CSIRO DIVISION OF RADIOPHYSICS

THE AUSTRALIA TELESCOPE

AT/16.2/011

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Report to the 11th Meeting of the AT advisory Committee

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System Overview

This report deals mainly with the system ahead of the correlator. Considerable effort has gone into this area because the delay in arriving at a workable conversion scheme had the potential to delay the completion of the AT more than any other problem. In addition many other system decisions depend on the exact nature of this scheme.

Some attention has also been given to the areas of interface between the correlator, correlator control computer, array processor and the synchronous and asynchronous VAXs. Decisions in this area hinge largely on the choice of array processor and are being delayed by the slowness of manufacturers in providing specifications and prices.

Compact Array Receiving System

Figure 1 shows schematically those parts of the receiver system located at the antennas. UHF and K/Q and W/F bands are shown although they are currently not funded. The detailed design of these bands will be carried out at an appropriate later date. Sufficient planning is being done at this stage to ensure their smooth integration into the system.

Wide band signals from the feed horns are split into orthogonal linear polarizations at 45° and 135° to horizontal (labelled X and Y in figures). These are further split into two separate frequency bands (e.g. C and X).

At this point provision is made for injection of modulated noise equally into each polarization. This will facilitate the measurement of gain, system temperature and the relative phase delay in the two polarization channels. In turn these parameters will be used to normalise correlation data, calibrate polarization observations and to equalise gains and phases so the compact array can be "tied" for use in the Long Baseline Array.

After amplification in the cryogenically cooled low noise amplifiers provision is made for the phase of the signal to be periodically reversed. The maximum rate of switching will be determined by the capability of the devices used but must be such than many phase reversals are completed in an integration time. The purpose of the switching is to remove the effects of interference coupled into the system after the phase switch. It has no effect on interference accepted by the feed horns. The switching will also remove any DC offset remaining when the IF signals are digitized. Other measures are also being implemented to remove both of these effects so phase reversal switching may ultimately be unnecessary. The phase switching is removed from the signal itself by synchronously reversing the sign of the digitized data. The switching waveforms at the 6 antennas will be a set of Walsh functions. Only one waveform is required for all 4 channels at each antenna.

A transfer switch is included to allow the signals at the two polarizations to be directed down either IF path. This is a slow switch and is included primarily for test purposes.

The four RF signals derived from a given feed horn are each split into two identical signals. This gives a choice of 8 inputs for the 4 IF conversion modules which follow. Only two independent LO's are provided so the selection is restricted to two sets of orthogonally polarized pairs selected from anywhere within the two bands available.

The conversion to IF is shown in figure 2 and will be described in more detail later. Here we will point out that the 4 conversion modules convert 2 polarized signals from each of the two selected frequency bands down to suitable IF's and bandwidths for sampling and digitizing. They do so with appropriate regard for image rejection and control of LO leakage. The tuning of the modules is in steps of 2 MHz. Finer tuning is done at the central building. Included in the modules is provision for phase rotation for "fringe stopping", phase offsetting to equalize the phases of the oppositely polarized signals when "tying" the array and coarse level control so that the samplers are presented with signals of the correct level. Fine level control and DC offsetting are done later in the digitizers by controlling the reference voltage levels.

Following conversion and prior to sampling the signal levels are monitored for coarse level control and for correlation coefficient calibration. A phase sensitive detector monitors the channel gain by measuring the amplitude of the switched noise component added before the LNA.

Three options are provided for sampling and digitizing the IF analogue signals. A 64 MHz bandwidth can be sampled at 128 MHz and digitized to 4 bits (16 levels), a 128 MHz band can be sampled at 256 MHz and digitized to 2 bits (4 levels) or a 256 MHz band can be sampled at 512 MHz and digitized to 1 bit (2 levels). The latter option is considered to be necessary only at the highest RF frequencies (W/F bands) and will not be implemented initially. In each case the data to be transmitted via optical fibre to the central building will be at a rate of 512 MBaud per IF. As mentioned above the reference voltage levels of the digitizers will be controlled to provide DC offset correction and for multibit digitizing, optimum sensitivity. The distribution of samples amongst the various digitizer levels will be monitored at the slower data rates available in the correlator and used to provide periodic updates of the reference voltage levels.

Figure 2 shows the RF-IF conversion scheme as it is currently envisaged. This has gone through numerous iterations but no serious flaws have so far been uncovered in the latest version. The main problems encountered in arriving at a suitable scheme relate to the wide bandwidths that need to be accommodated and the high level of phase stability that needs to be achieved. In the final design the tuning ranges of the synthesized LO's have been kept to a minimum by providing a choice of two IF bands after each mixer. Consequently, the LO frequencies do not now fall within any of the RF bands. There is a suitable range of input frequencies that can be mixed into either IF to provide a smooth transition from one regime to the other. Frequencies in C band and above are ultimately converted down to either L or S bands and tuned in steps of 320 MHz. It is envisaged that the UHF band would be up converted with a fixed LO into S band. A mixer using a synthesized LO at ~ 2 GHz is then used in upper side band to convert S band and in lower side band to convert L band signals to a selection of IF bands. The tuning steps at this stage are 20 MHz. This is adequate for the 256 MHz bandwidth option. For the 128 and 64 MHz bandwidth options a further conversion using 2 MHz tuning steps is implemented. At the central building the 64 MHz bandwidth will be reconstructed from the digitally transmitted data and filtered into a selection of bandwidths from 64 MHz down to ½ MHz in factors of 2. For bandwidths below 32 MHz additional fine tuning in steps of 50 KHz will be available.

In 1 bit operation fringe stopping phase rotation will be applied to the 2 GHz synthesizer. The array cannot be tied at this bandwidth (256 MHz) so no phase offsetting between orthogonally polarized channels is required. For 2 and 4 bit operation phase rotation will be carried out with the 500-800 MHz LO. Phase offsetting will also be provided on this LO when the array is to be "tied" via the 64 MHz, 4 bit option. The phase of the sampling clocks will be rotated to provide fine steps of delay in the signal path.

The local oscillators required for frequency conversion in figure 2 are derived from reference frequencies transmitted from the central building and returned via the same path so that round trip phase can be maintained constant. Because of reciprocity problems on optical fibres and the instability of optical connectors this transmission will now probably be on coaxial cable. The frequencies transmitted will probably be 160 and 5 MHz.

Figure 3 indicates schematically what happens to the digitized data from each IF channel when it arrives at the central building.

First the data is reclocked in a FIFO flip flop to remove any path delay variations occurring during transmission to the centre. Coarse steps of delay are then inserted to complement the fine steps inserted at the sampling clocks.

The 256 MHz (1 bit) and 128 MHz (2 bit) bandwidth data then go directly to the broadband continuum/line correlator. The 64 MHz (4 bit) bandwidth data may be used in several ways. For line work the data will be converted from 4 to 2 bits and directed to the 64 MHz continuum correlator. If spectral lines are to be observed in a 64 MHz band this data will also be directed to the line correlator. If spectral lines in narrower bandwidths are required the 4 bit data is first reconstructed into a 64 MHz wide analogue signal at base band. This signal is then filtered to the required narrower band using a scheme such as detailed in figure 4 and then resampled and digitized to 2 bits for input to the line correlator. Prior to the sampler the signal level is monitored and controlled in coarse steps and the gain is measured by monitoring the modulation of noise added at the receiver front end. Fine level control is again provided by using sampler statistics derived in the line correlator to control the reference voltage levels of the sampler.

