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Feasibility Study of the Enhanced Correlator for 3-way ALMA I.

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ABSTRACT

Here we report the feasibility study of the enhanced correlator proposed by Japan for 3-way ALMA. First we briefly review the scientific significance of the enhanced correlator, which does NOT depend on the correlator architecture. Then we describe the proposal of a high-performance FX correlator system for an enhanced correlator of 3-way ALMA. **This FX correlator system 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.** This FX system consists of 1024 x 1024 – point FFT parts, 4-bit cross-correlation parts, and control parts. **Re-quantization *and* flexible frequency-channel smoothing *is newly installed*. Re-quantization** reduces the lines of connection between F and X parts compared with the previous FX system. **Flexible frequency-channel smoothing** makes the output frequency channels from 524288(=512 x 1024) to 8192 per baseband and eliminates the fear that the large amount of frequency channels might increase the costs of post-detection computing and archiving. Realization of this correlator system will allow us to make breakthrough in both sub-millimeter line and continuum observations with 3-way ALMA. We present the detailed specifications, block diagrams, estimated hardware size and power consumption of the high-performance FX correlator system. Preliminary plan for its implementation to the 3-way ALMA is also commented.

1. DESIRABLE FEATURES OF THE SECOND-GENERATION CORRELATOR FROM SCIENTIFIC REQUIREMENTS

The performance of correlators can be basically specified by the following two aspects: (i) the total bandwidth of the input signal, and (ii) the spectroscopic capabilities. Although the total bandwidth of the input signal is directly related to the continuum sensitivity, it is hardly expanded after the construction of the array. We will therefore compare the spectroscopic capabilities of the Baseline Correlator designed with various scientific requirements for ALMA[1], and discuss desirable features of the second-generation correlator for enhanced ALMA. Figure 1 shows performance parameters for typical operating modes of the ALMA Baseline Correlator[2]. When one observes an emission line to study the velocity structure in some astronomical objects, it is usually sufficient to resolve the line into ~100 frequency bins along the velocity axis. The Baseline Correlator will achieve $R_{1b} >= 10^3$ where R_{1b} = (velocity coverage across one baseband)/(velocity resolution) for any velocity resolution (see Figure 1a), indicating that, in a conventional sense, it will enable us to reveal the velocity structure of any astronomical object. Even if one would like to search a narrow absorption/emission line whose central velocity is not known, the total bandwidth covered by all the basebands is always greater than a few thousands times the width of the minimum frequency resolution(see Figure 1b), giving an adequate window along the velocity axis. In summary, the Baseline Correlator will fulfill most of the scientific requirements for line observations in the beginning phase of the array operation.

It is expected, however, that demands for more comprehensive / more challenging observations unable to be made with the Baseline Correlator will be growing as the performance of the ALMA is being improved (by increase of antennas, progress of sub-millimeter receiver technology etc). A possible example of such observations is an imaging line survey of star-forming regions. In order to conduct this kind of observations efficiently, uniform velocity resolution as high as ~ 1km/s across all the basebands is required, but the Baseline Correlator cannot provide such modes of observations (see Figure 1c). Another example is a sensitive spectroscopic search for a gap cleared by a proto-planet in a circumstellar disk around young stellar objects. Although the full-width of the rotation velocity in a disk is as large as ~100 km/s, the velocity

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width of "absent emission" due to the gap can be as small as ~0.1 km/s because the gap width may be fairly small compared to the disk radius[3]. In addition, it is necessary to obtain line-free channels with a sufficient bandwidth within the same base-

