# Options for the LBA communication links

## A Report of the LBA Working Group

## 12 October 1984

## 1.0 SUMMARY

This document summarises the arguments and conclusions of the meeting of the LBA working group of 20th September 1984. At the end of this report are summarised the options available for the LBA, and two recommendations made by the group.

## 2.0 OVERVIEW OF THE ALTERNATIVES FOR THE LBA DATA LINKS, LO'S, AND MONITORS.

Four separate tasks can be identified:

1. Transfer of data from each remote site to Culgoora, at a bandwidth > 20Mbit/s. Commercial radio links come in two standard speeds: 34 and 140Mbit/s. The 34Mbit/s systems cost about 2/3 of the 140Mbit/s systems, so we might as well concentrate on the 140Mbit/s systems.

2. Transfer of monitor data from remote sites to Culgoora. This requires a bandwidth of << 1Mbit/s, and is unlikely to be a problem.

3. Transfer of control data from Culgoora to remote sites. Again, small bandwidth, unlikely to be a problem.

4. Transfer of LO stability in both directions between remote sites and Culgoora. Although this presents no bandwidth problems, the requirement of reciprocality between the outward and return paths imposes considerable problems. In particular, the transmit and receive frequencies must be identical in order to avoid multipath problems.

To perform these tasks, the following options are available:

1. Terrestrial radio links to every AT antenna (i.e. Culgoora, Siding Spring, and Parkes). Note that this option precludes the use of any non-AT antenna (e.g. Hobart) other than Tidbinbilla, to which we already have some sort of radio link.

2. Terrestrial radio link to Siding Spring, but another system for other AT and non-AT antennas. Note that this option means that

    1. Development work is required for two sytems prior to the start of LBA commisioning.

2. If the 'other system' is tape-recording, then tape recorders have to be bought for Siding Spring whether or not it has a radio link too.

3. VLBI-type tape recorders used for data transfer from all remote stations, and AUSSAT radio link for LO transfer.

4. VLBI-type tape recorders for data transfer, and oscillators (either H-maser or cooled sapphire-loaded cavity) used for LO's.

## 3.0 SUMMARY OF AVAILABLE TELESCOPES OUTSIDE THE LBA

Since much of the discussion of possible systems involves discussion of flexibility to include other telescopes in the LBA, it is worth while to review what those telescopes are.

| Telescope | Diam/m | Fmax/GHz | Available? | LO |
|---|---|---|---|---|
| Parkes | 64 | 22 | 1984 | ? |
| S. Spring | 22 | >50 | 1988 | ? |
| Culgoora | n*22 | >50 | 1988 | ? |
| Hobart | 26 | 10? | 1987? | ? |
| Tidbinbilla | 64/34 | 22 | 1984 | ? |
| Molonglo | 180 equiv. | 0.843+_1.5 | 1984 | Rb |
| New Zealand | 10 | 4 | 1985 | Rb |
| Adelaide | ? | ? | >1988 | ? |
| Carnavon | 15 | 10 | future uncertain | ? |
| Fleurs | 6*45 | 3 | 1984 | Rb |
| Alice Sp. | 10 | 3/10? | ? | Rb? |

Notes

LO's for all stations will need to be AUSSAT links, etc to use the high frequencies, except for those dishes for

which 'Rb' is shown as LO. These dishes will only work at frequencies at which a Rb standard is perfectly adequate.

People at Molonglo are v. interested in participating in LBA work. This could be done by setting up an 843MHz sub-array consisting of Molonglo, Parkes, SS, and one Culgoora antenna.

The NZ dish is being constructed by enthusiastic amateurs who are very keen to participate in the LBA. We would presumably have to lend them a Rb standard and a recorder.

## 4.0 DO WE NEED A RADIO LINK TO SIDING SPRING?

### 4.1 The arguments for a radio link

The arguments for a radio link appear to be:

1. Siding Spring was unmanned and so tape-changing might present logistical problems.

2. A radio link would enable its use as a single dish antenna (e.g. for mm spectral line work). The link could be used to transmit either raw data (thus limiting the available observing bandwidth) or else the digital output of an spectrometer ( reqyiring considerable development).

3. A radio link would provide the potential for expansion of the CA to other radio-linked stations between Culgoora and SS. Development of this link could be initiated within the initial AT capital budget, but funds for this development might not be available in the future.

## 4.2 Arguments against a radio link

In answer to each of the arguments above, we note that:

1. the cost (~$0.5M) of developing a radio link system seems a high price when compared to the cost of arranging with ANU or AAO for one of their engineers to change tapes at SS, or even employing a man full time for this function!

2. The radio link would provide a single-dish facility which

    1. was not in the AT systems definition (AT/01.13/004).

    2. would duplicate a facility already available for some of the time at the Culgoora 6km dish. The $0.5M might be better spent towards another AT dish at a manned site (e.g. Epping) which could be used to extend the AT aswell as providing a single-dish facility.

