AT/17.3.1/002

The feasibility of using tape recorders for AT LBA data transmission

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for the LBA Working Group

13 August 1984

1.0 INTRODUCTION

1.1 The LBA Working Group

In May 1984 an *ad hoc* working group was established to consider some issues specific to the LBA which are not covered by other groups. One such issue is the part that VLBI-style tape recorders might play in the LBA, and this is the report of the group on this issue.

The membership of the group is as follows:

Jon Ables
Bryan Anderson (*)
Rick Forster
Dave Jauncey
Mike Kesteven
Dick Manchester
Peter McCulloch (*)
Ray Norris (convenor)
Jim Roberts
John O'Sullivan
Alan Young

(* - while at CSIRO RP)

1.2 The scope of this report

This report aims to evaluate the costs of tape recorders, and discusses their pros and cons. It is hoped that the material is presented in such a way that a direct comparison may be made with other systems, without unexpected 'hidden costs'. It does not attempt to evaluate or discuss the rôle of optical fibres, radio links, or the AUSSAT satellite as alternative data transfer media. Instead, it is expected that these will themselves be the subject of individual reports. The present report, therefore, may be considered to be one of several which will supply the information necessary for a debate in which the advantages of the various systems can be discussed and compared.

1.3 The Specification

The specification for which costs have been evaluated in this report has been constructed to allow easy comparison with the costs of radio or fibre links, so that there are no 'hidden extras' which are not discussed.

The minimum specification for a data transfer path is that it must transfer data at a rate of 20Mbit/s from each of the remote telescopes to the correlator at Culgoora, and it must do so in such a way that the phase relationship between the data channels is preserved. We also impose the specification that it must be possible to leave the telescopes unattended for 24h.

The 20Mbit/s figure appears to be a minimum LBA specification (see e.g. AT/01.10/005, Fig 7a-8). This allows a total of 10MHz bandwidth per station, which would generally be arranged as 2 polarisations x 5MHz each. We call this Case 1. In addition, there has been much discussion of wider bandwidths than this, and so we have also evaluated the costs of wider bandwidth systems. The system which we call 'Case 2' transfers data at a rate of 50Mbit/s, giving bandwidths of 2 x 12MHz, whilst 'Case 3' transfers data at 100Mbit/s, giving 2 x 25MHz bandwidth.

1.4 LBA or VLBA?

In the past there has been a distinction made between the AT LBA, which was envisaged as a radio linked array with baselines upto 300km or 600km, and the AT VLBA, which was seen as a future extension of the AT, and which would use VLBI techniques to link in telescopes as far away as Western Australia. In this report, we are investigating the use of VLBI-type tape recorders for the <u>LBA</u> and showing that this is a realistic alternative to radio links. Naturally, such an LBA may easily be extended to the scope of the AT VLBA, and, indeed, this is one of the chief merits of the tape recording sytem. Thus the distinction between the AT LBA and AT VLBA becomes blurred. We have therefore abandoned the distinction in this report, instead referring to the AT array, at any scale >6km, as the LBA. This convention also removes the confusion occasionally created between the AT VLBA and the US VLBA.

1.5 The Alternatives

The AT LBA consists of the array of telescopes at Culgoora, or a subset of these, the 64m dish at Parkes, and a 22m dish to be constructed at Siding Spring. In addition, some use will be made of the 64m and 34m dishes at Tidbinbilla.

This report discusses the transport of data from these sites to the correlator at Culgoora. An additional requirement, although not the principal subject of the present report, is that the local oscillators at each site must be coherent.

The alternative methods of transferring data are:

1. Terrestrial broadband radio links.

2. Satellite broadband radio links.

3. Optical Fibres

4. Tape Recorders

At present, a satellite broadband radio link appears prohibitively expensive if used for a large fraction of the available observing time, and will not be considered further.

1.6 Local Oscillator Stabilisation

The method of ensuring coherent local oscillators is obviously closely related to the adopted data transfer technique. Possible methods are:

1. Terrestrial radio link

2. Satellite radio link

3. Optical Fibre

4. Hydrogen masers or other frequency standards

A terrestrial radio link or optical fibre link for the local oscillators is probably of interest only if the data are transferred along the same medium. Thus, a decision to use tape recorders for the data transmission implies a decision to stabilise the local oscillators by using either AUSSAT (at a guesstimated cost of $100k per station) or Hydrogen masers (at ~$200k per station). It should be noted, however, that stations (e.g. Molonglo) which would be used only at low frequencies (i.e. $\lesssim$3GHz) could be stabilised sufficiently by a cheap (~$15k per station) Rubidium standard.

