An Optimized Connectivity Scheme

for the EVLA Correlator

NRC-EVLA Memo# 028

Brent Carlson, April 13, 2007

ABSTRACT

This memo describes an optimized connectivity scheme for a 32-station EVLA Correlator, which is able to significantly reduce cost, power, and maintenance, while at the same time enabling more seamless observational modes. This scheme is feasible since there will be no New Mexico Array, and therefore integrating the VLBA into the correlator in real-time is not useful. However, capability of future expansion beyond 32 stations is still allowed. This scheme has minimal hardware and software impact and has come to light at a time in the project in which it may be implemented without serious schedule impact. A 16-station, 4 GHz standalone VLBA correlator is still allowed for, well within the savings realized.

Introduction

This memo discusses a new optimized method for interconnecting the 32-station EVLA correlator. Connectivity is presented, and following sections discuss the various operating modes of the correlator and how they fit into the new scheme. Mode designators are for discussion purposes only, and are not meant to put restrictions on how the correlator might be used, or how the correlator "mapper" software might be implemented.

Overview

Figure 1 is a simplified diagram of the new wiring in one particular station rack, which in this case holds all of the Station Boards for stations 1-4. Other station racks are identically wired. The figure shows high-speed cabling for one sub-band of the 16 available. The X-bar switch allows data from any BB (I/F) pair to be routed to any "quadrant" of the correlator. This switch allows the full flexibility of the correlator (in the old connection method) to be retained. In each station rack there are 64 short, 4-wafer cables for a total of 512 of these short cables in the system.

