ALMA Memo 556

Observational Modes Supported by the ALMA Correlator

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Abstract

Observational modes including multi-resolution operation supported by the ALMA correlator hardware and firmware are presented.

Introduction

A lot of work has recently been done on observational mode support in the ALMA correlator. Mode charts outlining the capacity of the baseline correlator were originally presented in the B version of the correlator specifications and requirements document, ALMA-60.00.00.00-001-B-SPE. In developing the firmware necessary to support the modes in the system, 4 modes defined in this spec were discovered to be impossible because of hardware connectivity limitations in the correlator.

The capacity for multi-resolution operation in the correlator has also recently been defined and will be described below.

Discussion in this memo will be from a hardware and firmware standpoint, giving the capabilities of the system.

With the entire correlator, an observer may specify a set of spectral regions; within the Front End and Back End, 16 GHz (8 GHz per polarization) total bandwidth is digitized. In principle, an arbitrary set of disjoint or overlapping regions could be specified, each one characterized by the following parameters:

- Bandwidth
- Central (or starting) frequency
- Resolution (or number of spectral points)
- Number of polarization products: 1 (AA or BB), 2 (AA & BB), or 4 (cross polarization products AB and BA also included)
- Improved sensitivity options: 4x4 bit correlation or double Nyquist modes (it is possible to specify both, but with very limited usefulness)

The ALMA correlator consists of 4 essentially identical but independent quadrants, each of which processes up to 4 GHz of the total receiver bandwidth. For initial operation where only a single quadrant of the correlator is available, this single quadrant will service all baselines for 16 antennas for all 4 baseband pairs received by the antennas. In the final 4-quadrant configuration, one quadrant of the correlator services all baselines for

64 antennas for one of the 4 ALMA baseband pairs. Most of the discussion below deals with the capacity of a single quadrant of the correlator.

As each 2 GHz IF channel (polarization pair) is connected to an independent correlator quadrant, they can be configured without mutual restrictions.

Glossary

The terminology is taken from the correlator documentation. Some terms are functionally equivalent (e.g. *filter* and *sub-channel*) but emphasize different parts of the correlator.

- **IF channel or BB pair**: one of the 4 independently tunable 2 GHz wide spectral regions. Each one has 2 polarizations.
- **Correlator quadrant**: Part of the correlator that processes one IF channel. Mapping between the two is fixed, so the two terms are essentially equivalent.
- **Correlator mode**: one of the ~70 modes listed in the correlator manual.
- **Spectral point**: one individual point in a spectrum.
- **Channel** (ambiguous, better to avoid): one of the two polarizations in a BB pair.
- **Sub-channel**: the output of a Tunable Filter Bank (TFB) filter.
- **Spectral region**: A continuous region observed by one or more sub-channels.
- **TFB (Tunable Filter Bank)**: a logic card in the correlator station hardware.
- **Filter**: One of the 32 digital filters in a TFB card, normally 62.5 MHz bandwidth. Usually one filter corresponds to one sub-channel; two filters are used for one sub-channel in 31.25 MHz bandwidth modes.
- **Correlator plane**: One of the 32 hardware portions of a correlator quadrant.
- **Bandwidth**: The frequency span analyzed in a single spectrum.

Basic configuration modes

A correlator quadrant can be configured in four basic groups of modes:

- **Time division modes**: The correlator quadrant analyzes the entire 2 GHz IF bandwidth with limited frequency resolution. This mode is well suited for continuum observations, and is mandatory for fast dumping rates (below a few hundred msec per dump).
- **Single region frequency division modes**: The correlator analyzes a portion (from 31.25 MHz to the entire 2 GHz) of the IF bandwidth with high spectral resolution (up to 8192 spectral points). Options to limit the sensitivity loss due to multiple quantization levels are available.
- **Multiple region modes**: One of the modes in the previous group is split into multiple disjoint spectral regions. Spectral resolution, polarization and sensitivity enhancement options must be the same for all regions.
- **Multi-resolution modes**: The correlator quadrant is split into independent sub-

units, each observing a specific spectral region. Different resolutions, bandwidths and polarization modes can be specified for each region. No sensitivity enhancement options are available.

