MASTER

OVERALL SYSTEMS AND PERFORMANCE
TECHNICAL NOTES AND REPORTS
AT/20.1.1/002

COPIES GONE TO:

LIST A AND LIST B
RP LIBRARY
RAY NORRIS
JON ABLES
JIM ROBERTS
DAVE JAUNCEY

+ 4 EXTRA COPIES FOR RPN

(20th June, 1984).

A PROPOSAL FOR A PARKES-TIDBINBILLA INTERFEROMETER

Ray Norris

15 June 1984

OVERALL SYSTEMS AND PERFORMANCE
TECHNICAL NOTES AND REPORTS

AT/20.1.1/002

COPIES GONE TO:

LIST A AND LIST B
RP LIBRARY
RAY NORRIS
JON ABLES
JIM ROBERTS
DAVE JAUNCEY

+ 4 extra copies for RPN

A PROPOSAL FOR A PARKES-TIDBINBILLA INTERFEROMETER

Ray Norris

15 June 1984

1.0 INTRODUCTION

This is a proposal for a scheme to utilise the Parkes- Tidbinbilla radio link as a interferometer, using a minimum of additional equipment or manpower. This proposal builds on the foundations laid out by an earlier preliminary proposal (19 Feb 1984). Here I consider the design in some detail and construct a specification and a scheme for the implementation of the interferometer. Only Phase 1 of the originally proposed interferometer is considered here, since the details of an upgrade to 'Phase 2' will necessarily depend on our experience with the 'Phase 1' version. Sections 1 and 2 of this report largely repeat the introduction and principles outlined in the preliminary report, but the subsequent sections will explore the design and its uses in some detail.

The interferometer would represent a significant step towards solving the problem of AT calibration. At present, we have no framework of reference sources for AT calibration. The interferometer would assist the establishment of a suitable reference frame prior to the start of AT observations.

The interferometer would constitute a test bed for some design aspects of the AT, as well as providing experience in some areas which are otherwise inaccesible. For example, we have at present no way of investigating the radio properties of the Australian troposphere and ionosphere on the scales which might cause problems for the LBA. In addition, the interferometer to be proposed here will constitute a powerful instrument for tackling some currently outstanding astronomical problems.

The problems of constructing such an interferometer may largely be circumvented by imposing the following restrictions :

a) Tackle as many problems as possible in software rather than in hardware. Software is easier to experiment on, and we dont need the long term use of hardware.

b) Restrict the bandwidth to 500kHz. This has the disadvantage of limiting the astronomical use to spectral line sources and strong continuum sources, but has the overwhelming advantage that the correlator will operate on large steps in delay, so that the delay tracking of the interferometer ceases to be critical. The reduction in continuum sensitivity is mitigated by the large collecting area available.

This proposal differs from conventional interferometer schemes by the incorporation of two novel ideas:

a) Use a spectrometer for correlation (even for continuum observations) and dump out the entire cross-correlation function every integration period. Then, in post-correlation software, identify the peak of the cross-correlation and shift it to the centre of the delay space before performing the FFT to frequency space. This has the effect of allowing delay and phase corrections to be applied to the data after correlation, provided, of course, that the signal has not decorrelated during the integration period.

b) Use a standard off-the-shelf synthesiser for phase rotation. This has the obvious advantage of minimising the construction effort for the interferometer.

2.0 DESIGN CONSIDERATIONS

2.1 The Requirements Of A Radio Interferometer

A wavefront from an astronomical source will reach the two radio telescopes of an interferometer at two different times separated by an amount T, the so-called astronomical delay. The maximum value of T is the light travel time between the telescopes. To this must be added the radio link delay, to give a total for Parkes-Tidbinbilla of about 3.2ms. The signals from the two telescopes will eventually be correlated, and it is important that they are correlated at the same wavefront. In other words, we will in general need to delay one signal relative to the other by upto 3.2ms. In addition to this requirement (the group delay) we also need to ensure that the phase difference between the two signals is approximately constant throughout an integration period. Because of the Earth's rotation, the change in delay between the telescopes causes a changing phase difference between the signals received by the two telescopes. This is the rate of change of the EW component of T, and its maximum value for Parkes-Tidbinbilla is about 19Hz. Therefore we also need to provide a source of variable phase (or, equivalently, of frequency), upto 19Hz.

2.2 Overview Of The Proposed Interferometer

A block diagram of the proposed configuration is shown in Fig.1, and some of its parameters are listed in Table 1. All local oscillators and reference signals are derived from the local frequency standard at each station. The numbers against each path show the frequency in MHz. Phases (which are often also shown on such diagrams) are omitted for clarity since all are assumed to be locked to the frequency standards (H maser or Rubidium). Only the Tidbinbilla-Parkes direction of the radio link is used, and carries a 500khz wide radio astronomy signal together with a reference carrier, which effectively monitors unknown phase and frequency changes inserted by Telecom. Both phase and frequency errors from this source are cancelled by this technique.

The configuration considered in the preliminary proposal tackled the local oscillator stabilisation in two separate ways, which were called Phases 1 & 2. Phase 1 used a Rubidium frequency standard and a Hydrogen maser standard to stabilise the local oscillators, allowing coherence times of upto a few minutes at L band, whereas Phase 2 used the radio links to lock the Parkes and Tidbinbilla local oscillators, allowing indefinite coherence times. It is envisaged that the interferometer could be built initially using the Phase 1 LO system, and when operating successfully could be upgraded to the Phase 2 system. Here I consider only the Phase 1 system.

All frequencies used on internal data paths and the radio link are nominal, and may change slightly depending on equipment availability. This is discussed further in Section 5.5 below.

3.0 TECHNICAL JUSTIFICATION

3.1 Preparing For The AT

Broadly speaking, the technical uses of the interferometer will be as a test bed for the techniques and problems to be encountered on the AT. In addition, even after the completion of the AT there will be astronomical programs (e.g. many of those listed here in Section 4) which will use the single baseline interferometers of the AT at times when some of the other LBA telescopes are unavailable. The interferometer proposed here will by then have been upgraded to wide bandwidth and phase stability, but we may expect that much of the software (especially offline data reduction software) developed now will be useful for the upgraded AT system, especially if it is written with that function in mind. I will now list the individual technical aspects.