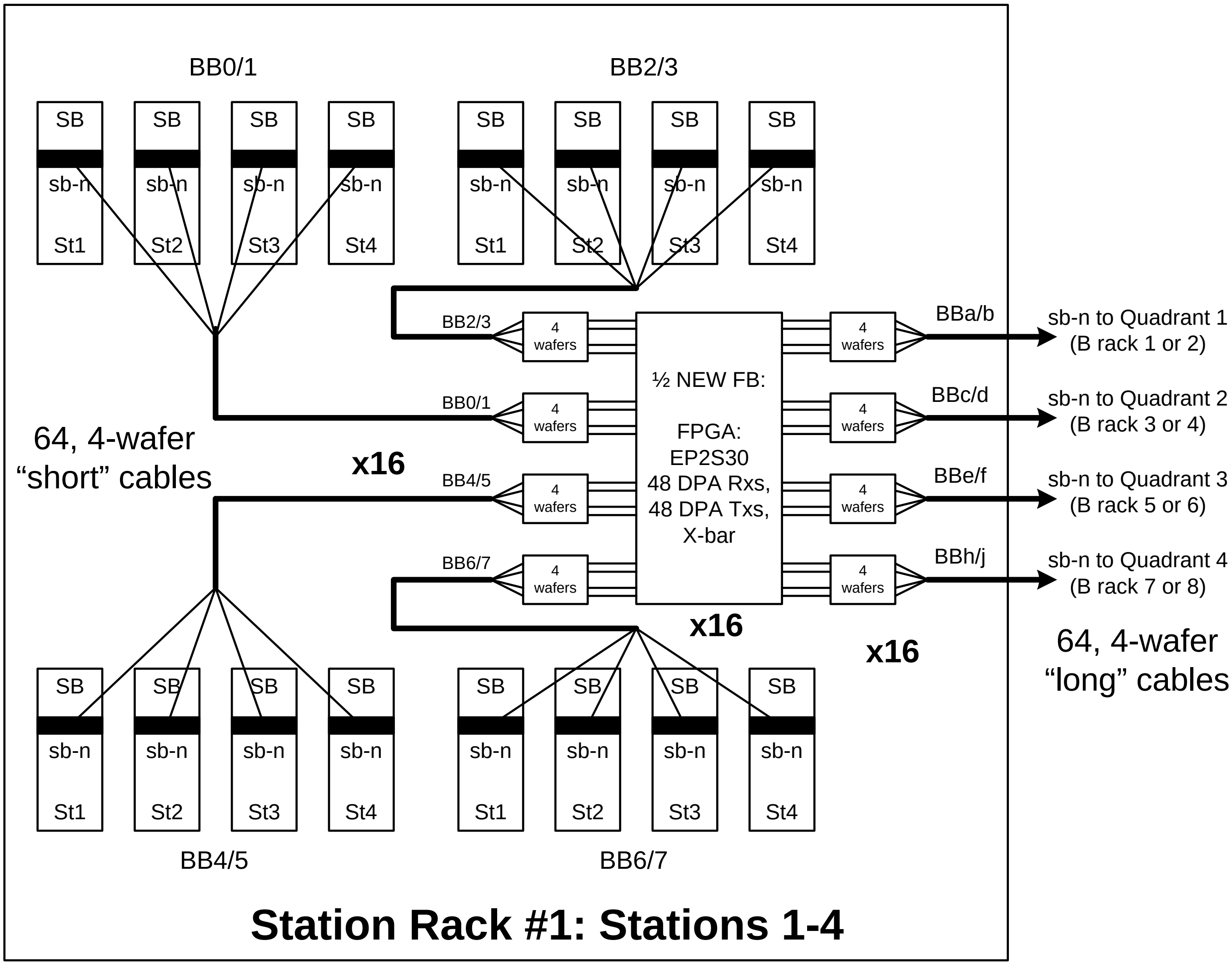

Figure 1 Station rack wiring. Only 1 set of cables for one sub-band are shown. There are 16 sets of such "short" cables, and 16 corresponding X-bar switches (requiring 8 dual-X-bar boards that fit in the existing 6U sub-rack). This X-bar switch is referred to as the "QXBAR" in mode discussions.

Figure 2 shows a particular baseline rack; there are 2 baseline racks per quadrant, where each quadrant processes all sub-band pairs for a BB (I/F) pair. With 4 quadrants there are thus 8 baseline racks, each with 16 Baseline Boards (BLBs), for a total of 128 Baseline Boards. There are 64 long 4-wafer cables entering each baseline rack from station racks, for a total of 512 long cables.

Pairs of Baseline Boards in a baseline rack are interconnected using a patch board—a PCB with press-fit vertical female connectors that plugs into the existing Common Backplane headers. This board, and the repeating and retiming of signals on each Baseline Board eliminates all of the old Fanout Boards (except some for Timecode distribution), and reduces the number of hi-speed HM Gbps cables by a factor of 3.

