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AUSTRALIA TELESCOPE NATIONAL FACILITY
CSIRO - Paul Wild Observatory

AT/31.6.1/001(a)
AT/01.17/025 (on disk)
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Australia Telescope - Observational Status Report

The following description is intended to provide potential users with sufficient information to prepare an observing proposal for the Australia Telescope. At this stage the AT is being commissioned, and many of its features have not yet been tried. As experience is gained refinements will be made to the (mostly theoretical) specifications given in the Tables, and actual performance figures will be included in later issues of the status report.

1. GENERAL

The AT is composed of two parts - the compact array (CA) and the long baseline array (LBA). The CA is a six-element, connected 6 km east-west grating array located at Culgoora, NSW. The LBA includes the six 22m CA antennas at Culgoora, another 22m antenna located at Mopra on Siding Spring Mt., and the 64m antenna at Parkes. The length of the LBA is ~320 km, oriented mainly north-south, and LO reference signals are transmitted to LBA stations via the AUSSAT satellite. The LBA and CA may be operated simultaneously.

The LBA is a VLBI network and can include additional antennas when available. Table 1 lists some parameters of the AT antennas, along with the 70m NASA dish at Tidbinbilla, A.C.T., and the University of Tasmania's 26m dish at Hobart. The minimum wavelength at which each element can operate, and the estimated sensitivity at 13cm (expressed as a system temperature in Jy) is included. Tape recording systems for the LBA have not yet been purchased; it is expected that four 64 MHz VLBA record & playback systems will be acquired in 1991.

The CA is currently being outfitted and tested, and proposals are being solicited for commissioning observations with a three-element, single-polarization, 128 MHz (32 channel) or 64 MHz (64 channel) system at 6 and 3cm (AT/31.4/002). A five-element, dual-polarization, 3 km array is expected to be available toward the end of this year. 20 and 13cm receivers will be installed on successive antennas beginning late this year, as will some narrow bandwidths. Routine operation of the full 6 km array at 6, 3, 13 and 20cm is expected by the end of 1990. The observing parameters for the (completed) compact array are given in Table 6.

2. RECEIVERS

All AT antennas will be equipped for observation in four bands centred near 20, 13, 6 and 3cm during the initial construction period. These receivers utilize cooled (15K) FET amplifiers providing receiver temperatures in the range 18K (at 20cm) to 35K (3cm). Additional (room temperature) receivers to cover the low-frequency bands at 90 and 50cm, and cooled receivers for higher frequency bands at 12, 7 and 3mm are planned for future development. The low-noise FET amplifiers operate over a wide instantaneous bandwidth in order to include as many spectral lines as possible, and to provide for bandwidth synthesis. The designated frequency ranges and percentage bandwidths for the current and planned AT bands are listed in Table 2.

The AT receivers on the new 22m antennas (Culgoora & Mopra) are packaged in pairs (30/13cm and 6/3cm) and mounted on a rotating turret at the secondary focus. Each pair shares a single feed, allowing for simultaneous dual-band operation, and all receivers are operational continuously. Changing from one dual-band package to another requires a rotation of the turret (~30 sec). Each package provides four IF outputs, normally corresponding to two polarizations in two bands. Currently, only single-band operation is available; simultaneous observation in two bands will be possible when the second LO system is installed (probably mid-1990). The IF signals are digitized at the antenna and sent to the control building on optical fibres.

On the Parkes antenna, the four initial AT bands are contained in a single receiver package mounted at prime focus. Currently only single-band feeds and two IF outputs are provided for each band. Band changes require a manual feed change (~1 hour). An upgrade to dual-band feeds and four IFs is planned for future development.

3. POLARIZATION

Two orthogonal *linear* polarizations are simultaneously received in each AT band. The position angle of the polarization splitter is stationary with respect to the antenna (alt-az mounts), so the position angle rotates on the sky. Measurement of both polarizations is therefore necessary to accurately map sources with appreciable linear polarization, or when circular polarization is required. Continuous calibration of the relative phase and gain of the two polarization channels is provided. This provision, along with on-axis feeds, should allow measurement of source polarization to high accuracy. The practical limits on polarization accuracy have not yet been determined, but preliminary results indicate that the instrumental polarization is quite low (~1%). Automatic conversion from the measured polarization products to Stokes parameters is provided.

