REPORT OF THE WORKSHOP ON

AUSTRALIA TELESCOPE COMPUTER SYSTEMS

AT/10.5/002

(also AT/25.3/001)

Held at Epping and Parkes - 25,27,28 July 1983

THE AUSTRALIA TELESCOPE

The Australian Bicentenary 1788-1988

National Project

CONTENTS

SECTION 1: INTRODUCTION

This report is the result of a workshop held at Division of Radiophysics, Epping on 25 July and Parkes on 27-28 July 1983. In attendance were:

R.H. Frater (Chairman), J.G. Ables, J.W. Brooks, D.N. Cooper, J.F. Deane, J.R. Forster, R.F. Haynes, A.J. Hunt, C.E. Jacka, A.G. Little, R.N. Manchester, J.D. O'Sullivan, P.T. Rayner, R.H. Wand, G.W. Bothwell (AAO) and D.J. Skellern (SU/EE)

The aims were to:

(a) determine the overall computing requirements for the Australia Telescope;

(b) establish manpower and cost estimates, and also the times when specific hardware might need to be purchased;

(c) identify any problem areas which may need more urgent and detailed study.

The approach adopted was to try to set a baseline system in terms of existing technology which could then be kept updated by any new advances until a final decision was necessary.

The computing requirements were divided into three main topics and at Parkes the workshop split into subgroups which were each assigned one of these areas as their prime responsibility. The topics and sub-groups were:

(i) on- and off-line computing; Frater (chairman), Haynes, Manchester, Rayner and Skellern

(ii) correlator system; O'Sullivan (chairman), Ables, Brooks Forster and Hunt

(iii) control/monitor system; Wand (chairman), Bothwell, Cooper, Deane, Jacka and Little

The reports of each of these subgroups form the basis of the material in sections 2, 3 and 4 of this workshop report.

SECTION 2: ON-LINE AND OFF-LINE COMPUTING

2.1 GENERAL INTRODUCTION

We identify one of the major problems confronting the on-line computing system to be the maximum data flow rate from the correlator of some 400kbytes/sec and typical data flow rate of 20-40 kbytes/sec. These flow rates would be maintained throughout a 12 hour observation. We note that these data rates are a compromise based on astronomical requirements and the capability of the correlator to handle the necessary computations within the budget.

These data flow rates imply a large problem in accepting, manipulating and storing the data.

The adoption of a system based on current technology could satisfy the initial requirements for observing in 1988 but requires new technology to cope with the peak data rates expected in later years.

Technological development in the computer area is so rapid that we expect suitable hardware will become available to overcome the present limitations. In particular, we expect major advances to be made in the storage media area.

Software and hardware development estimates (see below) make it essential that some hardware purchases be made immediately. Combining such purchases with existing computing facilities makes it possible to proceed with software design, coding and testing.

Expertise in Radiophysics is at present centred on Digital Equipment Corp. computers and the VMS operating system. In addition, many available synthesis data reduction packages are supported under VMS. It should be noted that these systems (e.g.AIPS, GIPSY) provide many, but not all, of the anticipated image processing requirements.

An image processing system has to be purchased for the analysis of AT data at Epping. This system must be additional to existing computing facilities. For flexibility of data manipulation it is desirable that the new equipment be interconnected with the existing facilities.

The volume of observational data that needs to be processed is too great for Radiophysics to handle alone. Consequently, other institutions will have to be involved in the processing of their own data obtained on the AT. However, Radiophysics has to provide the facilities at Culgoora for data collection and at and Epping for data processing.

All off-line software must be written in such a way that it supports subroutines, etc, written in standard VAX-11 languages. This will permit non-specialist programmers, i.e., astronomers, to contribute to the software package.

Reliability of the AT computing systems is considered of paramount importance.

2.2 THE CULGOORA COMPUTER SYSTEM

The Culgoora computer system must handle two broad categories of processing tasks which will be referred to as 'synchronous' tasks and 'asynchronous' tasks. Synchronous processing tasks are tied to the basic data collection time-frame and must be completed within the correlator integration period, currently specified to be 5 seconds. Asynchronous processing tasks are not tied to the data collection time-frame but must be undertaken to monitor the quality of the basic data as it is collected, as well as to assess the previous day's data.

2.1.1 Broad requirements

The broad requirements for the Culgoora system include:

1. The ability to process incoming correlator data at a rate as close as possible to the maximum data rate of 400kbytes/second.

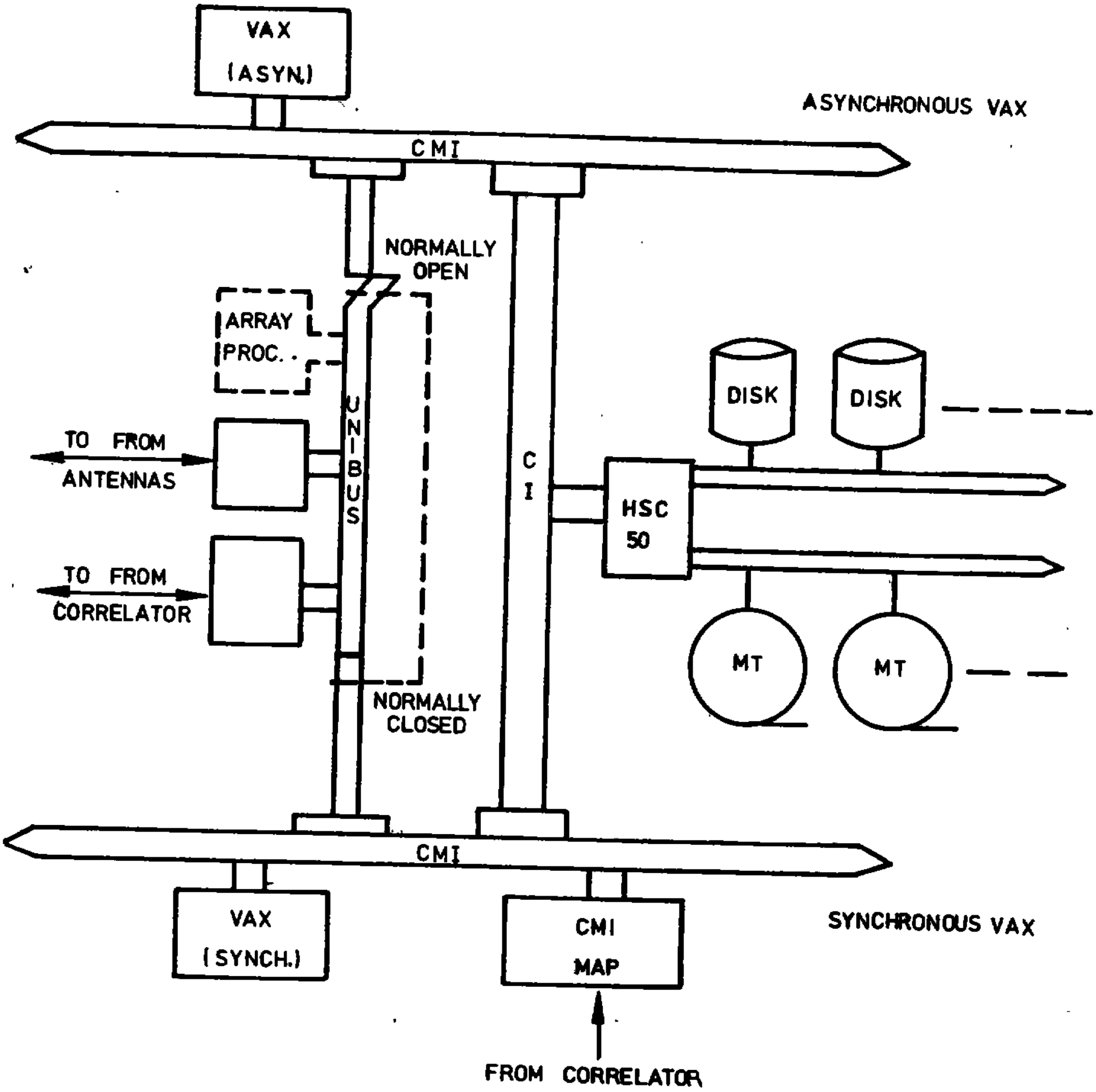
2. Continuous operation of the AT. Data taking should be possible even when one VAX is inoperable. To achieve this, the architectural design of the computer system at Culgoora should be such as to allow observations to continue in the event of a CPU failure.

3. Control of the AT array from Culgoora, Parkes or Epping. This implies a central computer at culgoora to control the entire AT. All operations could then be directed from a console at culgoora or else from one of the other sites via a communications network.

The solution best able to accomodate these requirements is a dual VAX-11/750 system (see Fig. 2.1). The two machines would be interconnected via a CI (Computer Interconnect) bus. The large disk packs and magnetic tapes required to support the data base are attached to this bus and hence available to both CPU's at all times. All peripherals which are required to control the array would be located on a piece of UNIBUS which can be switched for use by either CPU. Such a system would allow the functions of one VAX machine to be taken over by the other in the case of a malfunction of one CPU.

The 'asynchronous' and 'synchronous' tasks can then be allocated between the CPU's so that one will be responsible for all 'synchronous' tasks and the other for 'asynchronous' tasks.

Although the 11/750 has been selected as the most appropriate VAX currently available for the on-line computers, it does have a limitation of only 3 buffered data paths (whereas the 11/780 has 15). This may limit its I/O usefulness, especially if one of the 11/750s had to take the load of both the asynchronous and synchronous computers in the event of a breakdown of one of them. Further investigation is needed to determine how serious this problem may be.



CULGOORA COMPUTER SYSTEM
FIGURE 2·1

2.2.2 Correlator to Computer Connection:

The major problem identified in the above broad aims given in 2.2.1 is item (1). This data rate is very close to the maximum rate that can be supported by a VAX system. A number of different interface connections are possible and each will need to be investigated to find the most feasible one. The possible interfaces include:

1. Dual-ported disks. Data would enter via one port and be extracted by the VAX via an alternate port. Off-the-shelf DEC systems do not currently support this option.

2. Interfacing via a DR32. This device would provide the interfac to the AT correlator and attach directly to the VAX-750 backplane to support data rates of up to 3 Mbytes/sec. Problems exist with this solution in that the data path is at present on supported through the memory of the VAX itself rather than direct to the disk. Thus, this approach requires a backplane data rate of twice the desired correlator-to-mass storage rate, and is architecturally unsound.

3. Direct interface to the backplane of a VAX . This may require a piece of purpose built hardware which interfaces to the backplane and recognises a block of addresses. Transfers could then be done directly from backplane to magnetic tape via a disk storage buffer. The problem with building a special purpose interface of this type is that difficulties usually crop up later (e.g. support, inconsistency with vendor software updates).

4. As for (2) above but the DR32 would be connected to a separate processor on the CI bus. This third processor would then be solely responsible for servicing the correlator data. This approach would probably prove too expensive in practice.

All methods proposed above have problems but it was felt that (3) offered the best path for development in this area and this scheme is shown in Fig.2.1. Up to six man months should be allocated to investigating the problems of connecting the correlator data output channel to the computers. In particular, it will be necessary to see if there are any approaches similar to (3) which are (or will soon become) commercially available. For full redundancy of the system two identical connection devices would be required if system (3) was adopted. One would then be mounted on each VAX. Data could be switched to the appropriate VAX commensurate with the function being performed by a particular VAX system at that time.

It would be necessary to have at least three tape units (6250 bpi, 125 ips) to provide for uninterrupted telescope operation. The capacity of a magnetic tape is 140 Mbytes (assuming 8 kbyte blocks) which will record for 58 minutes at the typical data flow rate of 40 kbytes/sec. However, at the maximum data flow rate of 400 kbytes/sec a tape would need to be changed every 5.8 minutes.

Another problem associated with handling the maximum data rate is the total quantity of data collected in 12 hours of observation, amounting to some 20 Gbytes. Storing such a large amount of data would require over 140 magnetic tapes. This obviously is not sustainable. It is felt that video tape recording techniques may offer a longer-ter solution to this storage problem. VLBI experience demonstrates that data rates of 4 Mbits/sec stored onto 2 hour video tapes works. This gives a storage capacity of about 4 Gbytes/tape. It is foreseeable that a doubling of such storage densities and recording times may be achieved within the next 4 years which would allow a full 12 hour observation to be stored on 3 such tapes. Another possible storage medium that could be considered would be streamer tapes. With large 400+ Mbyte disks now becoming common throughout the "computer world" there will be extreme pressure for manufacturers to develop support backup media to hold such large volumes of data. Any purchasing plan for magnetic media must take account of the developments occurring in this field. In particular the form of the disk and magnetic tape "farms" for the computing system at Culgoora (and Epping of course) must not be decided at an early stage. Waiting some 2-3 years to mak(such a decision will result in a much improved cost/Mbyte of storage capacity.

2.2.3 The Synchronous System

This VAX computer (see Fig. 2.1) will be responsible for all of the tasks synchronised to the data taking cycle. The volume of data being handled in real-time and the telescope control operations associated with that data-taking require significant computing power in this machine. A VAX-11/750 is suggested as a suitable computer to perform this function.

Table 2.1 gives a list of tasks to be performed by this machine

<u>Table 2.1 - Synchronous Tasks</u>

1. Operator interface
2. Control of the communications links to antennas
3. Correlator configuration and control
4. Correlator checking and error flagging
5. Antenna Pointing
6. Receiver control
7. Phase and Delay control
8. Storage of output correlation data
9. Storage of monitor data
10. Monitor data checking and flagging (minimal system)
11. Initial data calibration

If the responsibility for checking the quality of the correlator data (item 4 in Table 2.1) lies with the VAX Synchronous system, the VAX machine must access the correlation data as it flows to the storeage medium. This would place a computational load of up to 1 million floating point operations per second (MFLOPS) on the VAX. A VAX is unable to handle that computational load. In that case an array processor must be an integral part of the Culgoora Synchronous Computer. Alternatively, the correlator data could be checked in the correlator system itself. Not all data need be analysed in real time to form a meaningful estimate of its quality. Nor do the engineers need to access all the monitor data to assess that the telescopes are operating correctly. However, a sub-set of the data does need to be processed for statistical analysis in real time.

The cost estimates shown in Table 2.4 do not include the cost of an array processor. The inclusion of such an item will run the estimates well over the allocated budget; however, the speed requirements of this monitoring function are such that an AP will almost certainly be necessary. A full investigation of this area is required before an AP is placed on the purchasing list.

Initial calibration of the data (item 11 in Table 2.1) calls for the "synchronous" VAX to calculate initial entries in the gain tables which in turn are entered into the archived data stream after each calibrator is observed.