We do not consider the local oscillator stabilisation any further in this report, since the specialised technical arguments are to be covered in a separate report. In the following sections we confine the discussion to the use of magnetic tape as a data recording medium.

2.0 TAPE RECORDERS FOR THE AT

2.1 Compatibility

There are strong reasons for adopting a tape format compatible with the standard VLBI formats. These are:

1. We can obtain or copy equipment which is known to work under VLBI conditions, and in which most of the bugs have been ironed out.

2. We can adopt data reduction techniques which are known to work for such data.

3. We can participate in international VLBI experiments. In cases when we are one of many participants this might be done by sending our data to be processed at JPL, NRAO, Bonn, etc. In cases where we were the principal investigator we could process other participants' data at Culgoora.

4. We could participate in QUASAT. This will be dealt with in more detail below.

It should be noted that compatibility with a system does not necessarily mean adoption of the system; for example, the US VLBA processor might be able to process standard MkII and MkIII VLBI tapes as well as whichever format is chosen for the US VLBA itself. In practice, the format chosen for the US VLBA is likely to determine the format of VLBI systems (including QUASAT) for some years to come, and so any compatibility argument for the AT probably implies compatibility with the US VLBA.

2.2 Availability

The following types of recorder and format are currently in use or are under consideration for future sytems:

1. IVC and Ampex MkII recorders: now rarely used.

2. Video cassette MkII recorders (VCR): In wide use. Max bandwidth=2MHz. Cheap, reliable, convenient.

3. Honeywell MkIII recorders: In wide use. Being considered for the US VLBA. Max bandwidth at least 112MHz. Rather expensive, and not available to some countries (e.g. USSR).

4. Video cassette (MkIIIa) recorders. Being considered for the US VLBA. Consists of a bank of video cassette recorders (VCR) together with an autochanger mechanism so that the unit needs human intervention only once every 24h. Bandwidth depends on number of recorders, and will probably be 8Mhz per recorder.

5. QUASAT format. Yet to be decided, but will be compatible with the US VLBA. (Or maybe VLBA format will be made to be compatible with QUASAT)

2.3 MkIII Instrumentation Recorders

Current MkIII recorders have 28 tracks on which data can be recorded at rates up to 4Mbps/track, giving a total bandwidth of 56MHz. When used at this rate, each tape is filled in only 20min. Alternatively, for lower bandwidths, the tape can be run more slowly, or tracks can be used sequentially, giving correspondingly longer record times.

Two enhancements of this system are being investigated. First, the longitudinal bit density of the tapes can probably be doubled. Second, the head assemblies can be replaced by movable stacks of narrow heads, giving an increase in lateral bit density by factors of 12, 20, or 36. We can expect with some confidence that these enhancements will by 1988 allow a record time of at least 12h per tape at a bandwidth of 56MHz, or 24h at a bandwidth of 28MHz.

The current status of these enhancements appears to be that Haystack have already developed a prototype which increases the lateral density by a factor of 40, giving a 10h recording at 128Mbit/s on one tape. They hope soon to use a longitudinal density increase together with longer (i.e. thinner) tapes to achieve single-volume 24h recordings at this bandwidth. The cost of these enhancements is not at present known, and so the costs quoted below for this system are correspondingly uncertain.

2.4 Video Cassette Recorders

VCR's have been used successfully for MkII VLBI for some years. In that mode, they operate at a data rate of 4Mbit/s, giving a maximum bandwidth of 2MHz. Each cassette lasts for 4h.

An enhancement of this system being considered for the US VLBA consists of encoding the data on the tape using pulse width modulation. It is expected that the data rate may be increased to 12Mbit/s or 16Mbit/s using this technique, giving maximum bandwidths of 6MHz or 8MHz respectively. 12Mbit/s has already been achieved in a prototype, and it is expected that 16Mbit/s will be achieved by the end of 1984. For wider bandwidths a rack of VCR's would be used. 24h operation may be accomplished by the use of either a cassette autochanger, or, especially for narrower bandwidths, a time-switched rack of VCR's.

A VCR autochanger system (the Data Acquisition Rack, or DAR) is being considered for the US VLBA. Each rack has a microprocessor to control the changing of cassettes, and the cassettes are kept in interchangeable bins of 48 cassettes, so that the daily changeover entails only the unclipping and replacement of a bin of cassettes. The expense and sophistication of this sytem could only be justified for wide bandwidths, and only if this system were adopted for the US VLBA.