Main operating modes

The correlator specifications and requirements, ALMA-60.00.00.00-001-B-SPE presented the observational modes to be supported by the correlator in tables 1, 2 and 3 of that document. These tables are reproduced as tables 1, 2, and 3 at the end of this memo with the 4 impossible modes removed. These tables described the functionality of a single quadrant of the correlator in which each quadrant processes one of the 4 BB pairs recovered at the antennas. The three general divisions of observational modes supported by a quadrant of the correlator are:

- Single baseband observations (table 1)
- Dual baseband observations, no cross products (table 2)
- Dual baseband observations with baseband cross-products (table 3)

Within these divisions, subdivisions exist for sampling and correlation details:

- Single or twice Nyquist sampling
- 2-bit by 2-bit, 3-bit by 3-bit, or 4-bit by 4-bit correlation

Another categorization of observational modes in the correlator is by total bandwidth covered.

Finally, a major division in the fundamental operation of the correlator is frequency division mode (spectral line) and time division mode (continuum).

In frequency division operation a 2 GHz baseband input drives 32 tunable digital filters each having a 62.5 MHz bandwidth (in a few cases 31.25 MHz operation is also possible). Each digital filter can be independently digitally tuned anywhere within the 2 GHz input range. In the widest frequency division mode (2 GHz), the 32 filters will be tuned to cover the entire input band with the output of each filter driving a correlator circuit. The resulting narrow band frequency plots from the 32 individual correlator circuits can be stitched together to create a continuous plot over the 2 GHz input. Bandwidth-for-resolution tradeoffs can be made with the system in which a fraction of the 32 filters are active and their outputs are processed in the entire correlator (resulting in more correlator circuits per filter and hence higher frequency resolution).

Time division mode is meant for low resolution, high dump rate, maximum sensitivity (with the 3x3 correlation option), continuum operation. In this mode, the digital filters of the TFB are bypassed and the input 2 GHz baseband is split into 32 time packets each with a 125 MHz clock rate.

For simultaneous continuum and spectral observations it is possible to use one quadrant in time division mode, and another, overlapping quadrant, in frequency division mode. The spectral region on the sky in each case depends on which digitized signals are provided to each quadrant.

A fundamental hardware sub-unit of the correlation section of the correlator is called a "plane". Each plane provides a 64-by-64 matrix of correlator circuits operating with a clock rate of 125 MHz. There are 32 correlator planes in the ALMA correlator; in frequency division mode, the available planes are distributed among the active filters. The more correlator planes that process the output of a given filter, the higher the frequency resolution across the band of that filter provided.

Correlator quantization

The ALMA digitizers at an antenna quantize samples at the 3-bit level, setting the fundamental limit on the sensitivity of the system. In frequency division mode, the 3-bit samples are processed in digital mixers and digital filters, the final outputs of which have many bits of resolution and must be re-quantized down to a level that the native 2-bit correlator circuits can accommodate.

This second stage of quantization reduces the correlator sensitivity from the 96% efficiency limit expected from 3-bit digitization to a lower number. To alleviate the reduction in sensitivity imposed by the second stage of quantization, frequency resolution may be traded for sensitivity in the correlator. The digital filter outputs can be 4-bit sampled and correlated 2 bits at a time in 4 correlator circuits. A linear combination of the 4 correlator circuit outputs produces the exact equivalent of a single 4-bit correlator. Thus, for a factor of 4 reduction in frequency resolution, a gain in sensitivity of about 10% (*i.e.*, improving *correlator* efficiency from 88% to 99%) may be obtained over that expected if 2-bit correlation were done.

In time division operation in which only one of the two basebands that drive a correlator quadrant is processed, all 3 bits of the ALMA digitizer are passed to the correlators in various 2-bit combinations. Again, a correct linear combination of 4 correlator circuits can synthesize a full 3-bit correlator. As above, this increase in sensitivity comes at a factor 4 loss in frequency resolution, which for continuum should not matter.