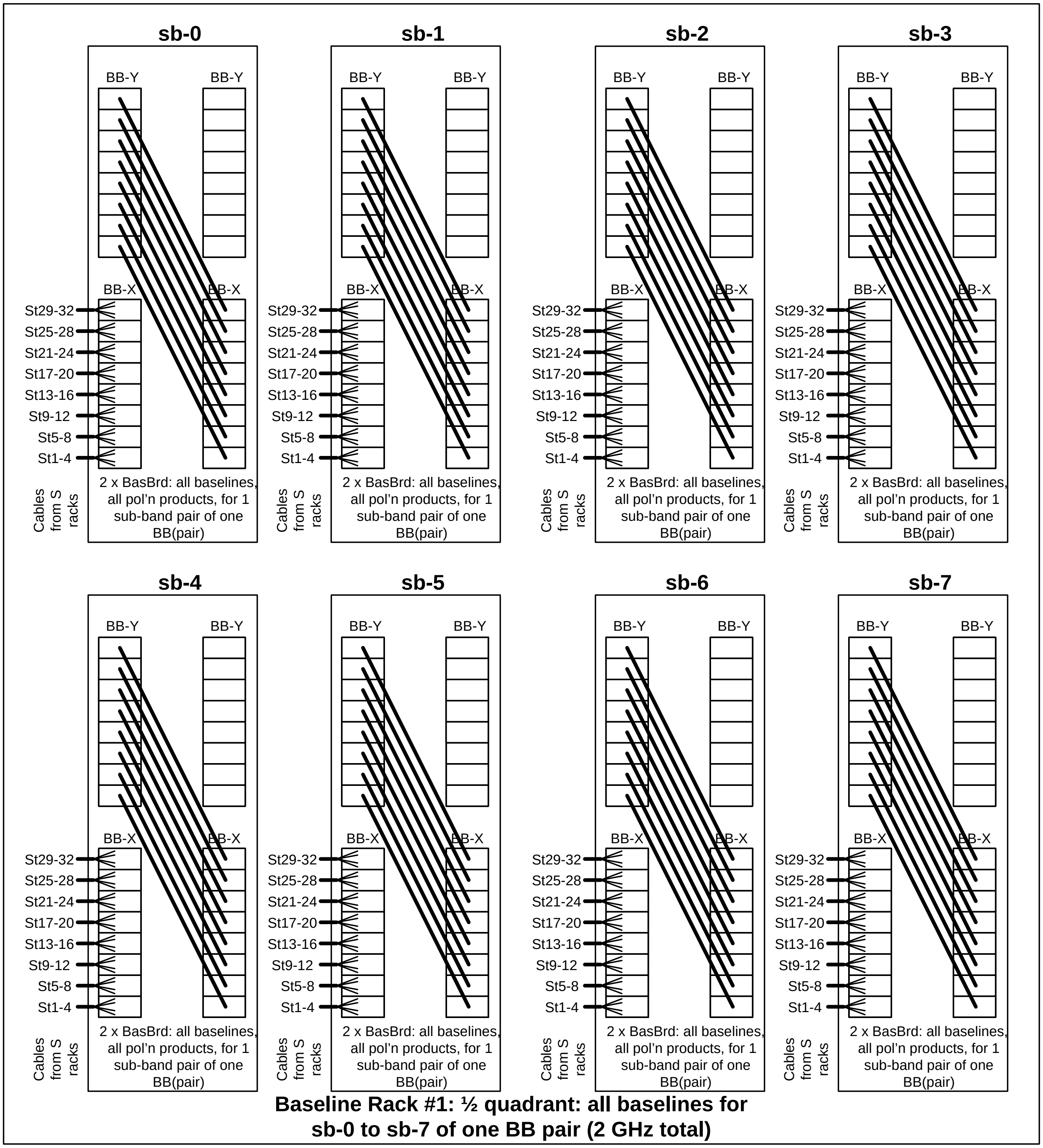

Figure 2 Baseline rack wiring. Each pair of Baseline Boards is connected together with a "patch board", and each pair performs all of the cross-correlations for 32 stations, 1 sub-band pair, of one BB (I/F) pair. Fanout of identical data to X and Y inputs on the board is performed with a re-timing FPGA and 1:2 buffers as shown in Figure 3.

