California Institute of Technology
VLBA Correlator Memorandum

To: VLBA Correlator Group — 17 October 1985
From: David Fort and Martin Ewing
Subject: Signal Switching

This memo describes the VLBA correlator signal switching scheme as it had evolved in the early summer of 1985. The correlator is assumed to have 16 input channels for each of up to 20 stations. For spectroscopic work, higher resolution steps are available for 14 or fewer stations, or 10 or fewer. The design is based on a VLSI gate array with 6-8,000 gate complexity running at 16 MHz. This chip would provide 8 "complex lags", shift registers, multipliers, and accumulators. Lobe rotation is performed on chip using a phase which is the difference between "station-channel phases" that come along with the signal data.

Since this design work was completed, a number of changes in the VLBA correlator specifications have been suggested. Most significantly, fringe rotation and delay corrections at the antenna via local oscillator and sampler offsets would greatly simplify the correlator. Another change is the increase in the channel bandwidth to 16 MHz, doubling the sample rate to 32 Ms/s. The former change, if adopted, might be radical enough to make a redesign of the correlator signal switching necessary. The latter, however, probably can be accomodated within the present scheme.

# I. VLBA CORRELATOR - SIGNAL SWITCHING - GENERAL

## Introduction

The basic organization of the correlator as outlined in the Architecture Report (Memo VC041) is that of one complete 20 station correlator (ECA - elementary correlator array) for each of the 16 channels. The 16 ECA's can be used independently in the non-polarized continuum case but are used in groups of 2, 4, 8 or 16 to achieve increased spectral resolution and/or polarization measurements. When used independently for high sensitivity continuum work an ECA need only be fed the signals from one channel of the 20 stations and all products are produced, including autocorrelation. However, for the spectral line and polarization case, each ECA must be fed two independent bundles (A and B) of 20 stations - delayed versions of each other for spectral lines and R and L for polarization. The signal switching must get the correct channels of the selected tape playback machines to the appropriate A and B inputs of the ECA.

## Requirements

The switching requirements of the VLBA correlator are as follows:

(a) Tape Changing (arbitrary tape playback units)

(b) Station Modes (10/14/20 Stations with 4/2/1 x lag concatenation)

(c) Spectral Line Modes (2, 4, 8, 16 x lags per channel)

(d) Polarization Modes (÷2 lags for LR & RL)

(e) Self Test/Self Heal (parallel data paths)

## Implementation

The Architecture Report combines (a) and (b) in an up-front "station crossbar" switch and implements (c) and (d) using a combination ofthe DPS internal channel crossbar and an unspecified switch before the correlator electronics. Requirement (e) is left unspecified. Figure 1 is a representation of the data paths as given by figures 4-4 and 4-5 in VC041.

The Station Electronics is composed of 20x16=320 units which delay the signals from the DSPs and add fractional delay and phase information according to the geometry of the VLBA. It may also extract phase calibration from the data.

The Correlator Electronics is composed of 16 ECAs each of which contains 20x20=400 ECs (Elementary Correlators) of 8 complex lags each. The output of the correlator electronics is sent to the TOP (Transform/Output Processor).

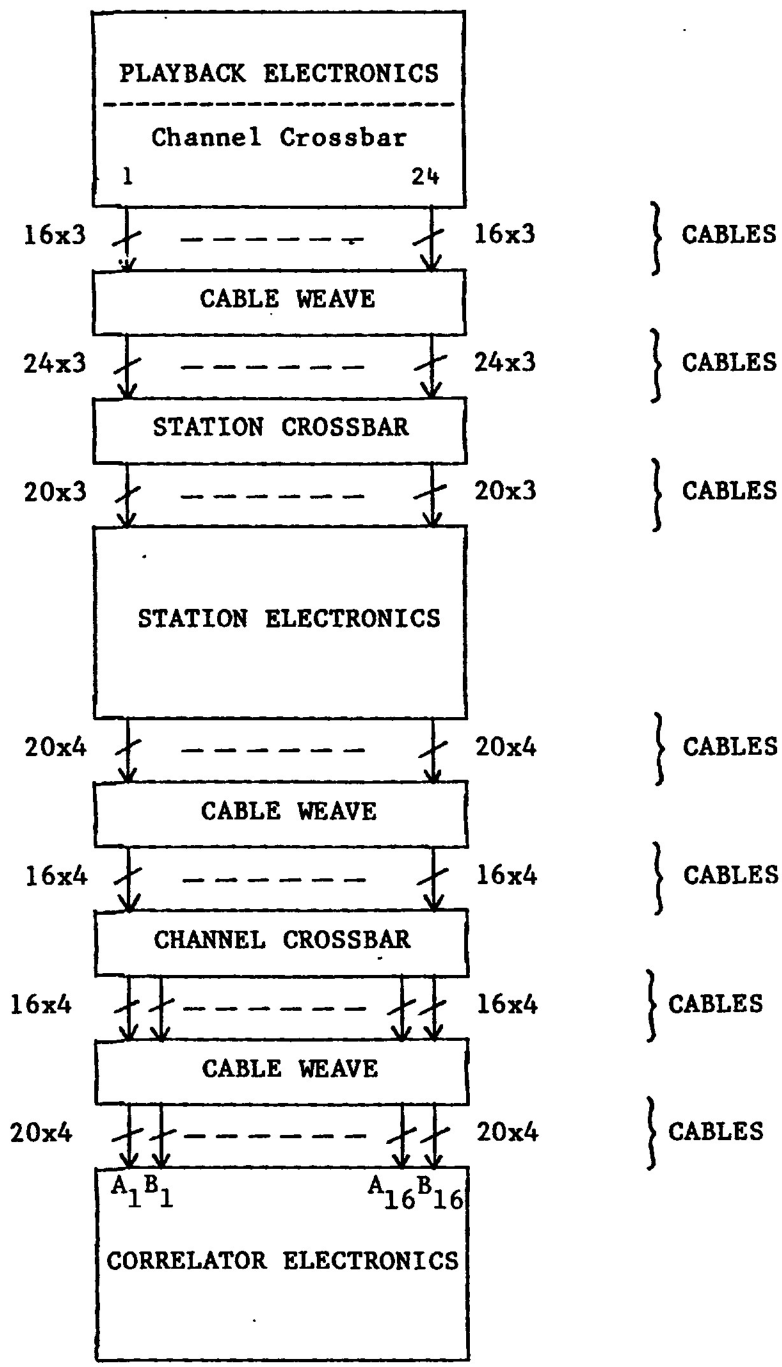



**FIGURE I-1. DATA PATHS IN THE ARCHITECTURE REPORT**

## Revised Implementation

The main inelegance of this arrangement is that requirements (c) and (d) are most easily implemented by a second channel crossbar which in turn requires an extra reorganization from station bundles to channel bundles and back again. This can be avoided by placing the station crossbar after the station electronics. Although this means more station electronics, (24 versus 20) it results in a significant simplification. As will be seen later, it presents a solution to other connection problems which reduces the cost. The data path diagram resulting from this reorganization is shown in figure 2.

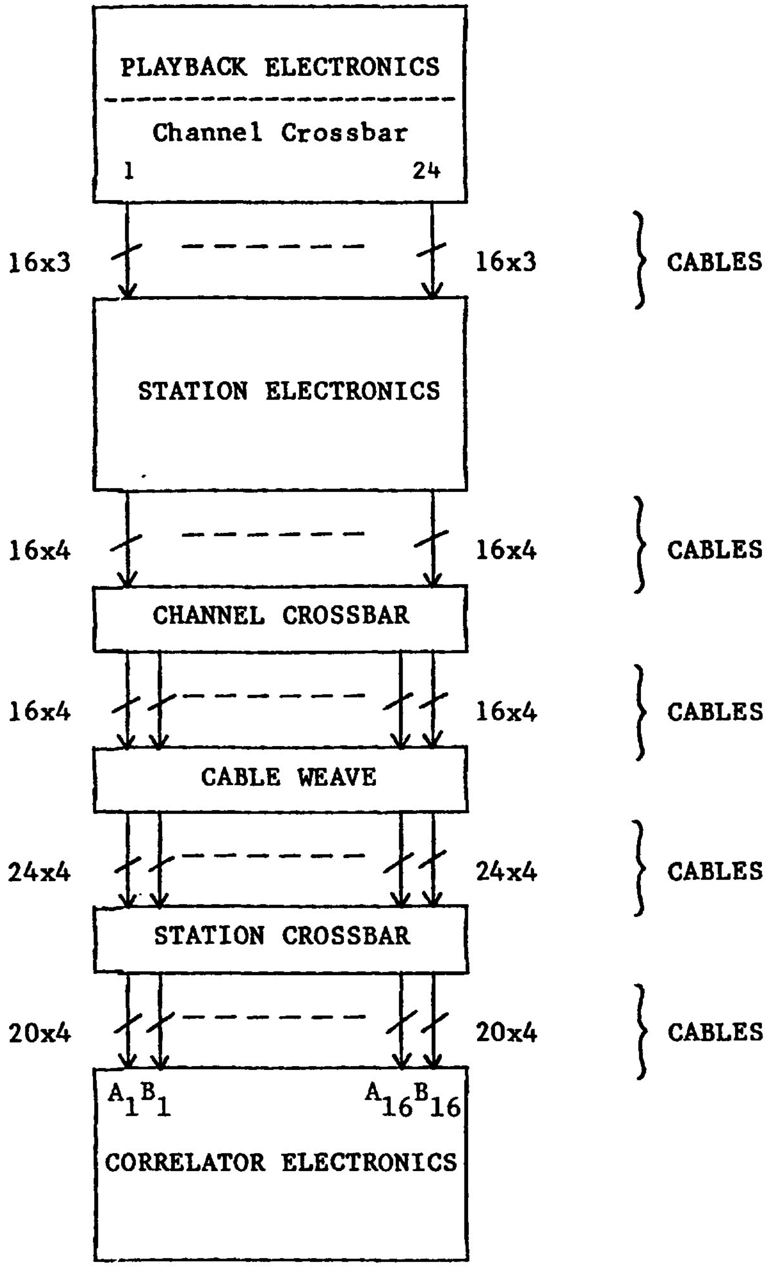



**FIGURE I-2. REVISED DATA PATH**

## Further Considerations

(a) As discussed in Memo VC043, it is advantageous (at 16 Mb/s) to bus the A and B station bundles inside an ECA and use a VLSI switch to select the stations to be correlated. As well as being simpler, this approach satisfies condition (e) since extra correlators could be switched in parallel. In addition, the station crossbar switch becomes internal to each ECA and can be removed from figure 2.

(b) The same arguments can be applied to the Station Electronics and the channel crossbar in the DSP could be eliminated. The output channel crossbar becomes internal to the Station Electronics. Run time testing of station electronics could be accomplished by building extra channels and making a bit-by-bit comparison inside the SE.

(c) The use of a general channel crossbar at the output of the Station Electronics to obtain the spectral line and polarization modes may seem excessive. In fact, at least one ECA has to obtain its A input from 8 different channels; therefore, allowing it to come from any of 16 is not such a big step (especially for a VLSI switch). Furthermore, a general switch allows the possibility of full sensitivity continuum polarization for 14 and 20 station modes (not included in the Architecture Report).