Correlator sample rate

Twice Nyquist sampling, except for 31.25 MHz modes, is obtained when two different filters sample zero and 1/2 bit time-shifted versions of the same 62.5 MHz band. Both are sampled at the Nyquist rate and processed in two different correlator circuits whose lag results are summed. In the 31.25 MHz case, a true twice Nyquist sampled stream at 125 MHz is delivered to the correlators. Twice Nyquist is possible only for frequency division modes analyzing less than 2 GHz bandwidth and costs a factor of two in frequency resolution (again, except for the 31.25 MHz modes).

Mode tables

Tables 1, 2, and 3 show all of the “full correlator” modes supported by the ALMA correlator. Mode parameter variations in these tables include frequency division/time division, total bandwidth covered, quantization level, and sampling mode.

Table 1 gives the modes and performance of the system when processing only one of the two baseband signals that drive a quadrant of the correlator. Table 2 covers operation in which both basebands are active but no polarization cross products are generated. Table 3 gives the system performance for full polarization observations.

Table 4 gives the 4 modes originally described in the correlator specifications and requirements document, ALMA-60.00.00.00-001-B-SPE, which were subsequently found to be impossible to support. All of the lost modes are full polarization with 4-bit quantization.

Multiple region modes

In the frequency division modes, the final spectrum is synthesized using individual filters 62.5 MHz wide. For modes with a total bandwidth between 125 MHz and 1 GHz, it is possible to move the individual filter positions to synthesize a number of disjoint spectral regions. The only constraints are:

1. The region bandwidth must be a multiple of 62.5 MHz;
2. The total bandwidth must be equal to that of the original mode;
3. The regions must fit within the 2 GHz IF bandwidth;
4. The other parameters (resolution, polarization and sensitivity options) must be the same for all regions.

This option is particularly suited to observe with improved resolution a number of spectral features across the IF bandwidth. For example, using a mode with 250 MHz total bandwidth it is possible to observe 4 separate transitions anywhere within the 2 GHz band with a bandwidth of 62.5 MHz each.

Multi-resolution modes

Each quadrant of the correlator will also support some “multi-resolution” modes. In multi-resolution operation, the correlator can simultaneously produce low spectral resolution results over a wide bandwidth and high resolution results over a narrow bandwidth.

It is possible to mix regions with different resolution and bandwidth. It is possible, for example, to zoom on spectral features analyzed with relatively coarse resolution on a wider region.

Multi-resolution modes split a correlator quadrant into sub-units and implement different sub-modes (or fractional-modes) in each sub-unit. The concept is to take defined full correlator modes from the system mode tables and implement each in fewer than the full 32 correlator planes of a quadrant. As many partially implemented correlator modes as it takes to utilize all 32 planes of a quadrant may be accommodated at the same time (as a practical limit, only up to 4 will probably be allowed).

A full-correlator mode is implemented in a fraction of a quadrant by keeping the mode bandwidth constant but lowering the resolution that should result from the mode. Mode 4, for example (see table 1), normally covers 250 MHz and generates 8192 spectral points across this bandwidth. If only 1/2 of a quadrant of the correlator (16 correlator planes) were used to process mode 4, it could still cover 250 MHz but would generate only 4096 spectral points across this band. The remaining 16 correlator planes of the system may then be used to process, say, mode 6 (also from table 1) which could develop 4096 spectral points across the 62.5 MHz band specified for mode 6 using the uncommitted other 1/2 of the correlator. The result would be one spectral plot which covers a wide bandwidth at low resolution simultaneously with a high resolution plot covering 62.5 MHz, centered, for example, on a spectral line in the interior of the wide bandwidth plot.

Fractional modes requiring 16, 8, 4, 2, or 1 correlator planes are possible (although 1 or 2 plane modes would be of questionable practical use).