3.2 Establishment Of A Radio Reference Frame For The AT

Calibration of the AT will require a framework of compact reference sources. Such a framework does not yet exist, and the interferometer will be invaluable for the compilation of such a framework prior to the start of AT observations (see Section 4.3 below).

3.3 Experience With Interferometry

Use of the interferometer at an early stage of AT development will be invaluable as a means of gaining experience within Radiophysics of the techniques and problems of long baseline interferometry. It will also represent a useful pilot scheme to evaluate the feasibility of astronomical projects being considered for the AT. For example, the calculated values of sensitivity and phase noise give us little idea of what may (or may not) be achieved by phase referencing, or the extent to which our positional accuracies will be degraded by atmospheric phase variations.

3.4 The Radio Link

Use of the interferometer will allow us to monitor the reliability and performance of the radio link. From the studies of atmospheric phase stability (see below) we should also get some idea of the link phase stability. A better test of the link characteristics would be obtained by sending white noise on a round trip of the radio link, and then correlating it in the spectrometer with noise that has been delayed in the digital delay unit. Such an experiment would be possible with little effort by using the software and hardware developed for the interferometer, and the normal calibration procedure would then yield the group and phase delays of the radio link. The round trip delay of 4.4ms can be accomodated in the digital delay unit by operating at a bandwidth of 250kHz. Another experiment would be to send the radio astronomy signal over the link in two narrow bands separated by tens of MHz. This would enable the measurement of the link dispersion, which may be a critical factor in the design of any radio links for the AT LBA.

3.5 Study Of The Atmospheric Phase Stability

It appears that the atmospheric phase stability differs markedly from one site to another (compare the conflicting accounts from Jodrell, Cambridge, and the VLA). This implies that a good estimate of the typical phase stability at a site may be obtained only by measurement. Our ignorance of the local phase stability has been a problem when, for example, trying to determine the necessary integration time for the AT. Atmospheric phase variations on the interferometer may be distinguished from link phase variations either by measuring the differential phase between two sources, by nodding the telescopes, or by measuring the phase variations as a function of observing frequency (e.g. at 1.3cm at low elevations tropospheric phase variations should be much greater than the link phase variations).

Apart from imposing restrictions on the astronomy, the atmospheric phase stability may have important consequences for LO design. If the phase stability is bad at 22GHz, then we should not expend too much effort on getting high phase stability in the LO's for 22GHz.

3.6 Test Bed For AT Hardware And Procedures

The interferometer will serve as a test bed for AT receivers and local oscillators, and possibly for other areas of AT development, particularly if it is decided to use radio links for any part of the LBA. Similarly, it will serve as a test bed for the procedures for synchronising operation of the two telescopes.

3.7 Development Of AT Software

When the AT is completed, telescopes such as Tidbinbilla (and possibly Hobart) will be available for only a few weeks per year. During the remaining time, Parkes, Siding Spring, and sometimes the 6km Culgoora dish will be available for other astronomical projects such as interferometry. Projects such as astrometry and pulsar parallax/proper motion are ideally suited to this type of operation, and so it is unlikely that the telescopes will stand idle. The high sensitivity and resolution of the non-synthesis LBA will also allow exotic projects such as a search for nearby planetary systems (Batty 1983). It will, however, be necessary to develop software to analyse this data, as the standard synthesis programs will not be appropriate. The software for the Parkes-Tidbinbilla interferometer will be written with this future function in mind.

4.0 ASTRONOMICAL JUSTIFICATION

4.1 Capabilities Of The Interferometer

Because of the narrow bandwidth, the interferometer will be ideally suited to spectral line work. In this connection, it should be noted that bandwidths even narrower than 500kHz will be used on occasion, thereby making delay errors even less significant. For example, at a bandwidth of 50kHz, which would be suitable for OH masers in star formation regions, the delay per channel would be 10 microseconds, and the delay range of the spectrometer would be 5ms, so that in principle no external delay at all would be needed, as the entire range of delay adjustment could be applied in the post- correlation software! The proposal above has been framed for an operating wavelength of 18cm, but there is no reason why it should not be extended to other wavelengths, provided that receivers are available at both telescopes. In particular, operation at 22GHz would be desirable so that positions of water masers could be measured.

As well as spectral line work, there are significant continuum uses of the instrument. The most notable of these is astrometry, which, in addition to its astronomical significance, will be necessary for the establishment of a Southern Hemisphere radio reference frame for AT calibration.

4.2 Sensitivity

It is assumed here that the 64m is available at Tidbinbilla. If the 34m is used instead, the sensitivities will be degraded by factor of about 2. For spectral line work, using a 1kHz channel bandwidth, the rms noise after a 10s integration would be about 0.7Jy. A best case (10kHz, 30s integration) would give an rms of 0.13Jy. These are considerably more sensitive than the Jodrell Bank interferometers (because of the use of two large dishes) and do not pose any serious limitation to the range of sources that could be studied. Most well known OH/HII sources (of which there are many) have flux densities of tens of Jy. It should further be noted that the flux limit quoted above refers only to the strongest features in a source; subsequent phase referencing on a strong spectral feature will enable the mapping of weak features down to a small fraction of a Jy.

For continuum work, the entire bandwidth of 500kHz may be averaged to give an rms noise of 0.03Jy for an integration time of 10s. This is not a serious limitation for projects such as those described below.

I now list some of the projects that could be undertaken with the interferometer.

4.3 Astrometry

It will be shown below that frequent (1 every 10 mins) observations of calibration sources will allow the local oscillator and link errors to be determined to a sufficient accuracy to allow astrometry. This may be used both for fundamental astrometry, in continuum, and also for spectral line measurements (optical identification, relationship to other objects,etc.)

Fundamental radio continuum astrometry in the Southern Hemisphere is at present limited compared to that in the North, and a major need at the moment is for a reference frame for the AT. This work may be done at S (or possibly X) band using either the 64m or the 34m dish at Tidbinbilla. In either case, a sample of candidates would first be observed for short periods to measure their visibilities. Those that are found to be unresolved would then be tracked for longer periods (possibly interleaving several sources) to measure their positions. Because of the need for frequent calibration, these positions will be relative to those of the primary calibrators. Thus, starting with a few primary calibrators, we will be able to construct a network of secondary calibrators by a bootstrap process.