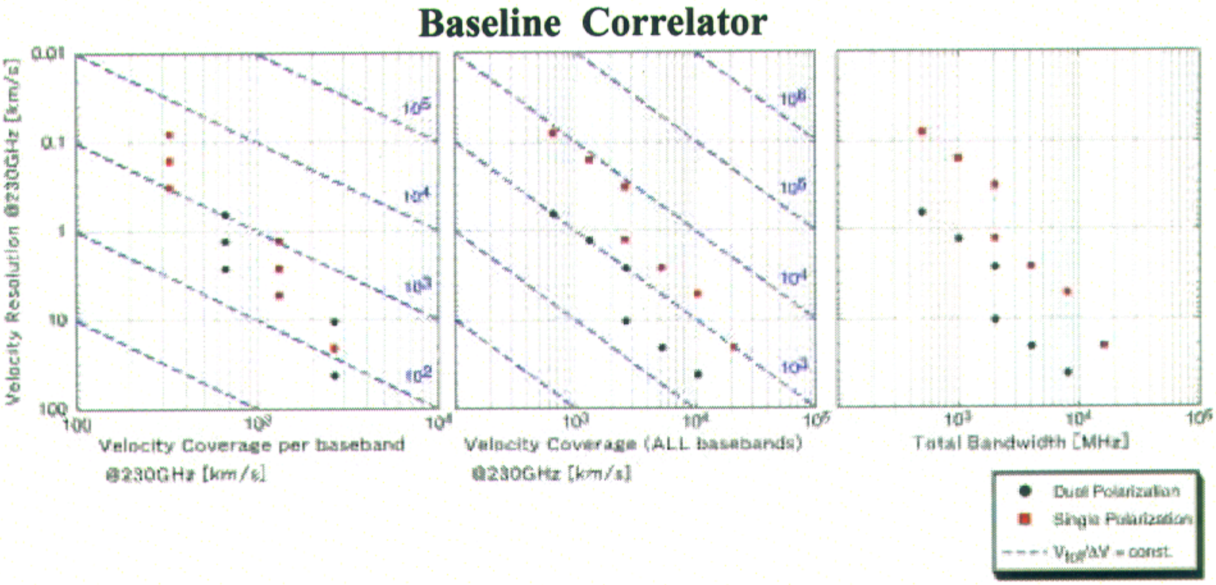
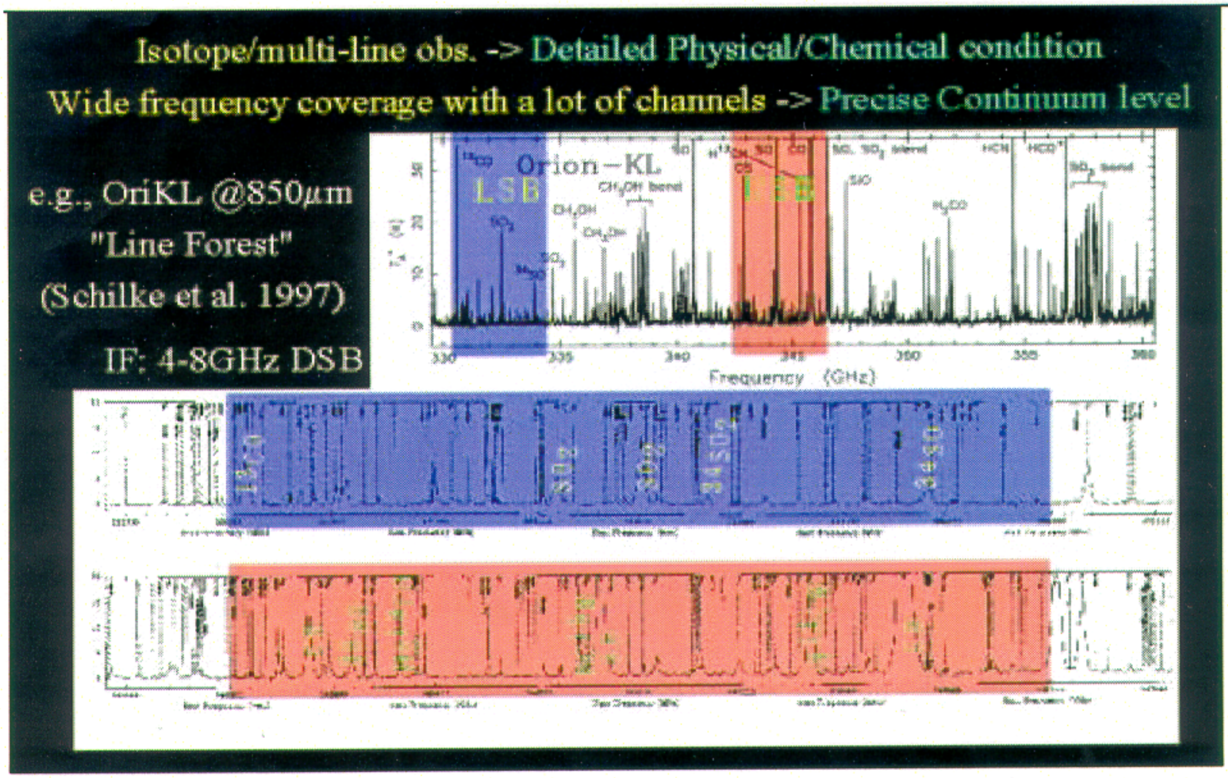


Figure 1. Performance parameters for typical operating modes of the ALMA Baseline Correlator;(a) velocity coverage per one baseband versus velocity resolution, (b) velocity coverage across all the basebands versus velocity resolution, and (c) frequency bandwidth across all the basebands versus velocity resolution. Note that Figures 1(b) and 1(c) are shown for the cases when the same operating mode is applied for all the basebands.



Isotope/multi-line obs. -> Detailed Physical/Chemical condition

Wide frequency coverage with a lot of channels -> Precise Continuum level

e.g., OriKL @850μm

"Line Forest"

(Schilke et al. 1997)

IF: 4-8GHz DSB

Figure 2. Orion KL 4-GHz wideband spectra at 850micron[4].

band in order to make precise subtraction of the continuum emissions from visibility data. Therefore R_{lb} of >~ 10^4, which cannot be available with the Baseline Correlator, is necessary to conduct the gap search toward YSO disks.