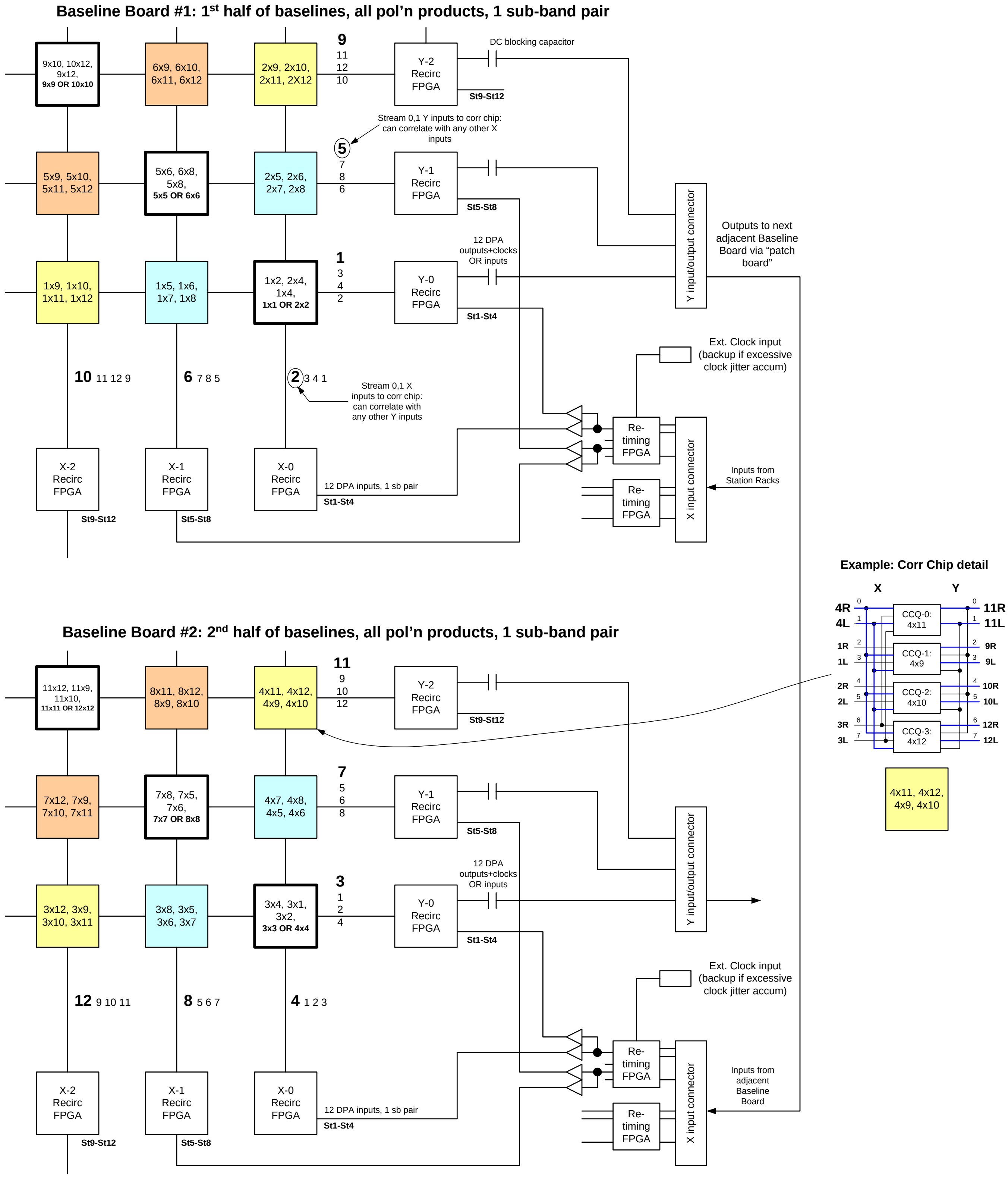

Figure 3 Baseline Board sub-band pair routing, and baseline allocations.

Figure 3 shows the on-board and board-to-board routing of a pair of Baseline Boards. In full wideband mode, with all polarization products, each Correlator Chip on each board processes 4 baselines with 4 polarization products each. There are 4 chips available, and so all16 baselines for the 4 X and Y stations can be processed.

The Y Recirc FPGAs normally re-time and re-generate the signals to go out the Y connector. However, with a different FPGA personality and the connections planned for the board, these could, instead, be inputs. This allows the board to be used for expansion beyond 32 stations, wherein different inputs to the X and Y Recirc FPGAs are required.

Routing of data streams for one particular Correlator Chip is shown in Figure 3, and repeated below for better readability.

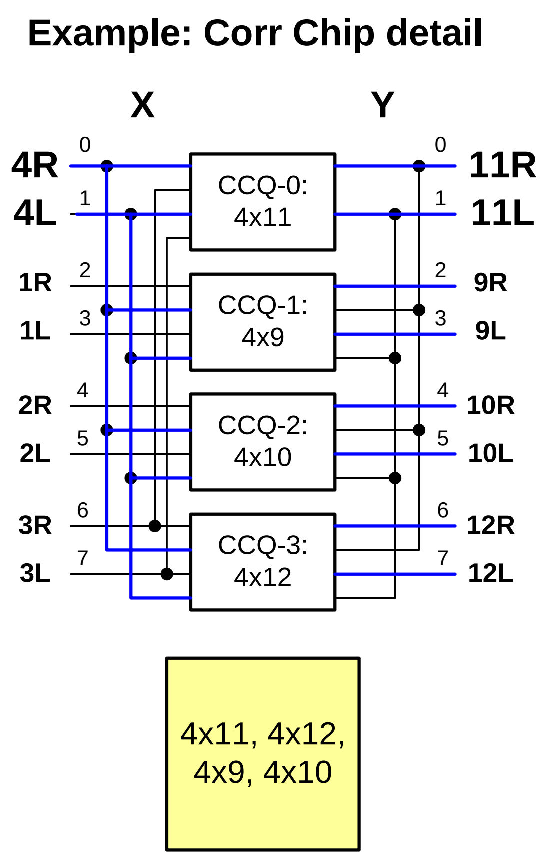

Figure 4 Detail of one particular set of 4 baselines processed by one Correlator Chip. The large bold station numbers in this figure and Figure 3, indicate station number assignments to "primary" Correlator Chip inputs. Any CCQ (and CCC) in the chip can connect to X and Y primary or secondary (normal font station numbers) as shown.

The remainder of this memo describes various operating modes in more detail, starting with 64SB-4PP:3IQ/4RQ:FB:NR, which is the mode for which Figure 3 was built. This mode is the "crux" of the new connectivity scheme since it requires the largest number of independent cross-correlations.

MODE: 64SB-4PP:3IQ/4RQ:FB:NR

64 sub-bands, **4 pol'n products**, **3-bit initial quantization, 4-bit re-quantization, full bandwidth, no recirculation**

MODE DESCRIPTION

3-bit initial sampling (4 Gs/s), all BB pairs active, each Station Board contains a poln pair, of 2 GHz BW each. 4-bit re-quantization, full sub-band bandwidth of 128 MHz, 16 sub-band pairs per Station Board. All 4 polarization products required on all sub-band pairs, of all BB pairs.