    3. would probably cost more than installing a correlator at SS.

3. The $0.5M development cost plus the incremental cost of adding radio links to further dishes would probably exceed the incremental cost of providing tape-recorders and AUSSAT links to these stations.

## 4.3 The feasibility of using optical fibres for Siding Spring

Optical fibre links to SS would probably be prohibitively expensive. Their apparent competitiveness with radio links is probably illusory, because the estimates for radio links were for a much higher reliability than we required. On the other hand, the estimates for optical fibres might not have taken into account the difficult terrain between SS and Culgoora, and furthermore the fibres could not be used for LO transfer.

## 4.4 Conclusion

In view of this doubt, the meeting made the recommendation given at the end of these notes.

## 5.0 TAPE RECORDERS FOR THE LBA

The report AT/17.3.1/002 shows that data can be transferred from remote sites to Culgoora for a cost of between $30k (for 20Mbit/s per antenna, VCR system) and $200k (for 100Mbit/s per antenna, MkIII system) per station. These figures include all record and playback facilities, and represent the total cost of transferring data from the telescope IF to the correlator input. However the latter figure ( which was based on US VLBA estimates) appear low compared to the cost of a currently available commercially produced MkIII recorder, which costs about $300k for a standard recorder and associated electronics alone. The difference presumably reflects the difference between commercial manufacturing costs and the cost to NRAO et al. of building electronics in-house. The lower figure might be applicable only if we could ask the VLBA to build recorders for us at the same time as they made theirs (as several observatories did with the MkIII recorders from Haystack), or if we made them ourselves. The range of costs listed in Section 10 below covers both extremes.

Is has now been established that the VLBA have decided to use an upgraded version of the MkIII recorder, but the exact details of the upgrade are unclear. However, the upgrade is expected to cost around $25k on top of the price of a MkIII recorder, although it is not clear whether the upgrade at this cost will meet the full VLBA specifications.

## 6.0 PROBLEMS AND FEASIBILITY OF LO DISTRIBUTION OVER TERRESTRIAL AND AUSSAT RADIO LINKS

Details will shortly be available in a separate AT document.

### 6.1 Terrestrial links

The difficulties of LO transfer over radio links had probably been underestimated previously. However, the planned links <u>are</u> capable of transferring the phase adequately, but with rather more complexity than was originally envisaged.

One possible technique would send one radio channel over the path Culgoora - Siding Spring - Parkes. This signal would be time-switched into 3 sections. For one time section the signal would transfer phase to each outstation. one section would be spent bringing phase back, and one section would be spent bringing data back. This encoding would have the disadvantage that effectively only one third of the bandwidth would be available to each station. It would also need a circulating store to spread out the data again, but on the other hand would be half the cost of using a dedicated link for each telescope.

It should be noted that the existing Parkes - Tidbinbilla radio link would, as it stands, be unlikely to give good phase stability for LO transfer, as outward and return paths use different frequencies and so multipath problems would limit the attainable stability. Monitoring of the Channel 8 microwave link has shown that, even though fading is a problem for only a small fraction (<<1%)of the time, multi-path effects are significant for typically 30% of the time.

## 6.2 AUSSAT links

Astronomical considerations dictate that the rms fluctuations shouild not exceed 2.3ps (this corresponds to roughly 1 degree per GHz, giving 5% decorrelation at 22GHz). A Rb standard can maintain this stability for ~ 1s, so can only be used as a 'fly-wheel' for this sort of period. If 100s integration times are required, then a fractional stability of $10^{-14}$ is required. This may be obtained on AUSSAT links byt separating the two tones by 192MHz, and using a ratio of carrier power to noise density of 48dBHz (less than previously envisaged). Thus each LO signal uses about 1/2000 of an AUSSAT transponder. A scheme may therefore be devised in which 6 telescopes can send all their LO and monitor data over 2 AUSSAT channels, which would cost only ~$20k/year in rent.

## 7.0 THE COST OF AUSSAT LINKS

The scheme outlined above seems acceptable to AUSSAT representatives. A suitable ground station is expected to cost ~ $50k (or up to ~ $100k including the costs of additional equipment) per station. Because we would want specific channels on the satellite (in order to get the required tone spacing), and many channels on AUSSAT 1 were already booked, we would probably have to use AUSSAT 3, due to be launched in 1987. The cost of renting the required channels would be about $20k per year. A small saving could be made by booking the channels only for the duration of an experiment. However, this is unlikey to offer a significant saving, and problems could arise since we would not have the guaranteed availability of the channels we needed. Furthermore, it might be an advantage to have the clocks and frequency stability available at all times at some stations for other purposes. AUSSAT would prefer us to use the wider beam rather than the SE spot (which is already over-subscribed). Development of the satellite link should not prove too difficult. NEC sell a suitable ground station which has an input/output port at 1GHz with a bandwidth of 500MHz.