A second-generation correlator for the enhanced ALMA should provide "enhanced" spectroscopic capabilities that enable us to make such comprehensive / challenging observations as described above. It should also be noted that higher spectral resolutions provided by the enhanced correlator will allow us: (i) to make ordinary line observations without any loss of continuum sensitivity, and (ii) to separate the contribution of line emissions from that of continuum emissions precisely even in a "submillimeter line forest" toward massive star-forming regions (see Figure 2). The Japanese correlator group is studying the FX-type architecture design[5] for the enhanced correlator to make such comprehensive / challenging observations available.

2. ENHANCED CORREALTOR SYSTEM PROPOSED BY JAPAN

2.1 COMMON EXTERNAL SPECIFICATIONS FOR THE ENHANCED CORRELATOR

Here we summarize the common specifications discussed with the correlator informal meeting and ALG held at Berkeley in September 2000. Maximum number of antennas for the enhanced ALMA to calculate their cross correlations is 78. The number of basebands and the bandwidth of one baseband is the same as the Baseline ALMA IF system, and the enhanced correlator should assume the baseline ALMA backend sub-system; it consists of eight basebands and each has 2-GHz bandwidth. As the scientific requirements, the enhanced correlator should have the spectral resolution as high as 5 kHz. The loss of sensitivity caused by quantization of the signal should be minimized, thus the enhanced correlator should support >=3-bit correlation. One of the typical observational mode, sub-array observations more than 4 have to be available with the enhanced correlator.

Table 1. Specifications of the high-performance FX correlator system for enhanced ALMA

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*** (**see *flexible frequency-channel smoothing*** in section 2.2.)
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.

2.2 SPECIFICATION OF ENHANCED CORRELATOR PROPOSED BY JAPAN - HIGH-PERFORMANCE FX CORRELATOR -

As the enhanced correlator system, **we propose a high-performance FX correlator system** in order to satisfy the requirements described in section 2.1. The specifications of the FX correlator system are summarized in Table 1. This FX correlator system 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(see Figure 3). 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.

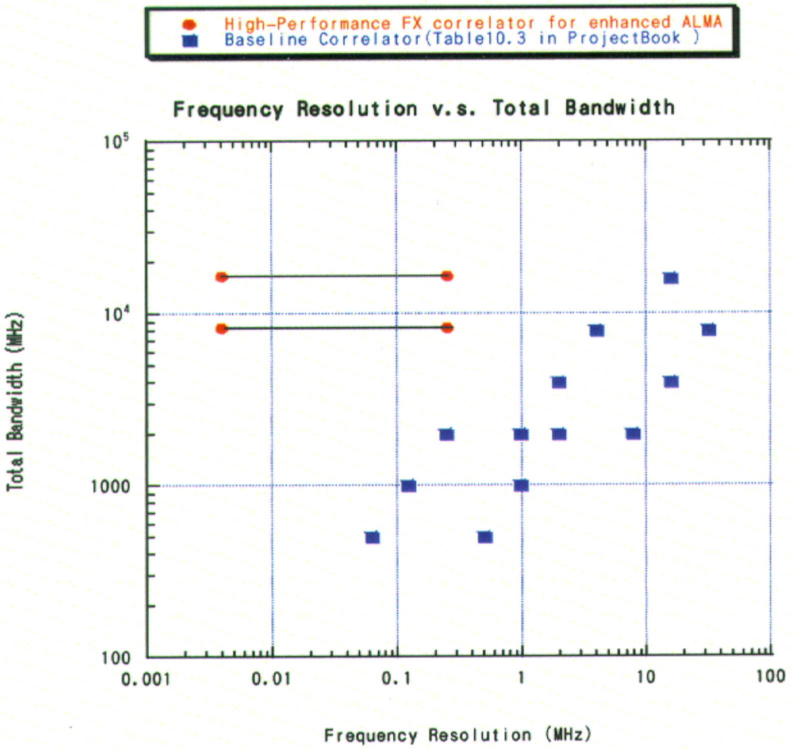


Figure 3. Total bandwidth versus frequency resolution for typical operating mode of ALMA Baseline Correlator(Table 10.3 in Project Book) and the high-preformance FX correlator system(Table 1). X-axis is the frequency resolution, and y-axis is the total bandwidth across all the basebands of ALMA. Left circle of FX correlator shows the highest frequency resolution obtained with the frequency resolving points of 524288(=512 x 1024) over 2-GHz bandwidth and the right one is the average frequency resolution with the output of 8 x 1024 frequency bins over the 2-GHz bandwidth.

We show the block diagram of the FX correlator in Figure 4. 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(Figure 4 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 (Figure 4 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[6]. 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.