If the data is to be used for LBA observations the outputs of the narrow band filters from the 6 antennas need to be combined with equal gains and phases. This is normally done separately for each of the 4 IF channels unless a circular polarized output is required from the tied array. In this case the oppositely polarized pairs of IF's also need to be maintained in accurate phase relationship. The gains are monitored by measuring the amplitude of the modulated noise injected at the front end and are set approximately equal using steps of attenuation.

Figure 4 shows in some detail a proposed scheme to implement the narrow band filtering sketched in figure 3. At bandwidths below 32 MHz fine tuning in steps of 50 KHz is also provided. Some modifications may be needed to this scheme as either at the analogue or digital level it needs to be integrated with the VLBA tape recorder.

As shown in figure 3 the digitized data from each IF channel can go to some or all of:-

(a) the broadband continuum/line correlator;
(b) the 64 MHz continuum correlator, and
(c) the "tied" array.

Figures 5 and 6 indicate schematically how the data are treated in each of these areas.

The main correlators can form all products between each X,Y pair of channels from one antenna with the same pair from each of the other antennas. The products are formed for a range of positive and negative lags. The maximum lag increases for narrower bandwidths. Besides this main function of the correlators they also provide some data which is required at the aerials for controlling parts of the receiver. As explained previously the slower (16 MHz) data rate available in the correlator allows the accumulation of sample statistics which can be used to set the reference voltage levels in the digitizers. For example for all 3 coding schemes there should be an equal number of positive and negative samples if no DC offset is to appear in the data. For 2 bit coding if optimum performance is to be obtained then ~0.171 of samples should be in each of the highest and lowest ranges. Similar specifications apply to the 4 bit coding although only the one pair of levels (other than zero) that are preserved through the 4 to 2 bit converter can be controlled in this way.

Associated with each main correlator is a set of small switched correlators whose function is to measure the phase difference between pairs of oppositely polarized channels. The output being integrated from each correlator is reversed in synchronism with the switched noise signal that is injected equally into each polarization before the LNA. This information is used to calibrate polarization measurements made with the array.

Figure 6 shows how the signals from the size compact array antennas may be combined for use with the Long Baseline Array. The twelve inputs at each frequency will be adjusted to have equal gains and phases.

Phase between aerials will be monitored using quasi real time self calibration of the line correlator data. Those parts of the system not common to the signals to the tied array and to the line correlator will therefore need to be made phase stable. The rate at which phase data is updated will depend on the integration time required to achieve the desired accuracy and therefore on the source strength. This time must be short compared to the timescale for large atmospheric phase variations.

To achieve high accuracy in polarization measurements it is necessary to maintain phase equality between a given X,Y pair of signals to a much greater precision than that required between aerials. This is again done by monitoring the relative phase of the common switched noise signal superimposed on the two channels. For the tied array this monitoring is done in a set of switched analogue correlators which accept signals in the range 0-64 MHz. The phase corrections are updated at a rate determined by the integration time required to achieve the desired accuracy.

(Attachment No. 1(12))

5.

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The X and Y linearly polarized channels are summed separately and may either be recorded directly or combined 90° out of phase to produce circularly polarized signals. The 90° phase shift would be achieved by offsetting the LO's by an additional 90° rather than with a 90° hybrid as suggested in the figure.

The analogue outputs from the tied array will be sampled and digitized to 2 bits either in the VLBA tape recorders or more likely in a manner identical to that applied to the narrowband Compact Array signals. This latter option assumes that the RF/IF electronics of the VLBA recorders is dispensed with.

Correlator and Computer Interfaces

As mentioned previously decisions in this area depend to a large extent on the choice of an array processor and correlator control computer. Related questions are whether separate array processors and control computers should be used with the LBA and CA correlators or whether one set can readily perform both tasks. In this case the trade-off is between cost on one hand and software complexity on the other. In the former case both correlators would not necessarily have to be at the same site. Other considerations however have led to the decision to locate both at Culgoora.

Figures 7-10 show possible configurations of the correlator modules, array processor and correlator control computer and the two VAX computers. It is hoped that firm decisions and more detailed designs can be completed early in 1986.

Interference Suppression

The design of the AT antennas is such that interference generated in the vertex room can readily gain access to the feed horns by radiating out the large hole in the roof of the feed cone room and scattering off the sub-reflector and quadrupod. In addition computers located in the pedestal room may also be sources of interference. Initial investigations suggest that the best way of suppressing these sources of interference is to screen the individual computers in the pedestal room rather than to make the whole room RFI tight. On the other hand the diverse sources of interference in the vertex room and the mechanical complexity involved suggest that this room should be totally screened rather than to try and screen individual components. It is however recognised that attempts to screen the room can only be partially successful so great care will be exercised in the design of modules containing for example LO's, comb generators, and fast digital signals.

Some of the measures planned for the vertex room are:-

(1) a rotating ceiling with contacts (or a quarter wave choke) around the edges,

(2) conducting rubber gaskets around doors.

(3) mesh over air conditioning and fan ducts,

(4) termination and bypassing of all cables at bulkheads at the point of entry to the room, and

(5) lining the walls of the vertex and feed cone rooms with absorbing material. Those procedures that require integration with the antenna construction such as the rotating, contacting ceiling will be implemented initially. Others will be added later when the magnitude of the problem is known.

