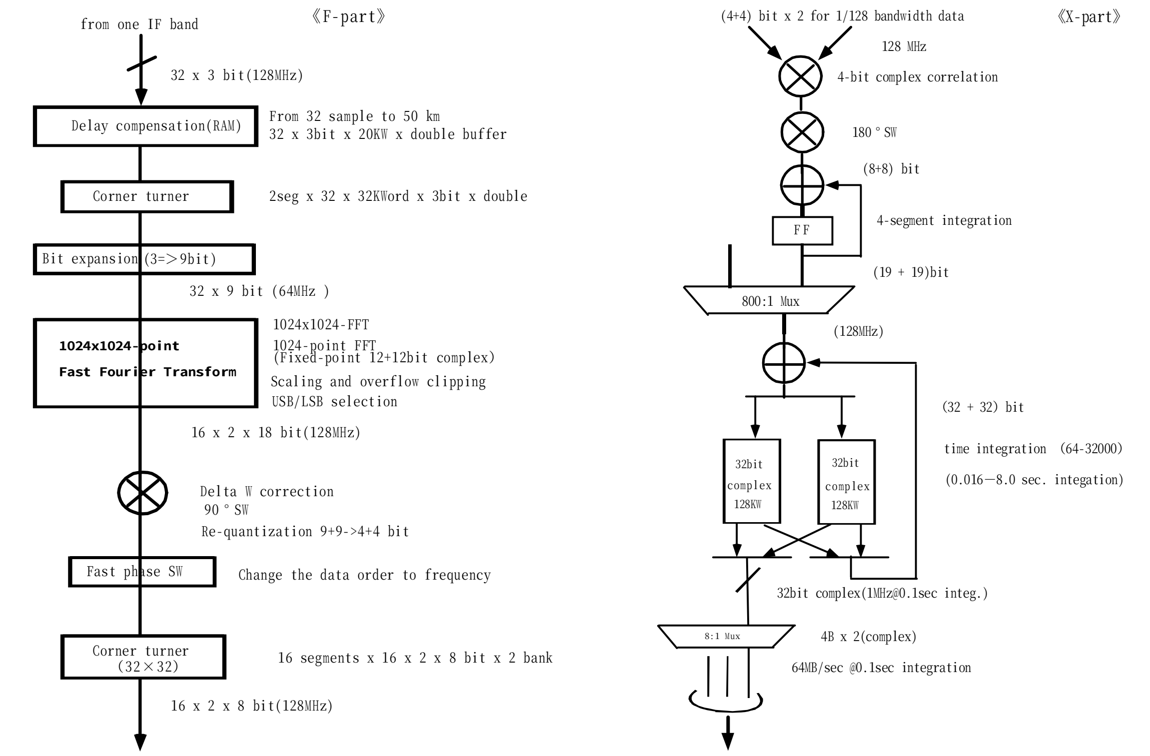

Fig. 1. Block diagram of the high-dispersion FX correlator. Left panel shows the F-part and the right panel shows the X-part.