3.0 THE IMPLEMENTATION OF A TAPE RECORDER SYSTEM

3.1 Cassette or MkIII recorder?

It will be shown below that a VCR system is considerably cheaper than a MkIII recorder system for bandwidths of 10MHz or so. In addition, the video cassettes are much easier to handle and transport than the cumbersome heavy, and fragile MkIII tapes. However, it is nevertheless possible that a MkIII system might appear more attractive either because we choose to go to larger bandwidths (when the MkIII sytem becomes more competitive) or, more probably, because it would give us greater compatibility with VLBI sytems such as QUASAT or the US VLBA.

The costs of each of these systems will be given below, but for the moment we want to pick on a system to illustrate the discussion of how a system might be implemented. For this purpose, we assume a VCR system will be used, and we assume the Case 1 system (20Mbit/s). If a MkIII recorder, or a wider bandwidth, were to be used instead, few of the arguments below would be changed.

3.2 Recording system

We assume that two 5MHz IF channels (generally corresponding to two polarisations) are available at each telescope. To interface these to the VCR's requires only a down-converter to baseband (which is probably also required for radio-link sytems) and a formatter unit for each channel. The formatter unit samples the IF and encodes it into the frames on the VCR. It also encodes a time for each frame, together with station identification and any other digital data (e.g. bandwidth) that is needed.

Current cassettes run for a maximum of 4h. For 24h operation, therefore, it is necessary either to provide a switched bank of 6 recorders or else a cassette autochanger. The latter is not yet available for 6 cassettes, although Sony market (at \$400) an autochanger for 4 Betamax cassettes, and, if the VLBA uses VCR's, NRAO will develop the DAR, which may be desribed as a sophisticated autochanger for 48 VHS cassettes. However, because of the cheapness (\$500 each?) of domestic VCR's, it may be worthwhile to forego the convenience of an autochanger unless a suitable one becomes available on the domestic market. Equipping each antenna with 12 VCR's will cost only \$3k per station, and removes the potential problems of untried technology.

3.3 Playback System

The tape playback unit, consisting of a bank of VCRs (possibly with autochangers), is essentially identical to the record unit at the telescope. On playback, the signal from the tapes has to be turned into a digital bit stream and fed in to the correlator. This must be done so that bit streams are input to the correlator at the correct time. Thus an interface unit is required, which must perform the following functions:

1. Read the control information on each tape. This control information gives the time, and maybe some station parameters.

2. Position the tape on each recorder at a common start time (accurate to ~1s).

3. Start the tape recorders together, and adjust the head phases to synchronise the frames.

4. Decode the digital signals, and feed them into buffers from which they can be extracted with a variable delay, to allow synchronisation of the signals within each frame.

The interface unit contains relatively straightforward electronics, and it is expected that we would be able to base our design either on that used for the VLBA, or else on one of the existing VLBI processors (NRAO, JPL, MPI, etc.). The cost of the interface appears to be included in the costs upon which Table 1 is based. However, it is recommended that some firm information on the likely cost of this interface is obtained before any firm decision is made.

3.4 Tape handling

Correlation of the LBA tapes is expected to occur at a fixed number of days after recording, in order to simplify the logistics of tape handling. If tapes are sent from remote sites by post (feasible only if VCR's are used) or courier, then some time must be allowed for all tapes to arrive before processing starts. Processing can be expected to be done at the record rate, so that the tapes can be recycled a few days after processing. The US VLBA allows a turn-round time of 60 days, which is probably conservative. The capital costs below include this initial purchase of 60 days worth of tapes, and the running costs include replacement of tapes after 300 passes (VCR's) or 500 passes (MkIII).

4.0 ESTIMATED COSTS

We have evaluated the costs of three alternative systems for three possible bandwidths, and the results are shown in Tables 1 to 3. The figures are based on those given for the US VLBA, and include all the electronics from the telescope IF signals to the correlator input. The costs thus assume that all tapes are played back simultaneously, and therefore include one record terminal and one playback terminal for each station. However an alternative, and cheaper, configuration might have fewer playback terminals than record terminals. This would be attractive if only a minority of the observations were made with all the available telescopes.