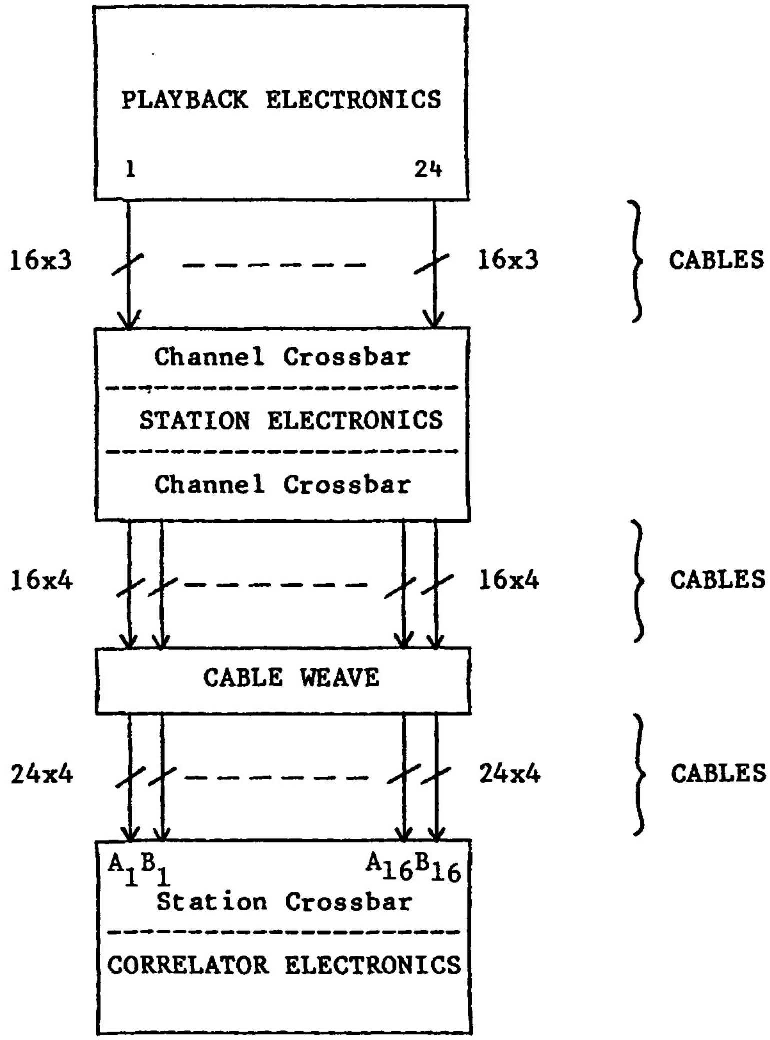



**FIGURE I-3. RE-REVISED DATA PATH**

Examples of Major Modes

Station mode switching (10/14/20 stations) is done internal to each ECA. Spectral Line/Polarization mode switching can be done as follows:

(a) Non-Polarized Continuum Mode: Sixteen different channels are recorded. Each channel is sent to a different ECA. The A and B bundles sent to a particular ECA are identical (A=B).

(b) Polarized Continuum Mode: Eight different pairs of R and L circularly polarized channels are recorded. The ECAs are combined into eight groups of two. Each of the two ECAs in a group is sent both R and L channels (A=R, B=L). The ECAs then require internal switching to form RR, LL in one ECA and RL and LR (for example) in the other. This mode does not appear in the Architecture Report. In that report the polarized modes (continuum and spectral line) are done by combining the ECAs into four groups of four and forming one of RR, RL, LR and LL products in each of the ECAs in a group (see (d) below). This latter scheme does not require the ECA internal switching but is limited to four frequency bands. This limitation is OK for spectral lines but results in a loss of sensitivity for continuum work.

(c) Non-Polarized Spectral Line Mode: One, two, four or eight different channels (frequency bands) are recorded. The ECAs are combined into groups of sixteen, eight, four or two respectively. Each ECA in a group is fed identical B bundles but the A bundles are advanced and delayed versions of the B bundles (one of the A bundles is identical to the B bundles). As an example, if a group consists of four ECAs, then:

| Group | ECA | A (lag) | B (lag) | Lags Covered $\pm$ |
|---|---|---|---|---|
| 1, 2, 3 or 4 | 1 | (32) | (128) | $\|96 \rightarrow 128\|$ |
| | 2 | (64) | (128) | $\|64 \rightarrow 96\|$ |
| | 3 | (96) | (128) | $\|32 \rightarrow 64\|$ |
| | 4 | (128) | (128) | $\|0 \rightarrow 32\|$ |

The case of 16 frequency bands is equivalent to the non-polarized continuum mode.

(d) Polarized Spectral Line Mode: One, two or four different channels (frequency bands) are recorded. The ECAs are combined into groups of sixteen, eight or four respectively. Each group is further divided into sub-groups of four to do the polarization products (RR, LR, RL and LL).

As an example, if two channels are recorded (R and L) then:

| Sub-Group | ECA | A (lag) | B (lag) | Lags Covered ± |
|---|---|---|---|---|
| 1 | 1 | R(32) | R(128) | RR\|96→128\| |
| | 2 | R(32) | L(128) | RL\|96→128\| |
| | 3 | L(32) | R(128) | LR\|96→128\| |
| | 4 | L(32) | L(128) | LL\|96→128\| |
| 2 | 5 | R(64) | R(128) | RR\|64→96\| |
| | 6 | R(64) | L(128) | RL\|64→96\| |
| | 7 | L(64) | R(128) | LR\|64→96\| |
| | 8 | L(64) | L(128) | LL\|64→96\| |
| 3 | 9 | R(96) | R(128) | RR\|32→64\| |
| | 10 | R(96) | L(128) | RL\|32→64\| |
| | 11 | L(96) | R(128) | LR\|32→64\| |
| | 12 | L(96) | L(128) | LL\|32→64\| |
| 4 | 13 | R(128) | R(128) | RR\|0→32\| |
| | 14 | R(128) | L(128) | RL\|0→32\| |
| | 15 | L(128) | R(128) | LR\|0→32\| |
| | 16 | L(128) | L(128) | LL\|0→32\| |

This method of doing the polarization uses all the available lags in the spectral line case but is limited to four separate frequency bands. This limitation is within the correlator specifications. In any case, eight polarized spectral bands is equivalent to the polarized continuum mode and can be done as in (b).

If it were decided to reduce the number of channels recorded to eight (while doubling the bandwidth per channel to 16 MHz) then mode (b) would not be used at all. This statement assumes that the station electronics and correlator electronics remain the same (sixteen channels) in order to achieve 1024 lags per baseline in 10 station non-polarized spectral line mode. Mode (d) would be sufficient for both the polarized continuum and polarized spectral line case, simplifying the correlator electronics.

One might wonder why not do both continuum and spectral line polarized cases using (b)? The answer is that the 20 station polarized case produces problems when using (b) and 400 ECs per ECA. While these problems can be resolved, the most likely solution precludes the possibility of the cross-polarized autocorrelation function being measured. This limitation can be tolerated in the continuum case but not for the spectral line case.

**Summary**

Requirements (a), (b), (c) and (d) are met by providing a per station channel crossbar switch before and after the station electronics and a per channel station crossbar switch at the input of each ECA in the correlator electronics. In the station electronics each station is independent of the other stations while in the correlator electronics each channel is independent of the other channels, thereby simplifying connections.

# II. VLBA CORRELATOR - SIGNAL SWITCHING - IMPLEMENTATION

This section deals with a possible implementation of the following major subsystems in the VLBA correlator:

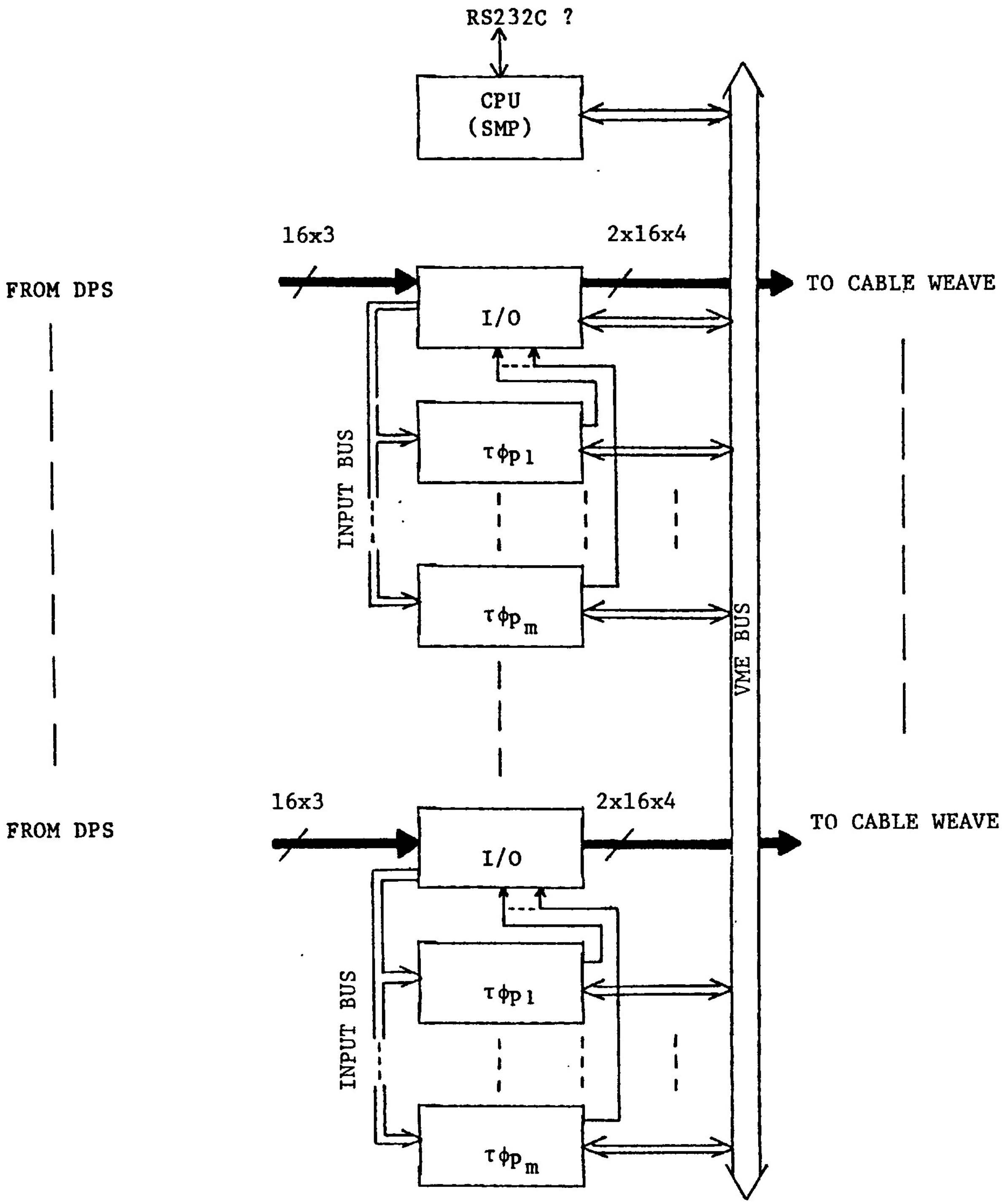
1. Station Electronics
2. Correlator Electronics

Each of the above subsystems is decomposed into a number of crates. Each crate has a CPU and communications inside the crate would be done over a VME bus. The crates are independent and communicate (via standard interfaces) to the control computer (a "communications concentrator" could be placed between the crates and the control computer). As a workable system (at 16 Mb/s data rate) we have chosen a triple height VME board (of arbitrary length). A crate could hold 20 such boards.

If off-the-shelf integrated circuits are used for the Station Electronics then it would be reasonable to put two stations in one crate. It would then take about 3 racks. If VLSI were used then 8 stations could fit in one crate and hence one rack would be more than enough.

It should be possible to put a complete ECA in one crate using the 8 lag VLSI correlator chip and 8 of 24 VLSI switch chip. Hence, the correlator electronics (16 ECAs plus power supplies) could fit in 4 racks.