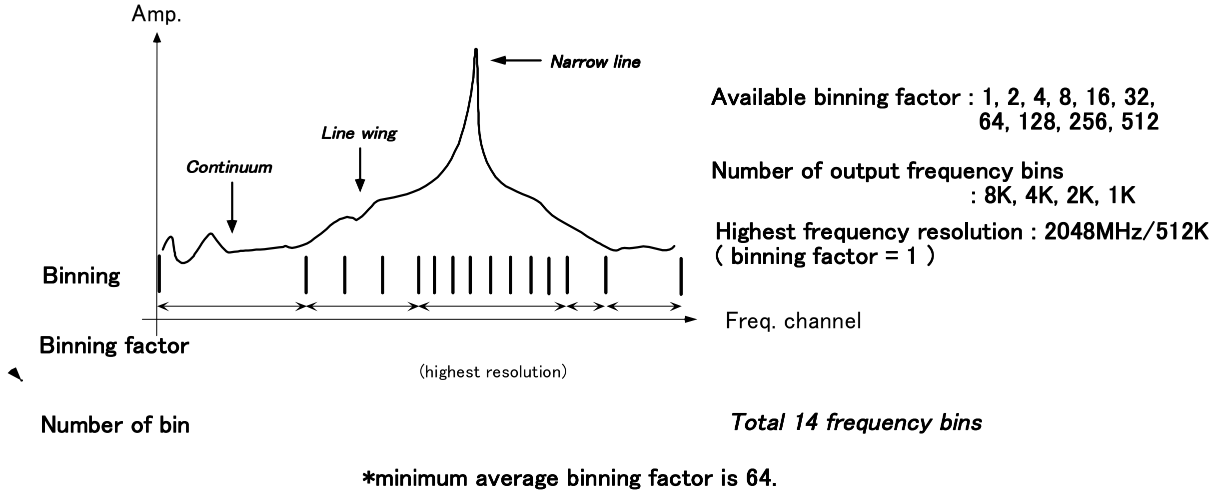

Fig. 2. Example of the flexible frequency-region smoothing. K means 1024.

Flexible frequency-channel smoothing is also newly applied for the spectral data just after the calculation of correlation in the X-part. Observers can determine the appropriate frequency-resolution for the corresponding frequency regions freely at the unit of highest frequency-resolution over the full 2-GHz baseband. The example of the frequency-channel smoothing is shown in Fig. 2. Such frequency binning has similar effect to the data overlapping[2] for recovering the sensitivity relative to XF correlator. We can obtain 1 % of relative loss of signal-to-noise ratio to XF correlator in the case of 64-channel binning, which is the minimum average binning factor in the frequency-channel smoothing from 524288 to 8192.

Using this FX correlator system, **we can always map all the lines in the 2GHz-bandwidth 8 basebands with super-high velocity resolutions (< 0.1km/s at 40GHz), and obtain 16GHz-continuum data and line data with enough velocity coverage (> 700 km/s at 850GHz) .** *Realization of this correlator system will allow us to make breakthrough in both sub-millimeter line and continuum observations with the enhanced ALMA.*

FEASIBILITY STUDY OF THE PROPOSED FX CORRELATOR SYSTEM

Estimated Physical Size and Power Consumption

Here we roughly estimate the hardware size and power consumption for 78- and 64- antennas along with the above-mentioned architecture with the reference of those of the test FX correlator. The numbers in the parentheses are for the 64-antenna case. F-part for two antennas consists of one delay-tracking board, two FFT boards, and four corner-turner boards including re-quantization and arrangement of data-order. Eight special-purpose LSIs to calculate FFT are installed on one FFT board. Seven printed boards are necessary for F-part of one baseband of two antennas. The total number of boards for F-part of 78(64) antennas per one baseband is 273(224). In the X-part, 10 data-gathering boards, 16 correlation boards, and two multiplex boards are needed for the calculation of 3003 correlations and integration of 1/8 spectral data of one baseband. Four special-purpose LSIs to calculate correlation are also installed on one correlation board. Total number of boards of X-part per one baseband is 112. Other than the F- and X-parts, the FX correlator has the control part in order to interface the data and control network of ALMA system. It consists of eight data-buffer boards, five CPU boards, including 10 "Gbit-ETHER" circutes for 1/4 spectral data of one baseband. The total number of printed boards of control part is 52(39). Thus the total number of boards for the FX correlator per one baseband is 436(375)+30(24)=466(399). Here we need 30(24) interface boards among F-, X-, and control parts. We use relatively large back-plane to connect about 30 printed boards. The number of back-plane for the FX correlator per one baseband is 10(8) for F-part, 4 for X-part, and 4(3) for the control part. In this case, block diagram of the structure of the printed boards and back-planes for one baseband of 78-antennas are presented in Fig. 3.

Power consumption rate of LSI are getting better due to the recent progress of technology. Now it is less than 0.02 μ W/gate/MHz at the end of 2000 (0.18 μ m process, low-power mode). So we are able to put 1 - 2 Mega-gate circutes into LSI at 128MHz clock cycle with usual air-cooling operation. Power consumption is roughly estimated based on the above block diagrams. Main contributions are two kinds of special-purpose LSIs(FFT and correlation) and large-scale memories. The FX correlator for one baseband, 640(512) FFT-LSI and 256 correlation-LSIs are assumed with 0.18-micron process gate-array. Typical power consumption of such gate-array installed Mega-gate circutes is about 2 Watt. The total power consumption will be estimated about 12.0(9.6) kW for one baseband of F-part, 4.5kW for X-part, and 1.5(1.1) kW for the control part. Thus the estimated total power consumption per one baseband is 18(15.2) kW and that of all the basebands is 145(122)kW as a typical value except for fan motors.