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 Figure 5. Such frequency binning has similar effect to the data overlapping[7] for recovering the sensitivity relative to XF correlator. The effect of binning on relative sensitivity is presented in Figure 6. 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.*

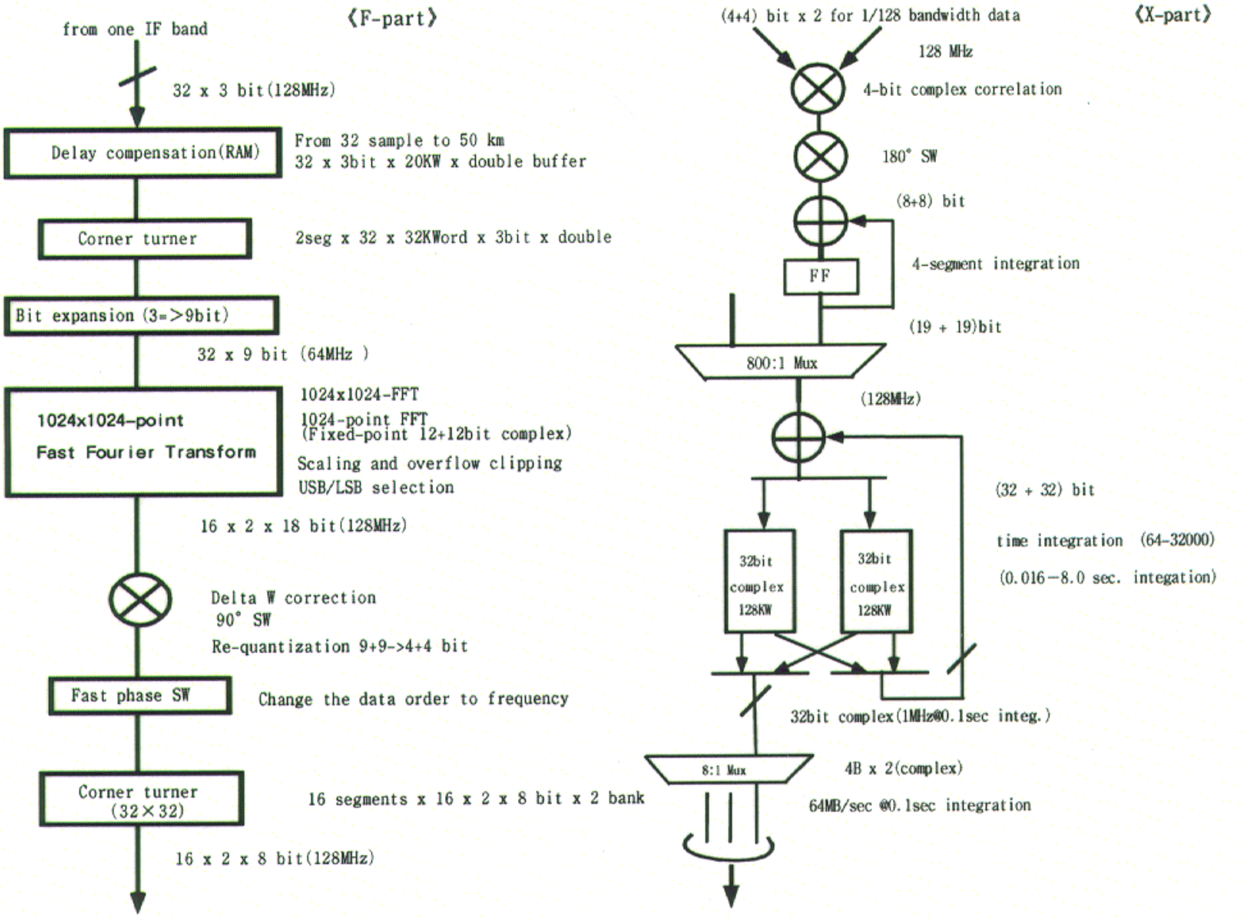


Figure 4. Block diagram of the high-performance FX correlator. Left panel shows the F-part and the right panel shows the X- part.

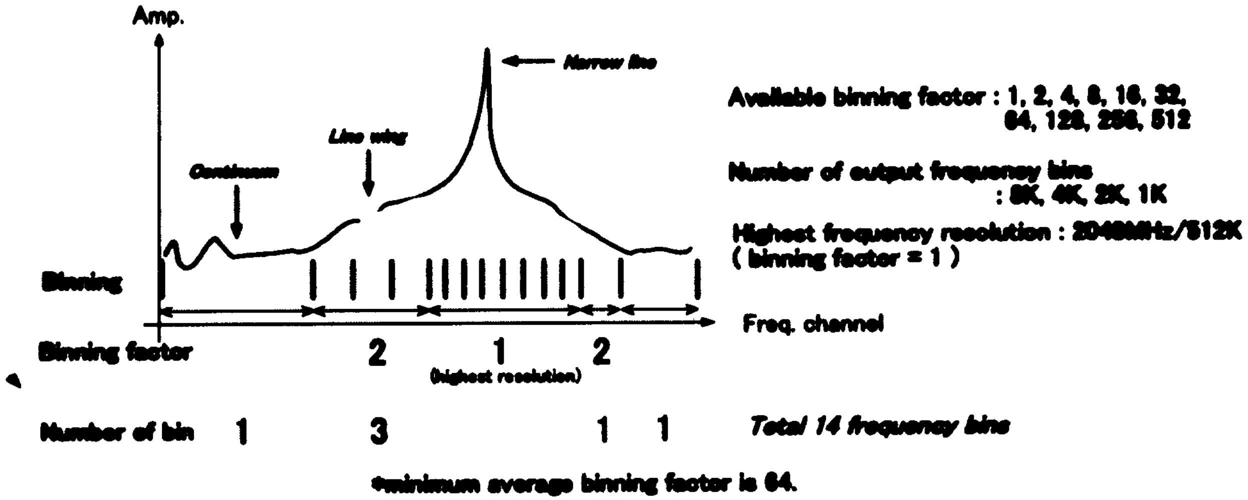


Figure 5. Example of the flexible frequency-region smoothing. K means 1024.