CONNECTION/PROCESSING SYNOPSIS

Two Baseline Boards (BLBs) process all baselines and all polarization products for a sub-band pair. Since there are 16x4=64 sub-band pairs, a total of 128 BLBs are required. This is the maximum bandwidth, minimum spectral resolution operating mode of the correlator. There are 64 spectral channels per unique polarization product, amounting to a total of 16,384 channels per baseline (not including auto-corr products). Only 2 (opposite) polarization products can be obtained for sub-band auto-correlation products obtained along the diagonal set of Correlator Chips on each BLB (e.g. Stn-LL and Stm-RR OR Stn-RR and Stm-LL)

Each Correlator Chip on each BLB processes 4 baselines, all poln products. Each chip is fed 4 polarized X and Y station data streams, with each row and column being fed the same data streams from the same antennas, but with different "primary" Correlator Chip data stream station assignments (primary inputs are X0, X1, and Y0, Y1 into the chip). Primary X input streams can be correlated with any Y input streams, and primary Y input streams can be correlated with any X input streams. Refer to Figure 3 and Figure 4.

This connectivity and mode is the crux of the new connectivity model.

SUMMARY

Total bandwidth per antenna:	16 GHz.
Total number of sub-band pairs:	64
Number of polarization products:	4
Sub-band bandwidth:	128 MHz.
Total # channels:	16384 per baseline.
# channels per cross-product:	64

MODE: 64SB-2PP:3IQ/4RQ:FB:NR

64 sub-bands, 2 polarization products, 3-bit initial sampling, 4-bit re-sampling, full bandwidth, no recirculation.

MODE DESCRIPTION

Virtually identical to mode 64SB-4PP:3IQ/4RQ:FB:NR, except that only 2 polarization products are obtained.

CONNECTION/PROCESSING SYNOPSIS

Same as 64SB-4PP:3IQ/4RQ:FB:NR, except that each CCQ in each Correlator Chip obtains only 2 polarization products rather than 4. Thus, the number of spectral channels per product is doubled.

SUMMARY

Total bandwidth per antenna:	16 GHz.
Total number of sub-band pairs:	64
Number of polarization products:	2
Sub-band bandwidth:	128 MHz.
Total # channels:	16384 per baseline.
# channels per cross-product:	128

MODE: 64SB-4PP:3IQ/4RQ:RB:RC

64 sub-bands, 4 polarization products, 3-bit initial sampling, 4-bit re-sampling, reduced bandwidth, recirculation.

MODE DESCRIPTION

Virtually identical to mode 64SB-4PP:3IQ/4RQ:FB:NR, except that sub-band bandwidths are reduced to obtain more spectral channels on a narrower sub-band of interest (sub-band bandwidths don't have to be reduced if sensitivity losses are acceptable—i.e. wideband recirculation).

CONNECTION/PROCESSING SYNOPSIS

Same as 64SB-4PP:3IQ/4RQ:FB:NR, except that with reduced sub-band bandwidth, recirculation is turned on to increase the number of spectral channels obtained in each cross-product. Each sub-band pair may have a different bandwidth and recirculation factor, subject to possible limitations in generating multiple (up to 16 different) DUMPTRIG sequences on the Station Board. R2 "internal" recirculation must be invoked because there are 8 active data streams going to each of the X and Y inputs of each Correlator Chip (data stream assignments and Correlator Chip routing is identical to 64SB-4PP:3IQ/4RQ:FB:NR). Maximum number of spectral channels per cross-product is 4096 (possibly 8192) implying a maximum sub-band bandwidth of 128/(4096/64) = 2 MHz, and a recirculation factor of 4096/64 = 64. Total number of spectral channels per baseline is 16384x64 = 1,048,576

SUMMARY

Total bandwidth per antenna:	variable.
Total number of sub-band pairs:	64
Number of polarization products:	4
Sub-band bandwidth:	variable; 128 MHz down to minimum;2 MHz max to match max recirc factor of 64.
Total # channels:	1,048,576 max per baseline.
# channels per cross-product:	up to 4096, possibly 8192

MODE: 64SB-2PP:3IQ/4RQ:RB:RC

64 sub-bands, 2 polarization products, 3-bit initial sampling, 4-bit re-sampling, reduced bandwidth, recirculation.