As discussed in memo VC043, the 400 VLSI correlator chips that make up an ECA have been organized into 4x4 blocks to facilitate station mode/concatenation switching. The following figures show a possible hardware realization.




m = 2 for VLSI τφp
m = 8 for off-the-shelf components

**FIGURE II-1. SE CRATE (16 Mb/s data rate)**

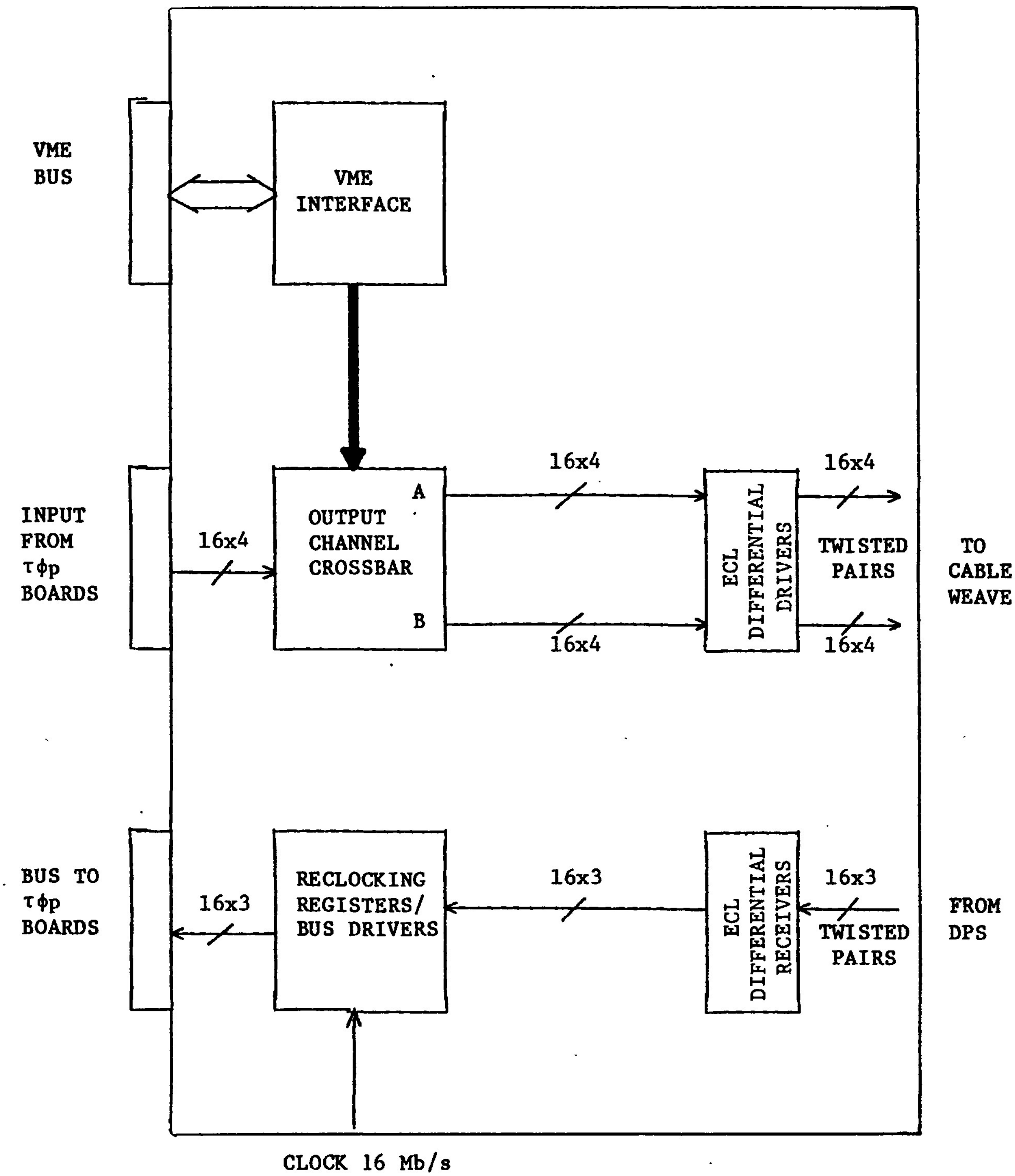



**FIGURE II-2. SE I/O CARD**

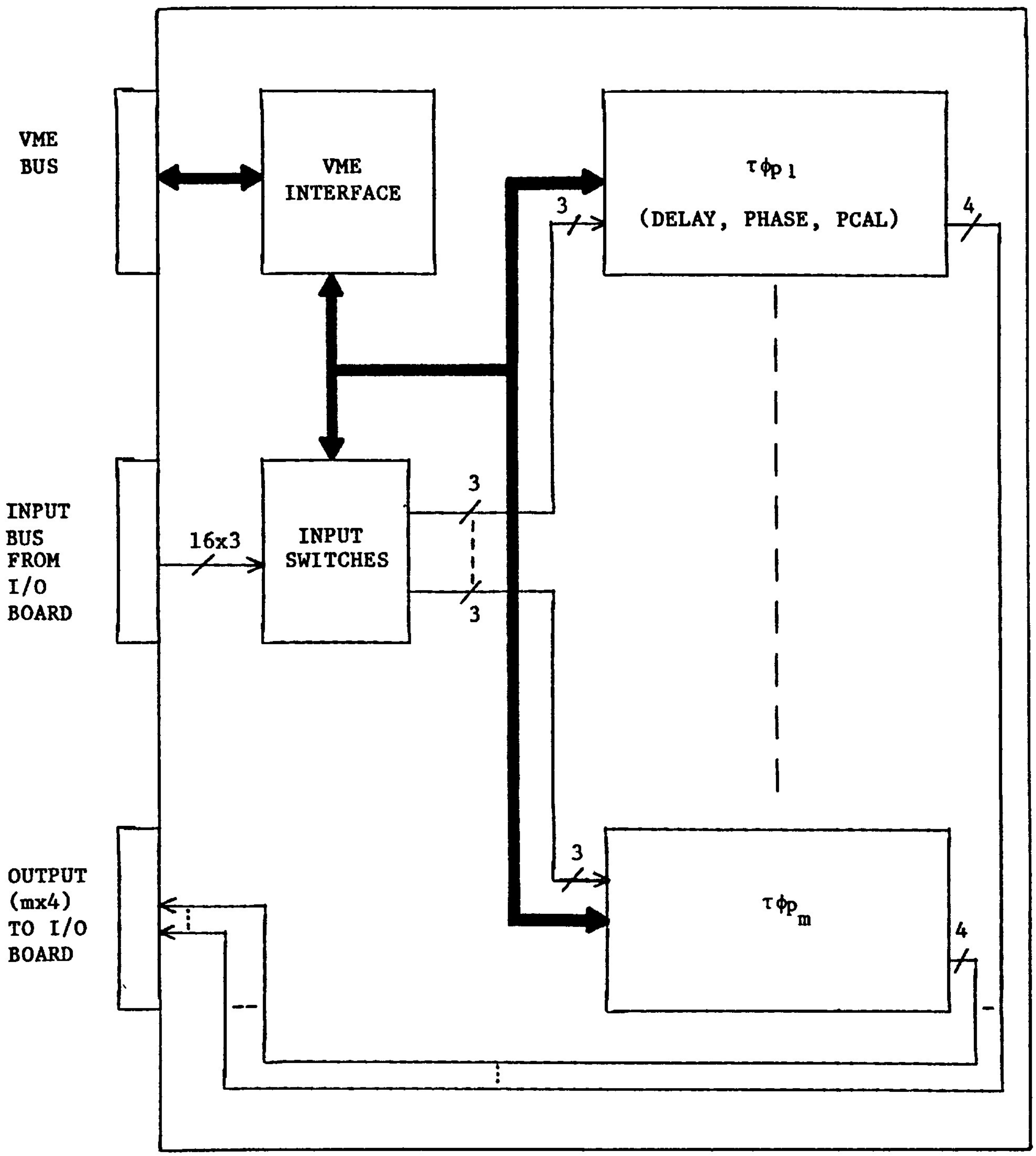



FIGURE II-3. SE STATION CARD

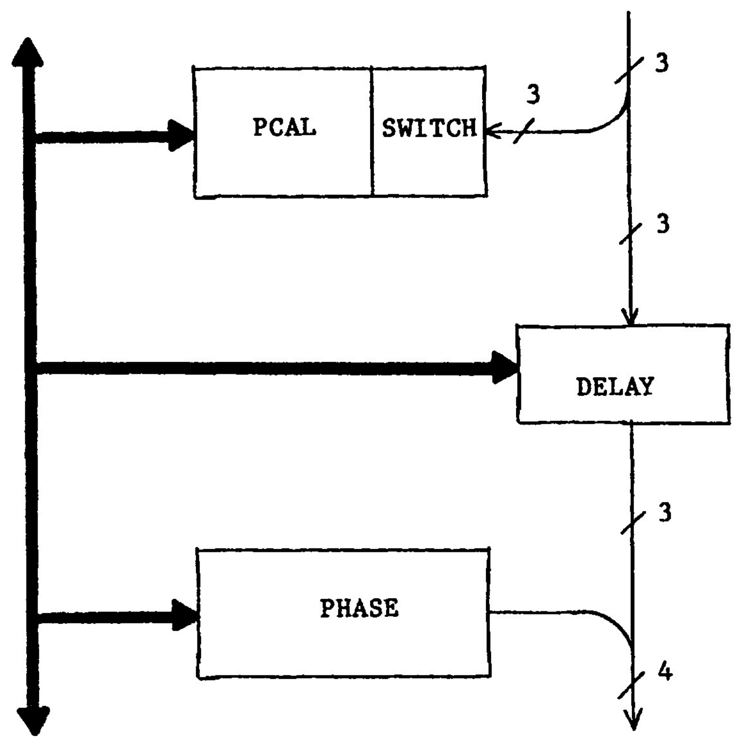



**FIGURE II-4. $\tau\phi p$ DETAIL**

Converts 24 stations of 16 channels (A and B)
into 16 channels of 24 stations (A and B)