Estimates of the manpower requirements for the synchronous computing system are detailed in Table 2.2.

Table 2.2 Manpower requirements for development of the Synchronous Computing system at Culgoora.

	TASK	MANPOWER REQUIREMENTS (Man years)
1)	Correlator interface design	1.5
2)	Data quality assessment	0.75
3)	Video recorder system	0.75
4)	Communications network to antennas	1.5
5)	Array control (operations control, Rx, antenna, turret,LO,cal contrl, fringe rate and delay calculations, correlator setup, observation scheduling, assessment of monitor information)	5.5
	TOTAL	10.0

The engineering design work necessary to develop the correlator interface and the antenna communications system are included in other sections of this report. The development of the required software interfaces to the antennas and the correlator will require interaction with these microprocessor engineers.

Items (1),(2),(3),(4) call for an investigation of methods that can be used to satisfy operations requirements. Item (3) is long term and may not be satisfied for some years.

2.2.4 The Asynchronous System

This computer system performs all observational tasks which are not time-critical to the visibility data collection and telescope control functions. Time-critical tasks completely occupy the synchronous computer.

Since there are no time critical tasks to be performed by this asynchronous computer, the data rates are not critical to its performance. However, the quantity of observatonal data to be monitored is in excess of 1 Gbyte for each day's observation assuming typical, not maximum, parameters.

Table 2.3 gives a list of tasks to be performed by this machine together with estimates for the software development time for each task.

Table 2.3 Manpower requirements to develop software for the Culgoora Asynchronous Computer.

TASK	MANPOWER REQUIREMENTS (Man years)
Software management	1.5
Scheduling software	0.75
Monitor database interrogation	3.0
Baseline calibration	0.75
Visibility data edit and check	0.75
Visibility data display	0.75
Initial data calibration and mapping	3.0
Data transportation system	0.75
Data archival system	0.75
TOTAL	12.0

2.2.5 Cost Estimates

Cost estimates for the Culgoora computing system are given in Table 2.4.

Table 2.4 Hardware costs for Culgoora Synchronous and Asynchronous Computers.

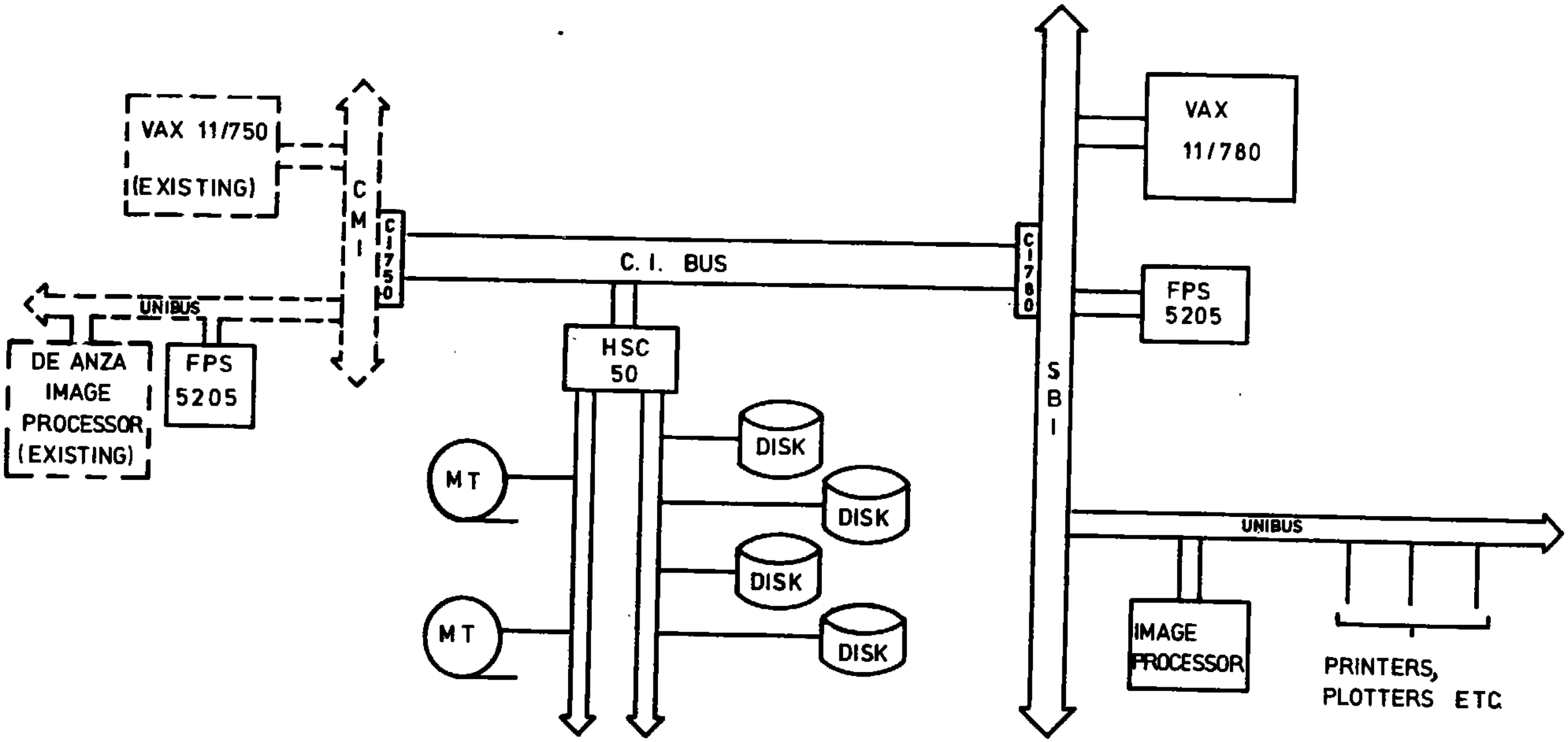
ITEM	COST ($k)
2 x VAX 11/750 with 2 x RA81 disks, 3 x TA78 magnetic tapes	370
2 x FPA750 floating point accel.	20
CI bus system	130
2 printers	15
1 colour display	10
floppy disks	5
incremental plotter	10
unibus switch	20
software licences	20
	TOTAL: $600 k

Major item costs will probably drop with time. All items except one VAX 11/750 and the CI bus will be purchased at the end of 1984. The remaining items will be purchased in late 1986 for delivery in early 1987.

2.3 EPPING ASTRONOMICAL REDUCTION SYSTEM

2.3.1 Introduction

The basic purpose of the Epping Astronomical Reduction System (EARS) (see Fig. 2.2) is to take partially calibrated visibility data and associated monitor data from Culgoora and produce publication quality images, graphical displays and associated numerical parameters. Intervening steps include data calibration and editing, map-making, image restoration (CLEAN and MEM), self-calibration, data-cube (two spatial dimensions plus velocity) manipulation and display, and model fitting. In addition, the EARS must support a number of ancilliary tasks such as schedule preparation, network communications, and word processing.



EPPING DATA PROCESSING SYSTEM
(EXISTING HARDWARE SHOWN DASHED)
FIGURE 2·2

It is clear that we should not 'reinvent the wheel' in a number of the off-line computing areas. Existing software packages for map-making, image restoration, self-calibration and data-cube manipulation must be assessed, and where possible incorporated into the software system. An immediate consequence of this is that the hardware must be VAX-based since existing software packages such as AIPS, GYPSY, STARLINK etc, all operate on VAX machines. Since AIPS uses the AP-120B array processor, a further probable consequence is that the array processor(s) must be Floating Point Systems units compatible with the AP-120B. Software written for this system must operate on the VAX systems owned by users outside Radiophysics, with the proviso that other users provide their own interface to image processing systems and possibly hard-copy devices. EARS software will be written so that interfacing is as simple as possible. Similarly, interfaces to the array processor will be kept as clean as possible so that they can be replaced by VAX software or some other device. The estimates for capital expenditure and man-power which are given below are for the period from now to the AT commissioning in 1988. They are intended to provide a minimum data processing system at the time of commissioning.

2.3.2 Map-Making considerations

The compact array is planned as a precisely 'east-west' array, so the two-dimensional FFT is adequate for map-making. The Long Baseline Array is clearly not 'east-west'. However, for the small fields expected the 2D FFT is adequate. This can be shown as follows:

The phase term in the usual definition of visibility is

$$2\pi\ [u\ell+vm+w(1-\ell^2-m^2)^{1/2}].$$

For small ℓ,m the w term can be written

$$2\pi w[1-0.5(\ell^2+m^2)],$$

so we require $\pi w(\ell^2+m^2)$ to be small. Following Thompson (VLA Synthesis Mapping Workshop, 1982),

$$w(max) \sim 1/(synth.\ beamwidth)$$

so the maximum phase error on the map is about

$$\pi(fieldsize)^2/(4synth\ beamwidth)$$

where all angles are in radians. For a **MAXIMUM** error of 0.2 radians

$$fieldsize < (0.25synth\ beamwidth)^{1/2}]$$

For the LBA at 1.4GHz, the synthesized beamwidth is about 0.07" and so a field of up to 1 arcminute in size can be mapped without substantial distortion. This corresponds to a 2kx2k map, larger than would be generally used - especially if there are only four elements in the array.

2.3.3 Data Rates

The average data rate into the system is assumed to be about 2.1 Gbytes per 12 hours with a basic 5-second integration time. This corresponds to 120 baseline/IF combinations each having 256 frequency channels. The 5-second integration time gives a 1% amplitude drop at the edge of a 1K x 1K map. With current tape technology (6250bpi) this will require 15 magnetic tapes per 12 hours for data storage, or about 9000 tapes per year. Clearly the data cannot be archived indefinitely in this way. However, existing video recorders have a data capacity of about 4 Gbytes. We must either develop, or buy when available, computer interfaces for such recorders. Their cost is moderate ($2k to $3k per unit) and it is not unreasonable to expect other users to provide their own video tape drive(s).

For a basic spectral-line observation of 256x1Kx1K maps x 4 polarizations the time required for the Fourier Transform is about 3 hours with the basic FPS 5205 unit (12 Mflops). This unit can be upgraded to 48 Mflops. An equally fast method of gridding the data will have to be found.

2.3.4 Cost Estimates

The power/dollar of computing equipment is, in general, increasing with time. Hence, it is in our interests to leave major purchases until as late as possible. However, the software system is very extensive and development must commence as soon as possible and certainly within the next 12 months. We propose to use the present Epping VAX 11/750 as a base for this development work. This system has a De Anza image processor and most of the necessary peripherals. It does not, however, have an array processor. We propose that a Floating Point Systems 5205 array processor (12 Mflops) be purchased for this machine as soon as possible.

The remaining EARS hardware should be purchased for delivery in early 1987. A block diagram of the system is shown in Figure 2.2, and major capital items are listed in Table 2.5.

Table 2.5 Capital Expenditure for the Epping Data Processing System.

Item	Current Cost (1983 $k)	Delivery Date
VAX 11/780	300	1987
2x FPS 5205 array processors	140	1984, 1987
4x 400 Mbyte disks	150	1985-1987
2x 125ips, 6250bpi, Magnetic tape units	120	1987
Image Processor	100	1987
Image hard copy devices	50	1987
Printers, plotters, floppies	50	1987
2x CI-bus interfaces	50	1987
HSCxx file server	42	1987
CI Star coupler	10	1987
CI - disk and tape channels	20	1987
TOTAL	$1032	

This system is entirely based on currently available equipment. Hence it does not include video recorders. It is hoped and/or expected that a CPU superseding the VAX 11/780, and higher capacity disks and tape drives will be available at the time of order. It may be necessary to purchase one of the new disk drives before 1987 to add to the 11/750 system for development work.

For versatility, reliability and ease of data transfer, it is proposed that the new VAX will be connected via a CI bus to the existing VAX 11/750. This also gives redundancy for many of the peripherals.

Clearly in this minimal configuration it will not be possible to store full databases for spectral-line maps (up to 18 Gbytes of data). Data compression, selection and/or pipelining (e.g.sequential by day) will be required. After gridding, the full database for one polarisation and frequency band will be typically 128 maps each 1k x 1k, which is about 500Mbytes. In general, it will be possible to have several of these on disk. The system will be able to cope with one or two such users at a time.

2.3.5 Manpower Requirements

These are listed in Table 2.6. Estimates are for the period from now to 1988.

Table 2.6 Manpower requirements for the Epping Data Processing System

Item	Estimate (man-years)
System management	3.0
Array processor integration	0.5
Assessment of available software packages	1.5
Visibility data input	1.0
Visibility calibration	1.0
Visibility editing	1.5
Mapping, image restoration, self-calibration etc.	4.5
Data-cube manipulation and display	7.5
High quality data presentation	1.5
TOTAL	22.0

System management (Table 2.6) includes operating system updates, storage management, fault diagnosis etc.

Half a man-year is allowed for integration of the array processor into the existing VAX 11/750 system.

Considerable time will have to be spent on assessing available software packages such as AIPS, GIPSY, DWARF and STARLINK. The aim o this assessment is to rate the functionality of these systems and the ability to integrate them (or portions of them) into a total system suitable for use on AT data.

Visibility input, editing and calibration functions are unique to the AT and will have to be provided from scratch.

We estimate that 4.5 man-years will be required to set-up, interface and supplement existing software packages for mapping, image restoration and self-calibration.

One of the main problem areas is the data-cube manipulation and display. This is a highly interactive process requiring the image processor and involving large amounts of data. With the possible exception of GIPSY, existing packages are not adequate for our purposes We thus anticipate considerable software effort in this area and have allocated 7.5 man-years in Table 2.6.

The final item in Table 2.6 is an allowance of 1.5 man-years to make improvements in the area of data presentation to satisfy astronome requirements.

2.4 OUTSTANDING

* The main area not covered is the recording and archival of data, presumably on video tape. Commercial activity in this area needs to be closely monitored.

* The question of whether or not special purpose processors for map-making, map restoration, etc. should be constructed was not considered by the workshop in any detail. The advantages of such processors over general purpose computers needs to be investigated.

* Further investigation is needed to determine the optimum way of interfacing the correlator to the synchronous computer so as best to handle the maximum data rate of 400 kbytes/sec.

2.5 RECOMMENDATIONS

The recommendations are:

* that two VAX machines be purchased for the Culgoora observatory. These two machines should be interconnected in a symmetrical manner so that their functional role may be interchanged.

* that purchases of computing hardware be made commensurate with the developments in other parts of the AT project. In particular, the purchase of bulk magnetic storage media should be delayed for at least two years.

* that the VAX 11/750 at Epping be used in the initial stage of the project until the delivery of the first AT VAX planned for early 1985

* that developments in the on-line and off-line computing systems take place in the VMS environment. Other contemplated microprocessor systems will have to interface ultimately to VMS.