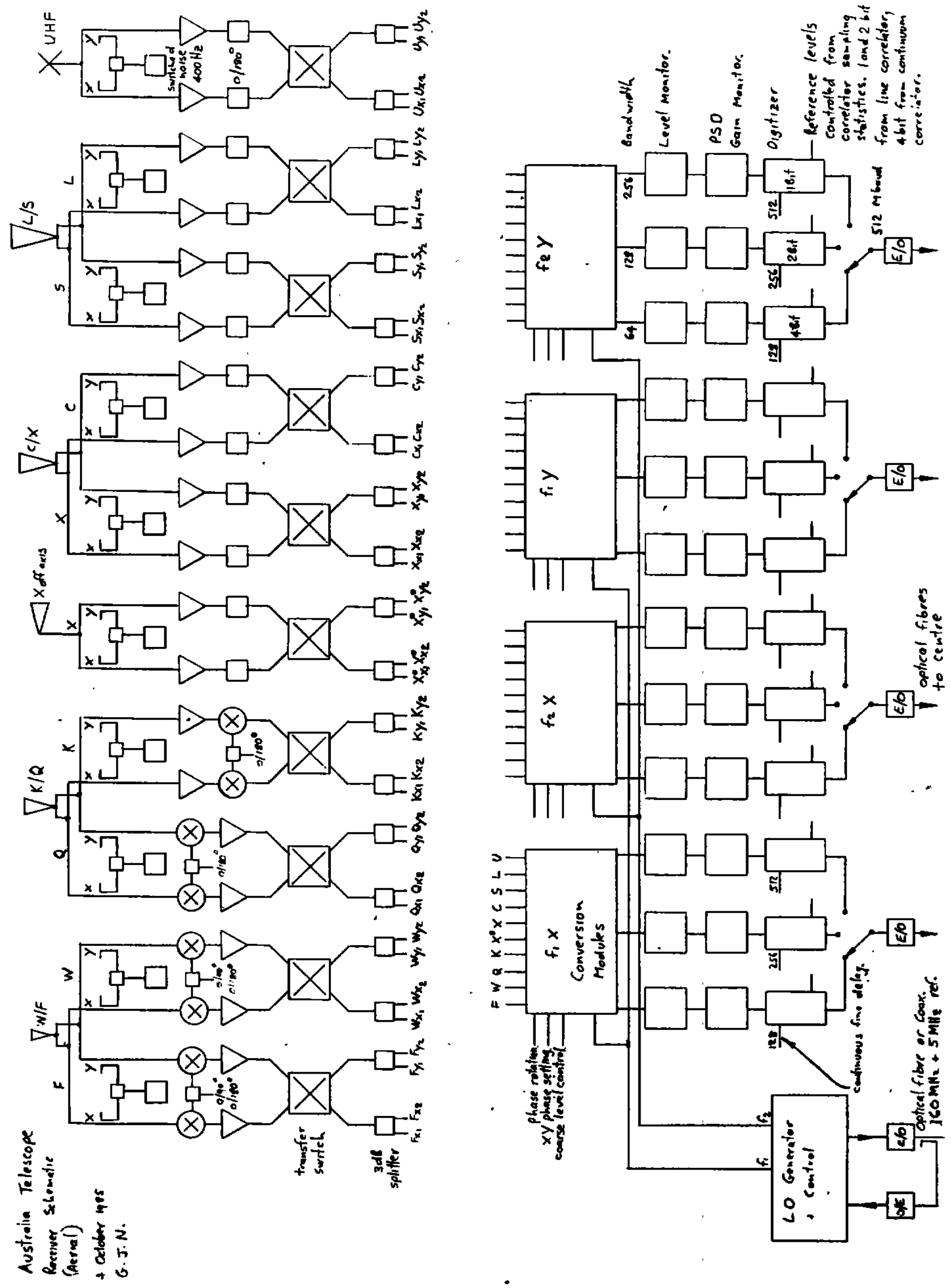

Australia Telescope
Receiver Schematic
(Aerial)
4 October 1985
G.J.N.
UHF
switched noise 400 Hz
L/S
C/X
X off axis
K/Q
W/F
transfer switch
3dB splitter
Bandwidth
Level Monitor
PSD
Gain Monitor
Digitizer
Reference levels controlled from correlator sampling statistics. 1 and 2 bit from line correlator, 4 bit from continuum correlator.
512 M baud
f2 Y
f1 Y
f2 X
f1 X
Conversion Modules
E/O
optical fibres to centre
continuous fine delay
phase rotation
XY phase setting
coarse level control
LO Generator + Control
Optical fibre or Coax.
160 MHz + 5 MHz ref.

Figure 1

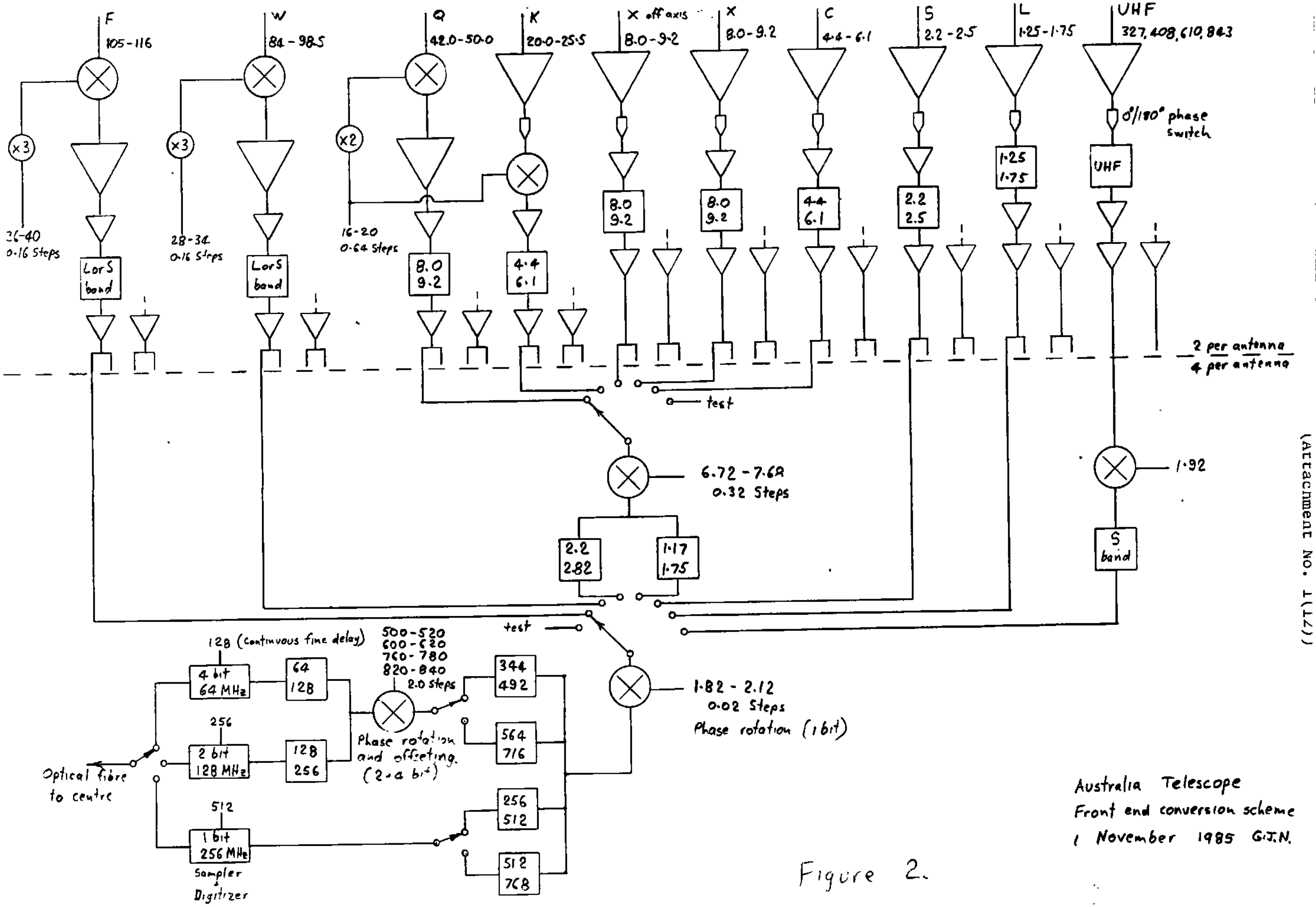


Figure 2.

Australia Telescope
Front end conversion scheme
1 November 1985 G.J.N.