MODE DESCRIPTION

Same as 64SB-4PP:3IQ/4RQ:RB:RC, except that only 2 polarization products are obtained.

CONNECTION/PROCESSING SYNOPSIS

Since only 2 polarization products are obtained, 2X as many "real lags" are available for each cross-product. However, because R2 is used, the maximum number of channels is still the same as 64SB-4PP:3IQ/4RQ:RB:RC, except that the max recirculation factor required is only 32, thereby increasing the bandwidth at which the same number of spectral channels can be obtained.

MODE: 64SB-1PP:3IQ/4RQ:RB:RC

64 sub-bands, 1 polarization product, 3-bit initial sampling, 4-bit re-sampling, reduced bandwidth, recirculation.

MODE DESCRIPTION

Same as 64SB-4PP:3IQ/4RQ:RB:RC, except that only 1 polarization product is obtained.

CONNECTION/PROCESSING SYNOPSIS

Since only 1 polarization product is obtained, 4X as many "real lags" are available for each cross-product. Additionally, R2 is not required since there are only 4 active data streams entering each Correlator Chip and so the maximum number of channels per cross-product is increased to 262,144.

MODE: 16SB-4PP:3IQ/4RQ:FB:SRC

16 sub-bands, 4 polarization products, 3-bit initial sampling, 4-bit re-sampling, full bandwidth, static recirculation.

MODE DESCRIPTION

Only 4 GHz (2 GHz per poln) of total bandwidth per station is processed. This means that only 1 quadrant (2 racks) of BLBs are essential to process the entire bandwidth, leaving 3 quadrants unused. These unused quadrants may be employed to improve the number of spectral channels per cross-correlation product from 64 to 256, by copying the same sub-band data to all quadrants with the "quadrant cross-bar" (QXBAR) switch.

CONNECTION/PROCESSING SYNOPSIS

Connections in baseline racks and BLBs are identical to mode 64SB-4PP:3IQ/4RQ:FB:NR, except that each quadrant is fed the same data and processes ¼ of the lags for each cross-product (or alternatively, and more simply, each quadrant processes 1 polarization product). "Static" recirculation is invoked; quadrant 1 processes recirculation block 0, quadrant 2 processes recirculation block 1, quadrant 3 processes recirculation block 2, and quadrant 4 processes recirculation block 3. A total of 512 lags (256 channels) per cross-product are obtained.

SUMMARY

Total bandwidth per antenna:	4 GHz.
Total number of sub-band pairs:	16
Number of polarization products:	4
Sub-band bandwidth:	128 MHz per poln.
Total # channels:	16,384 max per baseline.
# channels per cross-product:	256

MODE: 16SB-2PP:3IQ/4RQ:FB:SRC

16 sub-bands, 2 polarization products, 3-bit initial sampling, 4-bit re-sampling, full bandwidth, static recirculation.

MODE DESCRIPTION

Virtually identical to 16SB-4PP:3IQ/4RQ:FB:SRC except that since 2 polarization products are obtained, the number of lags obtained for each product doubles. Static recirculation may still employed: quadrant 1 obtains recirculation block 0, of 256 lags etc., or pairs of quadrants obtain each polarization product.

SUMMARY

Total bandwidth per antenna:	4 GHz.

Total number of sub-band pairs:	16
Number of polarization products:	2
Sub-band bandwidth:	128 MHz per poln.
Total # channels:	16,384 max per baseline.
# channels per cross-product:	512

MODE: 16SB-4PP:3IQ/4RQ:RB:RC

16 sub-bands, 4 polarization products, 3-bit initial sampling, 4-bit re-sampling, reduced bandwidth, static and dynamic recirculation.

MODE DESCRIPTION

Less than 4 GHz (2 GHz per poln) of total bandwidth per station is processed. This means that only 1 quadrant (2 racks) of BLBs are essential to process the entire bandwidth, leaving 3 quadrants unused. These unused quadrants, as well as dynamic recirculation, may be employed to improve the number of spectral channels per cross-correlation product by copying the same sub-band data to all quadrants with the "quadrant cross-bar" (QXBAR) switch, and producing one polarization product in each quadrant.