4. BANDWIDTHS

Bandwidths of 128 and 64 MHz are currently available on the AT receivers with 2-bit sampling. Bandwidths of 32, 16, 8, 4, 2, 1 and 0.5 MHz for spectral-line observations will be provided in mid-1990. A maximum bandwidth of 256 MHz (1-bit sampling) will be provided at a later date. The continuum sensitivity of the 256 and 128 MHz bandwidths is the same; the wider bandwidth is intended for high-frequency spectral-line work and bandwidth synthesis.

The minimum IF bandwidth sent from the antennas is 64 MHz (4-bit sampling); narrower bandwidths are obtained by filtering this signal in the backend. Correlation of the full 64 MHz bandwidth is provided by the 64 MHz continuum correlator (CC), which operates simultaneously with the spectral-line correlator (LC).

5. CORRELATORS

Three separate digital correlators are planned for the AT; the compact array line (LC) and continuum (CC) correlators, and the long baseline array correlator (LBAC). All are based on the same design, differing mainly in configuration, flexibility and interfacing. The number of spectral channels produced depends on the bandwidth and bit mode, and on the number of IF pairs (polarization products) correlated. The LC and LBAC have the same capacity regarding the number of channels per correlation product, although multiple passes through the LBAC may be required if the number of stations involved is large. There is no equivalent of the CC planned for the LBA.

The basic unit of the AT correlators is the *module*. The number of frequency channels produced by a module is shown in Table 3 as a function of bandwidth. The corresponding velocity range covered and the channel separation in km/s is also given for the initial AT bands. Note that these velocities vary by the percentages listed in Table 2 over the tuneable frequency range. For bandwidths ≤128 MHz the number of channels can be doubled by using 1-bit mode. Modules can be strung together to increase the number of channels. A total of 8 modules (one *block*) per baseline are available in the LC (15 baselines) and the LBAC (6 baselines) and 2 modules/baseline for the CC. These modules can be distributed over the desired correlation products with varying flexibility for the different correlators.

Autocorrelations can be obtained provided all available modules are not being used for cross-correlation products. The architecture of the AT correlators is baseline rather than antenna oriented, so in most cases these modules must be drawn from different *blocks*. Dedicated autocorrelation modules are not provided in any of the AT correlators.

The CC has fixed bandwidth and limited configuration capability (four modes). The 64 MHz bandwidth correlated in the CC contains any spectral lines observed; the line signal may contaminate the continuum map unless some channels are removed before mapping (see AT/01.17/010). The available observing modes, number of frequency channels, and the naturally weighted frequency response of the CC are listed in Table 4.

The LC is scheduled for completion in late 1989, operating at bandwidths of 128 or 64 MHz and capable of handling 15 baselines simultaneously with 8 modules per baseline. The CC will be available along with the narrowband backend sometime in 1990. The complete LBAC is expected along with the LBA tape recording systems (hopefully in 1991).

6. SENSITIVITY

A general expression for the rms sensitivity of a single interferometer IF pair with identical antenna elements (eg. CA) is:

$$\Delta S \approx 300\ T_{sys}/(\eta_c \eta_a D^2 \sqrt{TB}) \qquad \text{mJy}$$

where:				
	Tsys	=	System temperature	(K)
	η_c	=	Correlator efficiency	(0.9 for 2-bit)
	η_a	=	Aperture efficiency	(~0.6 for AT)
	D	=	Antenna diameter	(metres)
	T	=	Integration time	(minutes)
	B	=	Bandwidth	(MHz)

For I interferometers [I = N(N+1)/2 for N antenna elements] and 2 IF pairs combined (eg. Stokes I) the rms sensitivity is improved by $\sqrt{2I}$.

The rms sensitivity in units of *brightness temperature* is given by:

$$\Delta T \approx 1.46\ (\lambda/\theta)^2\ \Delta S \qquad \text{K}$$

where:				
	λ	=	Observing wavelength	(cm)
	θ	=	Synthesized beam size	(arcsec)
	ΔS	=	rms flux sensitivity	(mJy/beam)

If the synthesized beam is non-circular, θ^2 should be replaced by $\theta_\alpha \theta_\delta$.