The only defined full-correlator modes available in multi-resolution operation are 2-bit by 2-bit, single Nyquist sampled modes plus three native twice Nyquist 31.25 MHz modes. This restriction limits the range of possibilities the correlator firmware and software must support and was deemed reasonable because multi-resolution operation inherently implies that spectral resolution is the prime consideration of such an observation. More complex modes such as twice Nyquist or 4x4 bit correlation are employed to improve sensitivity, and the factor of 2 or 4 cut in resolution resulting from such modes contradicts the primary motivation for multi-resolution operation.

Tables 5, 6, and 7 below show all of the full-correlator modes that can be used in multi-resolution operation. The idea is to select two or more modes from these tables and implement each in a fraction of a quadrant, until no more correlator resources remain. All modes are then processed simultaneously during a subsequent observation.

Tables 5, 6, and 7 list for each mode the minimum fraction of the correlator it needs (as determined by the bandwidth covered by the mode). For example, mode 2 of table 5 must have at least 16 planes or a minimum of 1/2 the correlator in which to process the output of 16 filters if 1 GHz is to be spanned. Hence, the only sub-mode possible for mode 2 uses 16 planes. Mode 11 of table 6, on the other hand, covers only 125 MHz for each of 2 basebands and as few as 4 planes will suffice for this. Hence, mode 11 can be used in sub-modes of 1/2, 1/4, and 1/8 of the correlator.

Table 8 gives all of the possibilities for the various eligible full-system modes for use in multi-resolution operation.

One restriction exists for multi-resolution operation. In general, no more than a total of 16 filters may be used in the combined sub-modes (for a total 1 GHz bandwidth). About the only practical way to exceed this limit is if mode 2 is one of the sub-modes. Mode 2 alone requires 16 filters, so one or more of these filters must either serve a dual function and be used in more than one sub-mode or essentially be reassigned so that they do not contribute to the mode 2 sub-mode but are assigned exclusively to one or more of the other sub-modes (see example below).

Multi-resolution mode examples

As an example of multi-resolution operation, consider a case in which mode 3 from table 5 (or table 1) uses 8 planes of the correlator, mode 6 uses another 8 planes and mode 25 is programmed to use the remaining 16 correlator planes.

The mode 3 sub-mode will cover 500 MHz and can produce 2048 spectral points across this band with the use of 8 correlator planes, giving 244 kHz resolution. The mode 6 sub-mode will span 62.5 MHz possibly centered on a line within the 500 MHz band above (or it could be in another part of the 2 GHz band) and produce 2048 spectral points, giving 31 kHz resolution. The mode 25 sub-band will cover 31.25 MHz with 4096 spectral points across it, giving 7.6 kHz resolution. The center frequency of any of the active filters in this example may be placed anywhere within the input 2 GHz band by appropriate tuning of the digital mixer in the filter.

As an example of the 16-filter limit, consider a multi-resolution setup using mode 2 in 16 correlator planes, mode 6 in 8 planes and a second mode 6 sub-mode using the remaining 8 planes.

Since only 16 filters may be used, the mode 2 sub-mode must share filters with the two mode 6 sub-modes. Thus in this case, the mode 2 sub-mode only covers 1 GHz – 125 MHz (16 filters – 2 filters) or 0.875 GHz, instead of the full 1 GHz of a normal mode 2. Each mode 6 sub-mode covers 62.5 MHz with a resolution of 2048 spectral points.

The filters assigned to the two mode 6 sub-modes could be tuned within the 0.875 GHz band covered by the wideband mode to expand on features of interest within that band or be centered on frequencies outside this band.

An alternate way to do the example above would be to have the 16 filters of the mode 2 sub-mode cover a contiguous 1 GHz band and use the mode 6 sub-modes to expand on any two of the filters in this band (at the possible cost of the features of interest not being exactly centered in the two high resolution modes).

