The Australia Telescope Millimetre-Wave Upgrade - A Progress Report

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Background

The Australia Telescope Compact Array (ATCA) began scheduled astronomical observations in 1990. Consisting of six 22 m antennas, the Telescope is located at Narrabri, in north-west New South Wales. In its original form, five antennas were moveable on a 3 km east-west rail track, with a sixth dish fixed at a position a further 3 km west. The original suite of wideband receivers is still used to observe in the frequency range 1 – 10 GHz. Down-converted signals are digitally encoded at the antennas, then transmitted to the central site via multi-mode optical fibre data links (4 x 512 Msps per antenna). Despite a site elevation of only 200 m, atmospheric opacity and stability measurements show that observations beyond 100 GHz are possible for at least several months of the year. With next-generation Southern Hemisphere mm-wave arrays in Chile unlikely to be operational before 2009, the science case for a mm-wave ATCA extension is compelling and, in early 1996, the Australian Government announced that it would fund the $A7M upgrade to the instrument.

The Upgrade

Two new observing bands are now being added to the ATCA: 12 mm (covering 16 – 25 GHz) and 3 mm (85-105+ GHz). Receiver and related systems are being designed to allow a (likely) 7 mm option in the future. With some 2000 m^2 of collecting area at 3 mm, the ATCA compares favourably in sensitivity terms with the best northern mm-wave telecopes. Projected to be operational in early 2002, the upgraded ATCA will be a technological and scientific stepping stone to the new-generation Atacama arrays. While the present correlator (256 MHz maximum bandwith) and related back-end systems will be retained for the first-round mm-wave upgrade, a new back-end (>1 GHz BW) will be the next ATCA development. Table 1 summarizes the expected mm-wave performance of the ATCA.

Technology Highlights

Major elements of the upgrade project are:

- extended high-frequency reflecting surfaces for the five closest antennas, giving overall rms surface errors of 200 µm and aperture efficiencies of 40% at 100 GHz;
- extra east-west array stations and a 230-m north spur rail-track, converting the ATCA to a 2-D array with improved instantaneous U-V coverage, allowing higher average antenna elevations during shorter synthesis session, and hence decreased sensitivity to the effects of atmospheric water vapour;

- cryogenically cooled (20 K) receivers using low-noise amplifiers based on indium phosphide (InP) monolithic millimetre-wave integrated circuit (MMIC) technology;
- a single-mode, optical-fibre, network for distributing the telescope local oscillator reference signals;
- a remote-sensing system, based around the 22 GHz astronomy receiver, to correct path-length distortion caused by blobs of atmospheric water vapour moving above the array.

A few aspects of the project are discussed in the following sections.

Table 1 - ATCA Millimetre Wave Performance Projection

Band (mm)	**12**			**3**		
Frequency (GHz)	16	22	25	85	100	110
Number of 22 m Antennas	6			5		
Antenna Efficiency	0.59	0.59	0.59	0.45	0.40	0.37
Array Physical Area (m^2)	2280			1900		
Maximum Baseline (km)	6			3		
Field of View (arcsec.)	211	153	135	40	34	31
Best Synthesized Resolution (arcsec.)	0.77	0.54	0.49	0.29	0.25	0.23
Receiver Type (SSB, Dual-polarization)	Cooled (20 K) InP MMIC					
T_{rx} (Flange) (K)	24	27	32	85	76	80
T^*_{sys} (Above-atmosphere equivalent, zenith, 10 mm PWV) (K)	28	57	46	138	136	162
Continuum Flux Sensitivity ΔS^* (6 hr, 10 mm PWV, 2 x 128 MHz IF, 2-bit sampling) (mJy/beam)	0.031	0.063	0.050	0.24	0.26	0.34

Antenna Re-surfacing

Originally, each 22 m diameter ATCA antenna had solid surface panels out to the 15 m point; perforated panels, effective below 50 GHz, were used to clad the outer section of the dish. Apart from limiting the sensitivity at 3 mm, the combination of 15 m reflectors and a 30 m minimum antenna spacing compromised the 3 mm imaging performance. Re-surfacing the outer section of the five closest antennas doubles their 3 mm sensitivity and alleviate substantially the “missing spacing” problem. All five antennas have now been re-surfaced and holographic measurements show surface errors ~150 - 200 µm rms, leading to an aperture efficiency estimate of ~40% at 100 GHz. Tests have also verified that the re-surfacing will not noticeably degrade the array pointing performance, which remains at ~10 arcsec rms with a global pointing solution, or better than 4 arcsec rms with local reference pointing invoked. Figure 1 shows the re-surfaced antennas in a close-packed East-West configuration.