CONNECTION/PROCESSING SYNOPSIS

Connections in baseline racks and BLBs are identical to mode 16SB-4PP:3IQ/4RQ:FB:SRC, except that each sub-band is operating at a reduced bandwidth and therefore a combination of static and dynamic recirculation can be employed to improve the number of spectral channels obtained. Each quadrant is fed the same data with the QXBAR switch. Each sub-band can be a different bandwidth, with a different recirculation factor. Since each quadrant processes only 1 polarization product, 4 X and Y streams are active in each BLB column/row, and dynamic recirculation can be used (without R2), allowing up to 64k channels per cross-product. For example, if a particular sub-band bandwidth is 1 MHz, a maximum dynamic recirculation factor of 128 can be used, so each quadrant may obtain 128x512 lags = 65536 lags or 32k channels, dynamically. With each quadrant processing 1 polarization product, a total of 128k channels per baseline per sub-band can be obtained, in this example.

SUMMARY

Total bandwidth per antenna:	less than 4 GHz.
Total number of sub-band pairs:	16
Number of polarization products:	4
Sub-band bandwidth:	128 MHz to minimum per poln.
Total # channels:	up to 64k max per cross-product, 4 Mchannels/baseline.
# channels per cross-product:	4096 max.

NOTE: if the number of sub-bands required is reduced, then active sub-bands can be replicated into unused sub-band BLB pairs using the Station Board (STB) sub-band X-bar switch to further increase the number of channels available.

MODE: 16SB-4PP:3IQ/7RQ:RB:RC

16 sub-bands, 4 polarization products, 3-bit initial sampling, 7-bit re-sampling, reduced bandwidth, static and dynamic recirculation.

MODE DESCRIPTION

Each sub-band is 64 MHz, sampled with 7 bits, and there are 16 sub-bands. This mode would be invoked only if there are sufficiently strong spectral lines in the band so that 7-bit re-quantization to obtain spectral dynamic range is required. Normally 7-bit re-quantization implies 8-bit initial quantization, but this is the simpler case that will be treated first.

CONNECTION/PROCESSING SYNOPSIS

Each quadrant processes only 1 of the 4 cross-products required to form the entire final result. For example, quadrant 1 could do the MSN x MSN correlation, all baselines, all poln products (as done in other modes), quadrant 2 does the MSN x LSN correlations, quadrant 3 does the LSN x MSN correlations, and quadrant 4 does the LSN x LSN correlations. Since each sub-band is max 64 MHz, dynamic recirculation by a factor of 2 can be used to improve the number of spectral channels obtained. Each cross-product is thus 128 spectral channels x 4 poln products = 512 channels per baseline per sub-band. Total of 512 channels per sub-band x 16 sub-bands = 8192 channels per baseline—1/2 of that possible with 4-bit re-quantization.

NOTE: Sub-bands can have different bandwidths, and if bandwidth is reduced, the number of spectral channels can be increased to a maximum of 4096 using R2 recirculation. If the number of sub-bands is reduced, then the number of spectral channels can potentially be further increased depending on whether R2 recirculation is required or not. If the number of poln products is reduced, more spectral channels can be obtained per cross-product. Finally, those sub-bands that require only 4-bit re-quantization can see further increases in the number of spectral channels they may obtain by distributing channels across quadrants.

SUMMARY

Total bandwidth per antenna:	less than 2 GHz.
Total number of sub-band pairs:	16
Number of polarization products:	4
Sub-band bandwidth:	64 MHz to minimum per poln; max 8 MHz for max channels.

Total # channels:	8,192 minimum per baseline; variable max depending on bandwidth.
# channels per cross-product:	128 minimum, variable max depending on bandwidth.

MODE: 16SB-4PP:8IQ/7RQ:RB:RC

16 sub-bands, 4 polarization products, 8-bit initial sampling, 7-bit re-sampling, reduced bandwidth, static and dynamic recirculation.

MODE DESCRIPTION

Each sub-band is 64 MHz, sampled with 7 bits, and there are 16 sub-bands. This mode would be invoked only if there are sufficiently strong spectral lines in the band so that 8-bit initial quantization and 7-bit re-quantization are required to obtain desired spectral dynamic range.

CONNECTION/PROCESSING SYNOPSIS

8-bit initial quantization places each polarization on a different Station Board. After the QXBAR switch both polarizations need to be in the same connector wafer going to the same BLB input. This requires slightly more sophisticated switching in the QXBAR to do the routing of the data and its associated PHASERR signal coming from separate wafers on its input to go to the same wafer on its output. PHASEMOD needs to be switched as well, however this can best be accomplished if each PHASEMOD signal of each wafer contains all of the phase models required by any switching that might be done. This implies some, but not unusually difficult, software overhead.

Otherwise, baseline processing of the data, and tradeoffs that may be performed, are identical to the 16SB-4PP:3IQ/7RQ:RB:RC mode previously described.