* that the purchase of the image processiing system be delayed. The machine should be installed by early 1987.

* that the image processing software system will be designed to be transportable to other VMS computing systems to encourage astronomers to process data at their home institutions.

SECTION 3 : CORRELATOR SYSTEM

3.1 SPECIFICATIONS AND REQUIREMENTS

For the purposes of this workshop, the 'correlator system' is the complete interface between the digitized, band-limited IF signals and the on-line data handling computer. Its functions are to (1) convert the high data rate (320 Mbits/s) serial input data streams into parallel streams at 10 Mbits/s; (2) adjust the time delay from each telescope so that all data streams are synchronized to the same instant with respect to the source direction; (3) form a properly delayed 'tied array' signal from the six compact array antennas; (4) correlate all sensible pairs of IF data streams for a designated number of relative delays (lags); (5) integrate the correlated data (visibilities) over a designated number of (10 MHz) correlator cycles; (6) transform the correlated data from the lag domain; (7) perform the van Vleck correction to account for the effect of digitizing the IF signals; (8) HANN the frequency spectra if required; (9) select (window) the frequency channels desired for output and, finally (10) present the data, sorted in either frequency or visibility (uv) sequence, to the input bus of the on-line computer.

A basic specification on the correlator is the ability to correlate a 160 MHz bandwidth. This sets the input data rate to the correlator at 320 Mbits/sec per IF channel. For 2-bit correlation, the maximum bandwidth at constant input data rate is therefore 80 MHz.

The output data rate is determined by:

(i) the number of input IF channels

(ii) the number of cross-correlation spectra generated

(iii) the number of auto-correlation spectra generated

(iv) the number of frequency points generated per cross- or auto-correlation spectra

(v) the integration time per frequency point.

The specifications on these, and the corresponding requirements on the correlator are discussed in this section. The implementation of these requirements in the AT digital correlator is discussed in the following sections. Cost and manpower estimates for the correlator, and the impact of the correlator output data rate on the on-line data handling computer are also considered.

The input data rate is given by the produce of twice the bandwidth (for Nyquist sampling) times the number of bytes per sample times the number of input IF channels. For the AT the maximum input data rate is of the order 1 Gbyte/s. The output data rate is given by the product of the number of correlation pairs times the number of frequency points per pair (times 8 bytes per complex word) divided by the integration time. The maximum output data rate required for the AT is shown below to be of the order of 0.5 Mbytes/s. The correlation system therefore performs a primary data reduction by a factor of more than 10^3 in some cases. However, since the input data rate is proportional to the bandwidth while the output data rate is inversely proportional to the bandwidth (assuming full use of recirculation), the greatest proportional data reduction performed in the correlator occurs at the widest bandwidths. For the compact array in line mode, with four correlation products per baseline, the maximum output data rate is reached at a bandwidth of 0.625 MHz. This assumes the full size correlator and an overall recirculation factor of 2^8 = 256. The input data rate in this case is 3750 kbytes/s and the output rate is 393 kbytes/s, corresponding to a reduction of about 10.

The number of input IF channels is expected to total 38 in the final system. The compact (6 km) array and the long baseline array (LBA-maximum baseline length 567 km) are both handled by the same correlator. Each IF channel is split into a wideband channel for continuum observations and a narrowband channel for line observations. Therefore the maximum number of input IF signals is actually 2 x 38. Furthermore, the input data rates for the wideband and narrowband channels, and for the compact array and LBA telescopes will, in general, be different. Although these complications have been accounted for in calculating the output data rates, they have not been considered in the correlator architecture, which assumes a maximum of 38 inputs. however, the final design of the correlator input stages must take into account the full number of IF inputs and their various input data rates. This does not affect the cost estimates provided in this document for day-one operation.

The 6 km array is comprised of 6 telescopes, each with four IF channels. The 4 IF channels may be composed of four different frequency bands, or two frequency bands, separated into two orthogonal polarizations, or three frequency bands, only one of which is split into two polarizations. The total number of input IF signals for the 6 km array is 6x4=24.

The LBA includes the 64m Parkes telescope, a new 22m dish at Siding Spring, and the 6 km array (considered as a single telescope). Provision for including the 64m (or 34m) telescope at Tidbinbilla, two smaller antennas provided later under Radiophysics Divisional funds, and possibly an existing telescope in the Sydney area, brings the total number of LBA telescopes to 7. Only two IF channels per telescope are envisaged for the LBA - typically a single frequency split into orthogonal polarizations. The total number of IF inputs for the LBA is therefore 7x2=14, bringing the number of IF inputs to the correlator to 24+14=38.

Although the infra-structure and overall layout of the correlator will be designed to handle this many signals, the initial machine will be built to handle only the six 6 km array telescopes plus four LBA telescopes.

The number of cross-correlation products desired between two telescopes depends on what frequencies and polarizations reside on the IF lines from the two telescopes. Both alike and opposite polarizations may be sensibly correlated to obtain combinations of Stokes parameters, but only alike frequencies can be correlated. Therefore the four IF pairs from two 6 km array telescopes can be combined to make either 4, 6 or 8 sensible correlation products. If an observer decides to utilize fewer than four IFs, fewer than 4 products may be generated. With the two IFs available from LBA telescopes, a maximum of 4 products may be generated per LBA pair.

The number of antenna pairs (baselines) which can be correlated must be multiplied by the number of correlation products per pair to obtain the total number of cross-correlation spectra generated in the correlator. For any number of antennas N, the number of unique pairings is N(N-1)/2. Thus for the 6 km array the number of simultaneous baselines present is 15. For the full set of 7 LBA telescopes it is 21. Since the "tied" array (whether consisting of all or a subset of the six 6 km array telescopes) is included in the LBA set, there is no reason to consider further pairings between the 6 km array telescopes and the LBA telescopes.

The number of autocorrelation spectra desired may be the same as the number of input IF channels in some cases, i.e., a maximum of 38. Autocorrelation spectra are useful for a number of reasons. For example, the autocorrelation spectrum of the "tied" 6 km array gives a high sensitivity, high angular resolution spectrum at the array phase centre. For a high sensitivity spectrum over the full primary beam of the 6 km array, auto-correlation spectra of the individual telescopes may be added. This feature may prove essential in making decisions on which frequency channels to save for permanent storage.

The number of frequency points required for astronomical observations of atomic or molecular lines is highly variable. Even for continuum observations over a large field-of-view, bandwidth smearing (chromatic aberration) generally requires that the band be split into narrower channels for individual correction before final summing. To a large extent, the wide continuum bandwidth (160 MHz) plus the restriction on bandwidth smearing determines the size requirement for the correlator. The number of frequency points required at a given RF band for 50% smearing at the -10 dB point of a 22-m dish primary beam is given in AT/05.4/001. The worst case is at L-band, where 58 frequency points are needed. 408 MHz and S-band require 26 and 36 points respectively, and at C-band and above fewer than 16 points are necessary.

From the spectral line point of view, the more points the better. Fortunately, few spectral line observations require bandwidths as large as 160 MHz (except above 44 GHz), so recirculation (or equivalent) techniques provide more frequency points without increasing the number of physical correlators. However, the output data rate is directly proportional to the number of frequency points generated by the correlator, and this is dominated by spectral line observations.

In order to calculate the number of frequency channels produced with various configurations of the correlator, we can use the following formulation:

F = BxPxN complex points/integration time

where F = number of frequency points produced per integration period

B = number of baselines correlated

P = number of correlation products per baseline

N = number of frequency points per spectrum.

The limits on B and P were discussed earlier. One constraint on N is that it be in multiples of 16 frequency points, the basic (and minimum) module size. The upper limit on N will be set by the maximum output data rate acceptable to the on-line data reduction system.

Estimates for the maximum, minimum and 'most frequently used' configurations of the 6 km array and the LBA in both line and continuum mode are given in Table 3.1. The data rates implied by simultaneous observation in more than one mode can be obtained by summing across the lines, with the proviso that simultaneous 6 km continuum and line observations are likely to be possible only for a continuum bandwidth of 40 MHz (i.e. the 6 km continuum data rate is halved). Only crosscorrelation spectra are considered in the table.

TABLE 3.1: Number of complex words/integration period (BxPxN)

	6-km continuum	6-km line	LBA continuum	LBA line
maximum	15x8x64 7,680	15x8x2048 245,760	21x4x16 1,344	21x4x2048 172,032
minimum	15x1x16 240	15x1x64 960	3x1x16 48	3x1x64 192
most frequent	15x8x16 1,920	15x4x128 7,680	10x4x16 640	10x2x128 2,560

It should also be mentioned that, in general, a reduction by a factor of two in the number of frequency channels transferred to the on-line computer may be gained if only alternate frequency points in HANNED spectra are kept.

The final factor on which the output data rate depends is the integration time. In order to avoid smearing the data over spatially independent points in the u-v plane (circumferential, or time smearing) for large fields, a maximum integration time of 5 seconds is allowed. Of course, for small fields this is relaxed. However using 5 seconds as the basic integrating period and assuming that each complex frequency point requires an 8 byte word, the output data rates in kbytes/second corresponding to Table 3.1 are given in Table 3.2.

TABLE 3.2 : Output data rates (kbytes/s) corresponding to configurations given in Table 3.1

k-bytes/s	6-km cont.	6-km line	LBA cont.	LBA line	Total
maximum	12.3	393.2	2.2	275.3	683.0
minimum	0.4	1.5	0.1	0.3	2.3
typical	3.1	12.3	1.0	4.1	20.5

Operation at integration periods significantly less than 5 seconds should be possible at the expense of the total number of channels measured. Currently, a correlator dump time of 20 ms is envisaged. The minimum feasible integration time will be of this order.

3.2 CORRELATOR ARCHITECTURE

3.2.1 General

The design of the correlator was not a formal aim of this computer workshop, however it was quickly apparent that much of the correlator required examination with regard to the impact on data and control rates further downstream. It should be emphasized here that detailed examination of many problem areas is urgently required.

In order to accommodate the very large data rates involved, a pipeline structure is indicated throughout the entire correlator. The total set of operations is split into successive operations with buffer memory between.

An overall diagram of the correlator is shown in Figure 3.1.

Two design goals have been maintained:

(i) ultimate goal for which the architecture is designed

(ii) interim goal which is intended for day one operation (and costing).

The ultimate goal corresponds to 512 correlator modules while the interim goal is to only provide 240 modules and the necessary infrastructure for the larger goal.

3.2.2 Input Section

The sampled data input to the correlator is the following:

(i) 6 compact array x 4 IF x 320 Msamples/sec

(ii) 4 LBA x 2 IF x 40 Msamples/sec
(7 LBA x 2 IF x 40 Msamples/sec eventually)

3.2.2.1 Serial to Parallel conversion

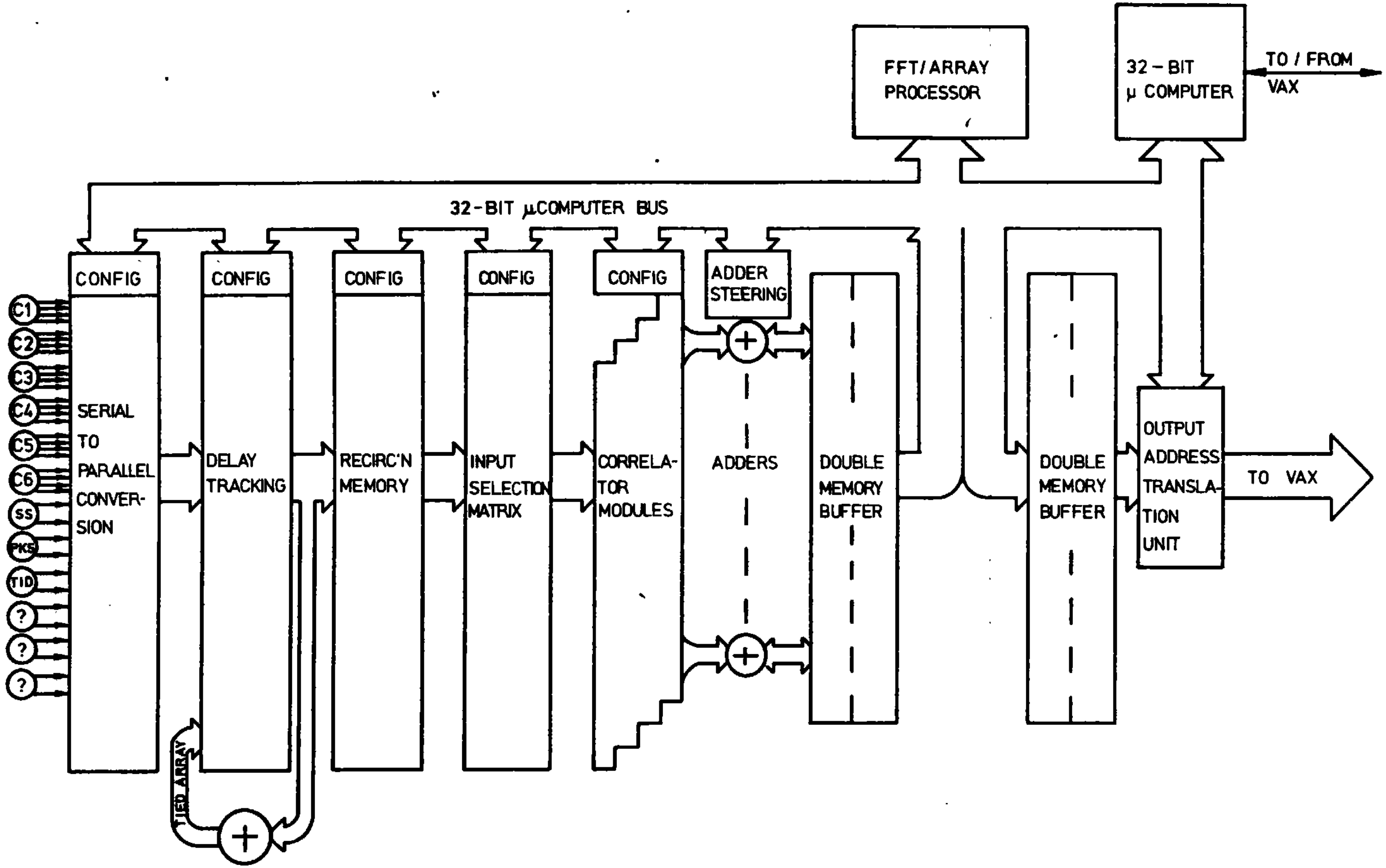
Each 320 Msample/sec bit stream must be converted into a 64-bit parallel bit stream at 5 MHz. it is envisaged that a system involving successive halving of the data rate will provide the most feasible solution.