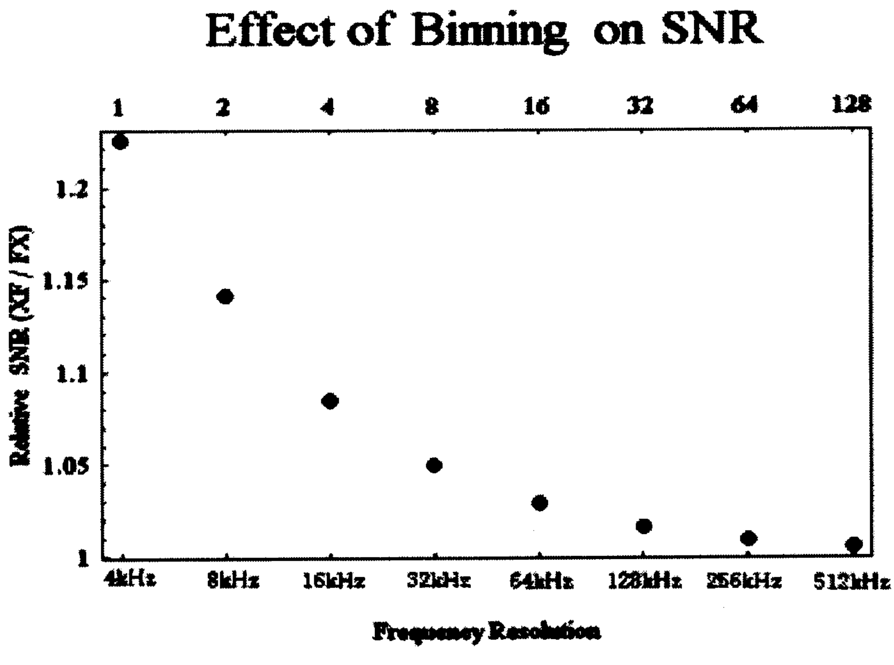


Figure 6. Effect of binning on relative FX signal-to-noise ratio to XF correlator

3. FEASIBILITY STUDY OF THE PROPOSED FX CORRELATOR SYSTEM

3.1 TECHNICAL KEY POINTS AND PHASE 1 ACTIVITIES

The important technical issues to be resolved for the realization of the high-performance correlator system are as follows:

a) **High-speed sampling (>= 4096Mega sample/sec with 3bits),**
b) **A huge number of point FFT with enough computational accuracy (e.g., >100 k point of FFT),**
c) **Pin limitation of boards between F- and X-parts, and**
d) **Power consumption of large LSI and large integration of circuit for a few thousands of correlation.**

Now we are making the development of a minimum test system of the FX correlator to make experiments for the overcome of the technical issue a) and b), and to demonstrate the high-resolution and wideband FX correlator[8]. This test system consists of two 4Gsps 2-bit A/D converters and one FX spectro-correlator(1 baseline) with the bandwidth of 2048MHz. Time table of the design and development of the minimum test system is shown in Table 2.

We have started the design and development of the 4096 Msps 2bit test A/D converter. Analog signal is sampled with 4096MHz clock using GaAs sample-hold chips, and the digital signal is de-multiplexed with 1:16 and 1:4. The output is 2-bit 64 parallel ECL data with 64 MHz clock. Goals of the development of this test A/D converter are to establish high-speed sampling technology, and to confirm the sampling performance for radio astronomy, and to measure the total 2GHz-BW spectral performance with the combination of the test FX correlator. Before starting the development of the above test A/D, we made an evaluational board in order to measure the fundamental sampling performance of the GaAs sample-hold chip : sampling jitter, DC offset, and the width of the indecision region. On the board, one sample-hold LSI and one 1:16 DMUX LSI are implemented. We made 1-bit sampling experiments of analog signal up to 8GHz using 2 sets of this boards. We have just confirmed that input noise data are correctly sampled with 8192 MHz clock and we obtained the 1-GHz noise spectra using UWBC[9] of NMA. Alan variance mainly due to sampling jitter is the order of 10^{-14} at the integration time of 1 sec and it decreases to 1×10^{-15} at 100-sec integration time. Estimated width of the indecision region is less than 50mV at the full scale of 1 V. Since the performance of the 1-bit sample-hold circute seems adequate for an digitizer of ALMA, we have decided to start the development of the test A/D converters using the above GaAs sample-hold chips. These activities are on the cooperation with the European High Speed Sampler group of baseline ALMA project and the technical information are exchanged with Europe and Japan.