For the narrow bandwidth case, the VCR system is clearly very much cheaper, but for the wider bandwidth the differential is reduced slightly. The running costs shown are for tape replacement and shipping. Maintenance is expected to cost a similar amount on any of the systems, and is probably around $5k per year per station (based on VLBA figures), plus additional manpower for tape handling (probably one extra man at Culgoora). It is likely that a choice between the systems is at least partially dependant on the decision of the US VLBA on their format.

5.0 POSSIBLE EXTENSIONS TO THE LBA

5.1 The basic configuration

The LBA configuration for which a minimum specification must cater consists of Culgoora, Siding Spring, Parkes, and Tidbinbilla. In addition, there exist a number of telescopes in and around Australia which might be used with the LBA occasionally, with a consequent increase in resolution and uv coverage. Construction of a terrestrial radio or fibre link to such telescopes is obviously impractical, and so inclusion of these telescopes would require VLBI-type techniques to be used <u>at all telescopes, including those for which radio or fibre links were also available</u>. We now list some of the telescopes which could be used with the LBA.

5.2 Hobart

There is a strong possibility that the University of Tasmania will have a 25m dish operational by 1988, and will be interested in participating in LBA operations. The value of this dish to the LBA should not be underestimated. Simulations (which have been described in AT/20.1.1/003, and an example of which is reproduced in Figure 1) show that the addition of this dish not only increases the resolution (by a factor of ~2.5), but also improves the quality of the maps, because of the increased uv coverage.

5.3 Molonglo

The Molonglo telescope (equivalent to a 180m dish!) could be used with AT telescopes (e.g. Parkes, Siding Spring, Culgoora 6km) at 843MHz, to provide a powerful low frequency (but narrow bandwidth) array.

5.4 Carnarvon

There is a possibility of using the ESA 15m dish which may be moved to Carnarvon from Perth. At present this dish is equipped for S and X bands, but it may be equipped for the standard VLBI frequencies and techniques if and when QUASAT (a joint ESA/NASA project - see below) is launched.

5.5 Other telescopes

In the longer term, there are possibilities of telescopes in Adelaide and New Zealand. An additional option would be to construct a mobile VLBI radio telescope mounted on a road or rail truck, similar to the ORION project in the US , but using a relatively rugged satellite link for local oscillators instead of the delicate hydrogen masers used in ORION.

5.6 The feasibility of extending the LBA

Use of any of the telescopes listed above would require VLBI techniques. If radio or fibre links were adopted for the basic configuration now, then an extension of the LBA to include any of the telescopes above could be done only at the expense of re-equipping all the telescopes. It probably follows that such an extension to the LBA is feasible only by adopting tape recorders (or, more expensively, a broadband satellite link) at the outset.

If the tape recorder option is chosen, then to add a telescope to the LBA requires only the purchase of a relatively inexpensive tape-recording terminal, together with local oscillator stabilisation equipment. The latter equipment may consist of a satellite terminal (again, relatively inexpensive) or, for S-band and below, an off-the-shelf Rubidium standard.

An additional facility possible with the tape-recorder option would be to keep a mobile VLBI terminal available for transporting to non-CSIRO telescopes. In the case of a low frequency New Zealand telescope (outside the AUSSAT beam) a Rubidium standard would provide sufficient local oscillator stabilisation.

5.7 Participation in International VLBI Experiments

As well as using Australian telescopes, even greater resolution could be obtained by collaborative experiments with telescopes in South Africa, Japan, and the US (including Hawaii). This would require our tape format to be compatible with one of the standard VLBI formats. Even greater opportunity would be provided by the QUASAT satellite, which will be discussed in more detail below.

6.0 QUASAT

QUASAT is a project under joint consideration by ESA and NASA to launch a satellite-borne VLBI telescope. This satellite would be used in conjunction with the Earth-based VLBI arrays (USVN, US VLBA, EVN, and AT LBA if we decide to participate) and, by having an elliptical orbit upto ~ 5 Earth radii, would extend the maximum baseline of current VLBI arrays by a factor of ~3.

We are fortunate in that half the sky is effectively inaccessible to Northern VLBI arrays, and so our participation in QUASAT experiments would be essential if QUASAT is to be fully utilised. To participate effectively, we would need to ensure that:

1. Our tape medium and format are compatible with QUASAT, which in practice probably means compatible with the US VLBA.

2. The uv coverage of our LBA must be extended (to Carnarvon, for example) so that there is not too great a gap in uv coverage between the QUASAT baselines and the terrestrial LBA baselines.