Table 1 Mode chart with one baseband channel per quadrant being processed

Mode #	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points	Spectral Resolution	Velocity resolution at 230 GHz	Correlation	Sample Factor	Minimum dump time*	Sensitivity**
1	32	2 GHz	8192	244 kHz	0.32 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
19	32	2 GHz	4096	488 kHz	0.64 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
38	32	2 GHz	2048	976 kHz	1.28 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
2	16	1 GHz	8192	122 kHz	0.16 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
20	16	1 GHz	4096	244 kHz	0.32 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
39	16	1 GHz	2048	488 kHz	0.64 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
53	16	1 GHz	1024	976 kHz	1.28 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
3	8	500 MHz	8192	61 kHz	0.08 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
21	8	500 MHz	4096	122 kHz	0.16 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
40	8	500 MHz	2048	244 kHz	0.32 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
54	8	500 MHz	1024	488 kHz	0.64 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
4	4	250 MHz	8192	30 kHz	0.04 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
22	4	250 MHz	4096	61 kHz	0.08 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
41	4	250 MHz	2048	122 kHz	0.16 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
55	4	250 MHz	1024	244 kHz	0.32 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
5	2	125 MHz	8192	15 kHz	0.02 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
23	2	125 MHz	4096	30 kHz	0.04 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
42	2	125 MHz	2048	61 kHz	0.08 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
56	2	125 MHz	1024	122 kHz	0.16 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
6	1	62.5 MHz	8192	7.6 kHz	0.01 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
24	1	62.5 MHz	4096	15 kHz	0.02 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
43	1	62.5 MHz	2048	30 kHz	0.04 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
57	1	62.5 MHz	1024	61 kHz	0.08 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
25	1	31.25 MHz	8192	3.8 kHz	0.005 km/s	2-bit x 2-bit	Twice Nyquist	512 msec	0.94
58	1	31.25 MHz	2048	15 kHz	0.02 km/s	4-bit x 4-bit	Twice Nyquist	128 msec	0.99
68	Time Division Mode	2 GHz	64	31.25 MHz	40.8 km/s	3-bit x 3-bit	Nyquist	16 msec	1.00
71	Time Division Mode	2 GHz	256	7.8125 MHz	10.2 km/s	2-bit x 2-bit	Nyquist	16 msec	0.88

*** Assuming all products, all lags, transferred from correlator to Correlator Data Processor computer (in milli-seconds).**

*** *Multiply numbers in this column by the 0.96 sensitivity imposed by the 3-bit input digitizer.**

Table 2 Mode chart with two baseband channels per quadrant processed with no polarization cross products.

Mode #	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points	Spectral Resolution	Velocity resolution at 230 GHz	Correlation	Sample Factor	Minimum dump time*	Sensitivity**
7	32	2 GHz	4096	488 kHz	0.64 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
8	16	1 GHz	4096	244 kHz	0.32 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
26	16	1 GHz	2048	488 kHz	0.64 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
44	16	1 GHz	1024	976 kHz	1.28 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
9	8	500 MHz	4096	122 kHz	0.16 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
27	8	500 MHz	2048	244 kHz	0.32 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
45	8	500 MHz	1024	488 kHz	0.64 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
59	8	500 MHz	512	976 kHz	1.28 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
10	4	250 MHz	4096	61 kHz	0.08 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
28	4	250 MHz	2048	122 kHz	0.16 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
46	4	250 MHz	1024	244 kHz	0.32 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
60	4	250 MHz	512	488 kHz	0.64 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
11	2	125 MHz	4096	30 kHz	0.04 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
29	2	125 MHz	2048	61 kHz	0.08 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
47	2	125 MHz	1024	122 kHz	0.16 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
61	2	125 MHz	512	244 kHz	0.32 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
12	1	62.5 MHz	4096	15 kHz	0.02 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
30	1	62.5 MHz	2048	30 kHz	0.04 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
48	1	62.5 MHz	1024	61 kHz	0.08 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
62	1	62.5 MHz	512	122 kHz	0.16 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
31	1	31.25 MHz	4096	7.6 kHz	0.01 km/s	2-bit x 2-bit	Twice Nyquist	512 msec	0.94
63	1	31.25 MHz	1024	30 kHz	0.04 km/s	4-bit x 4-bit	Twice Nyquist	128 msec	0.99
69	Time Division Mode	2 GHz	128	15.6 MHz	20.4 km/s	2-bit x 2-bit	Nyquist	16 msec	0.88