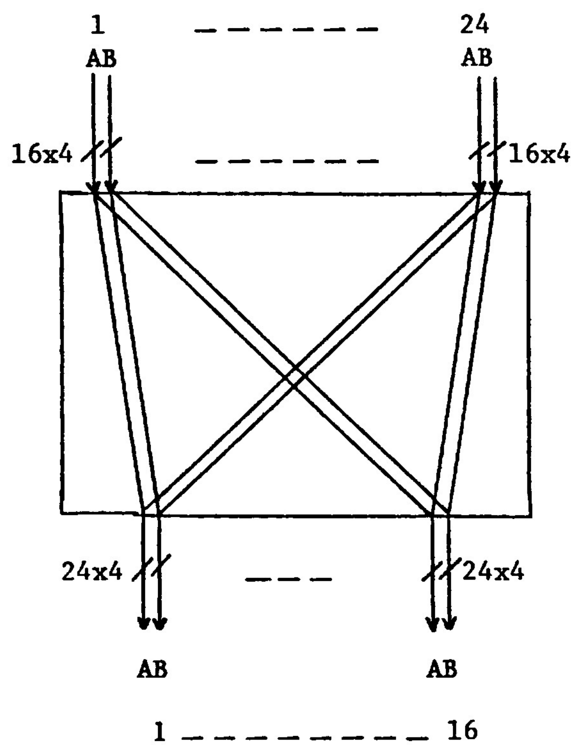



FIGURE II-5. CABLE WEAVE

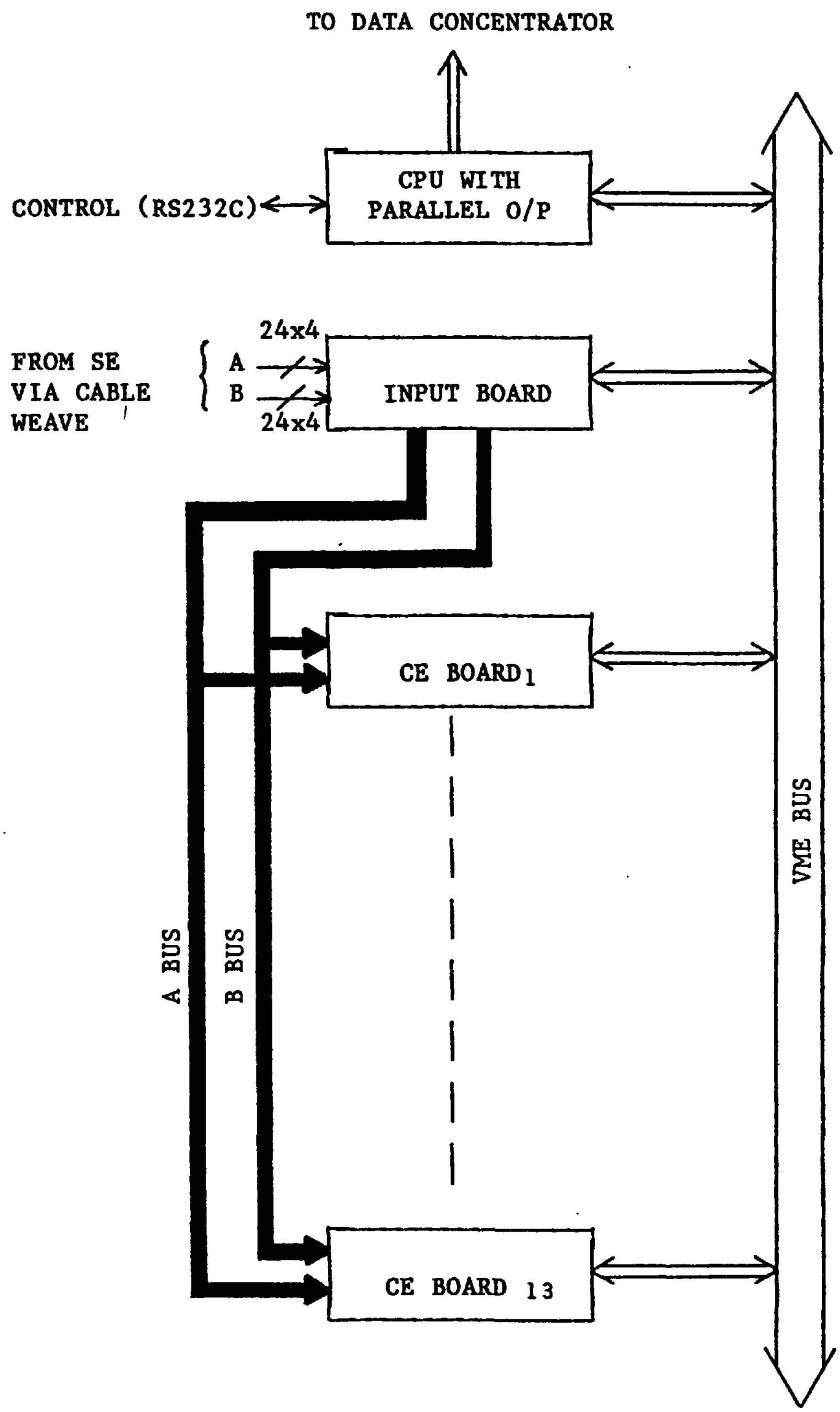
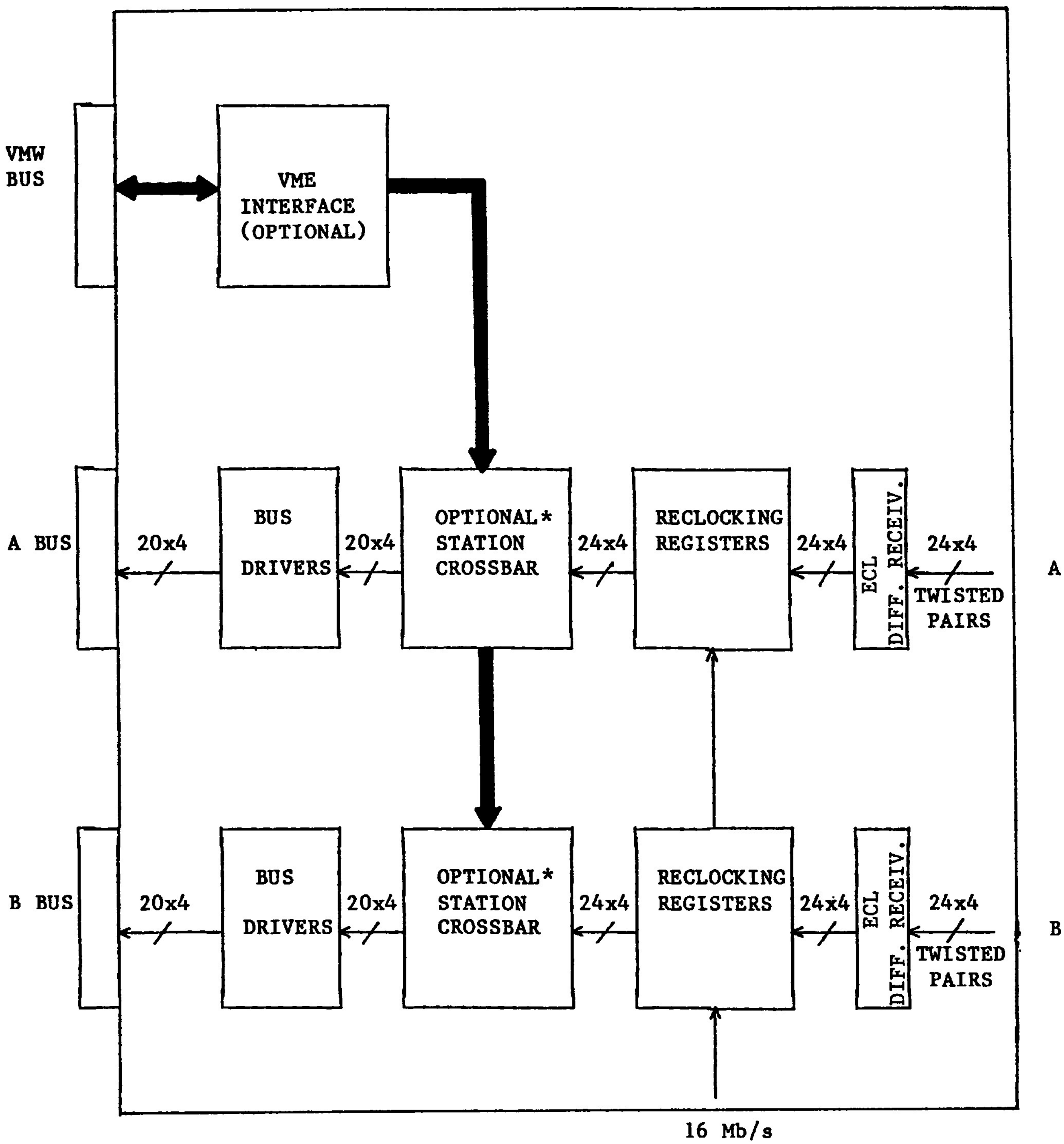



FIGURE II-6. CE CRATE




* This option would be exercised to reduce the number of bussed signals from 24x4 to 20x4.