(Attachment No. 1(12))

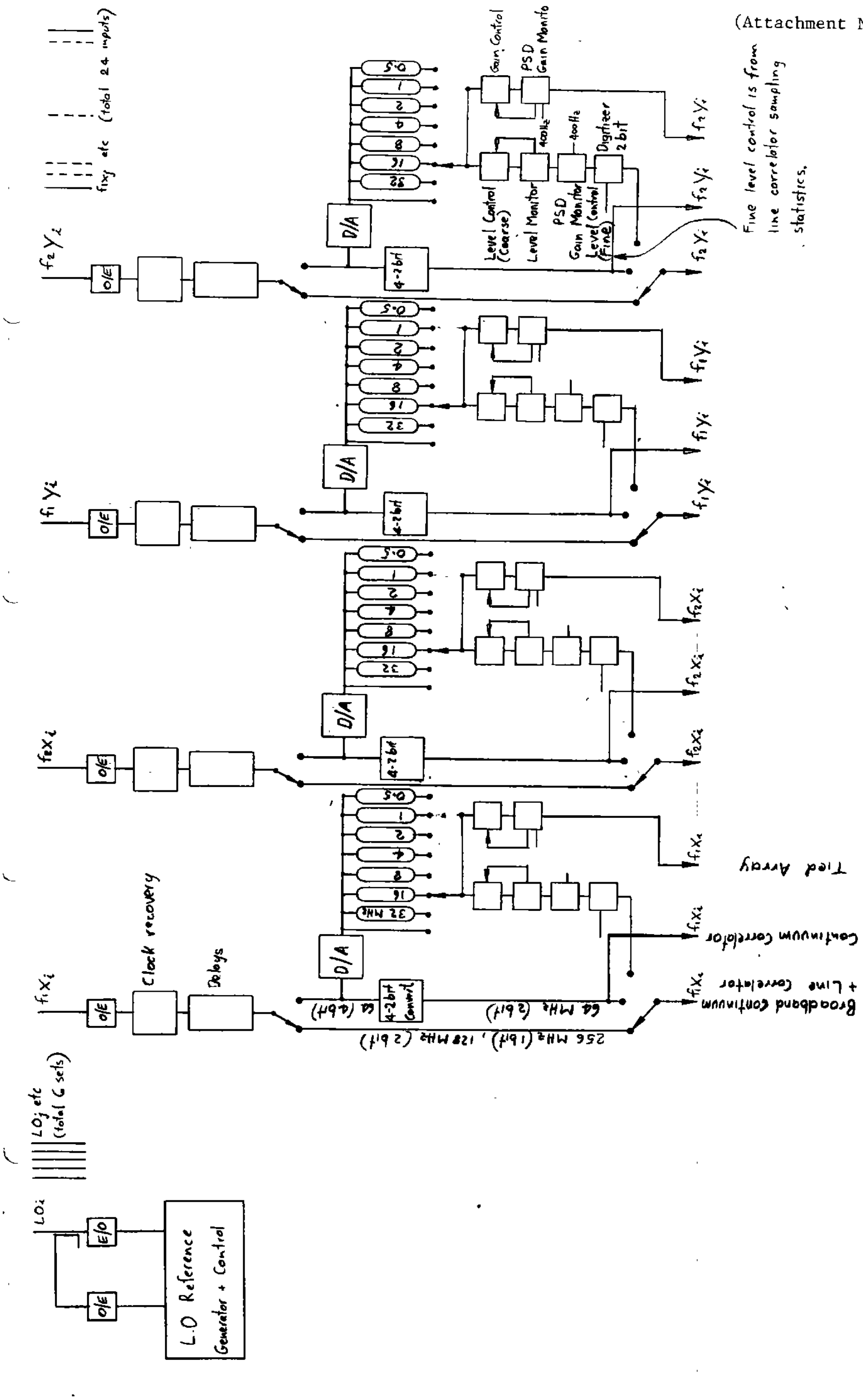


Figure 3

Australia Telescope
Receiver Schematic
Central Building
4 October 1985
G.J.N.

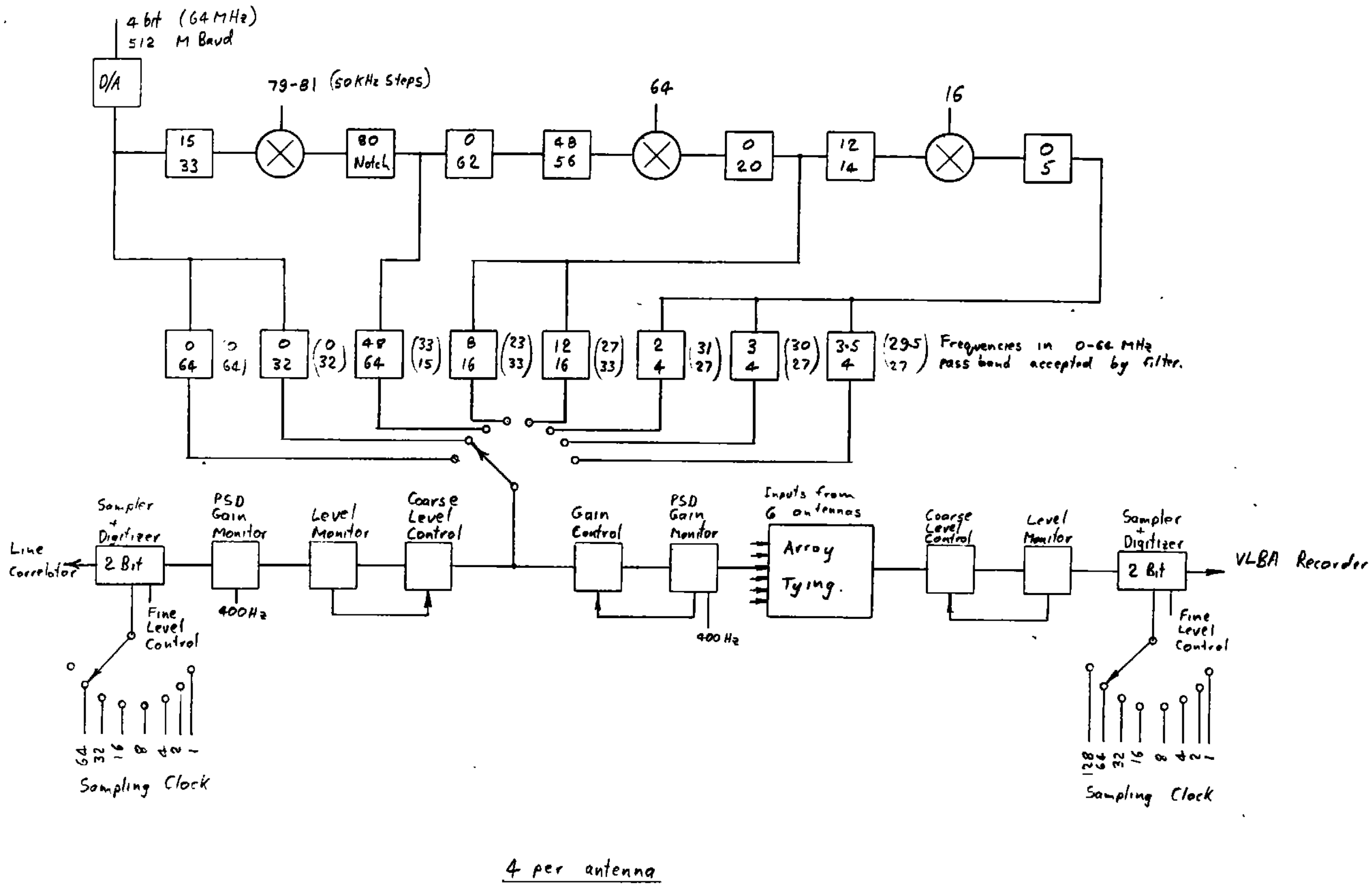
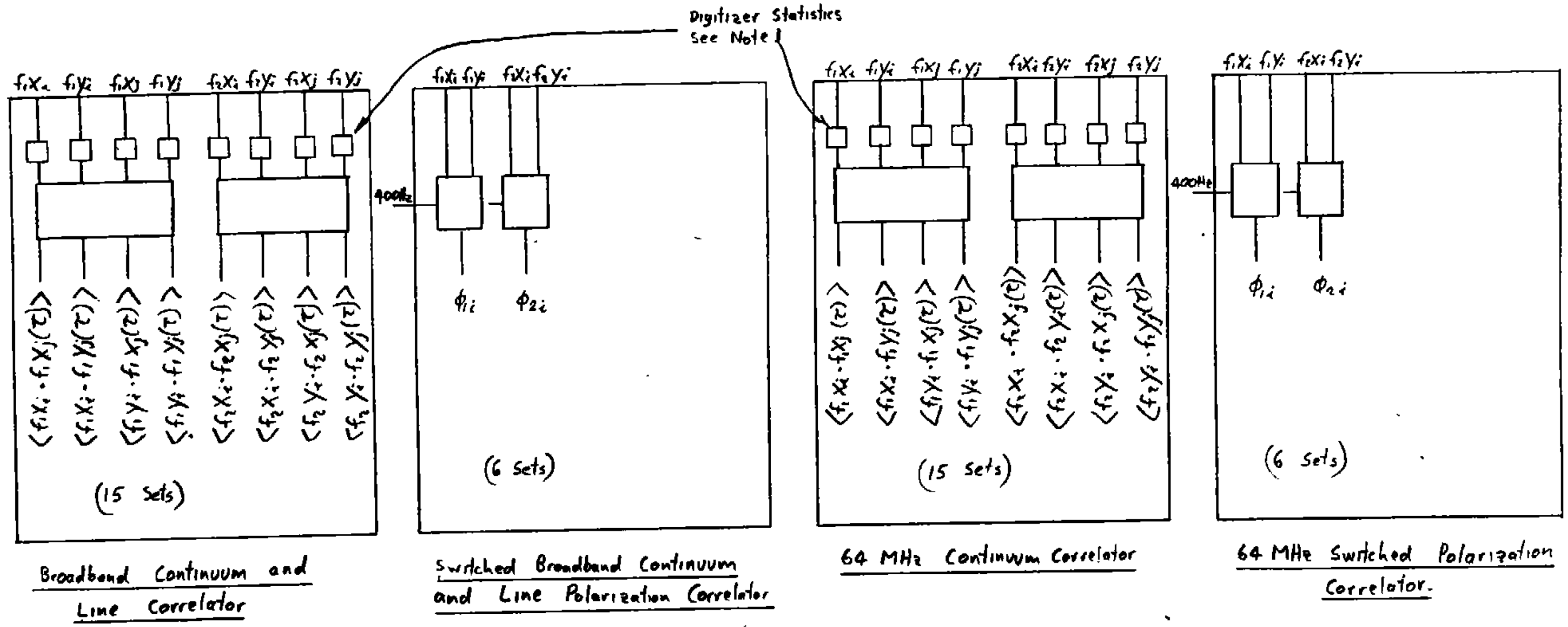