*** Assuming all products, all lags, transferred from correlator to Correlator Data Processor computer (in milli-seconds).**

*** *Multiply numbers in this column by the 0.96 sensitivity imposed by the 3-bit input digitizer.**

Table 3 Mode chart with two baseband channels per quadrant processed with polarization cross products.

Mode #	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points	Spectral Resolution	Velocity resolution at 230 GHz	Correlation	Sample Factor	Minimum dump time*	Sensitivity**
13	32	2 GHz	2048	976 kHz	1.28 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
14	16	1 GHz	2048	488 kHz	0.64 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
32	16	1 GHz	1024	976 kHz	1.28 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
15	8	500 MHz	2048	244 kHz	0.32 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
33	8	500 MHz	1024	488 kHz	0.64 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
16	4	250 MHz	2048	122 kHz	0.16 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
34	4	250 MHz	1024	244 kHz	0.32 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
17	2	125 MHz	2048	61 kHz	0.08 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
35	2	125 MHz	1024	122 kHz	0.16 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
51	2	125 MHz	512	244 kHz	0.32 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
18	1	62.5 MHz	2048	30 kHz	0.04 km/s	2-bit x 2-bit	Nyquist	512 msec	0.88
36	1	62.5 MHz	1024	61 kHz	0.08 km/s	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
52	1	62.5 MHz	512	122 kHz	0.16 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
66	1	62.5 MHz	256	244 kHz	0.32 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
37	1	31.25 MHz	2048	15 kHz	0.02 km/s	2-bit x 2-bit	Twice Nyquist	512 msec	0.94
67	1	31.25 MHz	512	61 kHz	0.08 km/s	4-bit x 4-bit	Twice Nyquist	128 msec	0.99
70	Time Division Mode	2 GHz	64	31.25 MHz	40.8 km/s	2-bit x 2-bit	Nyquist	16 msec	0.88

*** Assuming all products, all lags, transferred from correlator to Correlator Data Processor computer (in milli-seconds).**

*** *Multiply numbers in this column by the 0.96 sensitivity imposed by the 3-bit input digitizer.**

Table 4 Deleted mode chart: all two baseband channels per quadrant processed with polarization cross products. These modes are listed in Correlator Spec B but are not possible.

Mode #	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points	Spectral Resolution	Velocity resolution at 230 GHz	Correlation	Sample Factor	Minimum dump time	Sensitivity
49	8	500 MHz	512	976 kHz	1.28 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
50	4	250 MHz	512	488 kHz	0.64 km/s	4-bit x 4-bit	Nyquist	128 msec	0.99
64	4	250 MHz	256	976 kHz	1.28 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99
65	2	125 MHz	256	488 kHz	0.64 km/s	4-bit x 4-bit	Twice Nyquist	64 msec	0.99

Table 5 Multi-resolution modes with one baseband channel per quadrant being processed.

Mode #	Minimum size of correlator*	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points**	Correlation	Sample Factor
2	1/2	16	1 GHz	8192	2-bit x 2-bit	Nyquist
3	1/4	8	500 MHz	8192	2-bit x 2-bit	Nyquist
4	1/8	4	250 MHz	8192	2-bit x 2-bit	Nyquist
5	1/16	2	125 MHz	8192	2-bit x 2-bit	Nyquist
6	1/32	1	62.5 MHz	8192	2-bit x 2-bit	Nyquist
25	1/32	1	31.25 MHz	8192	2-bit x 2-bit	Twice Nyquist

Table 6 Multi-resolution modes with two baseband channels per quadrant with no polarization cross products.