3.2.2.2 Delay tracking

The delay unit is required to resynchronise the samples arriving from the antennas with the central clock and to provide up to 20 microsec of total data storage for the compact array and 2 ms for the long baseline array (at maximum data sample rates). The unified clock principle requires that the delay lines be a FIFO structure. It may be noted that only the first stages are required to be a general FIFO structure and the bulk of the delay may be provided in a standard RAM structure.

The size of the delay memory required is 80 Kbyte. The compact array is unfortunately not compatible with standard RAM formats. It is suggested that the compact array delays be in fact implemented entirely with FIFOs.

The control information for the delay is assumed to consist of initial FIFO occupancies (which correspond to delay in units of one sample interval. This is realistically provided once per 5 seconds although the unified clock principle allows a longer interval. A resolution of 13 bits is required for the compact array and 17 bits for the LBA is required. The total control information is 72 bytes.



CORRELATOR ARCHITECTURE
FIGURE 3-1

It might be noted that only integer multiples of the sample time are capable of correction here. A finer delay correction must be performed post correlation in the van Vleck/FFT array processors as a phase slope. Two further bytes of information per input would provide phase slope correction to an accuracy of 0.005 deg at band edge. The total delay correction control rate is 148 bytes/5 seconds.

3.2.2.3 Recirculation

The recirculation technique has been proposed to increase the number of correlator channels at low bandwidths. A maximum recirculation factor of 64 (in factors of 2) was originally proposed. AT/10.4/002 proposed a scheme where reconfiguration of the correlator allowed effective recirculation factors of 2, 4, 8 without a recirculation memory. This would be employed to provide an alternative to the first high speed (and expensive) recirculation steps and is assumed here. Considerable design effort is still required to produce an optimum overall design.

For the present, we assume a recirculation factor of 8 maximum is required to operate on a data rate already reduced by a factor of 8. That is the first three "recirculation" steps of 2, 4, 8 are replaced by reconfiguration. The corresponding recirculating buffer size is determined by the minimum correlator dump time (20 ms),

Recirculating buffer size:-

= 32 inputs x 40 Msamples/s x 2 buffers x 20 ms
= 6.4 Mbyte

The recirculating memory must be provided with flexible addressing facilities on output (hardware) and the necessary controller to update the readout address pointers every 20 ms cycle, and perform buffer switching at the completion of a full recirculation cycle.

Some consideration was given to the flexibility required in the controller. At present it is suggested that separate recirculation factors be specifiable per input(38 ultimate goal) although obviously not all combinations are valid. Approximately 38 bytes of control information is required.

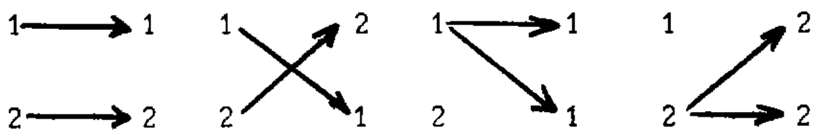
Recirculation can in principle be used to increase the number of baselines or IFs rather than frequency channels. This capability appears on first sight to require excessive complexity.

Finally, elimination of the actual recirculator for day one equipment may be considered as a fallback option. Note that correlator reconfiguration alone will provide up to a factor 8 increase in channels (i.e. output visibility spectra of 128 complex points).

3.2.2.4 Selector Matrix

The selector matrix represents the largest unknown in the correlator architecture. Quite possibly the total system capable of switching 38 (64 or 8 bits wide) inputs to any one of a total of 512(64 bits wide) correlator block inputs will prove impractical and compromises must be made. This problem corresponds in many ways to that of building a small high speed telephone exchange.

For the purposes of this workshop we postulate a selector based on a sequence (tree) of binary selectors. Each selector will be required to take 2 inputs and perform the following operations:



At best, log2(512) = 9 columns of such stages will be required per input, corresponding to roughly 38x9x9/2 switches. The control requirement will then be of order 450 bytes.

Provided dynamic reconfiguration is not required for recirculation, the selector matrix need only be set at some set-up period prior to observations.

3.2.3 Correlator Section

3.2.3.1 Correlators

The main correlation element is envisaged as an 8x8 XCELL chip. These can be connected in groups of 16 chips to create modules which are 32 samples wide by 32 lags deep. Internal switching can be provided to permit reconfiguration by factors of 2, 4 and 8 to a maximum lag configuration of 256 lags x 4 samples. A single input switch, albeit 64 samples wide, can also be provided to permit a choice of direct input or cascading from the previous module.

An output memory will be required so that the integrating adders can access the data in"lag" order. This could be either a serially loaded random access memory (possibly a second specially designed VLSI chip) or incorporated in the XCELL chip itself.

3.2.3.2 Adders

It is presently envisaged that one adder will be assigned to each 8 correlator modules. Each of these adders would be assigned a 16K x 32-bit word portion of the double buffered integration memory which it must be able to access independently of, and in parallel with all other adders. For each readout of the full correlator each adder will be expected to perform 8K additions of a 16-bit lag component into a 32-bit sum. This requires the adder to fetch data from both the correlator and buffer memory, perform the addition and write the sum back into memory in 2-2.5 microseconds. The 240-module interim configuration requires 30 of these adders, the maximum 512-module configuration requires 64.

A control table containing, in one 16-bit word per XCELL accumulator, a 14-bit storage address pointer and two flag bits is required to steer the adder's operation. Each adder requires a table containing 8k entries. The interim configuration will need 480k bytes of control table while the maximum requirement is for 1 Megabyte.

3.2.4 Output Section

3.2.4.1 Pipelined Post-Correlation Processing

After correlation in the XCELL the data enters a pipeline processor which eventually places integrated, van Vleck-corrected, Fourier transformed and windowed data on an input bus to the on-line computer which will in turn store it on magnetic media for eventual processing into maps. The first stage of this pipeline is the adder, decribed in the previous section. This adds the 20-ms correlator dumps into one half of a double memory buffer to build up integrated correlation functions. The integration interval is currently planned to be 5 seconds (maximum).

At the end of each integration interval, the two halves of this first double buffer are exchanged and the newly integrated data is made available to the 32-bit bus of the control microcomputer. This microcomputer now supervises the transfer of the data into two, or eventually four, single board array processors (for scaling, van Vleck correction, Fourier transforming, and windowing) and eventually transfers the processed data into a second double memory buffer. At the end of the next integration interval, the double buffer halves are exchanged again and the now processed data is presented to the computer.

3.2.4.2 Double memory buffers

There are two double buffers in the processing pipeline described in the previous section. Since they are both the same size it makes sense to make them as alike as possible. The first buffer is addressed by the adders on one side and a 32-bit microcomputer bus on the other. The second buffer is addressed by the 32-bit microcomputer bus on its input side and by some form of 32-bit VAX data path on its output.

Parallel processing of correlator outputs by up to 64 separate adders precludes traditional 2-port priority access to the memory with simple address bit switching to select halves. Each adder requires private uninterrupted read/write access to

16k x 32-bit words for the full duration of every integration interval. The buffers, therefore, must be made up of modules of this size, which, at least on the adder port, must be accessible on up to 64 separate 32-bit data buses. Each double buffer will thus comprise 128 memory modules each containing 64K bytes organized as 16k x 32-bit words. The ultimate configuration total memory is 8 Mbytes per double buffered memory. The maximum number of channels per integration period is thus 0.52×10^6 frequency points. The interim configuration will halve this figure. It is hoped that it will be possible to purchase memory modules of this configuration commercially.

The major design problem lies in the bus switching required to switch the memory modules between one of two broad address space 32-bit buses in the case of the second buffer, and between a broad address space bus on one side and 64 separate 16K x 32 bit buses on the other in the case of the first buffer.

3.2.4.3 Control Microcomputer and Array Processors

The control microcomputer should be a 32-bit machine such as the 68000 sitting on a standard 32-bit microcomputer bus such as the VME bus, VERSABUS or the extended 32-bit MULTIBUS. It has two major functions. The first is the set-up function of loading all the various control memories to configure the delay tracking, recirculation buffer, selector matrix, correlator inputs, adder steering and output address translation. The second function is that of supervising DMA data transfers to and from the single board array processors. The 32-bit bus must be capable of supporting sustained data rates of the order of half a million 32-bit data words per second at maximum recirculation.

The array processors must be chosen to interface to the same 32-bit bus as is chosen for the microcomputer. They must each be capable of performing 16 x 16K real FFTs (complete with corrections) in each 5-second integration interval. One candidate for this is the AGP-3000 which is a 24-bit floating point unit available with both VME and VERSABUS interfaces. Another might be the DSP FFT-1 which is an integer unit with an extended 32-bit MULTIBUS interface.

3.2.4.4 Output Address Translation Unit

An output address translation unit, to be loaded either directly from the VAX or via the microcomputer, can be placed in the address lines controlling the output port of the second double memory buffer. This would take advantage of the binary sized blocks of memory in which the data of equal U-V but different frequency are placed, to easily reorder the data into groups of equal frequency and differing U-V where this is desirable.

3.3 CONTROL AND DATA RATES

3.3.1 Control

Section 2 has enunciated the various set-up requirements for each of the correlator subsections. Some doubt exists as to the role of the control microcomputer in evaluating all tracking information, mapping tables, configuration selector control bits, etc. For typical standard operation, a small set of concise commands should be possible. To maintain full flexibility provision should be retained to externally calculate all parameters and download these for distribution to the relevant hardware controllers. Control data requirements are given in Table 3.3 and represent maxima predicated on this download option:

TABLE 3.3 : Data required for correlator control functions

Section	Number of bytes	Update rate
Serial to parallel delay	148	5 seconds
Recirculation	38	set up
Selector matrix	450	set up
Correlator configuration	240	set up
Adders	1M	set up
Lag selection for FFT	3K	set up
Output frequency channel selection	2K	set up
TOTALS:	1M	set up
	148	5 seconds

NOTE: The term "set up" may in practice mean once per 12 hour observation or series of observations with identical parameters

3.3.2 Data Rates

Very high data rates are encountered internally in the correlator system. For the purpose of the computer workshop, we adopt the attitude that only the output is relevant.

The requirements and specifications are extensively covered in Section 3.1. Table 3.4 sets out the maximum (hardware) limitations and expected typical usage.

TABLE 3.4 : Correlator output data rates

	Ultimate	Interim
Maximum*	800 Kbyte/sec	400 Kbyte/sec
Typical continuum	4Kbyte/sec	4Kbyte/sec
Typical line	16Kyte/sec	16Kbyte/sec

* determined by output buffer size

3.4 MANPOWER AND COSTING

Manpower and cost estimates are given in Table 3.5. The system which was costed is as shown in Figure 3.1.

TABLE 3.5 : Manpower and cost estimates

Item	Est.Cost $(July 83)	Manpower Engineer(man-yr)	Manpower Technician (man-yr)
Serial-parallel conversion	40k	0.5	0.5
Delay unit compact and long baseline	10k	0.5	0.5
Recirculating memory + selection matrix	100k	1.0	2.0
Correlator (240 modules)	384k	10.0	30.0
Adder + 1MB control memory	10k	0.5	0.5
Double buffered integration memory	25k	0.5	0.75
VFC/FFT/... Array processor + control micro-processor	40k	1.0	-
Double buffered output memory	25k	0.5	0.75
Output interface	10k	0.5	0.5
Integration and testing	-	4.0	8.0
TOTALS:	644k	19.0	43.5

3.5 CONCLUSIONS

As mentioned before in section 3.2, our group went into the correlator design rather more deeply than may have been anticipated. As a result of this several points emerged.

(i) There exists an urgent need for the prompt appointment of a section head in this area.

(ii) A concerted effort on the VLSI chip is needed (estimated 2 bodies for one year each) if the chips are to be available on the time scale required.

(iii) A correlator workshop along the lines of this computing workshop will need to be held as soon as possible.

(iv) The supply of a 2-channel correlator for evaluation of the first two element interferometer (PPWC input, page C11) for September 1985 should not distract the efforts of the correlator group, nor should it be considered in any way a prototype system for the full correlator.

(v) Estimated cost is $644k, to be compared with budgeted cost of $540k.

(vi) Manpower estimate is approximately 62 man years, of which approx 12 man years are allocated to system integration (September 1987-September 1988). This leaves approx. 50 man years for design and construction over the four year period, September 1983-September 1987, which in turn implies a staff level of about 12 people (4 engineers and 8 technicians.

SECTION 4 : CONTROL/MONITOR SYSTEMS

4.1 GENERAL

Control and monitor tasks are the prime responsibility of the synchronous portion of the Culgoora central computer which is designated to handle all the time critical functions. In order to do this the appropriate interfaces and communication links must be provided between the synchronous computer and peripheral telescope hardware, principally the correlator and the individual antennas in the array. As a design philosophy many of the control/monitor functions have been off-loaded to dedicated microprocessors which reside in the peripheral hardware. This approach serves to reduce the load on the synchronous computer and helps to avoid potential time latency problems. It also provides the peripheral with enough intelligence to work as a stand-alone unit which greatly facilitates self-test and maintenance operations.

Control and monitor operations for the AT correlator are handled by a microcomputer which forms an integral part of the overall correlator design. This allows the correlator to perform its functions with a minimum of control/monitor interaction with the synchronous central computer once initial set-up has been accomplished (see section 3).

The antenna elements of the AT array are at remote sites which are connected to the central synchronous computer via fibre optic or microwave communication links. At each antenna of the compact array and at Siding Spring an antenna control microcomputer distributes control information to the antenna electronics after it is received over these links. This control computer also concentrates monitor information collected from the various electronic packages at the antenna and forwards it to the central computer over the reverse path of the communication link. Other micro-computers at each antenna are employed for coordinate conversion and antenna servo control. In the cases of Parkes and Tidbinbilla many of the control/monitor functions which are performed by the antenna control computer at the other sites are done instead by the local hardware.

As the coordinate conversions to obtain elevation and azimuth pointing commands are performed locally at each antenna, it is necessary to have accurate clocking there also. This is also a requirement if fringe rotation is done at each antenna rather than being inserted on the reference LO before it is distributed from the central site. The ability to synchronize slave clocks at each of the compact array antennas via the fibre optic communication links proved to be an important factor in the design of the control/monitor system.

By locating separate antenna control computers at each antenna some flexibility is possible in the manner of implementing control/monitor operations. At least two main modes of operation are required; a regular observing mode and a maintenance mode. It is likely that the maintenance mode could be running on a single antenna of the array while regular observations are being conducted on the remaining antennas in the array.