7.0 SUMMARY OF THE ARGUMENTS

7.1 Pro

1. The tape recording option is cheap: probably about \$30k per station for a 10MHz bandwidth, or \$50k-\$100k for a 25MHz bandwidth (depending on recording system used). (+~100k per station for the satellite LO link).

2. The running costs are also low: typically \$2k-\$8k per year per station (+ maintenance)

3. It gives us flexibility to upgrade the LBA to wider bandwidths or other stations with relatively small incremental costs.

4. It allows us to collaborate with additional telescopes such as Hobart: without tape-recording there seems no realistic way of doing this.

5. It allows us to participate in international VLBI experiments at no extra cost.

6. It would allow future participation in the QUASAT project.

7.2 Con

1. The data will not be analysed for some days after it has been taken: therefore an equipment malfunction might cause the loss of several days data before the fault is detected. Note, however, that narrow-band monitoring may alleviate this problem.

2. Handling and shipping of tapes will consume additional manpower, probably requiring one extra man at Culgoora, and may pose organisational problems.

3. Telescopes will need to be visited every 24h to replace tapes. The only telescope for which this is a problem is Siding Spring. Fortunately, on Siding Spring mountain there exists a community of engineers who are experienced in the maintenance and running of telescopes. Perhaps we could come

to some arrangement with the ANU, AAO, or UK Schmidt for one of their engineers to visit our telescope daily.