We are also developing the test FX correlator in order to overcome the above technical key points b) and part of c). Using this test correlator, we will confirm the computational accuracy of FFT with a huge number of points and apply re-quantization to the spectral data. Re-quantization is the new idea to reduce the number of connection between F-part and X-part of the FX-type correlator. The test FX correlator consists of two F-parts and one X-part. It calculates one cross-correlation spectrum or one auto-correlation spectrum of 131072(=128 x 1024) frequency channels.

Input of the test FX correlator is 2bit 64 parallel ECL data at 64 MHz clock. The data are first put into the delay compensation buffer up to 19km. We are able to control it in both the usual delay tracking and the wave-front clock mode. After delay compensation, 256 x 1024-point FFT is performed with fixed point 18-bit expression (real part 9bits and imaginary part 9bits including a sign bit). 256 x 1024-point FFT is divided by two sets of 512-point FFT and the multiplication of 512 x 512 twiddle factors. The 64 parallel data are set to 32 sets of input data for Radix-2 512-point FFT, and 256 x 1024-point FFT is performed with parallel processing. After the FFT, 90-degree phase demodulation, delta W correction and re-quantization proceeded for 16 sets of the spectral data. The number of bits of the complex data is reduced from 9 bits to 3 or 4 bits with re-quantization. Then the data are sent to the X-part and the complex correlation is calculated

Table 2. Timetable of the design and development of the high-performance FX correlator

<A/D>	
Report of 8Gsps 1-bit experiments	: Feb. 2001
Test system(4Gsps 2-bit, 2sets)	: July 2001 (Start of Performance Test)
Sampling LSI Design (planned)	: June 2001 (Start of Design)
A/D experiments with Europe	: June-August 2001
A/D report for CDR(?)	: Jan. 2002
< FX correlator >	
Test system(2GHzBW 2-bit 131072-channel, one baseline)	: August 2001 (Start of Performance Test)
Enhanced correlator Interim report/PDR(?)	: Jan.-Feb. 2001
Definition of architecture	: End of 2001

with 3 or 4 bits. To confirm the performance of re-quantization, we can select the re-quantized and correlated number of bits, 3 - or 4 - bit complex. After the correlation, 180-degree phase demodulation is performed, and the data are integrated to 0.64 – 3.2 sec.

In the test correlator, only one LSI, 512-point FFT LSI, is designed and developed using 0.35-micron process gate array having a capacity of 1 Mega gates. Now the LSI design was finished and we use about 500 k gate for one 512-point FFT. The manufacture of the test FX correlator will be finished at the end of August 2001, and we will start the performance test with the combination of the test A/D converters next autumn.

3.2 ESTIMATED PHYSICAL SIZE AND POWER CONSUMPTION

For the technical issue c), we have found the convenient way to send the spectral data from F-part to X-part. First we perform the re-quantization and reduce the number of bits of the complex data from 9-bit to 4-bit in F-part. Then we send the data to the board of X-part without any fanout, which will be done in the correlation LSIs. In the X-part, all the correlation calculations of maximum 80 antenna(3160 correlations) are made for each 4096 frequency channel data (1/128 frequency data of one baseband) on one board. Therefore 128 correlation boards are needed for all the calculations of correlation spectra of one baseband. However, we are able to avoid the pin limitation of boards between F- and X-parts.

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 Figure 6. The corresponding physical size of the hardware is shown in Figure 7.

As for the technical issue d), 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.

3.3 EXPANSION POSSIBILITIES FOR FUTURE ALMA

ALMA will become the largest observational system of radio astronomy. It consists of a huge number of hardware components from antennas to correlators. It would not be easy to improve the hardware system after the construction. However, we need about 10 years to complete this observational system and to obtain the astronomical data using full-spec. ALMA. Therefore it is very important that we investigate the expandability of the enhanced correlator system to increase ALMA sensitivity and to obtain new observational capabilities. Some of the important expansions might be easily available with small additional circute and cost for the proposed enhanced correlator system. Considerting the progress of the digital technology, following expansions or implovements are potentially possible for the high-performance FX correlator.

ALMA SIS receivers will have their instantaneous bandwidth of about 4GHz with better receiver noise temperature. ALMA analog IF system will transmit two sets of 2-GHz baseband signal from both two sideband signals with both polarizations simultaneously from one receiver band. Thus if the high-speed sampler up to 8GHz or so will be available in future, the correlator system should process all the 4-GHz bandwidth analog signal at one time to obtain ***better sensitivity*** over the 4-GHz bandwidth and to ***save cost for backend subsystem down to half***. More simple analog system will help us to reduce the analog components and we would be able to ***save maintenance man-power and cost***. We have already proposed the 4-GHz bandwidth high-performance FX correlator system at the previous ASAC face-to-face meeting[10]. Its hardware size and cost are roughly similar to the proposed FX correlator here in case that the total processing bandwidth is 16GHz. We will easily apply higher data processing speed for FX correlator system, because FX architecture is essentially easy to make parallel singal processing.