In the regular observing mode a standard set of monitor data are sent back to the central computer from each antenna at a relatively slow rate (say 100 bytes every second). A number of checks and error flagging on this monitor data would be conducted by the antenna control computer before it is sent. At the central computer a subset of monitor data which is of direct interest to the observing astronomer (e.g. receiver calibration results and error flags) is combined with visibility data from the correlator for archiving on MT. The averaging interval of these data dumps would correspond to the correlator integration time, typically 5 sec.

A separate more complete log of monitor data is kept in the central computer for maintenance purposes. A suitable averaging interval in this case might be a few minutes. Recent entries in this log would always be available and the log would also be dumped to MT at regular intervals (the order of days) for archiving.

The monitor data also forms the basis of a system status display at the array operator's console and other sites. By this means any error conditions which are detected may be promptly brought to the attention of the operator and maintenance personnel.

Any malfunction in the antenna system detected via the standard monitor data sent back to the central computer may be investigated in more detail by switching to a maintenance mode. In this mode the antenna control computer might be required to supply monitor data at a higher rate just from a selected sub-package in the antenna electronics which is suspect. The maximum data rate from an antenna in the compact array could be approx 10 kbytes/sec in this mode.

4.2 ANTENNA LINK CONTROLLER AND CLOCK SYNCHRONIZATION

The on-line control system at Culgoora must control the operation of up to 12 antenna elements. Six of these antennas will be situated at a selection of 6 of 37 local station sites, whilst the other six antennas are fixed stations remote from Culgoora. The remote stations comprise a new antenna at Siding Spring, existing antennas at Parkes and Tidbinbilla, and three additional antennas which may be added in the future. Flexibility needs to be built into the system to enable a wide range of configuration requirements to be satisfied, and each antenna should be operated independently of the others. The antenna control process should neither be unduly influenced by, nor have undue influence on the efficient operation of other on-line processes.

To meet the above requirements, it is proposed that an "antenna link control" processor be interfaced to the on-line synchronous processor (Figure 4.1). This antenna link controller should consist of a microcomputer which has simple software and hardware interfaces to the synchronous control computer. The actual interface between these two processors is not specified, but the anticipated data rates between the two is low, with the required peak data rate being 10 kbytes per second, and the average being much less than this. There should also be no time-critical element in the data interchange between the two processors.

ANTENNA LINK CONTROLLER

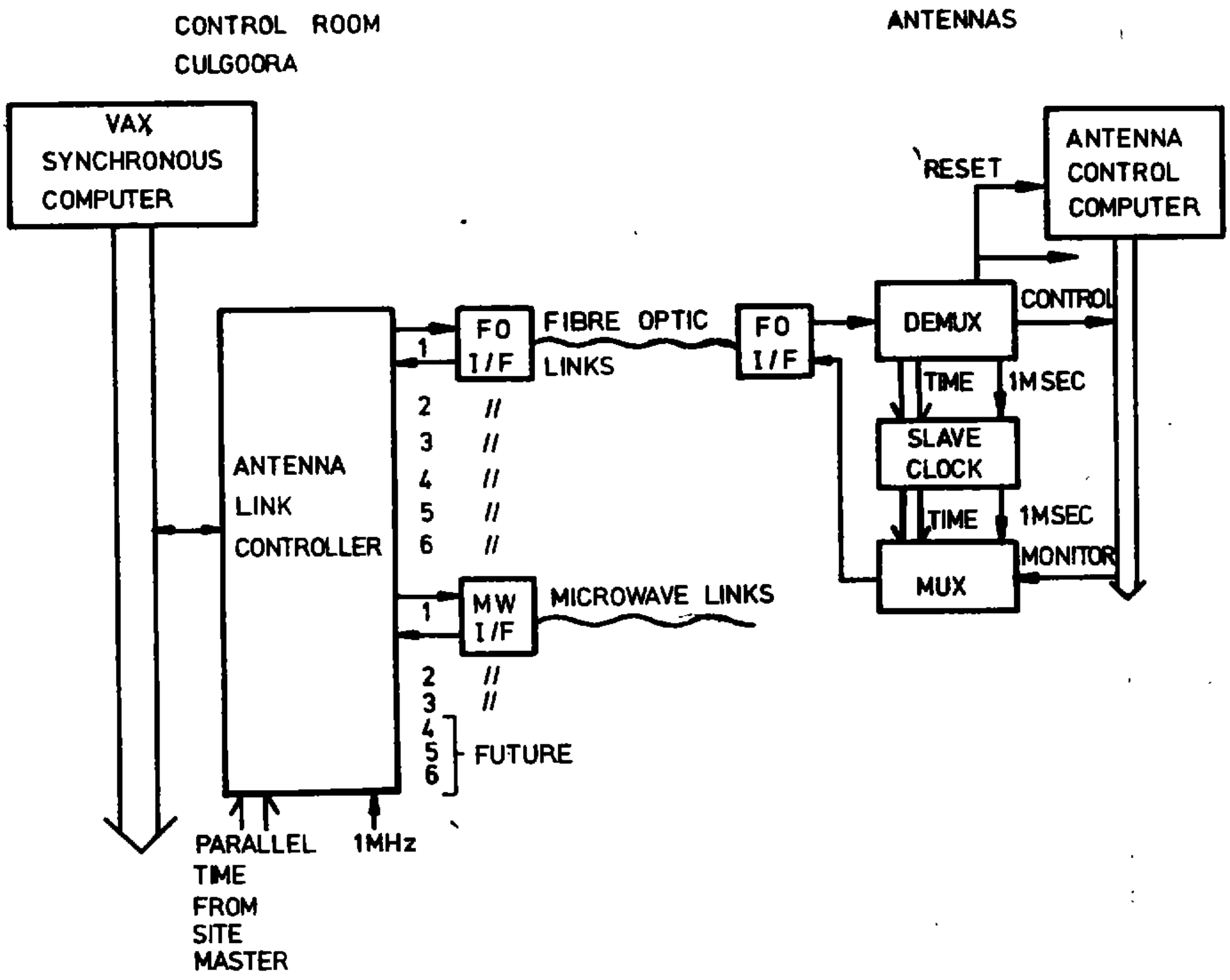


FIGURE 4·1

While the above interprocessor interface may well be vendor supplied, the interface between the antenna link controller and the antenna elements will need to be specially built. All the AT antenna units form a star network centred at the Culgoora on-line control system. The antenna link controller serves the role of a data communications controller to this star topology.

The control and monitor information are sent independently over a full-duplex channel to each antenna. These channels for the six compact array antennas at Culgoora are implemented on the fibre optic signal distribution system, each occupying one Megabit per second channel capacity for each of monitor and contol. The channels to the antennas remote from Culgoora need only be one hundredth of this capacity. This has been done to conserve the limited bandwidth available on the microwave links which connect these antennas to the control site, and has been achieved by eliminating the need for any critical timing and synchronization information to be exchanged.

The monitor and control information is sent in synchronized packets. The control packets on the fibre optic links are each one millisecond long, and contain one thousand bit-cells. Each control packet always contains a unique synchronization code to enable the detection and synchronization of a packet at the antenna. It also contains the absolute time (the format as yet unspecified) with a one millisecond resolution. An error detection field is also contained in each packet. The remaining capacity in each packet should allow for the transmission of approximately 100 data bytes per packet, and would only need to be occupied as required. Thus the synchronized packet concept allows for synchronous timing and asynchronous data transmission.

It is desired to achieve a time resolution and accuracy of synchronization at each antenna down to one microsecond. This is achieved by using a self-clocking code for the data transmission, and deriving all the timing information from the central site rubidium clock. The control packets sent out from the antenna link controller are synchronized to one millisecond ticks, and each data bit-cell is synchronized to the one microsecond ticks of the rubidium clock. The absolute time which is inserted into each control packet is also derived from this clock. The antenna link controller appropriately phases the packets being sent to each antenna so that the frame-synch pulse which is derived from each packet arrives at each antenna at the same instant of time to within one microsecond. The amount of phase shifting required is to be software contolled, but will in fact be a constant delay inserted by the software dependent upon which of the 37 local stations at which the antenna is positioned. This will achieve a time synchronization of the one millisecond frame-synch pulses at each antenna, accurate to one microsecond, which would otherwise be upset by the unequal time delays over the paths to the antenna sites. [The propagation delay over a 6-km path is approximately 30 microseconds.]

Each frame-synch pulse is used to reset a 10-bit counter at each antenna which is incremented by the separate clock pulses derived from the self-clocking data stream. Thus each antenna has the absolute time resolved down to one microsecond by the combination of the time on each packet and the count in the microsecond counter. Time accuracy of one microsecond is also achieved by the phase shifting of the packet by the antenna link controller.

Monitor information returned from each antenna also occurs in packets. Each packet contains the time which was sent out in the latest received packet, together with indication if that packet contained any data errors. The control microcomputer at the antenna is responsible for inserting the appropriate data in the monitor packet.

For the antennas remote from Culgoora, control and monitor data are also sent in packets, but the packet rate is one per 100 milliseconds rather than once per millisecond. This enables the control and monitor data each to occupy only 10 kbits/sec of the available channel bandwidth on the microwave links. Note that there is no time-critical information to be sent because the clock at each of these sites is set by a local site rubidium clock. Parkes and Tidbinbilla already have this facility, whereas a rubidium clock needs to be obtained for Siding Spring. The control path should allow for the clock at Siding Spring to be set and adjusted from the Culgoora control desk.

The ability to provide fringe stopping via local LO phase control at each antenna imposes a requirement on the accuracy to which clock synchronization must be maintained on the long baselines of the AT array. The maximum fringe rates at each antenna (using Culgoora as a reference) are given in Table 4.1 for a number of observing wavelengths and baselines. To keep phase accurate to 1 degree this means that for 3 cm (10 GHz) at Tidbinbilla the interval between phase updates must be 2 microseconds, or at Parkes it must be 4 microseconds. At these stations the clocks then have to be synchronized to that accuracy which is near the limits of what can be done. This means that once the fringe rate exceeds 300 Hz (10 microsec resolution) there could be problems, mainly due to the long delays between the widely separated stations. It might be possible to allow a 10 deg. phase step error which would lose only 2% correlation and relaxes the clock synchronization to 20 microsec. It seems reasonable at present to work on a basis of about 10 microsec for clock synchronization of the long baseline antennas.

Table 4.1 : Maximum fringe rates in Hz as a function of wavelength and baseline

Wavelength (m)	Baselines 3 km	6 km	(SS) 100 km	(PKS) 300 km	(TID) 500 km
0.3	0.73	1.5	24	73	121
0.03	7.3	15.0	240	730	1210
0.014	15.6	32.0	480	1460	2420
0.003	73.0	150.0	2400		

4.3 COMMUNICATIONS LINKS TO ANTENNAS

The control and monitor signals have to be transmitted in both directions to all antennas of the compact and long baseline arrays. There are two types of links available for this purpose: fibre optics for the 6km compact array and microwave links for the long baselines. Both these links carry local oscillator and IF signals as well as control/monitor. The data rates are 100 bytes/millisecond (see prevous section) for the fibre optic links and about 100 bytes/100 milliseconds for the microwave link.

4.3.1 Fibre Optic System

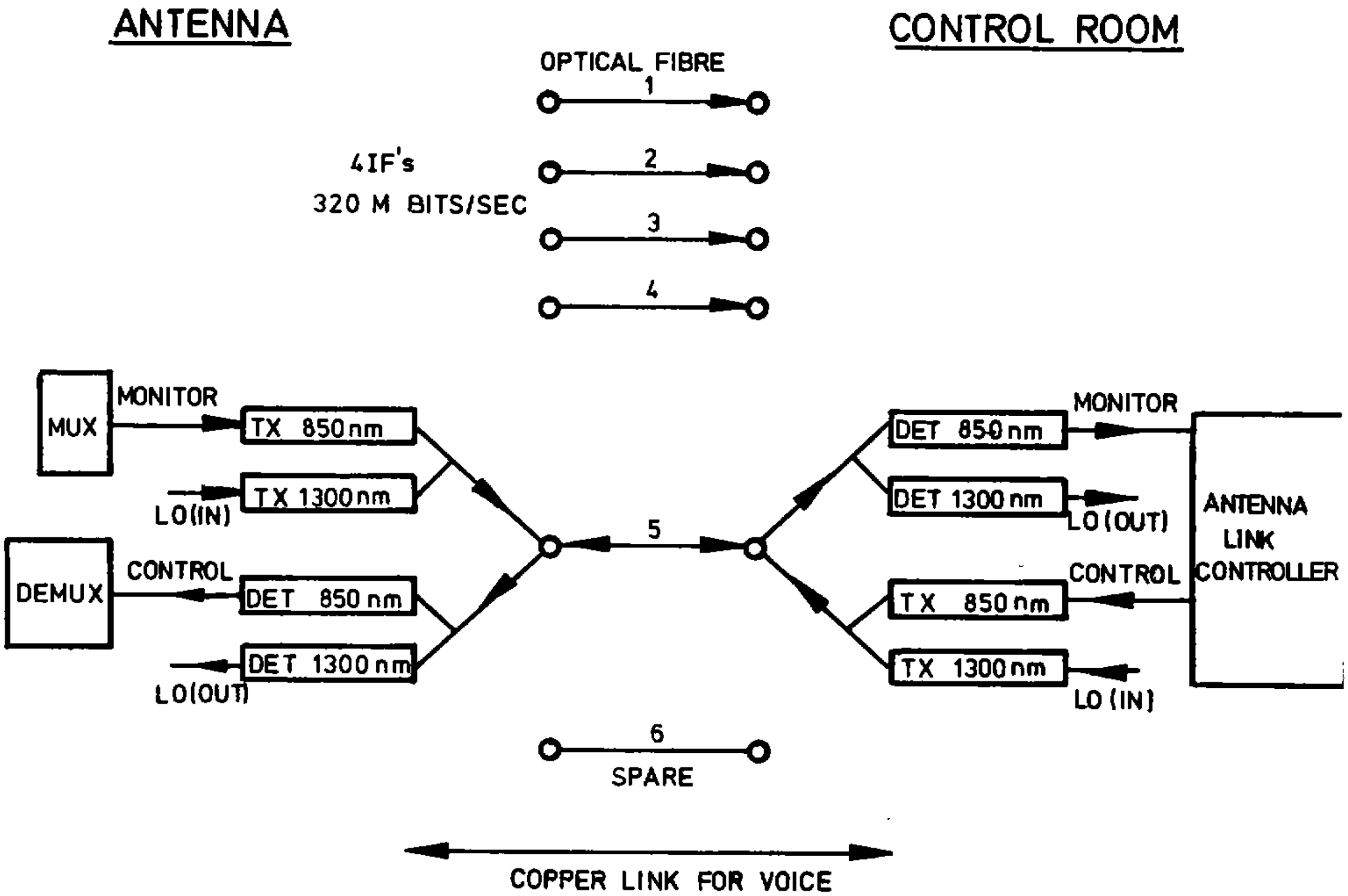
To minimise the number of fibres it is planned to wavelength multiplex the control and LO signals onto one monomode fibre. (If costs allow a separate fibre for each could be provided - a monomode for the LO and a multimode for the control.) In either case it is quite easy to get data rates for the control signals of a few Mbits/second which is adequate. A possible arrangement is shown in Figure 4.2.