Mode #	Minimum size of correlator*	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points**	Correlation	Sample Factor
9	1/2	8	500 MHz	4096	2-bit x 2-bit	Nyquist
10	1/4	4	250 MHz	4096	2-bit x 2-bit	Nyquist
11	1/8	2	125 MHz	4096	2-bit x 2-bit	Nyquist
12	1/16	1	62.5 MHz	4096	2-bit x 2-bit	Nyquist
31	1/16	1	31.25 MHz	4096	2-bit x 2-bit	Twice Nyquist

Table 7 Multi-resolution modes with two baseband channels per quadrant with polarization cross products.

Mode #	Minimum size of correlator*	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points**	Correlation	Sample Factor
16	1/2	4	250 MHz	2048	2-bit x 2-bit	Nyquist
17	1/4	2	125 MHz	2048	2-bit x 2-bit	Nyquist
18	1/8	1	62.5 MHz	2048	2-bit x 2-bit	Nyquist
37	1/8	1	31.25 MHz	2048	2-bit x 2-bit	Twice Nyquist

*** Fraction of the correlator required to maintain the specified bandwidth with the minimum feasible resolution**

**** Utilizing 100% of the correlator**

Table 8 Multi-resolution mode possibilities

Spectral Channel Resolution for each polarization data set as a function of the fraction of correlator resources assigned in Multi-reslution Mode (Total #spectral channels per polarization data set in parenthesis)

Corr Mode Number	BW	BITS	NYQUIST	POLZ	Full	1/2	1/4	1/8	1/16	1/32
2	1GHz	2x2	1N	1BB	122 KHz (8192)	244 KHz (4096)	na	na	na	na
3	500MHz	2x2	1N	1BB	61 KHz (8192)	122 KHz (4096)	244 KHz (2048)	na	na	na
4	250MHz	2x2	1N	1BB	30.5 KHz (8192)	61 KHz (4096)	122 KHz (2048)	244 KHz (1024)	na	na
5	125MHz	2x2	1N	1BB	15.3 KHz (8192)	30.5 KHz (4096)	61 KHz (2048)	122 KHz (1024)	244 KHz (512)	na
6	62.5MHz	2x2	1N	1BB	7.63 KHz (8192)	15.3 KHz (4096)	30.5 KHz (2048)	61 KHz (1024)	122 KHz (512)	244 KHz (256)
9	500MHz	2x2	1N	2BB	122 KHz (4096)	244 KHz (2048)	na	na	na	na
10	250MHz	2x2	1N	2BB	61 KHz (4096)	122 KHz (2048)	244 KHz (1024)	na	na	na
11	125MHz	2x2	1N	2BB	30.5 KHz (4096)	61 KHz (2048)	122 KHz (1024)	244 KHz (512)	na	na
12	62.5MHz	2x2	1N	2BB	15.3 KHz (4096)	30.5 KHz (2048)	61 KHz (1024)	122 KHz (512)	244 KHz (256)	na
16	250MHz	2x2	1N	2BB-P	122 KHz (2048)	244 KHz (1024)	na	na	na	na
17	125MHz	2x2	1N	2BB-P	61 KHz (2048)	122 KHz (1024)	244 KHz (512)	na	na	na
18	62.5MHz	2x2	1N	2BB-P	30.5 KHz (2048)	61 KHz (1024)	122 KHz (512)	244 KHz (256)	na	na
25	31.25MHz	2x2	2N	1BB	3.82 KHz (8192)	7.63 KHz (4096)	15.3 KHz (2048)	30.5 KHz (1024)	61 KHz (512)	122 KHz (256)
31	31.25MHz	2x2	2N	2BB	7.63 KHz (4096)	15.3 KHz (2048)	30.5 KHz (1024)	61 KHz (512)	122 KHz (256)	na
37	31.25MHz	2x2	2N	2BB-P	15.3 KHz (2048)	30.5 KHz (1024)	61 KHz (512)	122 KHz (256)	na	na