On the other hand, if we transmit DSB analog signals with 2-GHz bandwidth, it is also possible to save cost of both the backend subsystem and the FX correlator system itself. In FX architecture, the number of F-part is in proportion to the number of antennas and that of X-part is in proportion to the number of correlations. 90-degree phase demodulation is performed after FFT at the end of F-part. So FFT for 2-GHz DSB signals is carried out, and then two sets of 2-GHz SSB signals could be separated with the phase demodulation after FFT. In this case, hardware components of both the backend subsystem and most of the F-part in the FX correlator will decrease to about half than before. As the F-part takes two thirds of the total FX hardware, about 30 % of cost will be saved in the high-performance FX correlator. So we could ***save maintenance man-power and cost.***

Other than the high-speed processing, it is very easy for FX architecture to apply various calculation(calibration) to antenna-based singals, because the number of F-part is in proportion to the number of antennas and we make the bit expansion before FFT in F-parts. Therefore additional operations of calibration are easily applicable to the input data at each clock cycle, and these operations do not cause closure errors because all the operations are antenna-based. Another advantage of FX architecture is to increase the number of correlation bits. The proposed FX correlator will realize the 4-bit correlation, and we are able to keep the relative sensitivity to 96 % corresponding to the quantization efficiency due to the 3-bit sampling.

3.4 PRELIMINARY PLAN FOR THE IMPLEMENTATION

Now we have estimated the implementation plan of the high-performance FX correlator system for the enhanced ALMA. We need 2 years to make detailed design of LSIs and printed circure boards from the start of financial year 2002. After that we make the prototype system and carry out the performance test during a half year, then manufacture the site correlators. Preliminary plans are presented in Table 3.

Table 3. Principal milestones for the implementation of ALMA enhanced correlator

Critical Design Review(?)	2001-12
Start detailed design of LSIs and printed board	2002-spring
Deliver first 1/4 to Chajnantor site	2006-summer
Deliver last 1/4 to Chajnantor site	2009-summer

4. SUMMARY

We propose the high-performance FX correlator system as an enhanced correlator of 3-way ALMA. ***This FX correlator system 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.*

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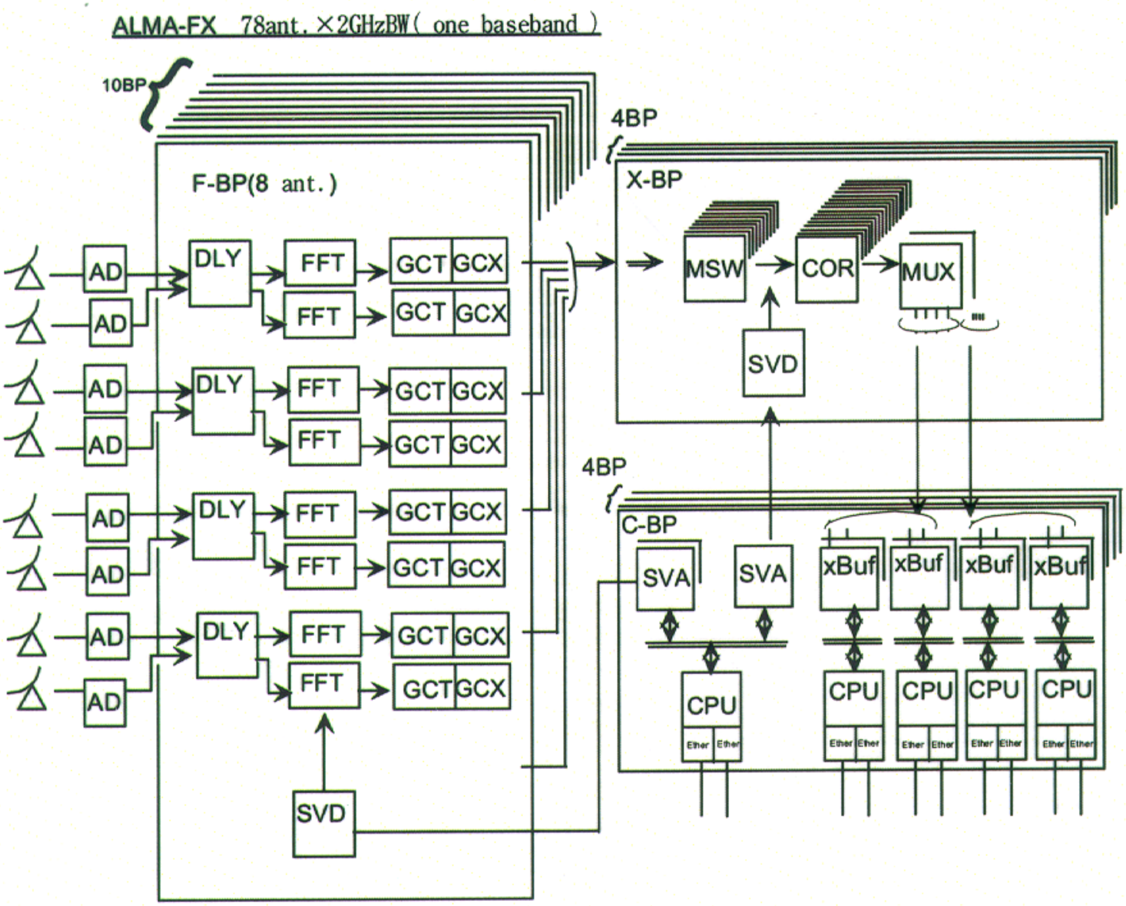