4.3.2 Microwave Links

The proposed microwave links have the bandwidth shown in Figure 4.3a. These links can therefore carry approx 40 MHz of IF with about 2 MHz spare on either side. The IF bandwidth will be used in various ways, depending upon the configuration, but there has to be two LO tones at the edges always. The IF signals are used on the return signals to Culgoora, while for the signal from Culgoora there are only LO signals and contol. This means that we have available only a limited bandwidth for monitor signals in this link, shown in Figure 4.3b. If there is enough bandwidth it would also be desirable to provide a channel on the microwave link for a synchronous data communications network (for example Decnet) which would permit operator control from sites other than Culgoora (see Section 4.8). On the link from Culgoora we do not have IF, so there is really no bandwidth limitation and the arrangement shown in Figure 4.3c is possible.

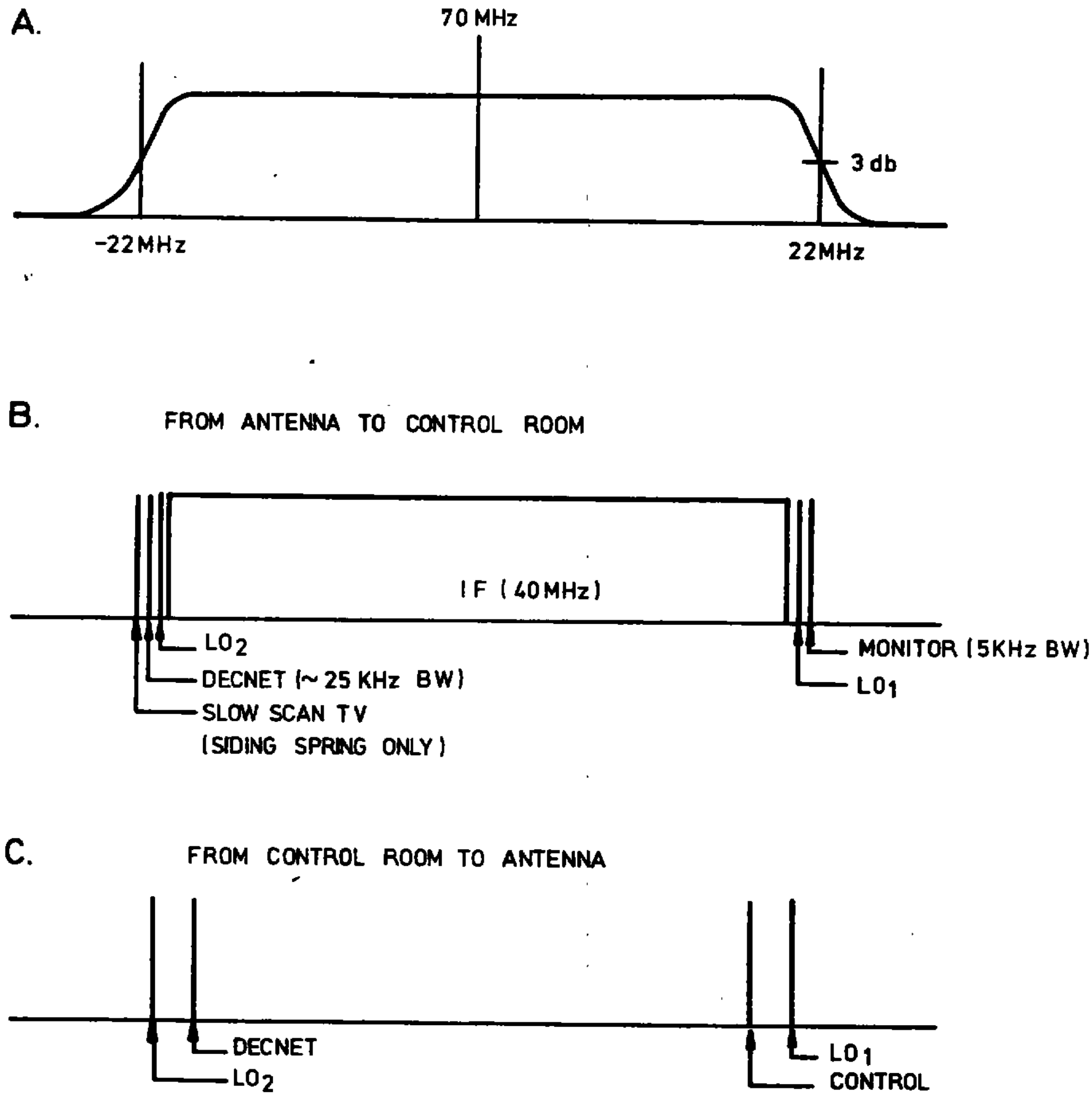
4.4 ANTENNA CONTROL COMPUTER

The antenna control computer (Figure 4.4) provides the interface between the communications link with the on-line synchronous computer and various antenna subsystems. It serves to distribute control information to these subsystems and processes monitor data collected from them. The type of processor to be used has yet to be defined, but it should have the capabilities of a Motorola MC68000 or a DEC MICRO J-11. The final choice may depend on the required interfaces, for example if there are a sufficiently large number of local items to control and monitor, then a local area network could be chosen for this purpose and the processor would need to be able to support that particular hardware and software. It would also be advantageous to have (at least) the control and coordinate microcomputers of the same type.



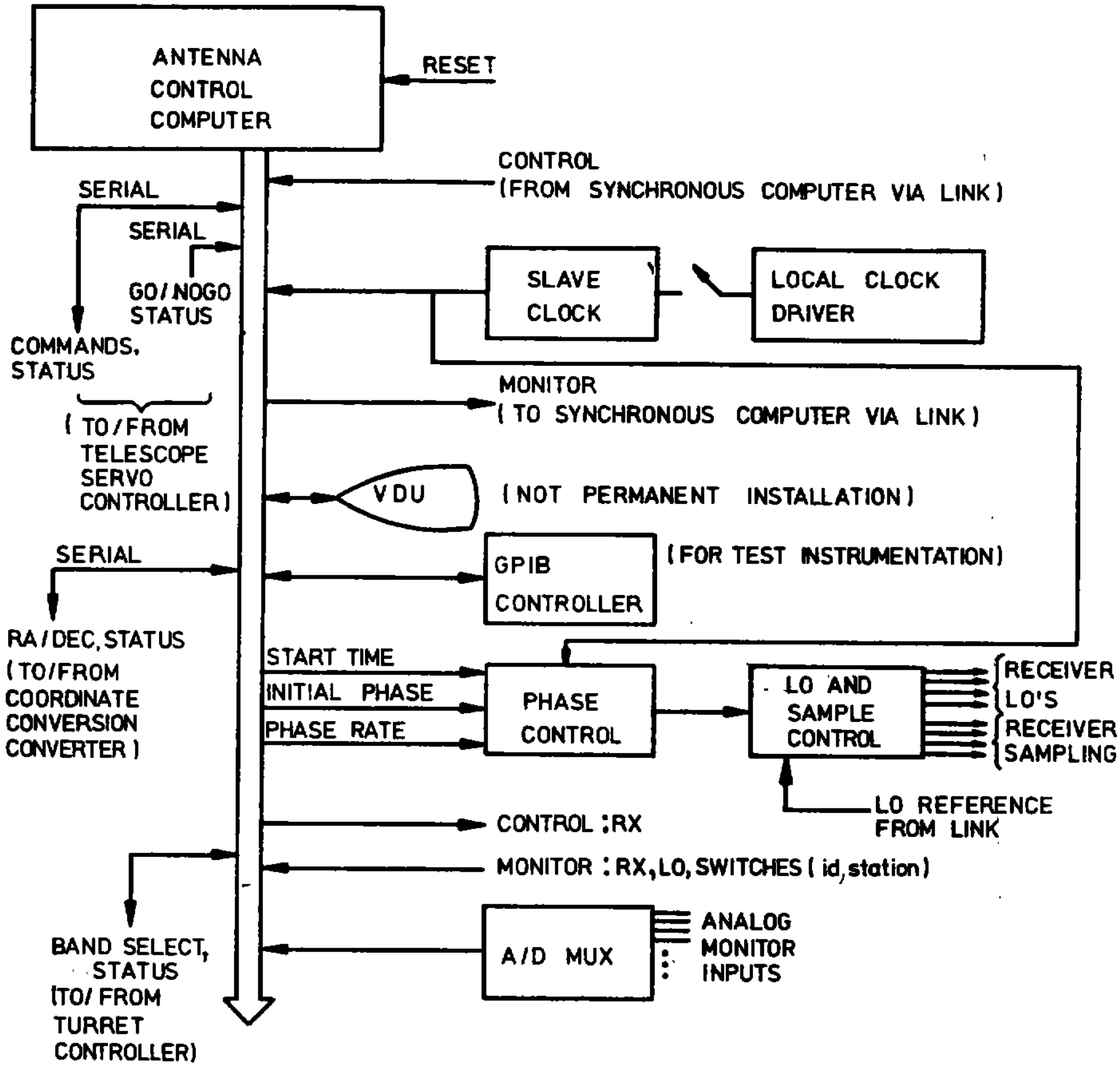
FIBRE OPTIC LINK TO EACH ANTENNA ELEMENT OF THE COMPACT ARRAY

FIGURE 4·2



BANDWIDTH ALLOCATION FOR MICROWAVE LINKS
(SIDING SPRING, PARKES, TIDBINBILLA)

FIGURE 4·3



ANTENNA CONTROL COMPUTER

FIGURE 4·4

Commands from the central synchronous computer are passed on the communication link in packets along with the information needed for clock synchronization (section 4.2). A special reset code can also be included in the packet for the antenna control computer and possibly for distribution to any of the electronics units which may require it. Command quality is verified by checking an error detection field placed in each transmitted packet. In case of an error a "bad message" response is included in the return packet so that the antenna link controller can retransmit the message. The communication link also provides a means for down-line loading of special purpose programs and new tables of antenna pointing corrections.

The VDU on the antenna control computer (Figure 4.4) is intended for maintenance purposes and might be a removable unit. A large subset of the on-line commands could be entered via this unit, but the format may be different. Responses and some monitoring capability would also need to be available at the VDU.

A GPIB controller is an optional unit which may be useful for supporting maintenance instrumentation.

The LO phase control unit shown in Figure 4.4 provides a method for fringe stopping, although an alternative scheme would be to locate this function at the central site rather than at each antenna. The phase control unit would have a parallel interface to the antenna control computer permitting the transfer of a time to start, initial phase setting and phase rate. Note that for the long baselines the provision of a fixed phase rate for each 5 second integration will not be adequate and it will be necessary to provide a continuously changing rate during the integration period. The unit would permit control of both LO phase and sample pulse generation (unified clock principle) for each of the four receiver IF channels.

A number of other direct control operatons to various antenna subsystems may be exercised by the antenna control computer (Figure 4.4). These functions could be implemented by parallel interfaces to the microcomputer bus, or if this proves unmanageable, possibly a local area network might be considered. Items controlled in this manner include turret rotation (see Section 4.5), receiver attenuator settings, IF channel and bandwidth selection, calibration on/off, etc.

Direct monitoring of digital data from antenna sybsystems might also be accomplished by parallel interfaces to the antenna control computer (or possibly a local area network). These data include IF power levels, calibration power levels, LO phase lock, etc. Provision for obtaining digital samples to monitor analog signals from the various points is provided by a 64-channel A/D converter and multiplexer unit.

Control/monitor operations for a separate coordinate conversion microcomputer are exercised via a serial link to the antenna control microcomputer, possibly a 9600 baud line. The message format is not yet defined but could entail byte counting with checksum verification and retry provision. The coordinate conversion computer controls antenna pointing - via the servo-computer (see section 4.5). Another serial line may be provided from the antenna control computer to the servo computer so that a status dump of servo housekeeping data could be obtained directly.

The antenna control computer averages monitor data over a suitable period and applies margin tests to detect out-of-tolerance conditions. An overall go/no-go status is generated based on the margin tests and go/no-go status returned from antenna subsystems. After processing by the antenna control computer the monitor data are assembled into packets for transmission to the central computer via the communications link. Under normal observing conditions only a subset of the total monitor data need be returned to the central computer together with the go/no-go status. However, when operating in a maintenance mode much more complete monitor reports could be obtained.