**FIGURE II-7. CE INPUT CARD**

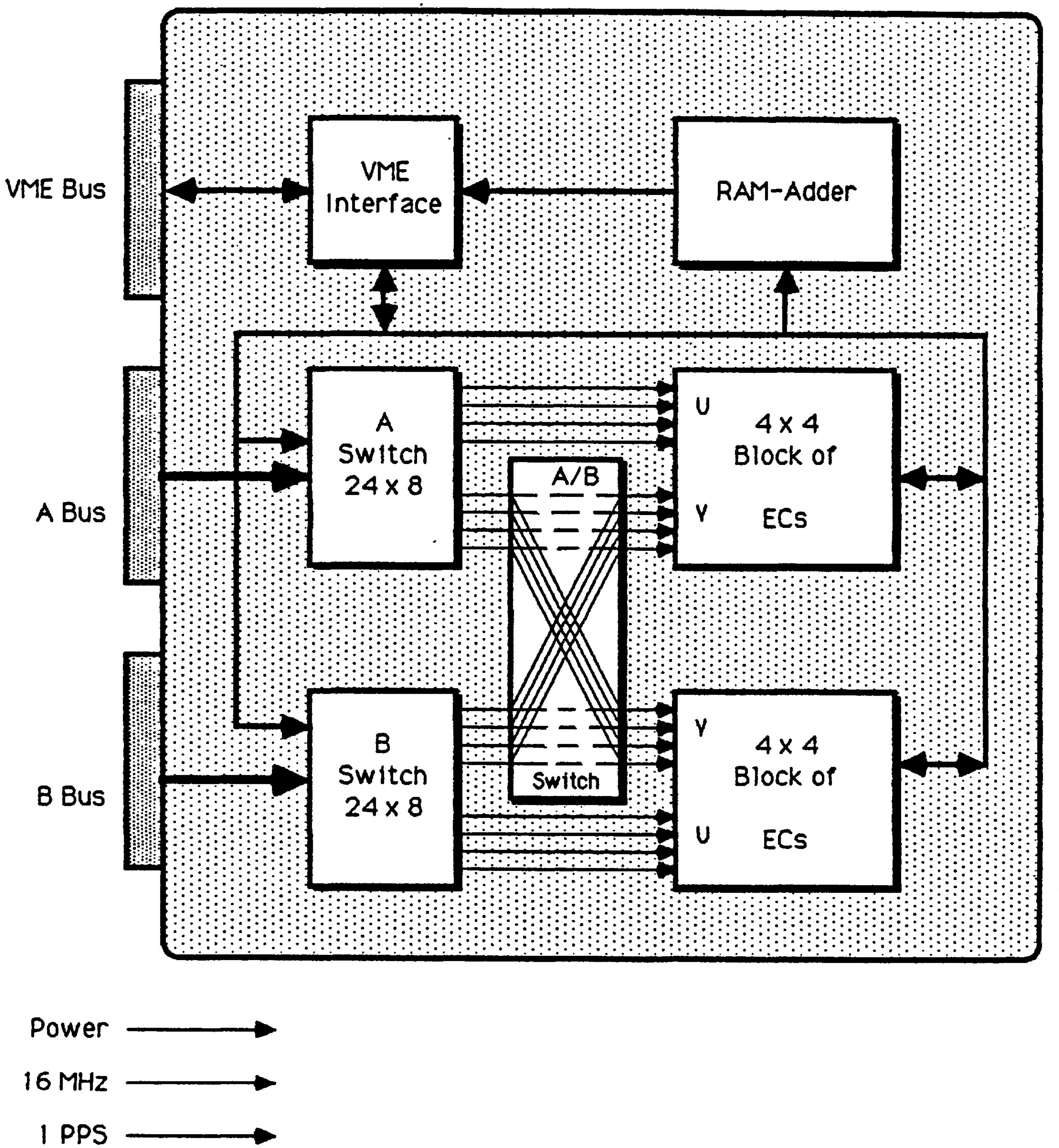



**FIGURE II-8. CE CORRELATOR CARD**

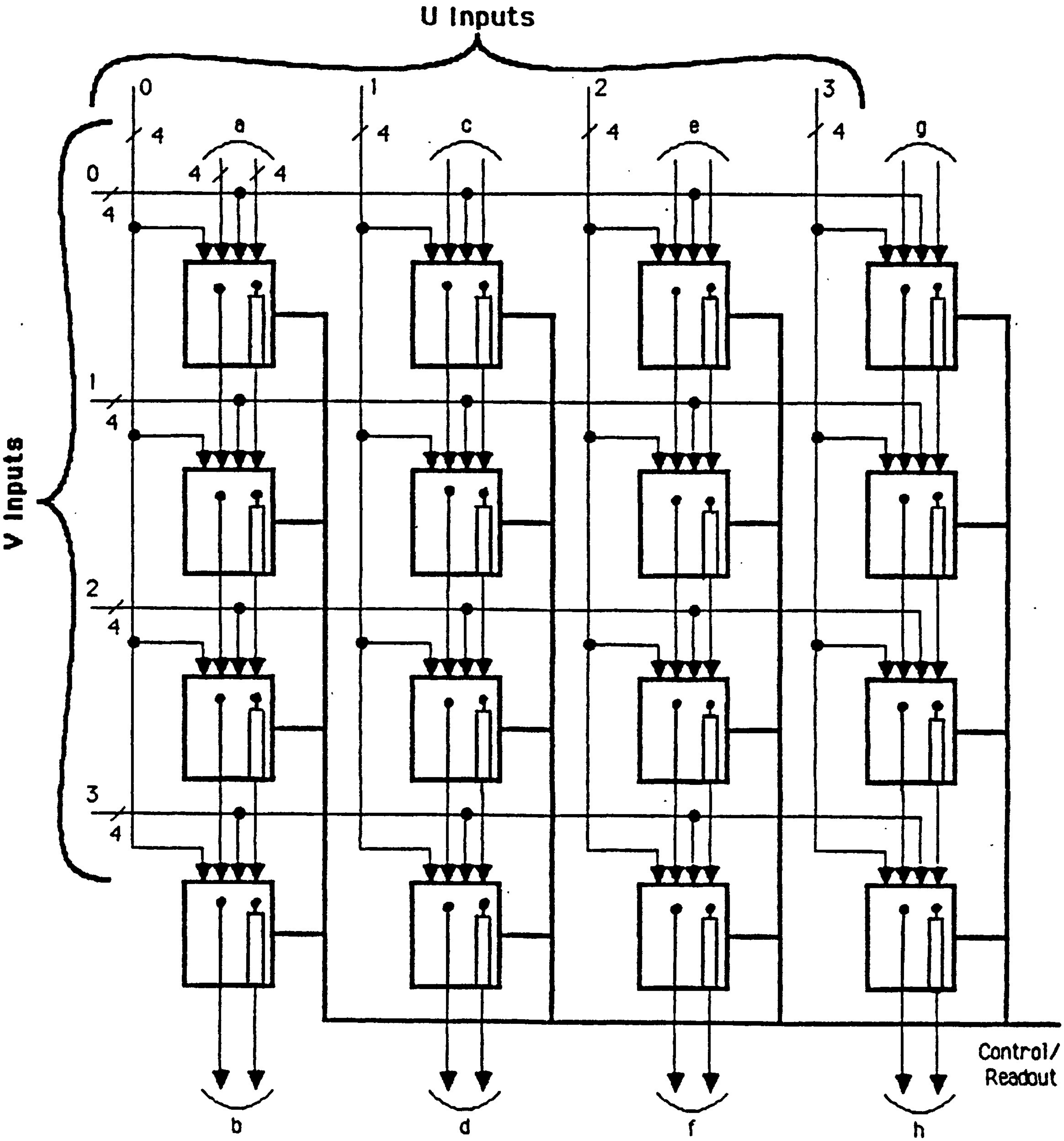



FIGURE II-9. 4x4 BLOCK DETAIL

Some Explanatory Notes

(a) Each ECA is arranged as a 20x20 array of elementary correlators (EC - 8 lags). This array is further subdivided into twenty-five 4x4 blocks. The A & B switches (Figure II-8) can select any four A stations and any four B stations as inputs to a 4x4 block. Normally, the block correlates the four A inputs against the four B inputs. However, since the number of lags per baseline must be traded off against the number of stations and against the number of polarization products, more complicated signal routing is necessary. The size of the block is governed by these modes and must be able to be connected as eight double lag correlators and four quadruple lag correlators. Concatenating ECs can be accomplished by feeding the output of one EC to the input of the next. Alternatively, each EC could contain switchable lags (0, 8, 16, or 24), thus reducing the number of external inputs to the EC at the expense of extra gates. As shown in Figure II-9, both the internal prompt and delayed signal can come from any of the four inputs to the EC. This switch is sufficient to handle the allowed station mode/concatenation tradeoffs. The polarized continuum mode requires more switching external to the EC. If A=R and B=L then only RL and LR products could be formed in a given ECA. Hence, the "A/B Switch" is included to allow the RR and LL to be formed inside a single ECA. It turns out that the A/B Switch must allow pairs of signals to be different switched independently.

(b) Normally, the positive and negative lags are formed in separate 4x4 blocks but the 20-station polarized continuum mode requires a factor of two more ECs than are available. A solution to this problem is obtained by putting a selectable 4 lag delay in the prompt side of the VLSI signal path to achieve a +/- 4 lag correlator in a single EC. A slight catch is that the cross-polarized autocorrelation functions cannot be measured (may be OK for continuum).

(c) Thirteen CE cards give each ECA 26 4x4 blocks, leaving one to be used as a spare or self-test/self-healing block.

(d) The (rather nasty) A/B switch would not be necessary if there were twice as many ECAs as there were channels. This may occur if it is decided to record only 8 channels as was discussed at the September Design Workshop. The bussed backplane scheme may not be good enough at a data rate of 32 Mb/s.

(e) Referring to Figure II-9, if the following connections are made on the board - b to c, d to e, f to g and a and b are available on the edge connector, then the whole ECA could be concatenated if anyone could think of a good use for it.

## III. VLBA Correlator - Signal Switching - Examples

This section contains examples of correlator configurations to support many of the key modes required in the VLBA. Figures III-1 to III-6 illustrate the inputs and operating modes of each of the 25 correlator blocks in an ECA. The particular square arrays as shown are quite arbitrary, since any block may be exchanged for another block in the ECA. (This flexibility will be used in self-test and repair functions, since the 26th block is a spare which may be operated in parallel with, or as a replacement for, any of the other blocks.)

Only Figures III-5 and III-6 require the "A/B switch" which is proposed for the correlator card. The switch would remain unnecessary if only 8 channels were recorded (as has been discussed) but the correlator remained a 16-channel system as might be justified by the need for keeping 1024 lags per baseline for the spectral line case.

Figures III-5 and III-6 do need the A/B switch (selectable in pairs) and the extra 4 lags for internal delay centering.

The internal switching of each block in an ECA is selected from one of five principal modes, illustrated in Figures III-7 through III-14. The bold lines indicate the settings of each EC's input multiplexors. The little boxes of Figure III-13 denote an extra 4-lag delay element required in this mode.

Mode. 20 Station Spectral Line Non-Polarized and Continuum Mode
(16 lags/baseline/polarization

Inputs to 4 x 4 Blocks-Delayed in EC

Inputs to 4 x 4 Blocks-Prompt in EC

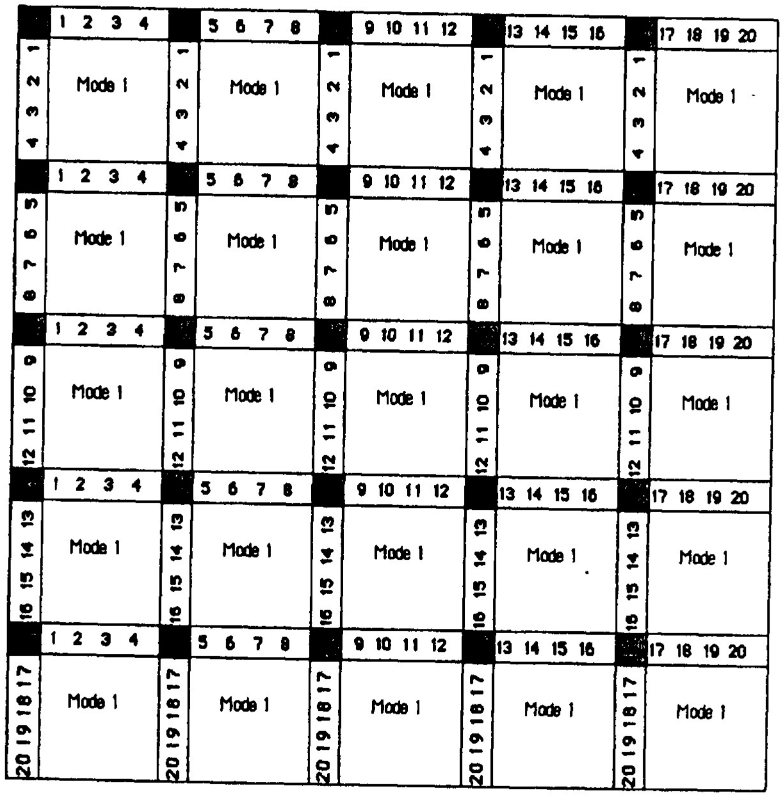
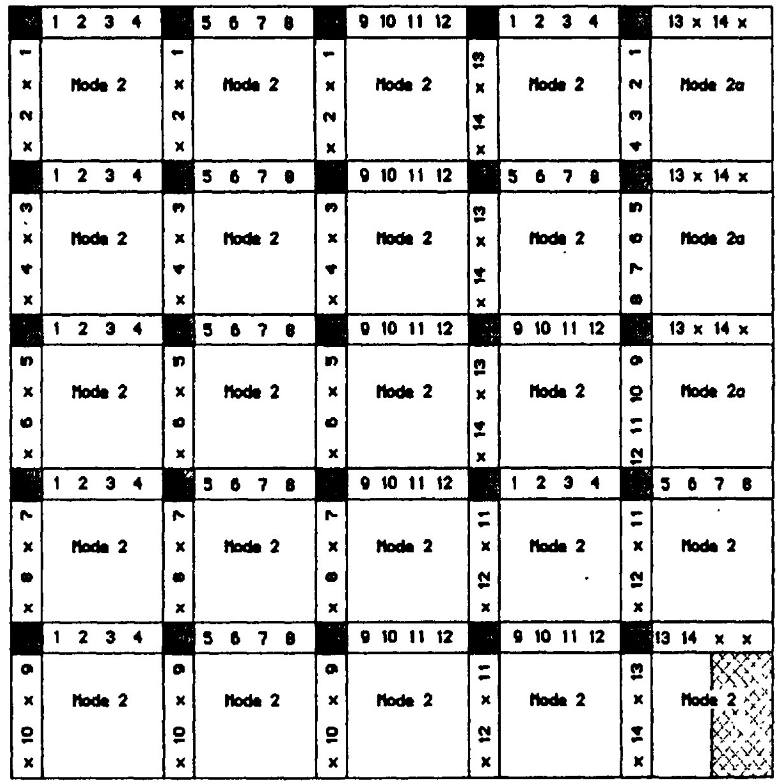



Figure III-1

Mode: 14 Station Spectral Line Non-Polarized and Continuum Mode
(32 lags/baseline)

Inputs to 4 x 4 Blocks-Delayed in EC

Inputs to 4 x 4 Blocks-Prompt in EC



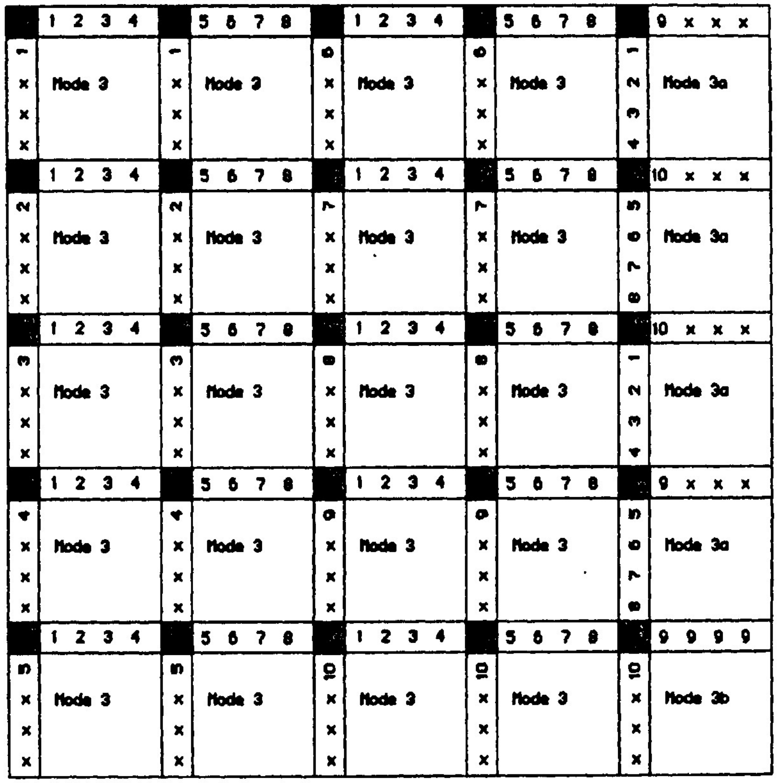

Note: (x) = Don't Care (Input comes from last EC)

Figure III-2

Mode: 10 Station Non-polarized (64 lags/baseline)