## 8.0 THE AUSTPAC SYSTEM FOR TEST DATA TRANSFER

AUSTPAC (a telephone packet switching system) might be a suitable way of transferring test data between sites, since this function would be needed only occasionally, and so might not justify the expense of developing an AUSSAT channel specially for it. AUSTPAC supports bandwidths of 2400, 4800, and 9600 baud. For a 2400 baud line between any two points in Australia, there is a $750 installation charge, an annual rental of $2640 (or $5940 for 9600 baud), and then a charge of $0.33 per hour for the line. Thus for a facility for exchanging test data between any 6 stations would be ~ $30k per year, plus development costs. The actual cost might be less, since apparently consideration is being given to installing AUSTPAC lines to several sites (e.g. Epping, Culgoora, Parkes) anyway for other purposes.

## 9.0 COOLED SAPPHIRE-LOADED CAVITIES

David Blair of the University of Western Australia has recently given a colloquium on the development of Cooled Sapphire-loaded cavities. These oscillators seem capable of providing a frequency stability better than that of Hydrogen masers on all time scales, are less sensitive to environmental changes, require less maintenance, and will probably cost ~$50k each, which is around one fifth of the price of a maser. He expected to get a prototype running in about a year's time.

If David Blair's optimism proves justified, then these oscillators would be significantly cheaper than any other way of stabilising the local oscillators, aswell as being easier and giving better performance. Thus any decision on the LO stabilisation must await his construction of a prototype. Although Kel Wellington had been involved in this project, there seems little other support from RP of it. The group therefore made the recommendation given below.

## 10.0 SUMMARY OF OPTIONS

The following options are based on a minimum data rate of 20Mbit/s per telescope, and each is considered by the group to be workable within the limitations shown, and has been selected as being an optimum choice of the many possible combinations of systems.

1. Radio links from Culgoora to Parkes, Siding Spring, and Tidbinbilla, carrying data and LO's.
   Pro: data in real time.
   Con: cannot use other telescopes; probably more development than other schemes.
   Cost: $1050k ± $450k

2. MkIIIa (VLBA compatible) tape recorders for Culgoora, Parkes, and Siding Spring. Tidbinbilla data to be transferred over radio link to Parkes and recorded simultaneously with the Parkes data on the same recorder, thus requiring tape changes at Parkes every 12h instead of every 24h. Note 1 suggests options for equipping other stations with recorders. AUSSAT links used for stabilising all LO's.
   Pro: Flexibility: can add other telescopes including QUASAT and international VLBI stations. Saves embarrassment of leaving Parkes-Tidbinbilla link unused. Expandable to higher bandwidth.
   Con: inelegant
   Cost: $1150k ± $450k ( minus $200k if cooled sapphire oscillators used) (see note 2).

3. VCR tape recorders for Culgoora, Parkes, Siding Spring, and Tidbinbilla Recorders are sufficiently cheap that they can be loaned to, or bought for,

NOTE 1: To include an additional station (e.g. Hobart) in the LBA would cost an additional $350k±$150k, including an additional playback terminal. This figure could be reduced if either cooled sapphire oscillators were used or if an additional playback recorder was not included, so that some other telescope would have to be left out when Hobart was running. Alternatively, it might be possible to have some cheap VCR recorders available, particularly for stations which were only occasinally used. There seems no fundamental reason why such tapes should not be correlated with the instrumentation tapes. although this would require a certain amount of development work.

other telescopes. AUSSAT links used for stabilising all LO's.
Pro: Flexibility and cheapness
Con: Cannot make use of QUASAT or other international VLBI stations, although it may be possible to modify the processor to correlate the VCR and MkIII data together.
Cost: $560k ±$100k ($200k less if cooled sapphire oscillators used).

## 11.0 RECOMMENDATIONS

1. The work on cooled sapphire cavities by the University of Western Australia should be given greater support (e.g. employment of Laurie Mann) by RP with a view to determining (in the next year) the potential use of this for the LBA as an alternative to the AUSSAT LO link.
2. A radio link to Siding Spring seems to have doubtful value, if tape recorders are chosen as the means of LBA data transfer. No sufficient reason has so far been advanced to support the link, and so a detailed cost analysis of possible benefits from this link should be made before any decision to develop it is made.

NOTE 2: The prices for recorders have been estimated as follows: For a pair of recorders (one record, one playback) plus all associated electronics, NRAO estimate ~$100k. On the other hand, the commercial cost of a fully equipped record terminal is currently $300k. To this latter figure must be added the cost of a playback terminal (which is a lot less electronics than a record terminal) - say $100k. Thus the price per station is $250k ± $150k, plus the cost of a satellite link ($100k) to give a total of $350k± $150k per station. In the case of Parkes and Tidbinbilla sharing a link, only one pair of terminals is needed to cope with both telescopes. At Culgoora, no spare recorder is included explicitly, although one of the playback terminals could be used to replace a faulty record terminal (or vice-versa) if necessary. It is hoped that better details of prices will become available in the next few months.