4.5 ANTENNA SUBSYSTEMS

4.5.1 Coordinate conversion computer

4.5.1.1 Functional Description

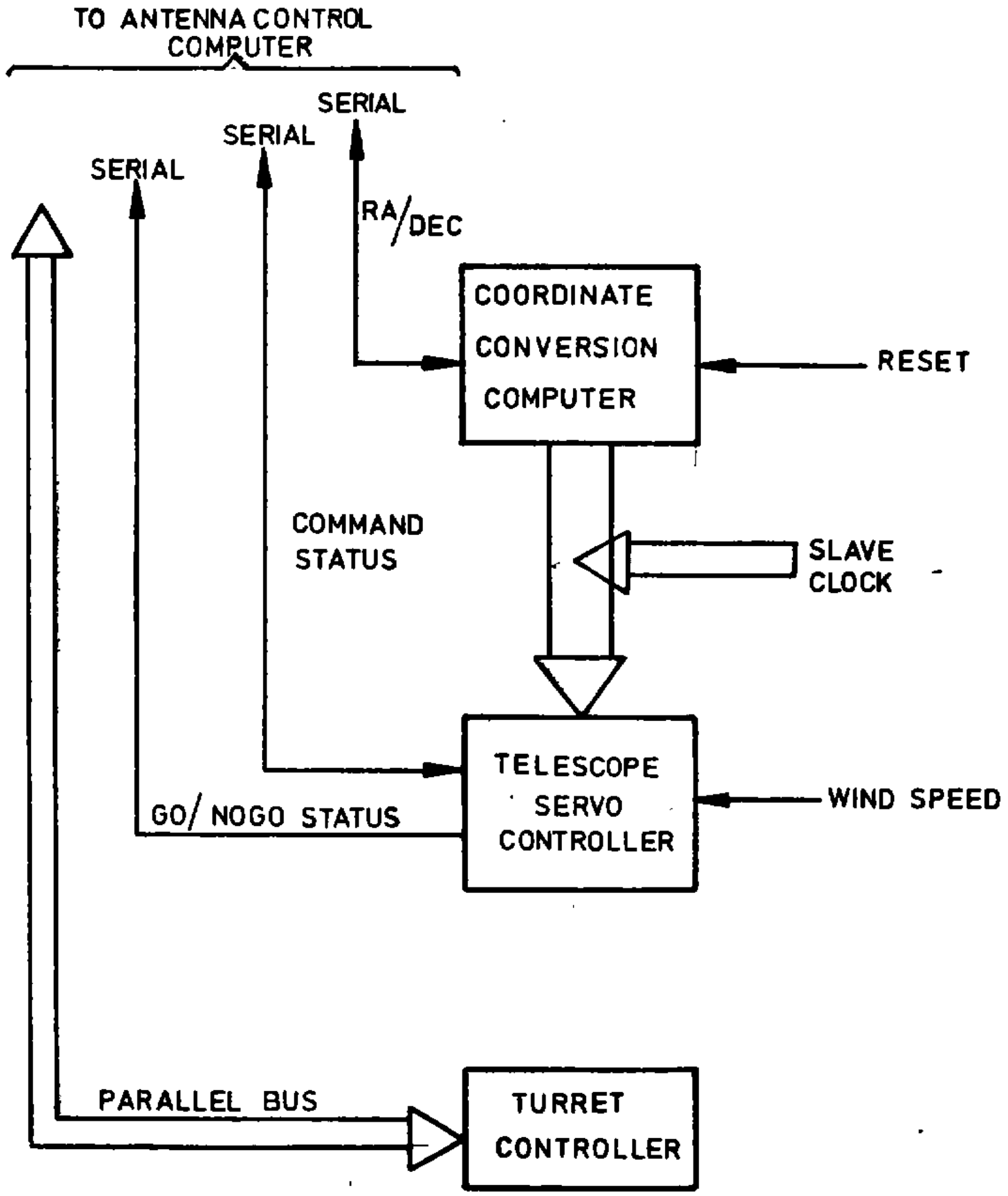
The coordinate conversion computer (see Figure 4.5) has three modes; track, scan and transparent. During observational tracking mode it constantly computes altitude and azimuth coordinate information to be passed onto the servo controller. The conversion computer will accept current right ascension and declination from the antenna control computer and use the local slave clock information for the coordinate conversion. The altitude and azimuth data will be passed continuously to the servo controller along a parallel bus at a rate no less than 15 times per second.

The second mode of operation will be either locally (via control computer) or remotely instigated scanning through a given right ascension/declination for antenna pointing calibration (remote requirement) and receiver system maintenance/evaluation (local requirement). Once again altitude/azimuth data is passed directly and continuously to the servo controller.

The third mode of operation is a transparent mode in which altitude/azimuth data from the control computer is passed directly to the servo controller (after any necesary local corrections have been applied).

4.5.1.2 Hardware Description

The coordinate conversion computer will be a fast micro-processor based system. As shown in Figure 4.5 it requires a bidirectional parallel interface to the servo controller and local clock, and a serial interface to the antenna control computer. A master reset line is provided to reinitialize the coordinate conversion computer.



COORDINATE CONVERSION COMPUTER, TURRET AND SERVO CONTROLLERS

FIGURE 4·5

Table 4.2 summarizes input, output and monitor data requirements for the coordinate conversion computer. Coordinate information from the central computer is received by the antenna control computer and is down-loaded to the coordinate conversion computer via a serial link. Provision must be made to update current position for precession as necessary during the tracking (very slow rate). Local time is supplied from a parallel bus from the local slave clock at the antenna. Alt/az data must be transmitted out to the servo computer at a rate no less than 15 times/sec. It may be asynchronous and need only be approximately spaced in time.

Table 4.2: Guide to data requirements for coordinate conversion computer

Input data:

Select operating mode (track, scan, transparent) 2 bit min
Master reset

(a) Tracking mode:	RA, Dec (current coordinate)	3 bytes ea.
(b) Scan mode :	RA, Dec (" ")	"
	Scan offsets (RA, Dec)	
	Scan rates (RA, Dec)	
	Start on/off source	
	Start scan	
	Number of scan points	
(c) Transparent mode:	Alt/Az	3 bytes ea.

Output data:

Servo controller Alt/Az 3 bytes ea.

Monitor data: (to antenna control computer)

Go/Nogo flag*, Bad request*, Read back of current RA/Dec, read back of current Alt/Az, operating mode, current source position (scan mode), set rate (RA/Dec), set offset (RA/Dec), current clock time

* sent automatically, rest sent only on request

4.5.2 Telescope Servo Controller

4.5.2.1 Functional Description

The antenna servo controller will have three basic modes of operation. These are auto-stow, standby-mode and tracking mode. All commands to the servo controller will be direct from the antenna control computer.

Auto-stow Mode: Auto-stow may be initiated remotely from the central computer or antenna control computer. It may also be initiated automatically by the servo controller if the wind speed exceeds 72 km/hour (20 m/s). In auto-stow the servo controller takes control of the antenna and drives to zenith at maximum slew rate and shuts down the antenna servo systems.

Standby mode: On command from the antenna controller the servo will shift to standby mode. Standby mode can be commanded from track mode or from the stowed position. A standby command issued during auto-stow will be ignored. In standby mode the servo silicon controlled rectifier (SCR) motor controllers are powered up (or remain so if coming from track mode), the antenna is driven to the current command position, stopped and the brakes applied.

Track mode: In track mode the servo controller accepts continuous alt/az position information from the coordinate conversion computer and tracks the sky position.

4.5.2.2 Hardware Description

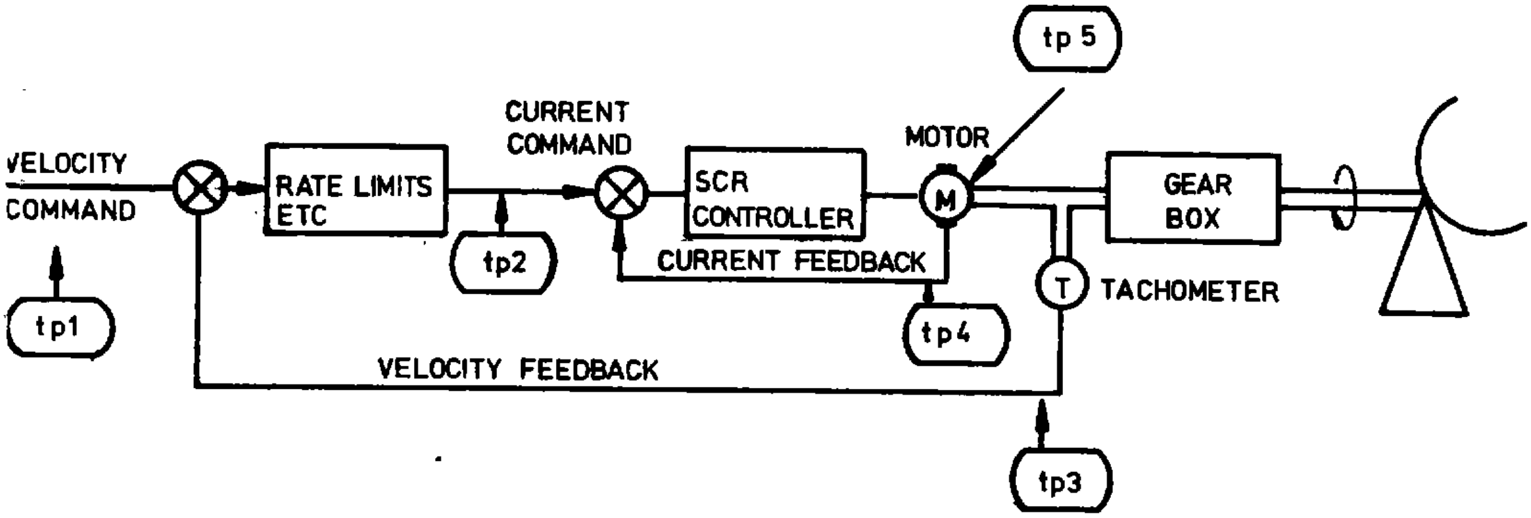
The basic servo system on each antenna is a combination of analog and digital feedback loops.

The drive on each antenna will have two motors per axis. The two motors in normal operation will be biased against one another to eliminate backlash in the gearboxes and drives. For high torque requirements (high slew rates in strong winds) each axis velocity loop will automatically command drive from motors in the one direction.

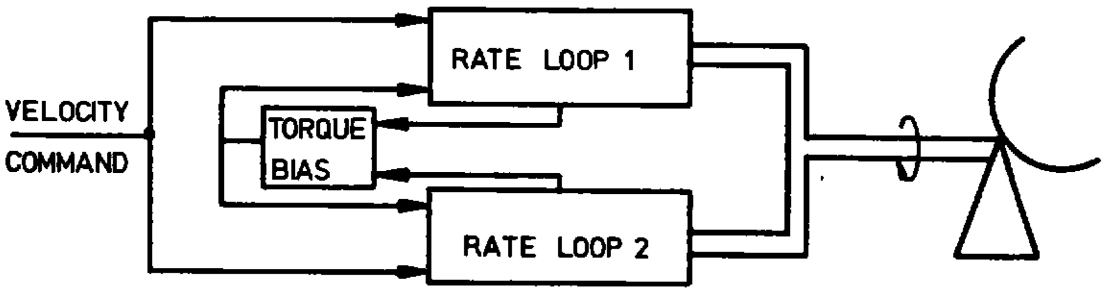
Each motor is controlled by a rate loop (Figure 4.6a). This loop accepts a velocity command to produce a constant axis rotation rate. Each motor pair is combined into an overall velocity loop (Figure 4.6b). This analog loop includes control circuitry to take care of the anti-backlash counter torque requirements. This loop accepts analog position information from the servo controller via a digital to analog converter.

The position loop (Figure 4.6c) provides the digital interface between the servo system and the outside world. A microprocessor servo controller compares input command position with the axis encoder output and closes the loop through the compensation algorithm. The servo controller also performs many internal test and monitoring functions on the overall servo system.

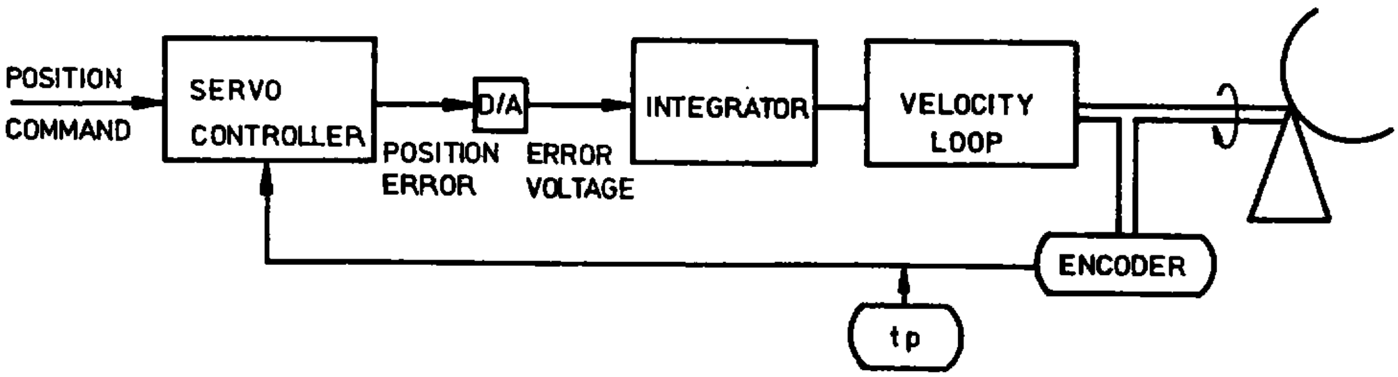
The servo controller commands come directly from the antenna control computer through a serial input line. This serial line is bidirectional and is also used to pass status and monitor information to the antenna control computer on request. A separate go/nogo line may be provided to give immediate indication of a servo system fault.



A. SERVO SYSTEM RATE LOOP (SINGLE MOTOR)
(tp = TEST POINT



B. VELOCITY LOOP ON EACH (El, Az) AXIS



C. POSITION LOOP ON EACH (El, Az) AXIS

ANTENNA SERVO SYSTEM

FIGURE 4·6

The actual position information comes on a parallel input bus from the coordinate conversion computer. This data is always present but its use is determined by the servo mode called up by the antenna control computer.

The servo controller also accepts direct wind information from a pair of anemometers mounted on the antenna. For wind speeds in excess of 72 km/hr (20 m/s) the servo controller automatically drives the antenna to the stow position.

Table 4.3 summarises the commands, input and monitor data requirements for the telescope servo controller.

Table 4.3: Data requirements for telescope servo controller

Input data

Alt/Az

Commands

Mode command : auto-stow, standby, track
Motor disable: az#1, az#2, el#1, el#2
Limit overrides: az CW, az CCW, el up, el down

Monitor data

Operating mode : local, remote (auto-stow, standby, track)
Fault indications: Go/Nogo overall status (possibly on high priority line)
Fault breakdown: (supplied on request, all 1-bit)

- Bad request (e.g. parity error on data)
- Emergency stop
- Stow pin engaged (az#1, #2, el#1, #2)
- Motor field fault (each motor az#1, #2; el#1, #2)
- Circuit breaker open (SCR controller az#1,#2;el#1,#2)
- Circuit breaker open (motor blowers az#1,#2; el#1,#2)
- Circuit breaker open (gearbox lubricating pumps az#1,#2; el#1,#2)
- Equipment rack over-temperature
- Limits (az1 CW, CCW; az2 CW, CCW, el1 up, down; el2 up, down)
- Brakes (az#1, #2; el#1, #2)
- Motor current fault (az#1, #2; el#1, #2)

Motor current (az#1, #2; el#1, #2)
Current command (" ")
Velocity command (az, el)
Tachometer output
Position error
Phase voltages (SCR contoller; A,B,C)
Encoder reading (az, el)

4.5.3 Turret Controller

4.5.3.1 Functional Description

The turret controller accepts a drive command from the antenna control computer to repositon the feed turret to select a frequency band. The turret will be locked in position with a positive pin engagement and its status read back to the control computer.

4.5.3.2 Hardware Description

The turret controller will be a simple microprocessor position control loop. The position feedback will be obtained from a synchro mounted from the slewing ring. [An alternative method would be to use a microswitch/optical switch system to locate angular position.] A stepper motor drive will allow a simple control loop to be employed.