For an interferometer with non-identical elements (eg. LBA) the rms sensitivity per IF pair is:

$$\Delta S \approx (0.09/\eta_c)\ (S^A{}_{sys}\ S^B{}_{sys})^{1/2}\ (TB)^{-1/2} \qquad \text{mJy}$$

where: $S_{sys} = 3.5\ 10^3\ T_{sys}/(\eta_a D^2)$ (Jy)

S_{sys} is the system temperature in Jy and the other parameters are as defined above. The sensitivity at 13cm λ after a 1 minute integration with 64 MHz bandwidth (2-bit) is listed in Table 5 for selected LBA (and extended LBA) baselines. The Table also includes the approximate baseline length and minimum fringe spacing. The antennas involved in each interferometer (abbreviated to one letter in Table 5) and their S_{sys} are listed in Table 1.

7. COMPACT ARRAY OBSERVING PARAMETERS

The basic instrumental parameters of the CA are listed in Table 6 for the initial AT observing bands. The parameters include the CA primary beam size (~1.07 λ/22m rad), the largest two-dimensional structure visible without appreciable attenuation (~0.5 λ/30m), the synthesized beam size (~0.9 λ/6km in RA; larger by 1/sin δ in DEC), the system temperature, and the sensitivity calculated for a naturally weighted map assuming a 10-hour integration (12-hour observation with 10 min. calibration per hour), DEC = -45°, 128 MHz bandwidth (2-bit), 15 interferometers and two IFs combined. The wavelength-dependent quantities vary over the bands by the percentages listed in Table 2.

8. COMPACT ARRAY CONFIGURATIONS

The CA provides minimum-redundancy pseudo-regular uv coverage in increments of four 12-hour observing periods for sub-arrays of length 1.5, 3 and 6 km. Five of the six 22m CA antennas may be located at any of 35 stations on a continuous 3 km section of rail track. It is expected that the array will be reconfigured every three or four weeks. The sixth antenna is located a further 3 km towards the west, and takes part only in observations utilizing the 6 km array. The "6-km" antenna may be used independently for LBA observations.

The shortest spacing available is 30 m, and the minimum grating increment is 15 m. Complete uv coverage from 30 m to 3 km in 15 m increments requires 25 reconfigurations; reasonably uniform coverage in larger increments is possible in 4 days. A small degree of redundancy is provided for observations requiring exceptionally high dynamic range.

9. WIDE FIELD MAPPING

The 15 m minimum grating increment provides a maximum non-aliased field of view of radius 0.73 λ/22m rad, ie. ~1.4 times the FWHM of the 22m antenna's primary beam. Accurate mapping of larger fields requires observing at multiple field centres (mosaicing). Measurement of visibility data on spatial scales less than 30 m (the minimum antenna separation) is provided by mosaicing, or by single-dish mapping with the Parkes 64 m telescope.

The effects of time and bandwidth smearing can be expressed in terms of the reduction in peak intensity suffered by a point source located at a radius r (primary beams) from the field centre:

$$\text{Time smearing} \approx (rDt/570)^2$$
$$\text{Bandwidth smearing} \approx 415\ (rD\ \Delta f/f)^2$$

where:	r	=	Distance from field centre	(λ/22m)
	D	=	Maximum baseline length	(km)
	t	=	Integration time	(sec)
	Δf	=	Bandwidth of map	(MHz)
	f	=	Observing frequency	(MHz)

For r = 0.73 (first grating response), D = 6 km and t = 20 sec, time smearing reduces the point source response by ~2.5%. Therefore an integration time of 20 sec is acceptable for most CA observations. The intensity reduction caused by bandwidth smearing is equal to that caused by time smearing for

$$\Delta f\ (\text{MHz}) \approx f\ (\text{GHz})\ t/12.$$

Thus for t = 20 sec, Δf (MHz) $\approx$ 1.7 f(GHz). Using this criterion, the maximum integrated bandwidth which may be mapped without appreciable distortion is listed in Table 7 for the four initial AT bands. The channel separation provided by a single LC correlator module at the full (128 MHz) continuum bandwidth is 8 MHz; therefore concatenation of modules is required for distortion-free mapping over a wide field at the lower frequencies. Similar restrictions occur for wide-field mapping of CC data.