Inputs to 4 x 4 Blocks

Inputs to 4 x 4 Blocks-Prompt in EC

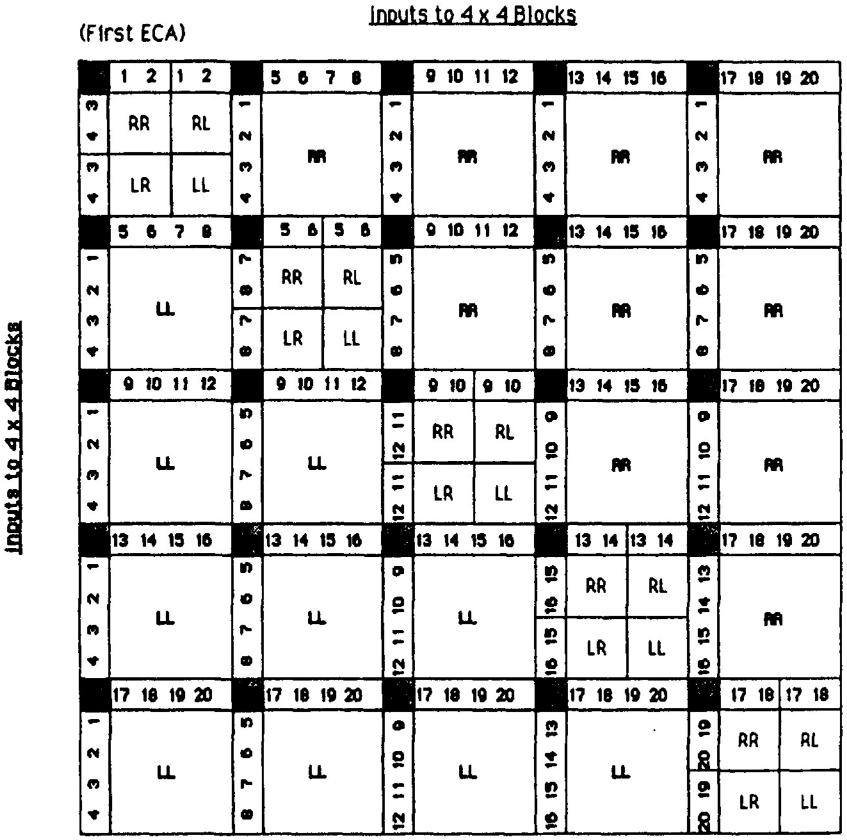



Note: (x) = Don't Care (input comes from last EC)

Figure III-3

Mode: 20 Station Polarized Continuum Mode (8 lags/baseline/polarization)
16 Channels

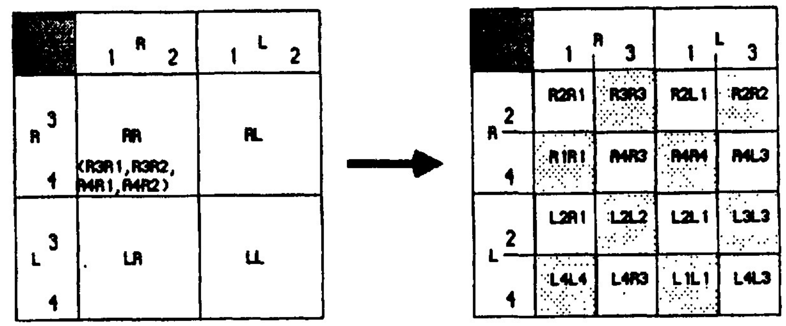
(First ECA)




Notes:

1. Requires A/B crossover switch (independently switchable in pairs) and A=R, B=L (for example).
2. For second ECA (of a pair), change RR->RL and LL->LR, except for diagonal blocks, which are shown below.
3. All 4x4 blocks except the diagonal in second ECA use mode 1 with extra lags switched into prompt side.

Figure III-4a



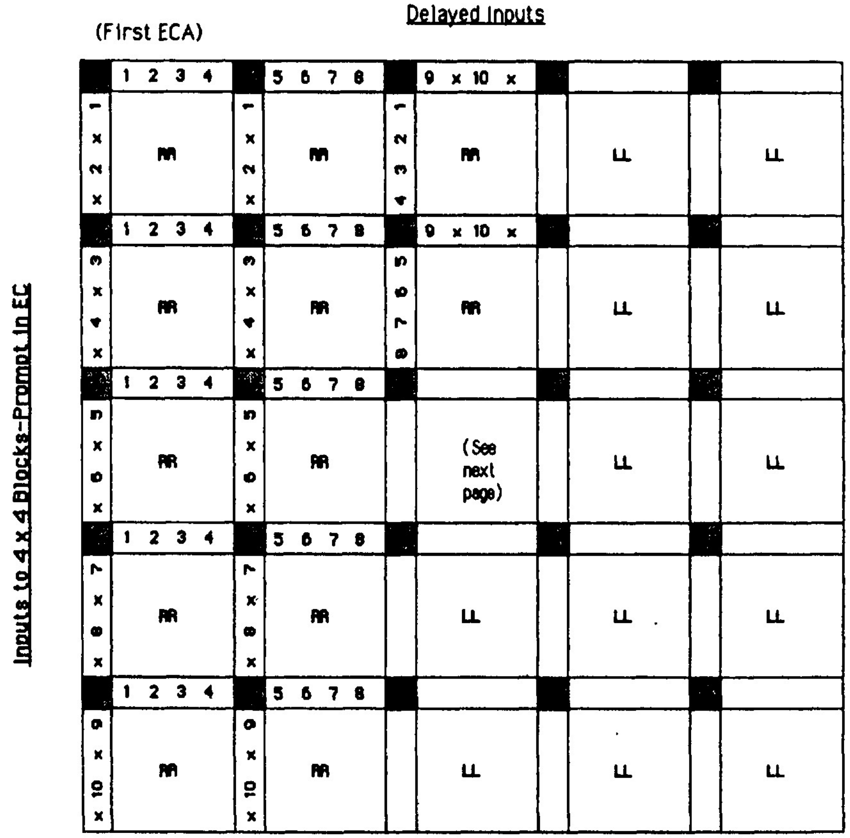

1st ECA

2nd ECA
(mode 4)

Note: The first ECA produces baselines 1-3, 1-4, 2-3, and 2-4, while the second produces 1-2 and 3-4, and 1-1, 2-2, 3-3 and 4-4 (the autocorrelations).

Figure III-4b

Mode: 10 Station Polarized Continuum (32 lags/baseline/polarization)




Notes:
1. Needs A/B Crossover Switch.
2. For second ECA, replace RR by RL and LL by LR, except for center block as shown below.
3. All Blocks are Mode 2 or 2a.

Figure III-5a

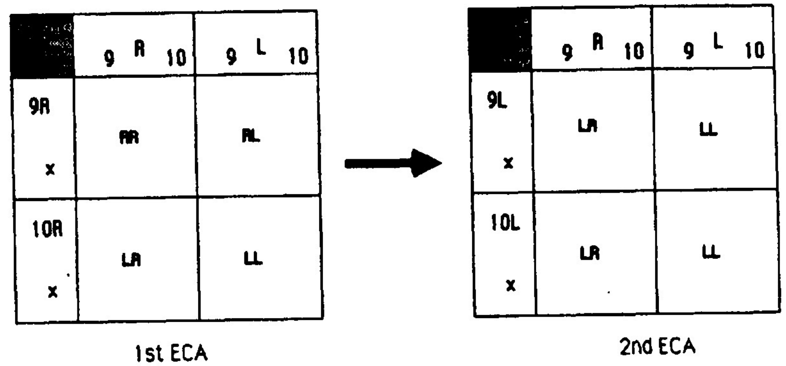


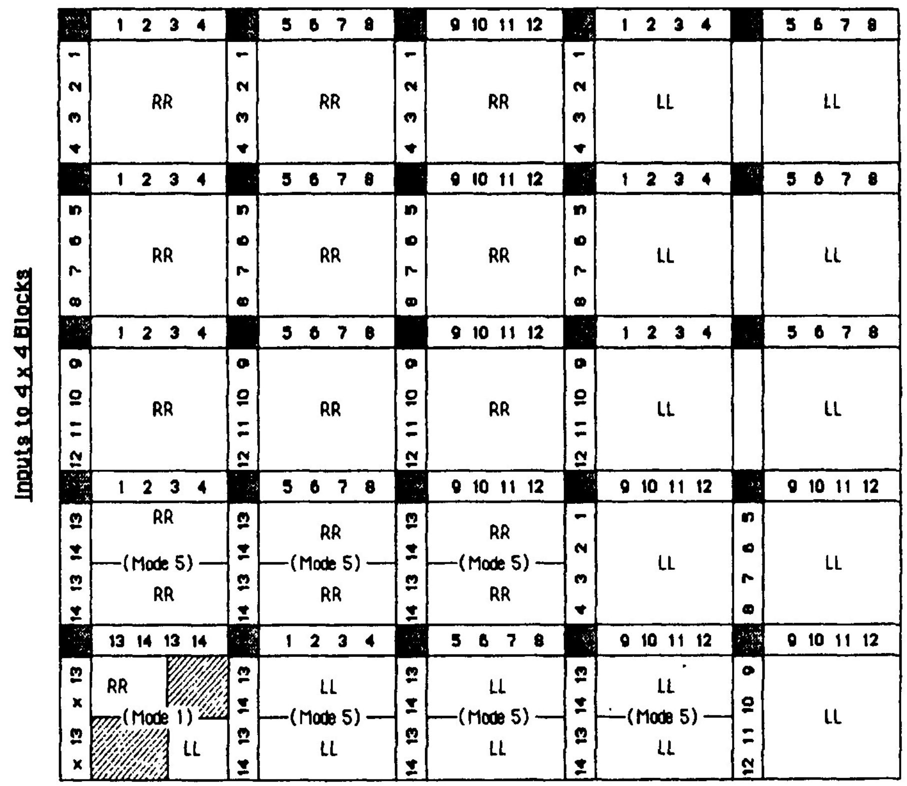

Figure III-5b

Mode. 14 Station Polarized Continuum (16 lags/baseline/polarization)

16 channels.

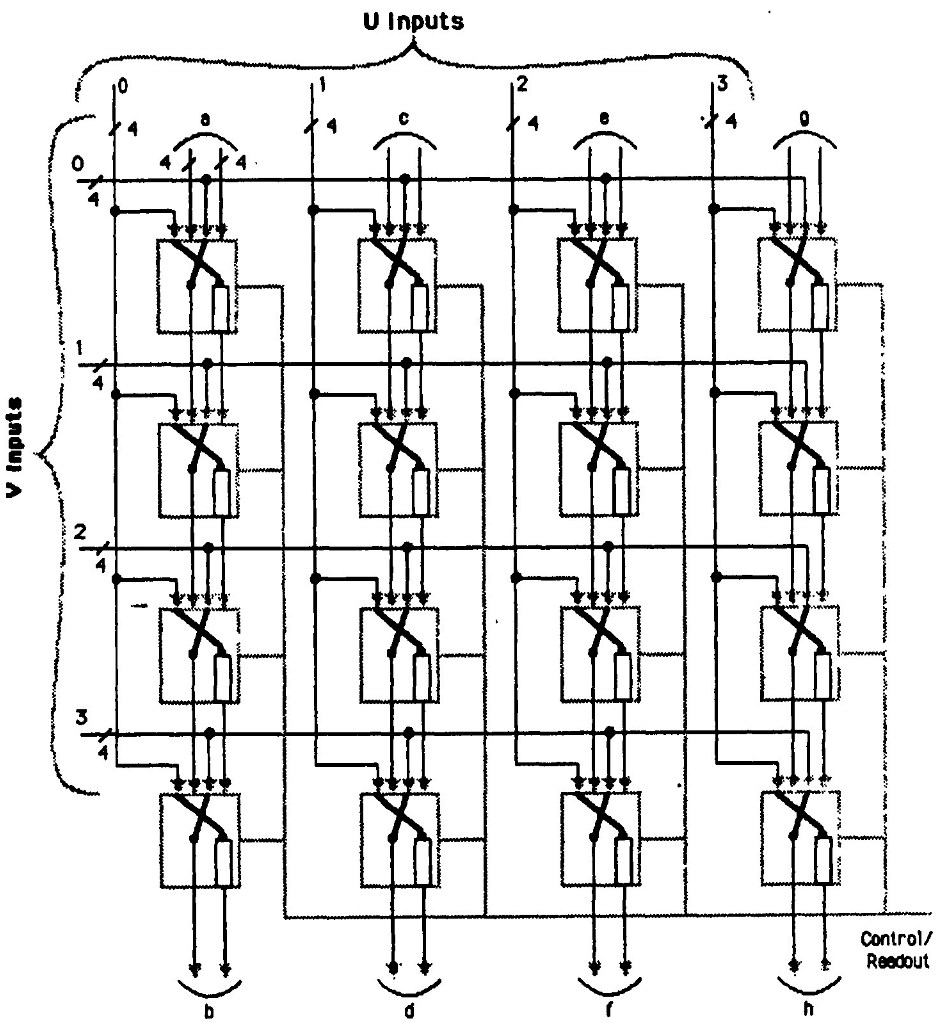
Inputs to 4 x 4 Blocks

(First ECA)




Notes.
1. Requires A/B Crossover Switch and A=R, B=L.
2. Other ECA (of a pair) is the same except for changing RR -> RL and LL -> LR.
3. All non-split blocks operate in Mode 1.