Figure 4

Australia Telescope
Conversion Scheme
(Control Building)
5 November 1985 G.J.N.

(Attachment No. 1(12))



Note. 1. Digitizer reference levels are set by monitoring data distribution.
ie. Positive and negative sample numbers should be equal and 0.171 of samples should be in each of the highest and lowest ranges for 2 bit sampling etc.

2. The ϕ_i from the switched correlators are used to equalise the phases of the pairs of linearly polarized channels.

Australia Telescope
Receiver Control Information obtained from Correlators.
4 October 1985. G.J.N.

Figure 5

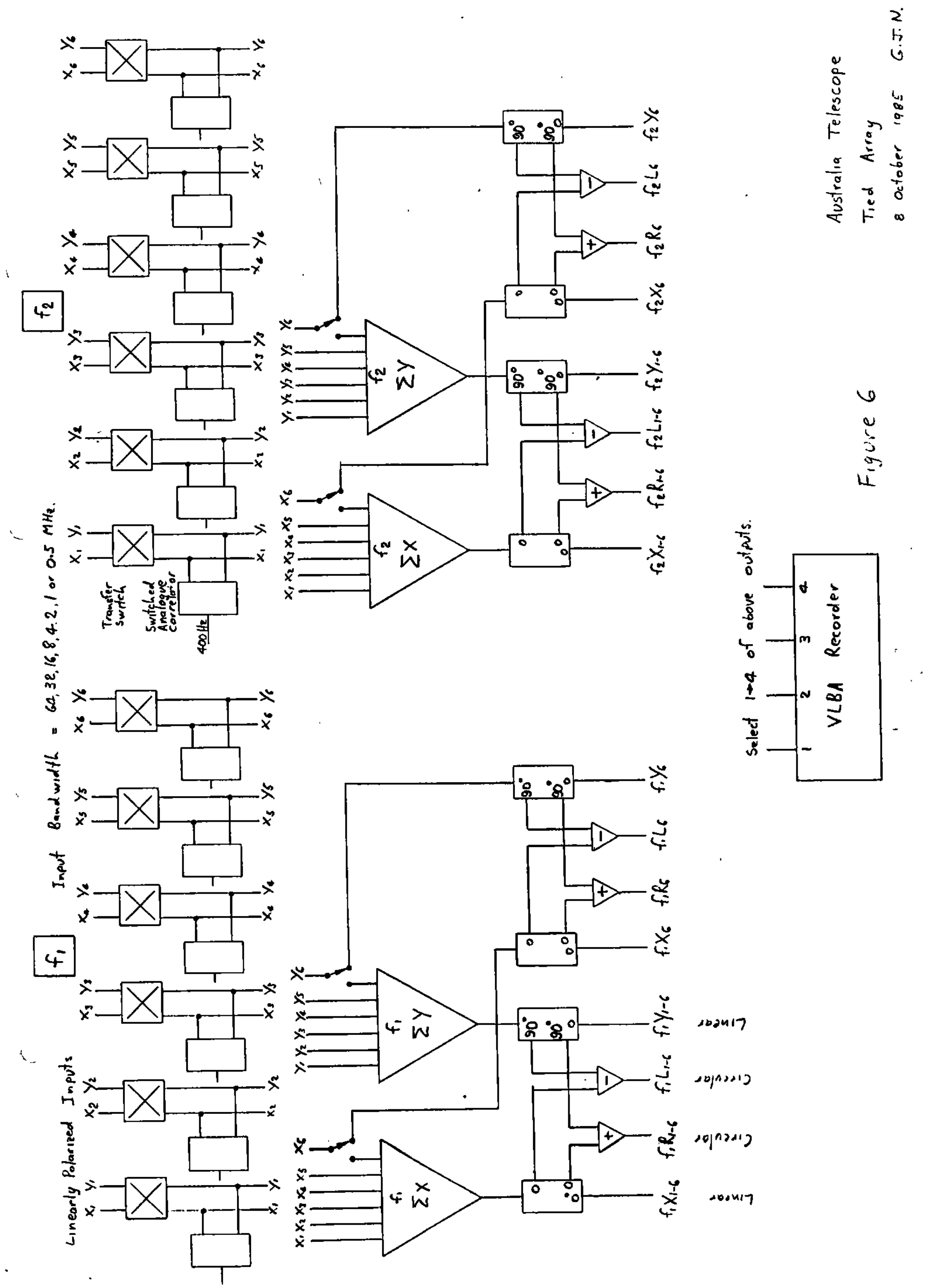


Figure 6

Australia Telescope
Tied Array
8 October 1985 G.J.N.