10. BANDWIDTH SYNTHESIS

The smearing caused by a large integrated bandwidth is due to assignment of a single uv coordinate for each visibility record when a range of values is actually measured. By utilizing the frequency separation provided by the AT correlators, correct assignment of uv coordinates is possible over a large bandwidth. Combination of the (correctly gridded) frequency channels in a map amounts to bandwidth synthesis, where the wavelength is varied to provide more complete uv coverage.

In addition to the instantaneous wavelength coverage provided by the bandwidth, the full tuneable frequency range of the observing band is available for bandwidth synthesis. Rapid frequency switching (0.2 Hz) within an observing band will be supported for this purpose (and also to allow near-simultaneous observation of several molecular lines). Substantial reductions in telescope time are possible by using bandwidth synthesis for dynamic-range limited fields, and observers are encouraged to use it (see AT/20.1.1/034). Mapping and reconstruction algorithms which can correctly handle fields with varying spectral-index are under development. Complete frequency cycling within the timescale of significant changes in visibility is required in order to avoid aliasing.

11. ANTENNA POINTING

The specified pointing accuracy of the 22m AT antennas is ~10 arcsec rms for wind speeds up to 30 km/hour. Little is known about the pointing behaviour of the AT antennas in windy conditions. The best pointing solution obtained so far gave a formal rms pointing error of ~5" under low-wind conditions. However, systematic pointing variations of order 1 arcmin caused by ambient temperature changes have been observed. Preliminary results indicate that most of this error can be eliminated using tilt-meters.

12. COMPUTING

Control of the compact array is directed by CAOBS running on a VAX 8250 at Culgoora. Observers may prepare observing files for CAOBS interactively either at Culgoora or Epping with SCHED. On-line monitoring of visibility data is currently provided by CACOR; this allows inspection of the instantaneous correlation function or its transform, and also plots time-series of various quantities. Off-line analysis of visibility data is currently provided by PTI-LOOK. Calibration, mapping and general analysis will be done within the AIPS environment, with some extra routines provided for AT-specific tasks.

Visibility data generated by the CA is calibrated on-line as far as possible and stored in a modified FITS data cube format. A VAX 8250 is available at Culgoora for preliminary mapping and analysis. The Culgoora system includes two 6250-bpi magnetic tape units, two imaging work-stations and ~1.5 GBytes of shared disc. The main AT data processing system is located at Epping. It includes a Convex C-220 mini-supercomputer comprising two processors, 128 Mbytes of memory, ~8 Gbytes of disc and two tri-density magnetic tape drives. In addition, two Sun 3/60 workstations are available for image processing of AT data. Additional workstations and a colour printer will be acquired later in 1989.

13. OBSERVING REQUESTS

Requests for commissioning observations with the partially-completed compact array (AT/31.4/002) should be sent to:

The Director
Australia Telescope National Facility
CSIRO Radiophysics Laboratory
PO Box 76
Epping, NSW 2121

14. DOCUMENTATION

The following is a list of some internal AT documents for further information. These may be obtained by writing to the AT Secretary at the address above.

General				
01.17	021	AT in Summary	RNM/JRF:	07 Jun 88
01.13.1	010	Systems Definition (version 10)	GJN:	21 May 88
		5th Annual Report of the AT Project		12 Dec 88
LBA				
17.3.1	015	The AT Long Baseline Array - status report	RPN:	17 Feb 88
17.3.1	008	The LBA Workshop		29 May 86
Compact Array				
01.17	020	AT Compact Array Specs for 1989	JRF:	29 Apr 88
20.1.1	030	Integration & Cycle Times in the AT	GJN:	24 Sep 86
20.1.1	013	Millisecond Integration Times on the CA	GJN:	11 Jul 85
20.1.1	034	Bandwidth Synthesis and Mosaicing	RNM,MJK:	30 Oct 86
20.1.1	014	Bandwidth Synthesis on the CA	RNM:	1 Oct 85
10.1	038	Better Redundant Configurations for the CA	DMcL:	15 Jul 85
10.1	036	A Configuration for the AT Compact Arrray	RNM:	29 Feb 84
20.1	005	Wide-Field Mapping Effects	JRF:	9 Nov 83
Spectral line				
01.17	025	The AT Compact Array Spectral Line System	JRF:	3 Jan 89
01.17	010	Simultaneous Line & Continuum Observations	JRF:	22 Feb 87
01.17	009	HI Observations with the Compact Array	JRF:	19 Dec 86
20.1.1	018	Molecular Lines and AT Frequency Bands	JRF:	25 Feb 86
Correlators				
24.1.1	010	The AT Correlator Block	DL:	27 Oct 86
24.1.1	008	The AT Correlator Chip	WEW/DB:	3 Oct 85
10.4	003	Workshop on AT Correlator Systems		21 Nov 83
Computing				
25.1.1	050	AT Data Transfer	RPN:	7 Jan 88
25.1.1	047	Data Processing for the AT	RPN:	11 Sep 87
10.5	002	Workshop on AT Computer Systems		28 Jul 83