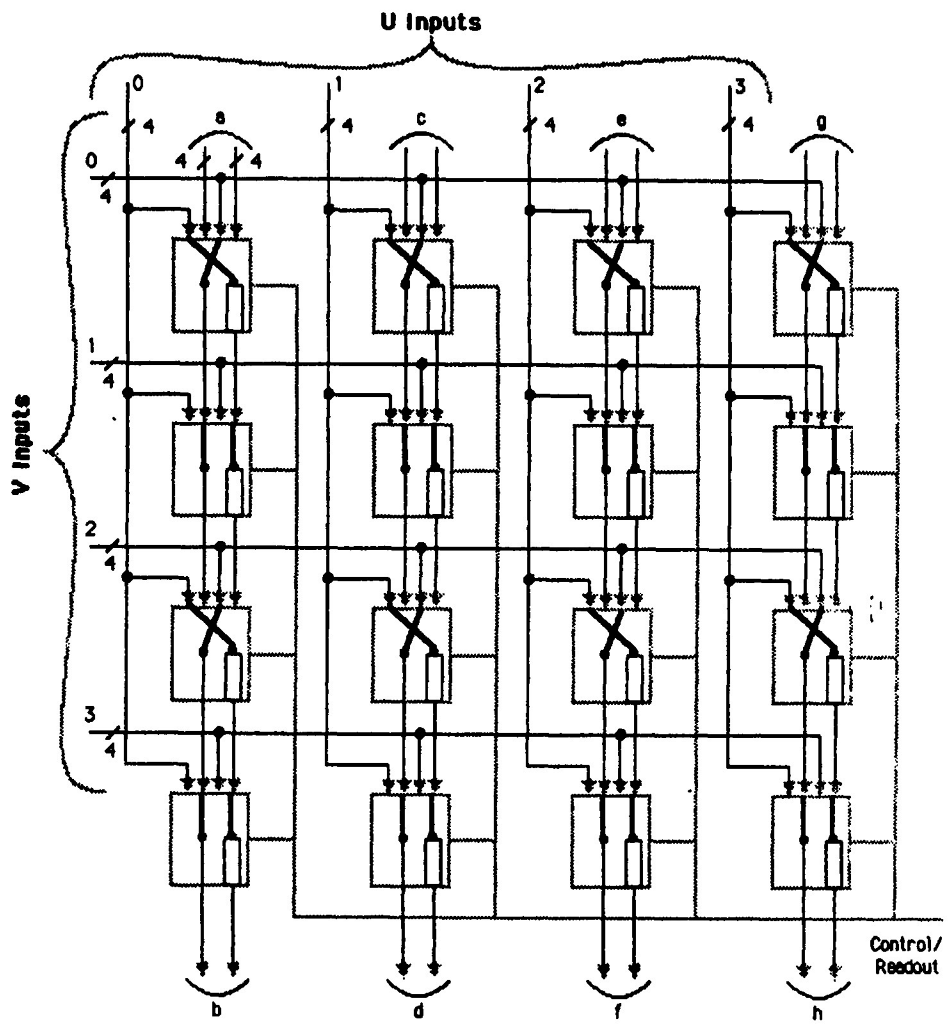
Figure III-6




4 x 4 Block of Elementary Correlators (ECs).

Mode 1. 4 x 4 x 8 lags

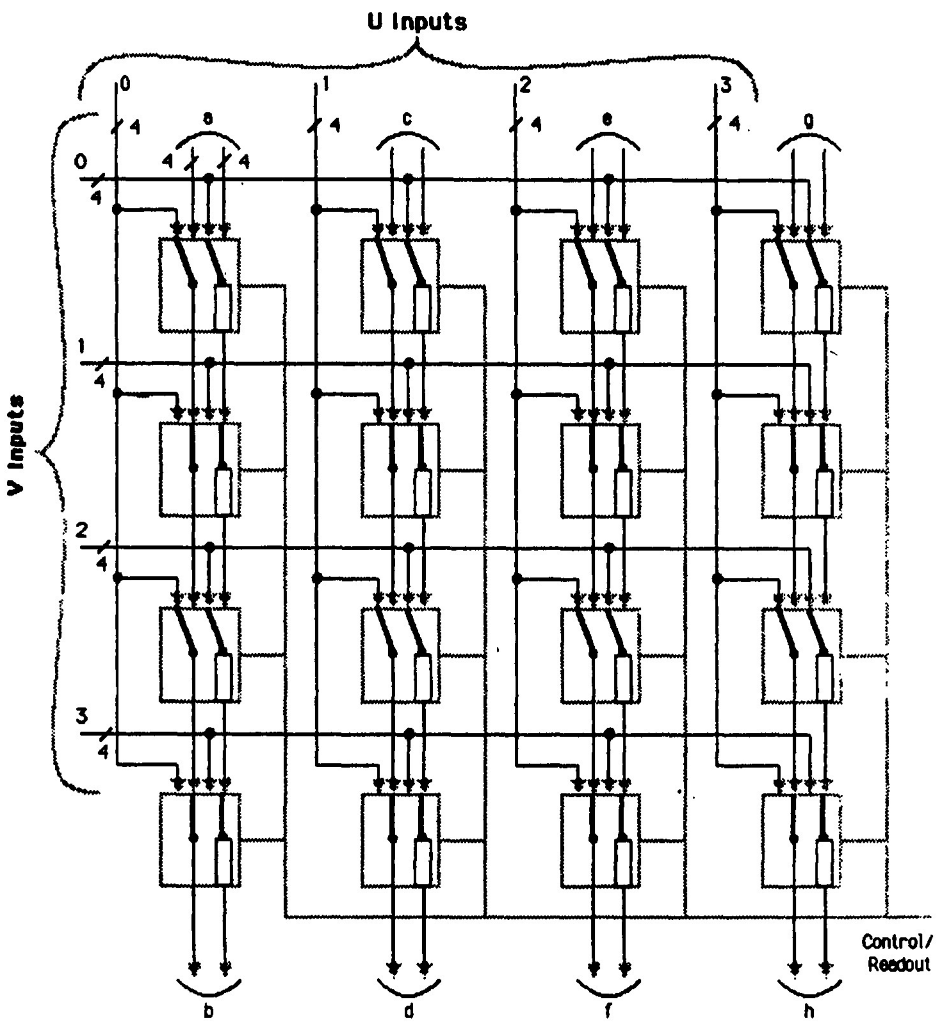
Figure III-7




4 x 4 Block of Elementary Correlators (ECs).

Mode 2. 4 x 2 x 16 lags

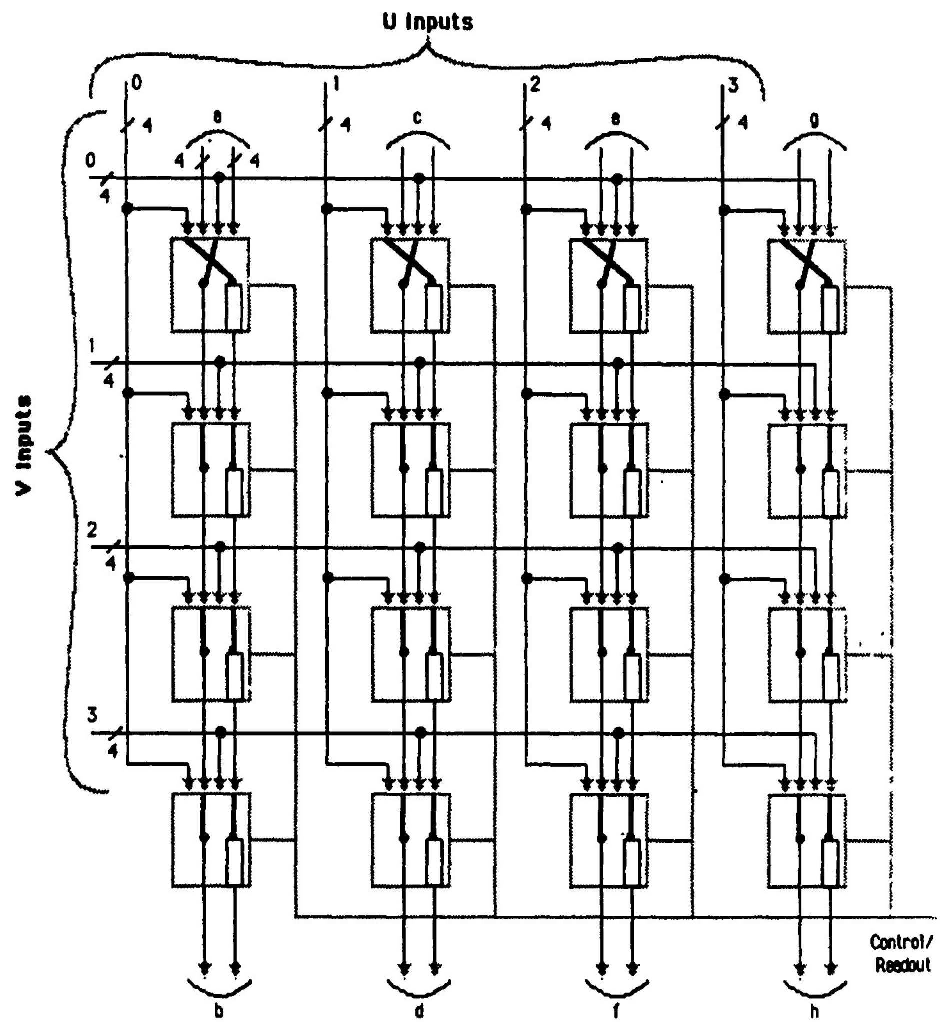
Figure III-8




4 x 4 Block of Elementary Correlators (ECs).