Astrometry may also be done in the spectral line mode. The interferometer could be used to determine the positions of OH masers to sub-arcsec accuracy, to determine their relationship to objects studied at other wavebands (e.g. Norris et al 1980; Norris 1980). Such information is of prime importance when trying to establish the dynamics of an HII region, which often occurs in a region of high confusion. It will also allow the optical identification of OH masers discovered in surveys, in order to elucidate the nature of the objects generating the emission.

4.4 Other Spectral Line Projects

4.4.1 Maser Spot Maps Of OH Masers In Star Formation Regions. -

Maps of clusters of unresolved masers were made with the Jodrell Bank phase stable interferometers prior to MERLIN, and were extremely successful in probing the dynamics of the gas during star formation (e.g. Norris et al. 1981,1982a). This is probably the project for which the interferometer is most suited. It will have a sensitivity in excess of any interferometers of comparable baseline, and will be the only interferometer capable of mapping sources at high Southern declinations.

4.4.2 Measuring Sizes Of OH Maser Shells Arond Red Giant Stars. -

Circumstellar OH shells have been found from aperture synthesis observations (e.g. Baud 1981,Norris et al. 1982b) to have typical sizes of a few arcsec, and to be roughly spherical. At any velocity, therefore, the shells have the appearance of a ring (a cross section through the shell) whose size may be reliably measured using a single baseline interferometer. Such information, when correlated with data from other wavebands, allow a detailed study of the death-throes of these stars. The high resolution and sensitivity of the interferometer will be particularly suited to distant OH/IR stars. Since much of the structure of nearby OH/IR stars will be resolved out, we can in those sources examine the compact hot-spots (representing the amplified stellar thermal emission) on the nearside of the circumstellar shell.

As well as being of use for the study of stellar decay, the OH/IR shells described above have the additional use of being primary distance indicators. By combining their angular diameter (measured with an interferometer) with their linear diameter (measured from the light-travel time as indicated by the phase lag between the light curves of the far and near sides) their distance may be obtained independant of any other astronomical assumptions (e.g.Herman,1983; Diamond et al. 1984). We are in a prime position to use this technique to measure the distance of the galactic centre. Since there are 14 known OH/IR stars within 200pc of the galactic centre with S>1Jy, we would need the high sensitivity of the Parkes-Tidbinbilla interferometer to measure the shell size, as well as a monitoring program of the intensities of the OH peaks to determine the light curves.

4.5 Other Continuum Projects

The sensitivity of the interferometer is limited by the 500kHz bandwidth. However this is largely offset by the large collecting area available, particularly if the 64m Tidbinbilla dish is available, so that the sensitivity is still comparable with other instruments having wider bandwidths. The following uses are apparent:

4.5.1 Pulsar Parallax/proper Motion -

By phase referencing to nearby calibrators, the interferometer should have sufficient resolution to be able to measure the proper motion and parallax of nearby pulsars (e.g. Lyne et al. 1982). Such a project would require monitoring over several years, and would be a prime project for the LBA. However, first epoch observations on the Parkes - Tidbinbilla interferometer would represent a useful extension of the secular baseline.

4.5.2 Measurement Of Source Structures -

Although this function is obviously better suited to aperture synthesis arrays, there will not be such an array in the Southern Hemisphere for another 4 years. In particular, a 300km baseline can look for compact objects (e.g. jets) in known sources, and perhaps even model superluminals.

5.0 THE INTERFEROMETER HARDWARE

5.1 The Correlator

The correlation of the two signals may be done in the existing 1024 channel spectrometer at Parkes. The resulting cross-correlation function (XCF) will be written to the VAX at intervals of the integration time, which will be 10s. Because the spectrometer samples a wide range of delay space, the externally applied delay correction need only be approximately correct. Any error in delay will simply shift the peak of the XCF to a different channel, from where it can be recovered by software, provided that the delay error has been calculated. In order that coherence is not lost, it is necessary only that the phase change in one integration period is a small fraction of a turn.

To adapt the spectrometer, the only non-standard connections are the interfaces to the digital delay and the phase rotators. The connections are shown in Figure 2. There are several way of arranging the sections of delay within the correlator. An alternative to that shown here is the configuration described by Ables et al. (1975). That shown here, however, is conceptually the simplest and eliminates the possibility of any 'zero-delay glitch'.

5.2 The Phase Rotator

Phase rotation may be accomplished using the Rockland 5100 frequency synthesiser currently installed at Parkes. This synthesiser generates a signal in the range 0-2MHz in 1mHz steps, and is continuous in phase when the frequency is changed. This specification is a considerable improvement on the minimum specification set out in the preliminary proposal, allowing greater ease of calibration and removing a task from the software. This synthesiser is already interfaced to the VAX, and may therefore be driven by the observing program without any modification.

The connections of the synthesiser are shown in Figure 2. The output of the synthesiser is taken down to the correlator via the present IF3 coaxial cable (attenuation < 6dB). It then replaces the 1.25MHz local oscillator on IF1, the input for which is available as a BNC socket. The maximum output level of the synthesiser is well in excess of that needed to drive the local oscillator, and so an attenuator may be used to reduce any problems of pickup and standing waves in the coaxial cable. The spectral purity of the synthesiser is expected to be better than that of the existing local oscillator.

5.3 The Digital Delay

If the spectrometer is operating at 500kHz bandwidth, then it samples and clocks at 1MHz, so that each delay step is 1 microsecond. It is convenient to clock the external digital delay at the same rate, so that to provide a maximum of 3.2ms, 3200 steps of delay must be provided. These may are cheap, one-bit shift registers.

To maintain the cross-correlation function within the correlator delay range, the actual number of bits must be selectable in blocks of 256. This selection will be assumed to be manual (e.g. via a thumbwheel switch) but an obvious enhancement will be to interface this to the VAX.