Table 1
AT and additional LBA antennas

Telescope	Diameter (m)	Baseline (km)	λmin (mm)	13cm Ssys (Jy)
Culgoora (tied)	54	6	3	60
Mopra	22	115	3	350
Parkes	64	320	7	85
Tidbinbilla	70	565	12	25
Hobart	26	1420	30	1260

Table 2
AT Frequency Bands

Band name	20cm	13cm	6cm	3cm
Freq. range (GHz)	1.25 - 1.78	2.20 - 2.50	4.40 - 6.10	8.00 - 9.20
% Bandwidth	35	13	32	14
Band name	12mm	7mm	3.5mm	2.6mm
Freq. range (GHz)	20.0 - 25.5	42.0 - 50.0	84.0 - 98.5	105.0 - 116.0
% Bandwidth	24	17	16	10

Table 3
AT Correlator Module & Bandwidths

B'width (MHz)	256	128	64	32	16	8	4	2	1	0.5
Bit mode	1	2	2	2	2	2	2	2	2	2
Channels/mod.	16	16	32	64	128	256	512	1024	1024	1024
Band	Velocity range (km/s)									
20 cm				6400	3200	1600	800	400	200	100
13 cm			8170	4085	2040	1020	510	255	130	65
6 cm		7315	3660	1830	915	460	230	115	55	30
3 cm	8930	4465	2230	1115	560	280	140	70	35	17
	Velocity increment (km/s)									
20 cm				100	25	6.3	1.6	0.4	0.20	0.10
13 cm			255	64	16	4.0	1.0	0.3	0.13	0.06
6 cm		455	115	29	7	1.8	0.5	0.1	0.06	0.03
3 cm	560	280	70	17	4	1.1	0.3	0.1	0.03	0.02

Table 4
64 MHz Continuum Correlator

Mode	Number of products	Number of channels	Channel spacing (MHz)	FWHM (MHz)	1st sidelobe level (%)
1	1	48	1.3	2.2	-8.3
2	2	32	2.0	3.5	+4.8
3	4	24	2.6	4.5	-8.3
4	8	16	4.0	7.2	+4.8

Table 5
Selected LBA Interferometers at 13cm

Interferometer	C-M	M-P	P-T	C-P	C-T	P-H	C-H
Length (km)	115	205	275	320	565	1095	1420
Fringe size (mas)	225	125	95	70	40	25	20
Sensitivity[1] (mJy)	1.8	2.2	0.6	0.9	0.5	4.1	3.4

(1) 1 minute integration; 64 MHz, 2-bit, 1 IF pair.

Table 6
Observing Parameters for the Compact Array

Band Name (λ in cm)	20	13	6	3
Primary Beam (arcmin)	33	22	10	5
Largest Structure (arcmin)	11	7	3	2
Synthesized Beam (arcsec)	6	4	2	1
System Temperature (K)	27	32	45	65
Aperture Efficiency (%)	65	55	65	60
Flux Sensitivity[1] (μJy/beam)	20	25	30	50
Brightness Sensitivity[2] (mK)	215	325	310	575

(1) 10 hour, 128 MHz, 2-bit, 2 IFs combined. (2) Full 6 km array, -45° Dec.

Table 7
Bandwidth Smearing

Band Name	20cm	13cm	6cm	3cm
Observing frequency (GHz)	1.5	2.3	5.3	8.6
Maximum bandwidth[1] (MHz)	2.5	3.8	8.8	14.3

(1) For 2.5% point-source sensitivity loss at field edge.