Mode 2a. 2 x 4 x 16 lags

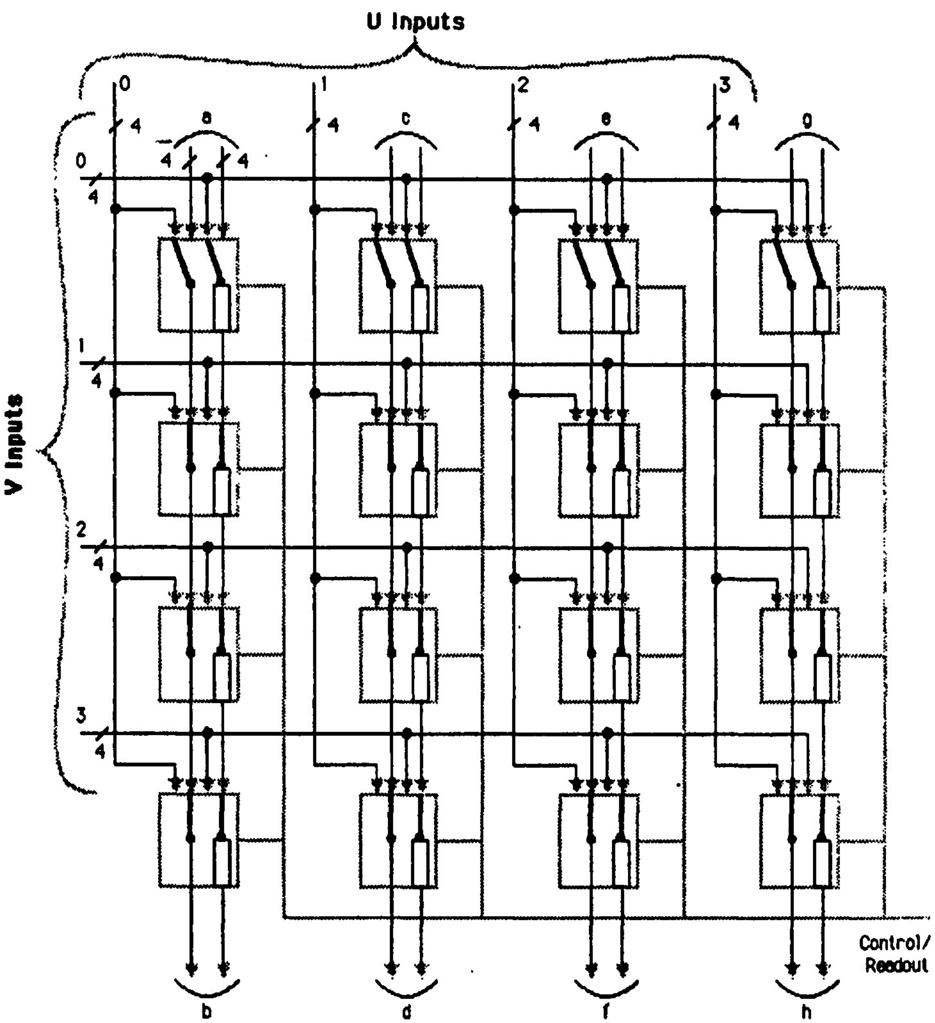
Figure III-9




4 x 4 Block of Elementary Correlators (ECs).

Mode 3. 4 x 1 x 32 lags

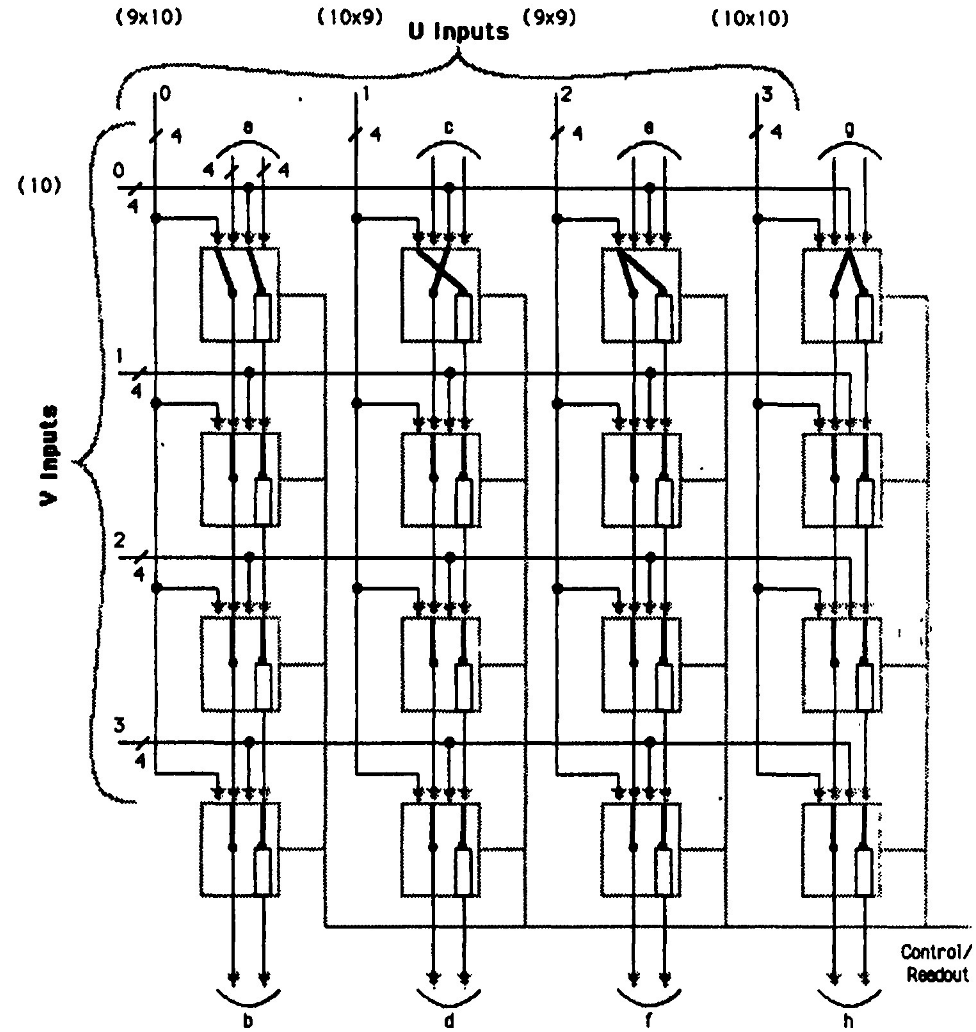
Figure III-10




4 x 4 Block of Elementary Correlators (ECs).

Mode 3a. 1 x 4 x 32 lags

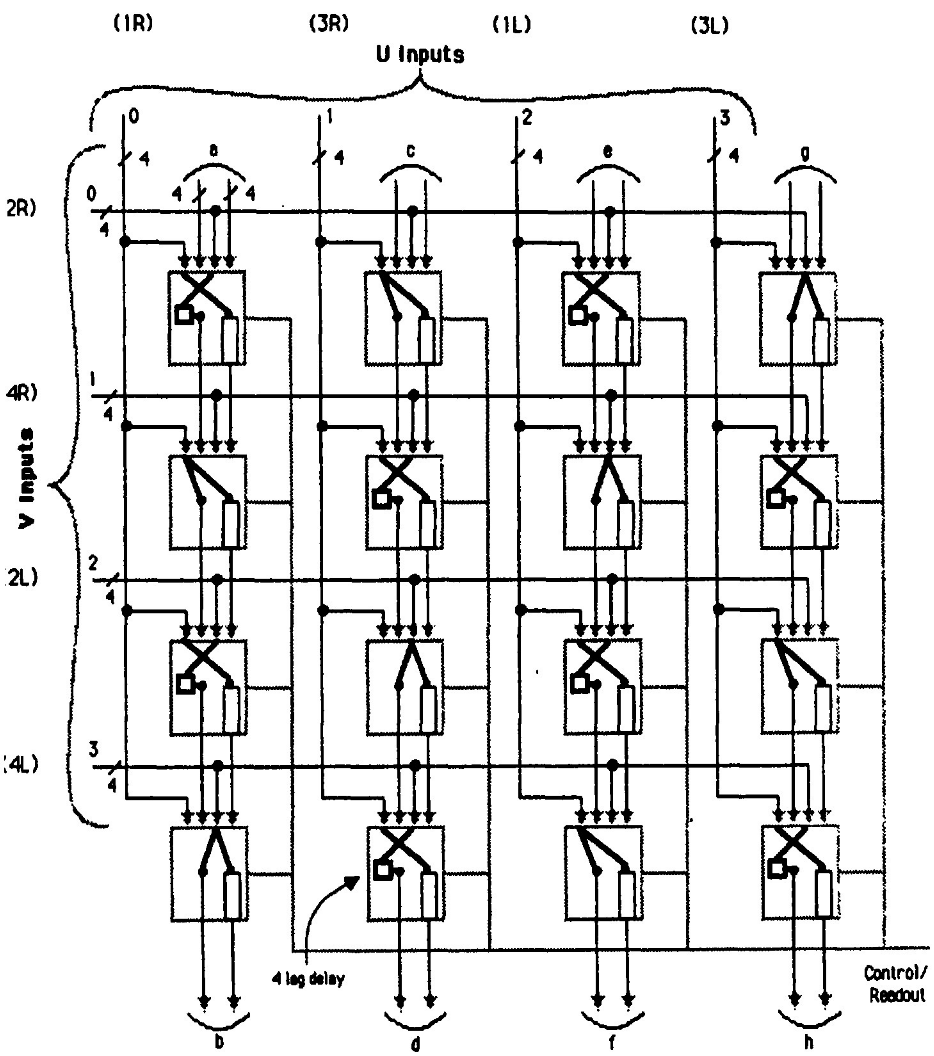
Figure III-11




4 x 4 Block of Elementary Correlators (ECs).

Mode 3b. Mixed Auto/Cross x 8 lags

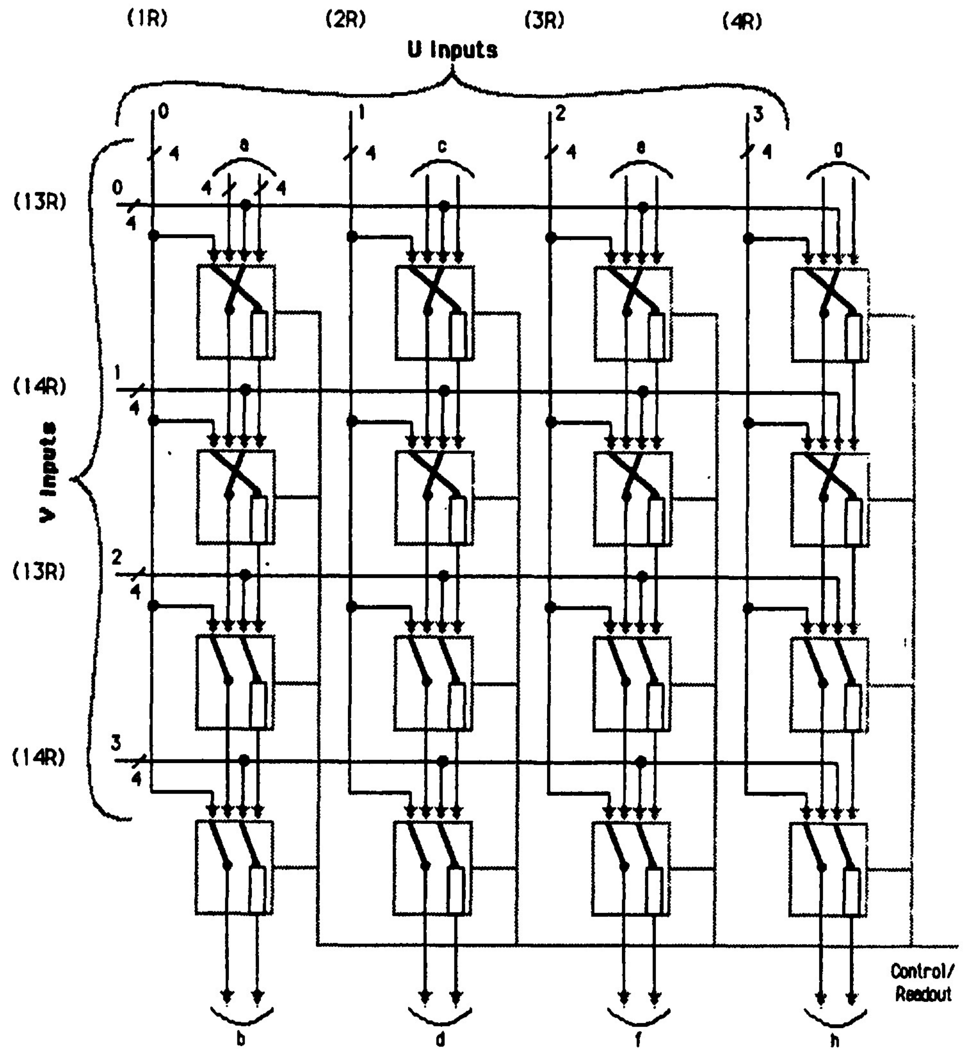
Figure III-12




4 x 4 Block of Elementary Correlators (ECs).

Mode 4. Mixed Auto/Cross x 8/±4 lags

Figure III-13




4 x 4 Block of Elementary Correlators (ECs).

Mode 5. Mixed

Figure III-14