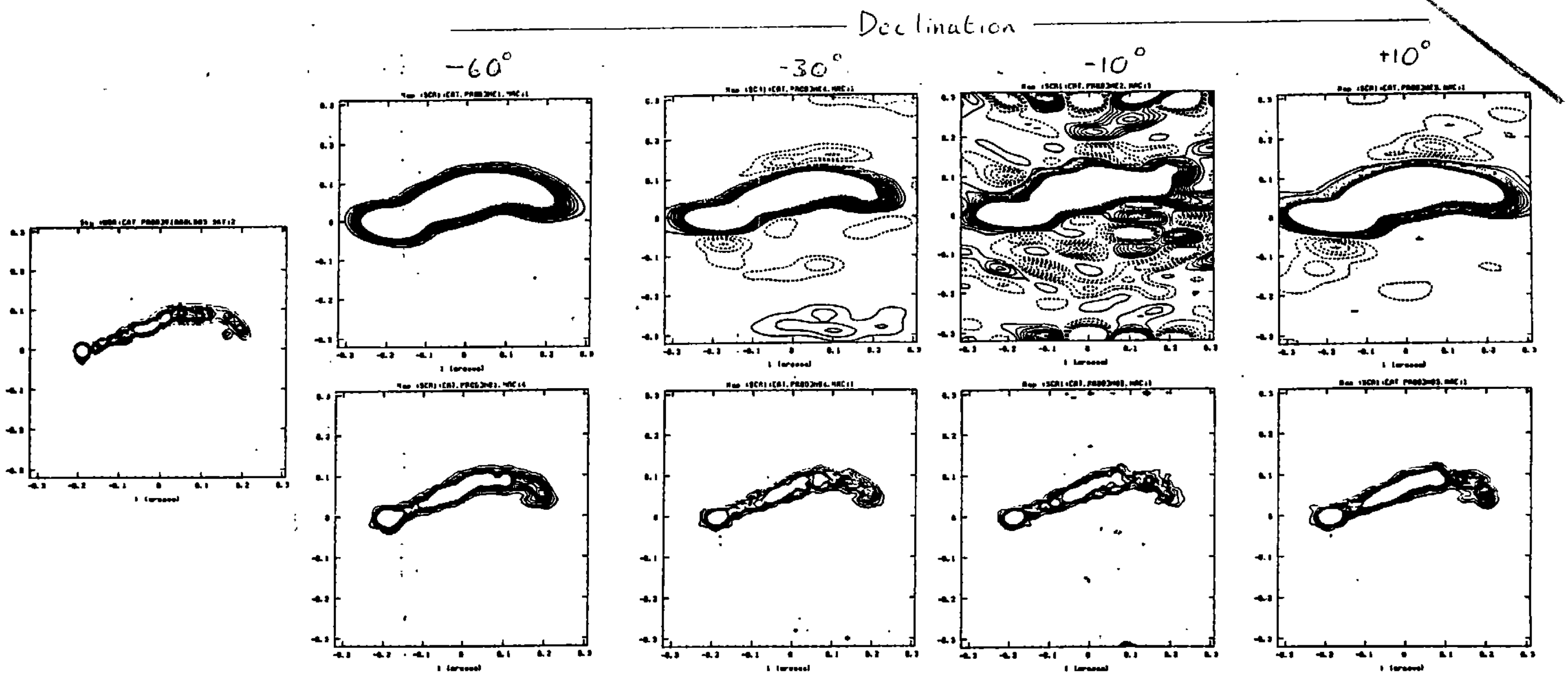

Figure 1. Simulated observations of the test source VIRGO (suitably scaled). The top row shows maps made with the Cul-SS-Pks-Tid array and the bottom row shows maps made with the Cul-SS-Pks-Tid-Hobart array. The extreme LH map shows the model sky used for the simulations. In each case not only has the resolution improved, but the map quality has also improved because of the greater uv coverage. Contours are drawn at 1% intervals.

Table 1. Costs per antenna for recording and playback facilities
Case 1: 20Mbit/s per antenna

System	Item	Capital Cost	Running Cost per year
10 Mbps VCR's with integral auto cassette changers *	5.5 (2 + 1 spare for recording, 2 + 0.5 spare for playback) VCR's equipped with auto cassette changers & auxiliary electronics for 10Mbps @ $4k each	22k	
	60 day supply of cassettes	5k	
	60 day supply of cassette carrying boxes	2k	
		29k	2k
10Mbps VCR system with 100% redundancy (using NRAO DAR's)	9.5 (4 + 1 spare for recording, 4 +0.5 spare for playback) VCR's and auxiliary electronics @ 3.25k each	31k	
	2 NRAO VLBA data acquisition racks (DAR's) with electronics and spares (Table VII-5)	50k	
	60 day supply of cassettes	10k	
	60 day supply of cassette bins	4k	
		95k	4k
Moving head (x20) MkIII Instrumentation Recorders	2.2 (1 record, 1 playback, 0.2 spare) recorders	77k	
	60 day supply of tape	15k	
	60 day supply of shipping containers	2k	
		94k	3k

*..Assumes 6-cassette auto changers available on domestic market at $750 ea.

Table 2. Costs per antenna for recording and playback facilities
Case 2: 50Mbit/s per antenna

System	Item	Capital Cost	Running cost per year
4x12 Mbps VCR's with integral auto cassette changers *	9.5 (4 + 1 spare for recording, 4 + 0.5 spare for playback) VCR's equipped with auto cassette changers & auxiliary electronics for 12Mbps â $4k each	38k	
	60 day supply of cassettes	10k	
	60 day supply of cassette carrying boxes	4k	
		52k	4k
4x12 Mbps VCR system (using NRAO DAR's)	9.5 (4 + 1 spare for recording, 4 +0.5 spare for playback) VCR's and auxiliary electronics â 3.25k each	31k	
	2 NRAO VLBA data acquisition racks (DAR's) with electronics and spares (Table VII-5)	50k	
	60 day supply of cassettes	10k	
	60 day supply of cassette bins	4k	
		95k	4k
Moving head (x40) MkIII Instrumentation Recorders	2.2 (1 record, 1 playback, 0.2 spare) recorders	77k	
	60 day supply of tape	15k	
	60 day supply of shipping containers	2k	
		94k	3k

*..Assumes 6-cassette auto changers available on domestic market at $750 ea.

Table 3. Costs per antenna for recording and playback facilities
Case 3: 100Mbit/s per antenna

		Capital Cost	Running cost per year
8x12 Mbps VCR's with integral auto cassette changers *	17.5 (8 + 1 spare for recording, 8 + 0.5 spare for playback) VCR's equipped with auto cassette changers & auxiliary electronics for 12Mbps @ $4k each	76k	
	60 day supply of cassettes	20k	
	60 day supply of cassette carrying boxes	8k	
		---- 104k	8k
8x12 Mbps VCR system (using NRAO DAR's)	17.5 (8 + 1 spare for recording, 8 +0.5 spare for playback) VCR's and auxiliary electronics @ 3.25k each	57k	
	2 NRAO VLBA data acquisition racks (DAR's) with electronics and spares (Table VII-5)	50k	
	60 day supply of cassettes	20k	
	60 day supply of cassette bins	8k	
		---- 135k	8k
Moving head (x40) MkIII Instrumentation Recorders	4.2 (2 record, 2 playback, 0.2 spare) recorders	147k	
	60 day supply of tape	30k	
	60 day supply of shipping containers	4k	
		---- 181k	5k

*..Assumes 6-cassette auto changers available on domestic market at $750 ea.