PULSAR PHASE BINNING

Pulsar phase binning may be turned on for any described modes. In fact, each sub-band pair of each BB pair could have different pulsar phase binning parameters and could be timed to simultaneously observe a different pulsar, subject to DUMPTRIG generation limitations in the Station Board. It is also possible to simultaneously mix pulsar phase binning in one or more sub-bands, which is tracking a pulsar, with dump timing synchronized to system timing in one or more other sub-bands that are not tracking a pulsar.

TRADING OFF BANDWIDTH FOR NUMBER OF BEAMS ON THE SKY

Each sub-band pair of each BB pair is very independent in terms of bandwidth, number of channels acquired, and recirculation (and number of re-quantization bits to some extent). Thus, there is no limitation on trading off bandwidth for number of beams on the sky; there could be one beam and 8 GHz per poln, all the way to 128 beams on 128 MHz, and 1 polarization.

SUB-ARRAYS

Since stations are fed into a BLB Correlator Chip row or column in chunks of 4 stations, then sub-arrays must logically and generally be in 4 station chunks. However, if all sub-arrays are real-time (meaning TIMECODE for all sub-arrays is the same), dump timing is synchronized to system timing, and dumps are harmonically related, then full sub-arraying flexibility is possible.

PHASED-ARRAY

The data streams in each baseline rack are more logically aligned for phasing. All of the data feeding out of one BLB pair (via the Y connector) can feed, via a set of short cables, into a Phasing Board. Each Phasing Board thus phases a sub-band pair from one BB pair for 32 stations. With 8 Phasing Boards in a baseline rack (which easily fits in one baseline rack's 6U backplane), a total of 8 sub-band pairs or 4 GHz of total bandwidth for 32 stations can be phased, from one BB pair. With a system total of 64 Phasing Boards, the entire bandwidth of 16 GHz can be phased.

AUTOCORRELATIONS

Some autocorrelations for every antenna and every sub-band pair are obtained simultaneously with cross-correlations, along the diagonal of the BLB matrix. Only 1 product can be obtained from one station at once, and it is the opposite product for the opposite station in the same chip. For example if stations 1, 2, 3, 4 are fed into the diagonal chip on a BLB, and its pair BLB, in the first chip in the first BLB, products 1Rx1R and 2Lx2L are obtained and in the 2nd chip in the adjacent BLB, products 3Rx3R and 4Lx4L are obtained.

If is desired to occasionally obtain much better autocorrelation spectral resolution, or if part of the correlator is not being used, then the BLB and Correlator Chips may be put into autocorrelator mode whereby 2048 channels are obtained for each autocorrelation self-product using all of the Correlator Chips on the board. For example 2048 channels on each of 1Rx1R, 1Lx1L, 2Rx2R, etc. These autocorrelations can have the same, or better, time resolution as cross-products, depending on CBE performance.

DUMP CONTROL

Since data streams for a group of 4 different antennas are fed into each Recirculation FPGA, the DUMPTRIG signal from one of the antennas should contain dump control information for all antennas in this group. To minimize/optimize bandwidth and processing to the CBE it may be desirable to have different LTA accumulation parameters, and that is the reason the dump control information will be different, although dump timing at the lowest hardware level will need to be synchronized. This may impose an unusual burden on software, and so the Recirculation FPGA could be upgraded to decode DUMPTRIG from each antenna's control signal to apply it to the associated data streams. This upgrade should be transparent to Recirculation FPGA driver software (i.e. it doesn't need to explicitly know this is happening, although some dump sync skew detection may be warranted).

VLBA CORRELATOR

It no longer makes sense to have a reduced-bandwidth correlator for the VLBA integrated with the EVLA correlator. In the new configuration, each antenna must use the full bandwidth configuration. Instead, it is only feasible to split-off one station rack of boards, and build an additional baseline rack of 16 boards to provide a 16-station, 4 GHz (2 GHz per polarization) separate correlator. This correlator can provide 8k channels per baseline at full bandwidth, with increases in the number of channels at lower bandwidths using static and dynamic recirculation, as described. The software for this correlator (including the CMIB device drivers, GUIs, CBE, MCCC/mapper, and CPCC) is a separate carbon-copy of the EVLA correlator, with additional driver software to control non-real-time TIMECODE synchronization, and disk-playback control.

Splitting off one station rack of the correlator for the VLBA still provides the EVLA with a 28-station correlator (i.e. one additional station input above the required 27 for the EVLA).