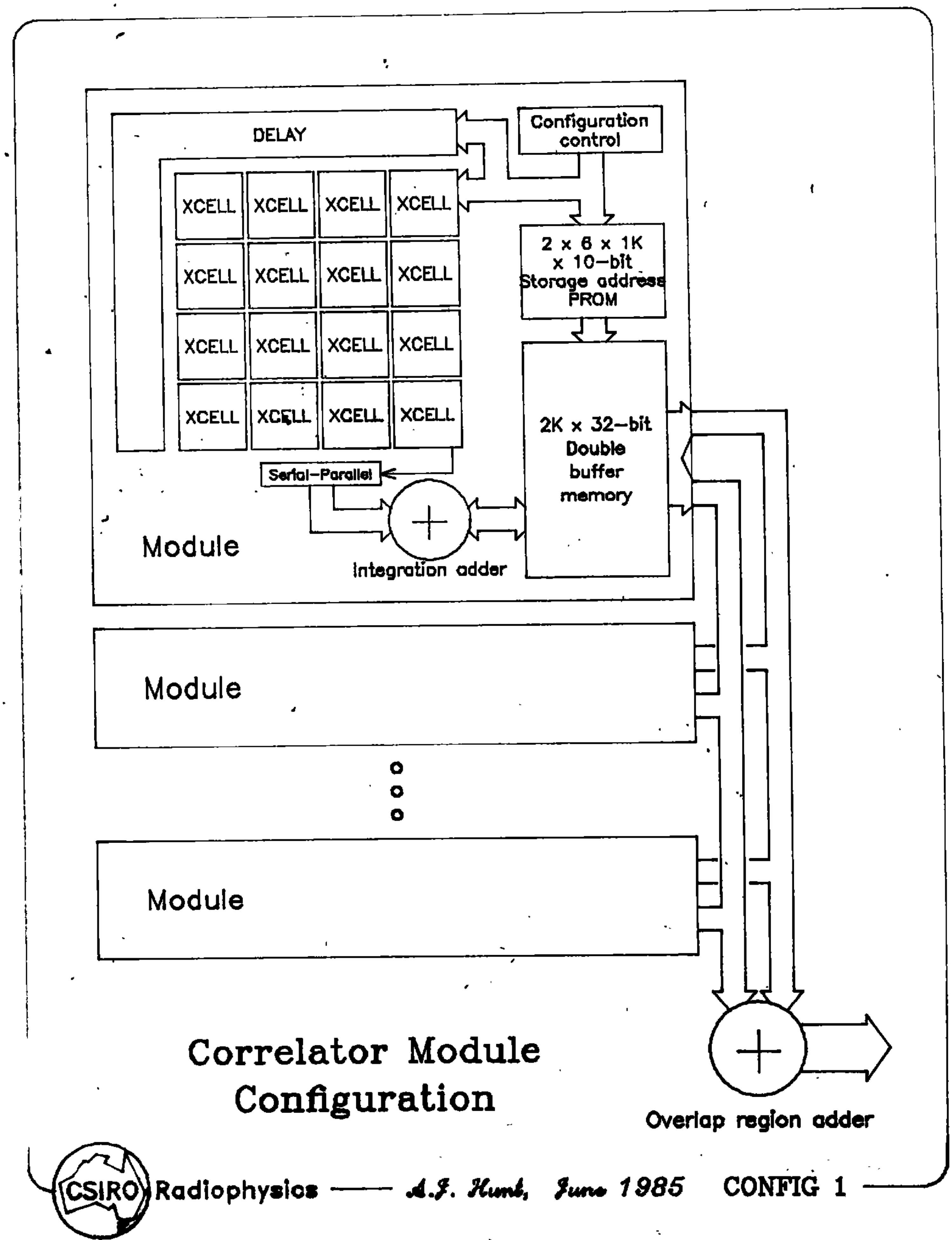

DELAY
Configuration control
XCELL
2 x 6 x 1K x 10-bit Storage address PROM
2K x 32-bit Double buffer memory
Serial-Parallel
Module
Integration adder
Module
Module
Correlator Module Configuration
Overlap region adder
CSIRO Radiophysics —— A.J. Hunt, June 1985 CONFIG 1