Figure 3 shows the digital delay unit, which contains its own sampler to avoid interface problems with the correlator. The output of this delay is at TTL levels, which may be connected straight into an existing input socket to a TTL-compatible buffer (originally included for the TEST project) on the correlator. CMOS chips are used for the delays, however, as no large TTL shift registers seem to be available. Thirty MC14562B shift registers are used to give a maximum delay of 3.8ms, allowing a margin for unexpectedly high link delays. The 50-off price of these is currently $3.89, so that the total cost of the whole unit should be approximately $150, and no more than a few man-days should be needed for its construction.

5.4 The Front Ends And RF Systems

These will be the existing (mainly L-band) front ends, with no modification except for the different destinations of the IF signals.

5.5 The Radio Link

The choice of carrier frequencies over the radio link will depend on the link performance and on the IF frequencies used at Parkes and Tidbinbilla. The standard IF frequencies may change as a result of LO improvements at either station. Therefore the frequencies used here should be regarded as nominal, but are consistent with the formal specifications of the link, as set out in Table 2, and with the current standard IF frequencies. It is necessary to send a reference carrier with the radio astronomy signal, in order to cancel the unknown phase and frequency changes inserted by the Telecom repeaters, and the phase changes due to the changing link path length. The repeater errors are cancelled exactly, but the path length phase errors leave a residual term which is proportional to the frequency separation of the data and carrier signals (1 deg. rms phase error per MHz, assuming the formal link specification).

Use of different IF frequencies at Tidbinbilla, or the availability of equipment provided for Giotto or Voyager, may mean that a slightly different scheme might become preferable. For example, an alternative scheme for the link would bring the Tidbinbilla signal down to video frequencies, and then the Telecom link terminals could be used. The video output at Parkes could then be mixed with the Rockland synthesiser output, filtered, and input directly to the correlator sampler.

5.6 The IF Converter Unit

The IF converter unit interfaces the RF signal from Tidbinbilla to the correlator. To do this, it separates the RF data at 70MHz from the reference carrier at 71MHz, using filters (or possibly a PLL for the 71MHz signal), and then mixes them to produce a 1MHz data signal. This is then mixed up with an externally derived 31MHz to produce the 30MHz IF signal required for the correlator. Note that the the other products of mixing are removed by the correlator IF filters.

The filters can be scaled from the designs developed for the AT, thus requiring little development work. The cost of parts, including the two mixers, is expected to be about $100, and the required manpower a few days.

The frequencies shown in Figure 4 should be regarded as nominal, and may be altered to suit the performance of the available equipment. In particular, equipment provided for the ESA/NASA projects may allow the filtering to be done at video frequencies, thus allowing a relaxation of the filter specifications.

6.0 THE INTERFEROMETER ON-LINE SOFTWARE

As the on-line software is unlikely to be used for the AT, it need not include the flexibility and generality expected of more widely-used software. To avoid re-inventing the wheel, I propose to base the program on an existing program such as SPECTRA. To this would have to be added the tasks specific to the interferometer, which are largely concerned with calculating the delay and applying the phase rotation. Rather than writing an extensive specification, I list here only the tasks which are additional to those in SPECTRA. Note that, as the Tidbinbilla LO is fixed, the LSR correction will be disabled and will be done by the off-line software.

6.1 Parameters To Be Input From MENU

1) All the parameters currently in SPECTRA (RA,dec,etc.)

2) Current pre-set value of digital delay

6.2 Tasks To Be Performed Every 1s

1) Calculate delay and its rate of change

2) Drive Rockland synthesiser

3) Display required delay

6.3 Tasks To Be Performed Every Integration Period

1) Transfer cross-correlation function (XCF) from correlator

2) Shift and select correct portion of XCF

3) Shuffle XCF, correct it, FFT

4) Output UV FITS file

5) Display spectrum and sample phase

7.0 THE INTERFEROMETER OFF-LINE SOFTWARE

7.1 Existing Software

Several packages of software which process single baseline data are currently available at Radiophysics:

1) AIPS VLBI programs

2) CALTECH VLBI programs

3) EVN Spectral line VLBI programs

4) Jodrell single baseline programs

Each of these requires a different data format. Since the software to be written will eventually be used for the AT, and will use the now-standard UV FITS format, it is sensible to incorporate the software into AIPS. Therefore the (rather basic) AIPS VLBI programs will be used, supplemented by additional programs (or modified existing programs) written to operate in the AIPS environment.

7.2 New Software

Additional programs are required to:

1) Display and edit data interactively

2) Correct data for bandpass shapes and phase gradients

3) Form interpolated difference phases from two data streams, for phase referenced data.

4) Perform LSR correction

5) Correct astrometric data using atmospheric slab models, telescope errors, etc.

6) Fit sine curves to relative phases

7) Model amplitudes and phases for simple structures (e.g. gaussians, circumstellar shells)

Items 5 and 7 here are necessary only for specialised applications, and could be deferred until the interferometer is working.

8.0 INTERFEROMETER OPERATION AND CALIBRATION

A limiting factor for delay and phase stability of the interferometer will be the radio link. The use of a reference carrier spaced 1MHz from the astronomy signal gives an effective link frequency of 1MHz, so that the specified maximum link delay drift of 1 microsecond/hour gives a phase drift of 1 turn/hour. This is probably small compared to atmospheric phase variations. The specified maximum jitter of 3ns rms gives a negligible rms phase noise of 1 degree.

The changes in the group delay along the link are not of course cancelled by this technique, and the delay changes can be corrected only by calibration. The drift of upto 1 microsecond/hour, corresponding to 1 delay channel/hour, can be calibrated by frequent (e.g. every hour) observations of a calibrator source, and corrected in the off-line analysis by applying a phase slope to the spectral data.

The calibration observations, and other source changes, can be accomplished by having observers at both telescopes. Alternatively, bettter synchronism and ease of operation can be achieved by using a microcomputer at Tidbinbilla, which would be slaved to the Parkes VAX via a telephone line or over the radio link. Such a system could not be justified for this interferometer alone, but will be needed anyway for eventual AT operation of Tidbinbilla.

9.0 INTERFEROMETER PHASE STABILITY

There are two different requirements for phase stability in the interferometer.

1) For relative phase mapping (e.g. of OH masers), the phase must not cause a decorrelation (loss of amplitude) within the integration period. Here we take this integration period to be 10s, and will allow a maximum reduction in amplitude of 10%.