Table 4.4 lists the input data and monitor data for the turret controller.

Table 4.4: Data requirements for turret controller

<u>Input data</u>

Frequency band
Engage alignment pin(s)
Release alignment pin(s)
Limit override

<u>Monitor data</u>

Status : band select
alignment pin (in, out)
turret position

Fault indicators : limits (CW, CCW)
bad request
motor fault

4.6 SUMMARY OF ANTENNA CONTROL/MONITOR FUNCTIONS

Summary lists of the control and monitor functions required at each antenna are given in Tables 4.5 and 4.6 respectively. It is seen that the proposal (section 4.2) to utilize data frames consisting of 100 bytes would permit all functions to be transferred from/to the central computer in a single frame. If frames are sent every msec then the rate is 1Mbit/sec or a bandwidth of 500 kHz. This is readily accommodated on the optical fibres but is too wide for the microwave link, so in this case the frame rate will be reduced by a factor of 100 to obtain a bandwidth of 5 kHz. Note however, for the out link, the full bandwidth of the microwave link is available (no IFs) and could be used. Also, bandwidth compression is a possibility through the use of complex coding.

Table 4.5: Control functions sent to antenna

Function	Number of bits (approx)
RECEIVER	
IF channel selection	8
Calibration on/off	1
Attenuation	2
LO frequency selection (4 channels)	9x4
Filter bandwidth selection (4 channels)	2x4
Digitization selection (1 bit, 2 bit, 4 bit)	2
Slow speed phase switch (every sec)	1
Doppler rate	10
TURRET CONTROL (see Table 4.4)	8
ANTENNA POINTING (" " 4.2)	100
SERVO CONTROL (" " 4.3)	10
OTHER	
Time to 1 msec	30
Master reset	1
TOTAL is approx. 30 bytes	

TABLE 4.6: Functions to be monitored at antenna

Function	Number of bits (approx)
RECEIVERS	
Noise generators (x2)	2x2
FET voltages (x8)	4x8
Power supply voltages (approx. x10)	6x10
Attenuator settings	2
LO power to 8 mixers	4x8
IF level for total power (x4)	8x4
Noise cal. level (x4)	8x4
IF level to digitizers (x4)	6x4
Fibre optic monitor (x4)	4x4
Filter bandwidth (x4)	4x4
LO lock (x4)	1x4
Phase control switch	1
TURRET CONTROL (see Table 4.4)	8
ANTENNA SERVOS (see Table 4.3)	200
CRYOGENICS	
Flange temp. (x2)	6x2
Compressor temp. (x2)	6x2
Ambient temp.	6
Dewar vacuum (x2)	4x2
Helium pressure (x2)	4x2
OTHER	
Doors open	2
Station identification	5
Antenna identification	3
Antenna bolted down/moving	1
3-phase mains	2
Humidity	6
Time from antenna slave clock	50
TOTAL is approx. 75 bytes	

4.7 CONTROL CONSOLES

4.7.1 Main operator console

This would comprise two units,

(a) standard alphanumeric video terminal with keyboard
Purpose: operator control

(b) Colour graphics display terminal
Purpose: Monitoring of telescope systems and observational status

These units would also be necessary at Parkes if full operator control is required from there.

4.7.2 Maintenance console

(a) standard alphanumeric display terminal with keyboard
Purpose: Monitoring and management of systems for evaluation of performance, research of problems, and on-going development

(b) X-Y plotter
Purpose: Analog presentation of any selected system parameter for determination of long term variation. The parameter may be derived from an analog or digital reading, or even a variable quantity within the system software only.

4.7.3 Astronomical Monitoring Console

(a) standard alphanumeric video terminal with keyboard
Purpose: Monitoring of astronomical data, a quick look facility of limited capability for use by an on-site astronomer. Could also serve as a schedule preparation console.

(b) two alphanumeric video displays
Purpose: Display of astronomical data related to the current observation.

Initially this facility is required at Culgoora, but a requirement is expected to develop at Epping also.

4.8 SYNCHRONOUS COMMUNICATIONS NETWORK

Up to this point we have only considered network communications at the level of sending and receiving telescope control, timing, and monitoring information to and from the individual antennas. At this level the network comprises a number of serial links radiating from the on-line VAX computer at Culgoora, there being one such link between the VAX and each antenna.

In contrast, operator and user control is a higher level application where the related hardware is almost entirely a part of the VAX on-line computer. It is proposed that at this level control and monitoring functions be accommodated using a synchronous communications network which links the VAX computers at a number of sites and allows operator and user terminals to be located at other sites than Culgoora, e.g. Parkes or Epping.

A standard computer network is proposed for this purpose which conforms to normal DEC communications practices in that:

(a) standard VAX inter-processor communications software is used, viz Decnet at the higher level and DDCMP (Digital data communications protocol) at the lower level;

(b) standard VAX communications interfaces, e.g. DEC's DMR11-AA or DMF-32.

The essential part of this network is a single link between Culgoora and Parkes, to allow operator control and surveillance from Parkes. An extension from Parkes to Epping would allow users to interact with the telescope from Epping.

Functionally, this is a general purpose network of VAX processors, and will have important uses additional to observation control. For example:

(a) software development/maintenance,

(b) system monitoring by engineering and maintenance staff from a remote base such as Epping,

(c) transfer of programs and small data files by telescope users,

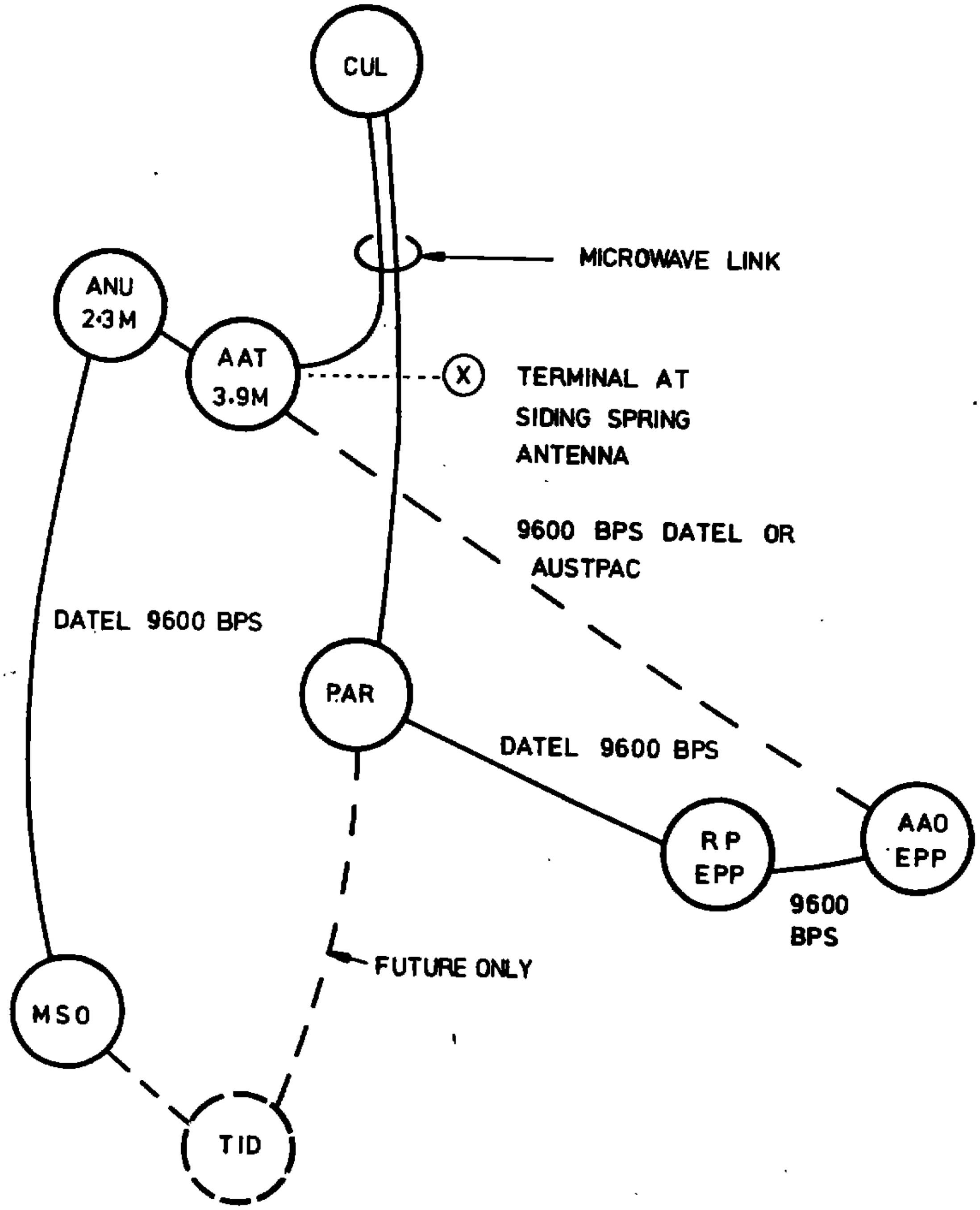
(d) exchange of electronic mail.

This is the network that should interface to the VAX computers of other organizations, possibly forming part of a larger network. Connections to the Anglo-Australian Observatory and the Australian National University would be useful - a possible scheme is illustrated in Figure 4.7. Apart from the AT, the AAO and the ANU have plans to instal a Decnet link between their respective VAX systems at Siding Spring (at the 3.9m and 2.3m telescopes, respectively). Also, there are plans to link the CSIRO's 11/750 at Epping with the AAO's 11/780 at Epping. The AAO expects to link its Epping and Siding Spring VAXes via a Telecom private line or Austpac.

The AT should consider a Decnet link between the AAO 3.9m telescope (AAT) at Siding Spring and the AT's VAX systems at either Culgoora or Parkes (the former is shown in the sketch). At the Siding Spring antenna there could be one or more terminals to the AAT VAX for engineering and maintenance purposes. (Alternatively there could be a direct connection allowing terminals at the Siding Spring antenna to have access to the Culgoora on-line VAX.)

The direct link to the AAT VAX improves the capabilities of the network. For example, there is then a circular connection between VAXes at Epping, Parkes, Culgoora and Siding Spring, giving two ways of routing between any two VAXes. (The decision to use an alternative though longer route in the event of breakdown of one of the links is handled automatically by the Decnet software.)

Where appropriate, this network would be routed via the microwave link, viz. Culgoora to Parkes and Culgoora to AAT. Barring further developments, the Parkes to Epping link is expected to be a Telecom private line.



SYNCHRONOUS COMMUNICATIONS NETWORK (DECNET)

FIGURE 4·7

Data rates of 9600 bps would be adequate. However, between Culgoora and Parkes, and possibly to Epping in the longer term, a higher data rate would be preferable, e.g. 19,200 or 56,000 kbits/second, provided there is enough bandwidth available on the microwave links (see section 4.3.2). (Note that current VAX communications interfaces can,in the case of some models, operate at up to 1 Mbit/second.) It should be noted also that owing to the way that Decnet formats the data for transmission, the net data throughput can be less than half the nominal transmission rate of the link. Data is transmitted in packets, allowing simultaneous multiple uses of the link.

If there were to be a high capacity link between Parkes and Epping and if the bandwidth were available, then the AAO may be interested in making use of part of this to form a private AAO connection between Epping and Siding Spring.

4.9 COST AND MANPOWER ESTIMATES

4.9.1 Cost

In Table 4.7 costs are itemized in three categories; antenna control/monitor systems, the synchronous computer network and control consoles. Note that costs of the actual communication links are not included, just the computer interfaces to them.

TABLE 4.7 : Cost estimates for control/monitor systems

		$k	
(1)	Antenna control/monitor systems		
	Culgoora antenna communications links ccontroller	20	
	Culgoora antenna computer systems* (six operational systems plus one spare)	70	
	Siding Spring antenna computer systems	10	
	Gateway computer systems to interface to Parkes and Tidbinbilla control systems	10	
	Rubidium timing standard at Siding Spring (costs may be shared with AAO)	9	
	SUBTOTAL:		$119
	* Does not include servo control system		
(2)	Synchronous computer network		
(a)	Culgoora-Parkes link		
	Synchronous communications interfaces at Culgoora and Parkes	6x2	
	Interfaces to microwave link	1	
	Decnet licences for VAXes at Culgoora and Parkes	4x2	
(b)	Culgoora-AAT link (excluding costs for AAO VAX)		
	Synchronous communications interface	6	
(c)	Parkes-Epping link		
	Synchronous communications interfaces at Parkes and Epping	6x2	
	Decnet licence for Epping VAX	4	
	SUBTOTAL:		$43k
	Note: In addition there may be a Telecom private line between Parkes and Epping costing approx. $10k per year for a 9600 bps line.		
(3)	Consoles		
(a)	Operator console, VDU at Culgoora and Parkes	2x2	
	Colour graphics Culgoora and Parkes	8x2	
(b)	Maintenance console: VDU	2	
	X-Y plotter	5	
(c)	Astronomical monitoring console, 3 VDUs	2x3	
	SUBTOTAL:		$35k
	TOTAL:		$195k

4.9.2 Manpower Requirements

Table 4.8 gives the manpower estimates for the antenna control/monitor systems. Note that they do not cover any software development required for the central computer system as this has been included in Section 2.

TABLE 4.8 : Manpower estimates for antenna communication link controller and antenna computer systems (in man-years)

Item	Engineering Design	Software Development
Antenna link controller and clock interfaces	1.0	1.0
Antenna control computer and associated interfaces	1.0	2.0
Antenna coordinate computer and associated interfaces	0.5	0.5
Gateway computer systems for Parkes and Tidbinbilla	0.5	0.5
TOTALS:	3.0	4.0

A complete control/monitor system for a single antenna should be ready for installation by November 1985.

4.10 ITEMS REQUIRING FURTHER ATTENTION

The following topics were identified as requiring additional study:

* Siding Spring clock: How will it be controlled and can costs of a rubidium clock be shared with AAO?

* Microprocessor development: The need exists for a MC68000 microprocessor (or other) development system, or possibly the existing system could be extended.

* Bandwidth utilization on microwave links: How can this be optimized what capacity exists for Decnet, what interfaces are required?

* Doppler control of LOs for fringe stopping: Should this be done at control room or at each antenna?

* Pointing corrections: What precision is required and do they need to be redetermined each time an antenna is moved to a new station?

* Monitor data dumps: How can these best be correlated with the correlator dumps of visibility data?

* Slow-scan TV for Siding Spring site. Can infrared or low level lighting be used for nighttime illumination without interfering with optical observatories?