Figure 7

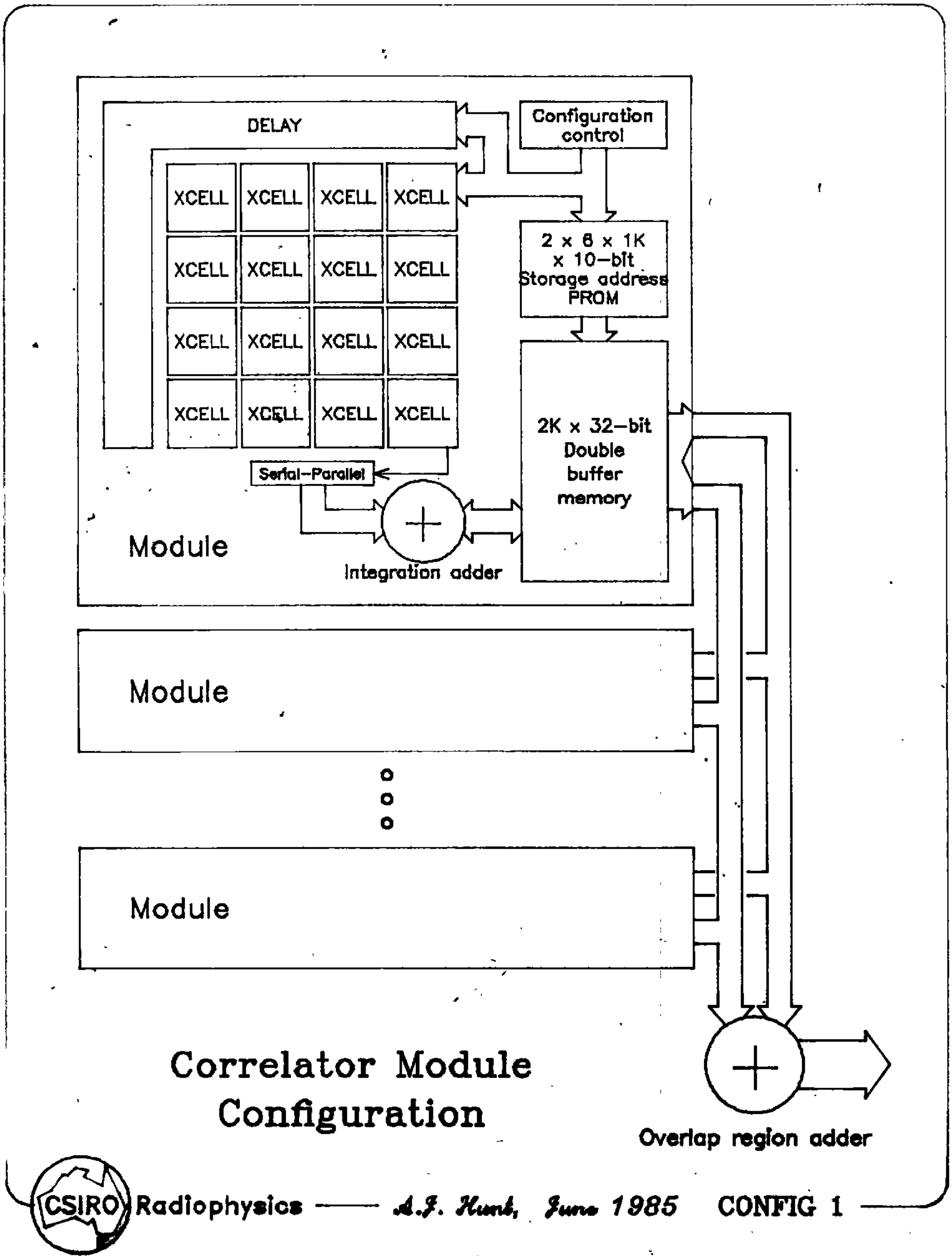

DELAY
Configuration control
XCELL
2 x 6 x 1K x 10-bit Storage address PROM
2K x 32-bit Double buffer memory
Serial-Parallel
Module
Integration adder
Module
Module
Correlator Module Configuration
Overlap region adder
CSIRO Radiophysics — A.J. Hunt, June 1985 CONFIG 1

Figure 7

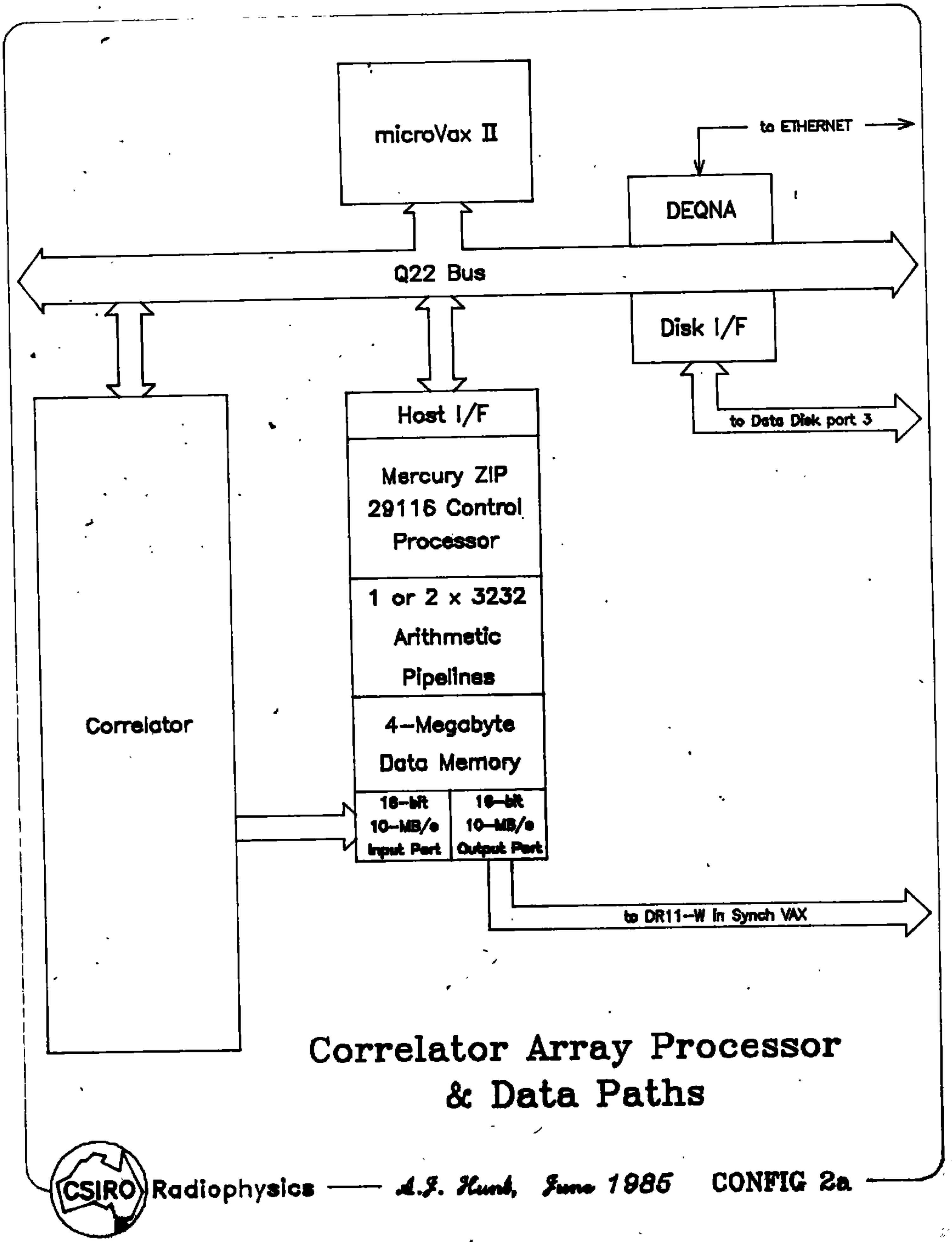
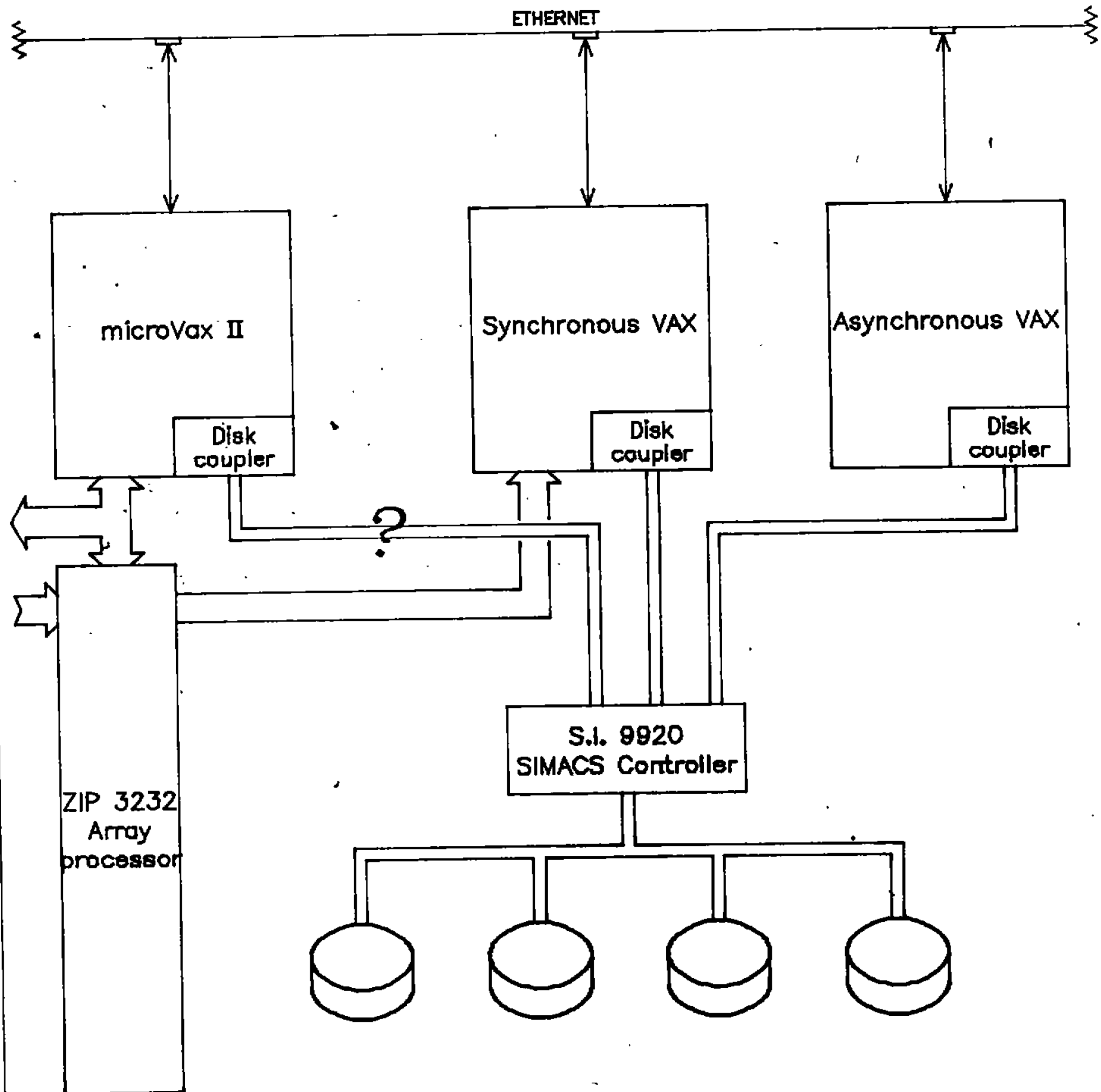