2) A much more stringent requirement, which is necessary for astrometry, is that the phase must not exceed, say, one radian in the interval between calibrations. It will be shown below that this is a realistic target at L and S band, so that astrometry is possible with the interferometer.

9.1 Local Oscillators

The local oscillators will be based upon a Hydrogen maser at Tidbinbilla and a Rubidium standard at Parkes. The results of Rogers & Moran (1981) then show a decorrelation in 10s of 0.1% at 1GHz, 0.6% at 3GHz, 6% at 10GHz, and 36% at 30GHz. Thus the interferometer is certainly useful to 10GHz. At 22GHz it would need either a shorter integration period (e.g. 4s) or else use of amplitude referencing techniques. However, MERLIN experience shows that amplitude referencing is necessary anyway at 22GHz, because of atmospheric fluctuations. The local oscillators do not therefore constitute a major problem for mapping at any usable frequency.

The severe requirement for astrometry is, perhaps suprisingly, met at the low frequencies. Audoin (1982) has shown that at 1GHz, an HP5065 Rubidium standard will give a 1 radian rms phase over 1000s. Thus calibration observations every 500s or so will be adequate to monitor the absolute phase over a 12 hour period, using either L band or S band.

9.2 Radio Link

Using a 1MHz carrier separation on the radio link will give an rms phase noise of 1 degree, leading to neglible decorrelation over a 10s integration period. The phase drift of 1 turn/hour is comparable to that from the frequency standards, and can be adequately calibrated for both astrometry and mapping by calibration. Even greater link stability could be achieved by moving the reference carrier closer to the data signal.

9.3 Atmosphere

As previously noted, the atmospheric stability is at present largely unknown. Some educated guesses are given in AT/20.1/008. Stability at low frequencies is dominated by the ionosphere, and we may expect phase variations of the order of a radian in tens of minutes. At high frequencies (5-22GHz) the tropospheric variations dominate, and reach maximum fringe rates (at 22GHz) of a turn in a few minutes. Thus the high frequencies cannot be used for astrometry, but present no problem for decorrelation in the 10s integration time.

9.4 Overall Stability

None of the effects above will cause any problem for mapping purposes, except perhaps at 22GHz where a shorter integration time (e.g. 4s) or the use of amplitude referencing techniques may be needed.

One rather unexpected conclusion is that astrometry is just about possible without a stabilised LO link. Provided the phase errors can be calibrated every 10 minutes or so, we should be able to measure the absolute phase of a source over a 12 hour period at L band or S band, thus providing astrometric positions accurate to about 10 milliarcsec.

10.0 A SCHEDULE FOR THE INTERFEROMETER

10.1 Manpower Estimates

I list here some very rough guesstimates of the manpower needed for individual tasks. I am happy to write the software myself, although anybody who wished to contribute would of course be welcome to do so. The small amount of hardware could presumably be done in one of the workshops without causing any disruption.

Construction of delay unit	1 week
Construction of IF converter	1 week
Sorting out LO's, etc.	2 days
On-line software	1 month
Minimum off-line software (Necessary anyway for the AT)	1 month

10.2 Telescope Availability

The telescope availability is summarised in Figure 5. It is assumed that we will use the 64m at L band, although if it is easier to get time on the 34m then this would be suitable for all the initial calibration and testing. The 34m is restricted to the S and X bands (although it is possible that the 34m may be equipped for L band at some future date), so astronomical projects such as astrometry and pulsar work would also be suitable for the 34m.

There seem to be three methods available to us for getting time at Tidbinbilla.

a) Host country time

b) Time under an AT agreement

c) Unscheduled slots available at short notice.

Option (c) will require us to have a system at Parkes ready and set up, together with the consent of the scheduled Parkes observers. This option may occasionally be practicable, but can certainly not be relied upon. Options (a) and (b) seem the most practicable, but it is not clear at present how much time we can expect. Hopefully, the situation will be clearer by the end of this year.

10.3 Proposed Schedule

All software and hardware should be constructed in 1984, so that tests may be carried out at Parkes towards the end of the year. As soon as the radio link is available, we should try sending signals down it on a round trip and correlating them using the interferometer software and hardware. Note that this requires a maximum delay of about 4.4ms which may be accomodated within the planned delay range by operating at 250kHz bandwidth. We may then expect to conduct the first astronomical experiments in early 1985.

11.0 CONCLUSIONS

1) The interferometer as described requires very little manpower or resources to implement.

2) There is a great deal of useful astronomy to be got out of such an instrument.

3) The interferometer will constitute a useful prelude to the AT, allowing us to test parts of the AT and also to investigate possible problems. It will also enable us to construct an astrometric reference frame which will be necessary for AT calibration.

4) Much of the off-line software for the interferometer will be necessary for AT operation when only a few telescopes are available for the LBA.

5) The only possible problem is that of telescope availability at Tidbinbilla. If this can be resolved, then the interferometer could be operational by early 1985.

12.0 ACKNOWLEDGEMENTS

I thank Jon Ables, George Chmiel, Dave Cooke, Geoff Crapps, Dave Jauncey, Terry Percival, and particularly Mike Kesteven and Kel Wellington for helpful suggestions and discussions.

13.0 REFERENCES

J.G.Ables, B.F.C.Cooper, A.J.Hunt, G.G.Moorey, and J.W.Brooks, 1975, Rev. Sci. Instrum., 46, 284.

C.Audoin, 1982, in 'VLBI Techniques', ed. F.Biraud, CNES Toulouse

M.J.Batty, 1983, Radiophysics Internal Report RPP2737

Baud,B. 1981 Ap.J. 250,L79.

P.J.Diamond, R.P.Norris, P.R.Rowland, R.S.Booth, L-A Nyman, 1984 MNRAS in press

Herman,J.,1983, Ph.D. Thesis., Sterrewacht Leiden

A.G.Lyne, B.Anderson, & M.J.Salter, 1982, MNRAS, 201, 503.

R.P.Norris 1980 MNRAS 193 39P.