SUMMARY

We propose the high-dispersion FX correlator as ALMA second-generation correlator. ***This FX correlator always realizes both super-high spectral-resolution (< 0.1km/s at 40GHz) and wideband (> 700km/s at 850GHz) observations simultaneously up to 850GHz for each 2GHz baseband of the ALMA IF system.*** We estimated reasonable hardware size and power consumption (less than 20 kW per one baseband) based on the detailed specifications. Realization *of this correlator system will allow us to make breakthrough in both sub-millimeter line and continuum observations with the enhanced ALMA.*

REFERENCES

[1] R. Escoffier, "The MMA Correlator", ALMA memo No.166, 1997

[2] Y. Chikada, M. Ishiguro, H.Hirabayashi, M. Morimoto, K. I. Morita, T. Kanzawa, H. Iwashita, and K. Nakajima et al., "A 6 x 320-MHz 1024-channel FFT cross-spectrum analyzer for radio astronomy", Proc. *IEEE*, 1203, p75, 1987

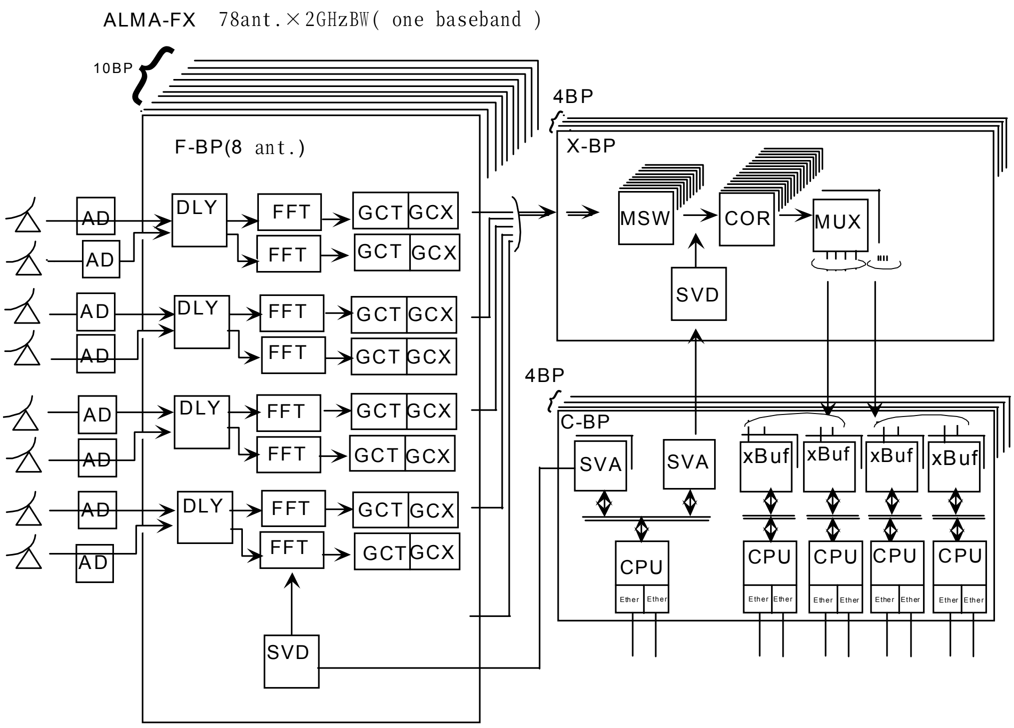

Fig. 3. Hardware image of the high-dispersion FX correlator (one baseband of 78-antennas). One square corresponds to one printed board of 381 mm x 237 mm. This is the case for 78-antennas. F-part consists of delay-tracking boards (DLY), FFT boards (FFT), corner-turner boards (GCT and GCX) including re-quantization and arrangement of data-order, and interface boards (SVD) with the control part. X-part consists of data-gathering boards (MSW), 16 correlation boards (COR), multiplex boards (MUX), and interface boards (SVD) with the control part. The control part consists of interface boards (SVA) with F- and X- parts, data-buffer boards (xBuf), CPU boards (CPU) including "Gbit-ETHER" circutes(ETHER).