microVax II
to ETHERNET
DEQNA
Q22 Bus
Disk I/F
to Data Disk port 3
Host I/F
Mercury ZIP 29116 Control Processor
1 or 2 x 3232 Arithmetic Pipelines
4-Megabyte Data Memory
16-bit 10-MB/s Input Port
16-bit 10-MB/s Output Port
to DR11-W in Synch VAX
Correlator
Correlator Array Processor & Data Paths
CSIRO Radiophysics — A.J. Hunt, June 1985 CONFIG 2a

Figure 8

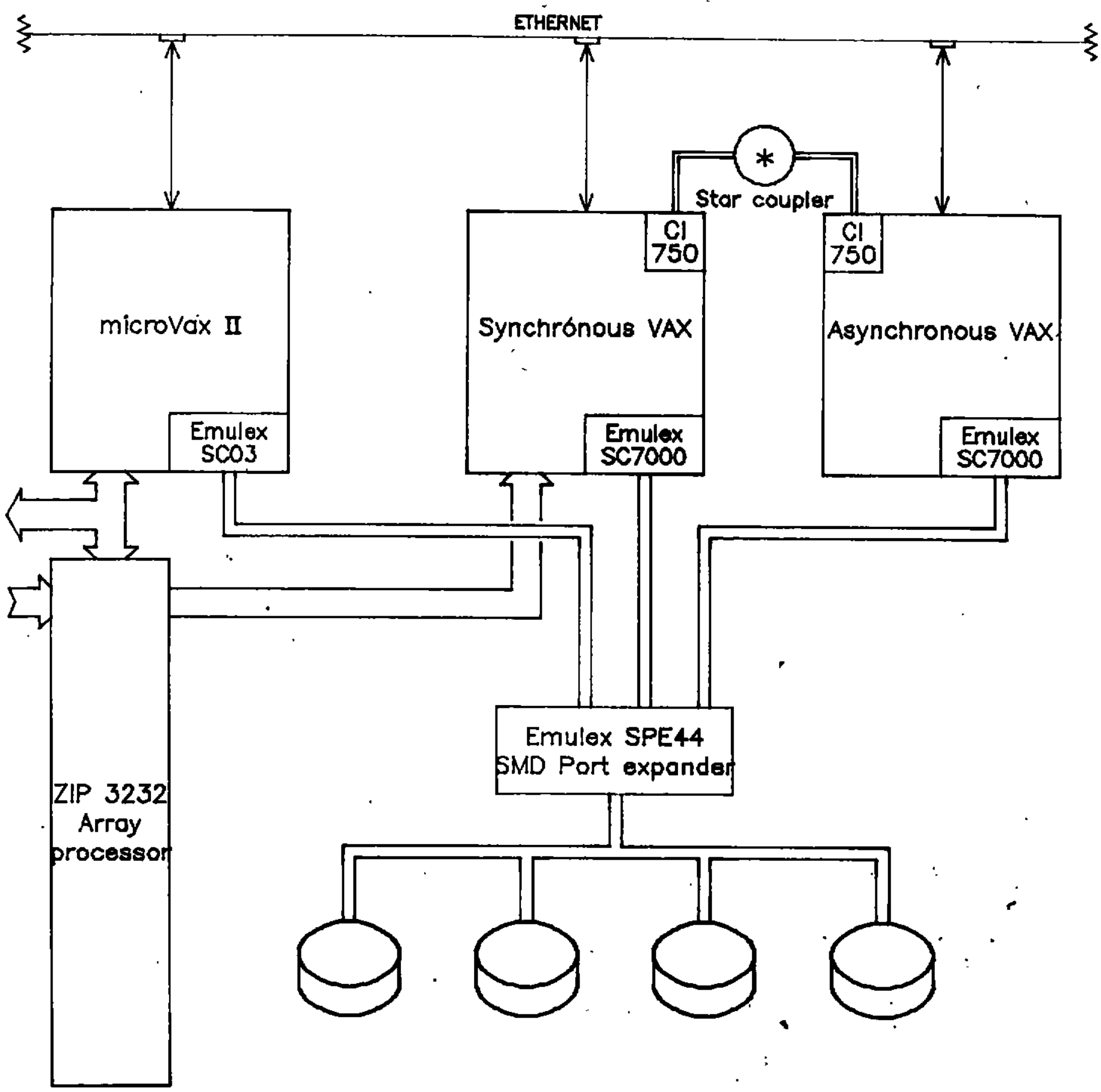


Correlator Data Paths to Disk

(SIMACS cluster option)

CSIRO Radiophysics —— *A.J. Hunt, June 1985* **CONFIG 3a**

Figure 9



Correlator Data Paths to Disk
(DEC VAXcluster option – preferred)

CSIRO Radiophysics —— *A.J. Hunt, June 1985* CONFIG 4a

Figure 10