R.P.Norris,R.S.Booth,& R.J.Davis,1980 MNRAS 190 163

R.P.Norris & R.S.Booth,1981, MNRAS 195,213

R.P.Norris,R.S.Booth,P.J.Diamond, & N.D.Porter,1982,MNRAS 201 191

R.P.Norris,P.J.Diamond, & R.S.Booth,1982,Nature,299,131

A.E.E.Rogers & J.M.Moran, 1981, CfA preprint #1453

B.Rowson,1963,MNRAS 125 177

TABLE 1: Some approximate parameters of the proposed interferometer

Initial operating wavelength	λ	18cm
Integration time	t	10s
Max baseline	D	275km
EW baseline	D_{ew}	68km
Max delay along baseline	T	1ms
Max rate of change of delay	$\dot{T}$	1.1E-8
Max fringe rate	$=4D_{ew}/\lambda$	19Hz
Max bandwidth	B	500kHz
Delay clock rate	r	1MHz

TABLE 2: Parameters of the microwave link (from KJW)

Max delay	2.2ms
Max drift in delay	0.001ms/hour over 12hours
Short term (60s) delay fluctuations	3ns rms 18ns peak to peak

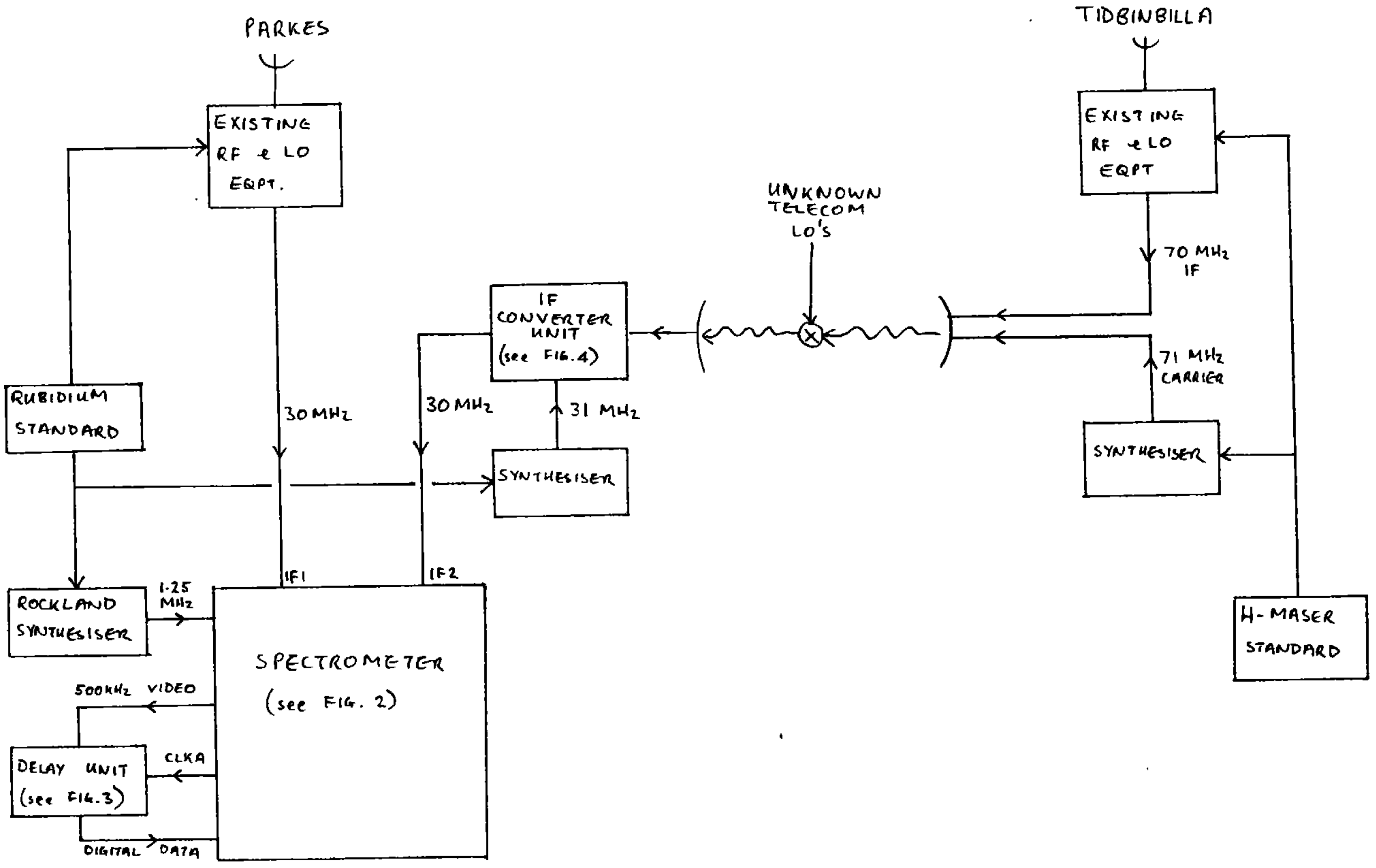