Figure 7. Hardware image of the high-performance FX correlator (one baseband of 78-antennas). One square corresponds to one printed board of 381 mm x 237 mm. This is the case for 78-antennas. F-part consists of delay-tracking boards (DLY), FFT boards (FFT), corner-turner boards (GCT and GCX) including 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).

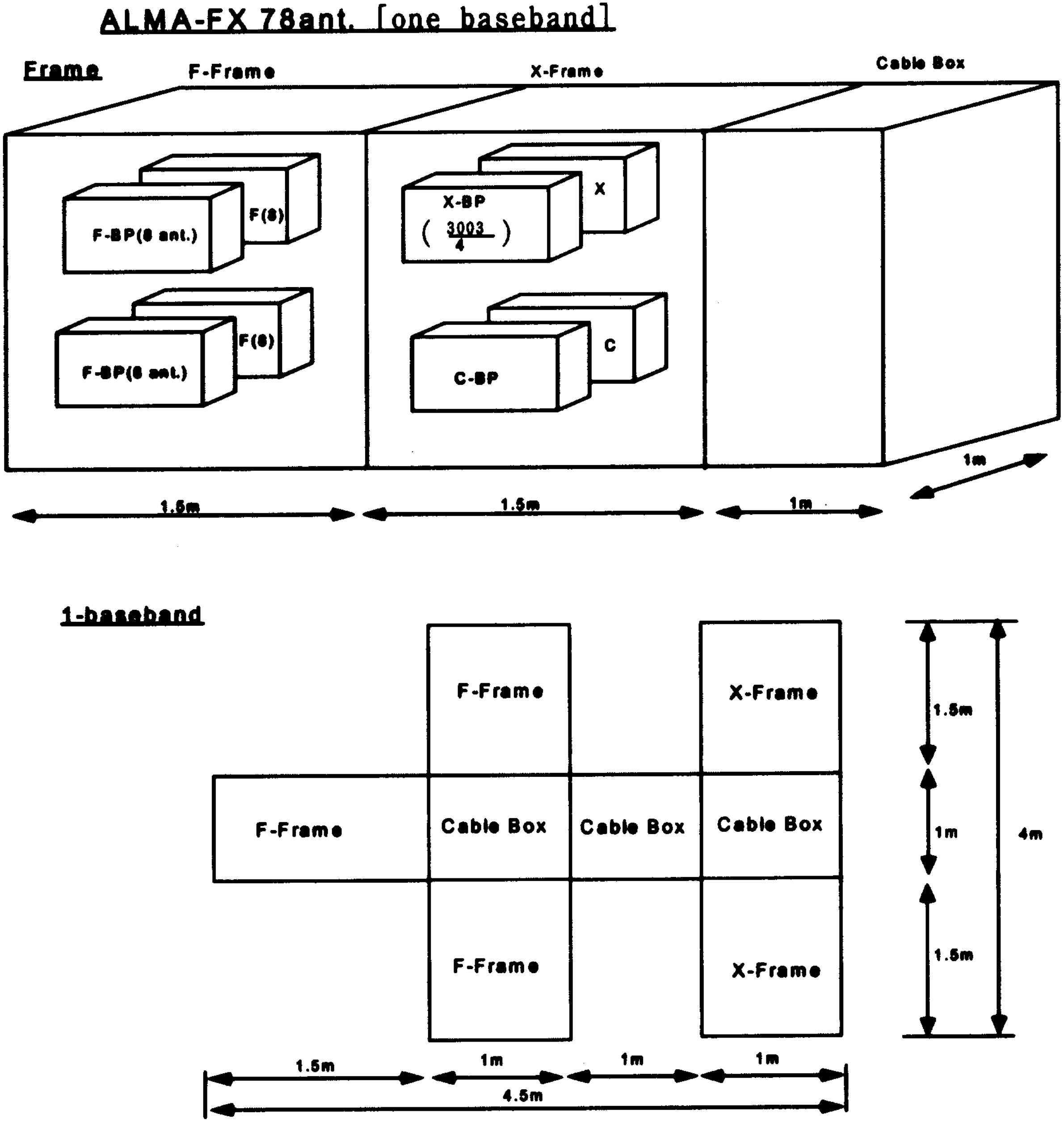

Figure 8. Hardware rack image of high-performance FX correlator (one baseband). One square corresponds to the one box including one back-plane. This is the case for 78-antennas.