Figure 1: OVERALL BLOCK DIAGRAM

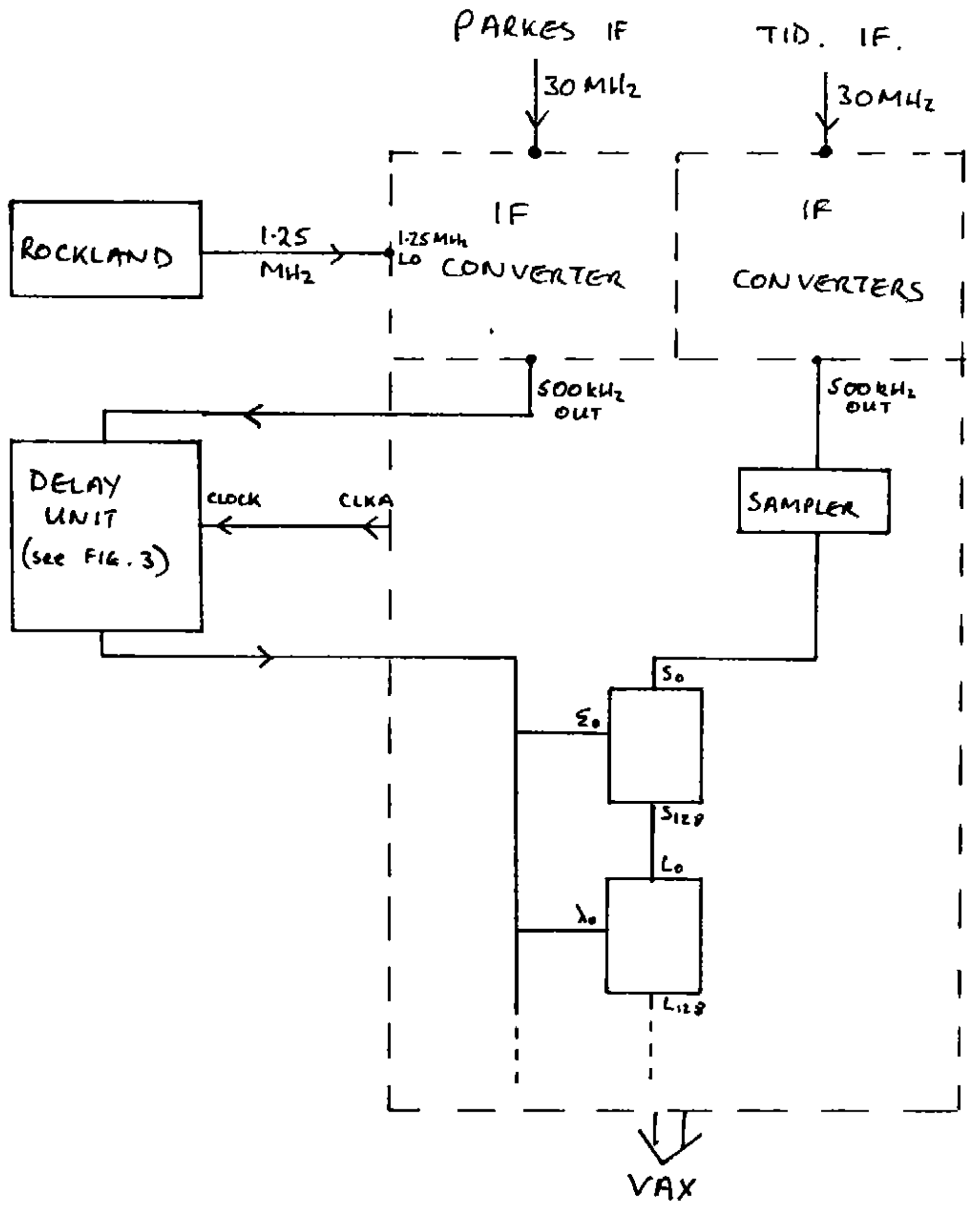

Figure 2: THE CORRELATOR

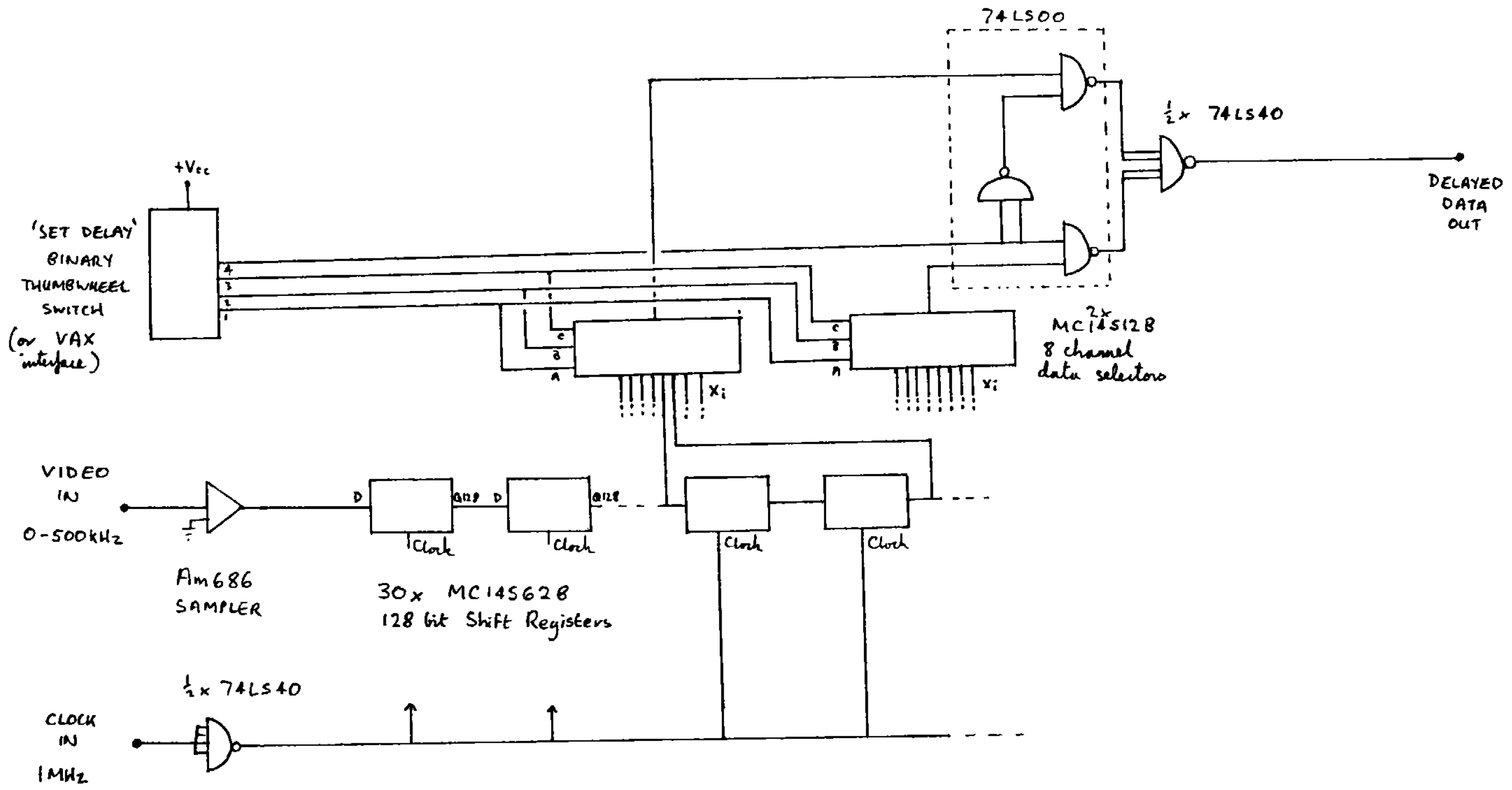

Figure 3: DIGITAL DELAY UNIT

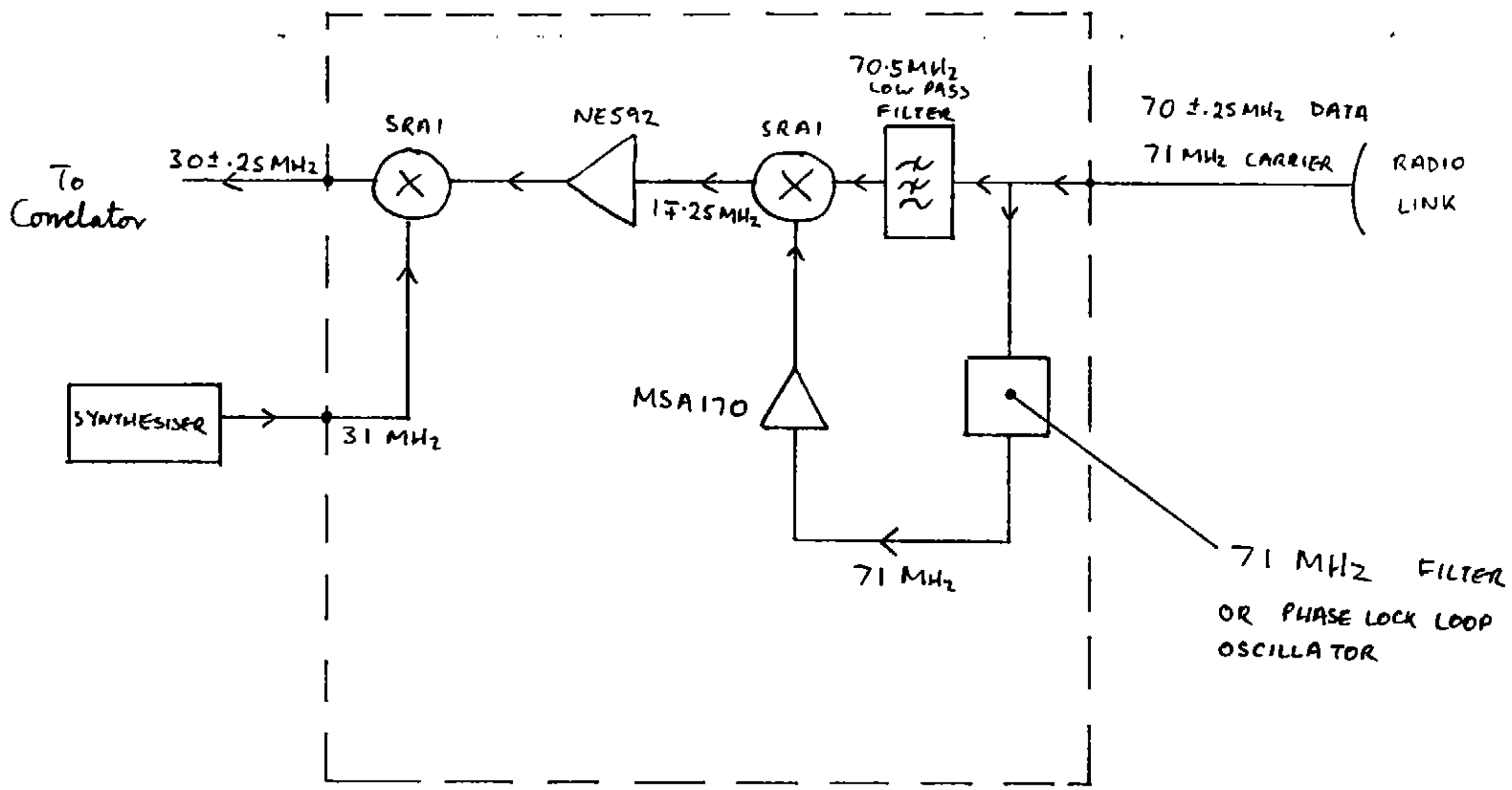

Figure 4: IF CONVERTER UNIT

NB: Frequencies shown are nominal, and may be revised to suit available hardware.

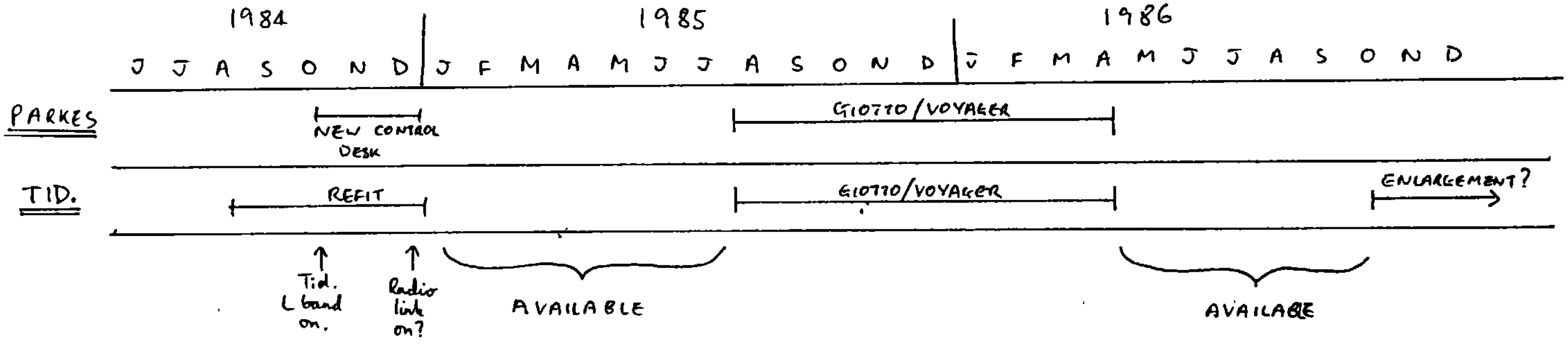

Figure 5: TELESCOPE AVAILABILITY