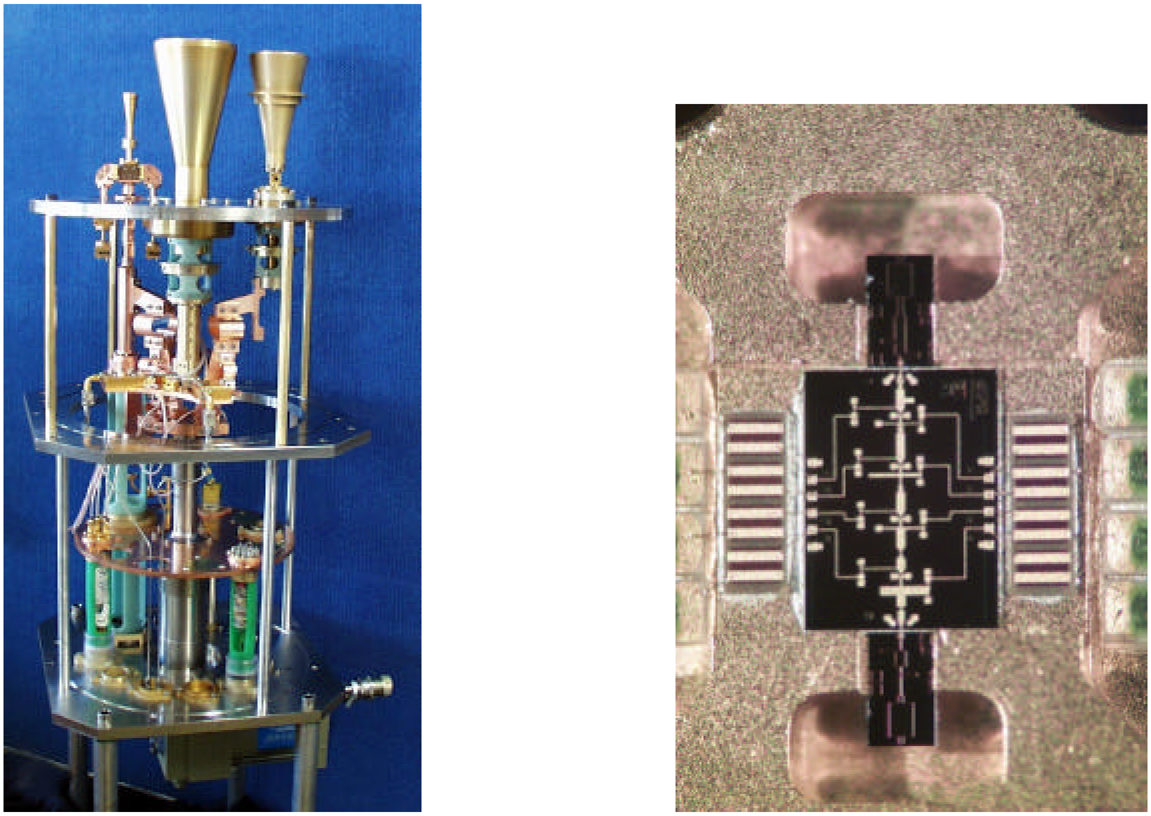
Figure 1 - Five antennas of the ATCA showing solid surfaces extending to the full 22 m diameter

North Spur Track and Antenna Relocation Arrangements

The new 230-m north spur intersects the original east-west rail track at its mid-point. After investigating several alternatives for moving the self-propelled ATCA antennas on to the spur, a simple solution made possible by fortuitous design of the original antenna mechanical arrangement has been adopted. The antenna to be moved is positioned at the track intersection and its rail bogies are raised using a hydraulic jacking arrangement; the bogies are then manually rotated the 90°necessary to allow the antenna to travel on the spur. Various modifications to the variable-speed transport drive were of course necessary to ensure correct bogie rotation direction on both the main and spur rail tracks.

Receivers

The new ATCA receivers are contained in a common cryogenics dewar (Figure 2a). The appropriate feed horn is placed at the secondary focus of an antenna using the existing turret rotator and, in the case of any future 7 mm feed, an additional linear translation of the dewar itself. The receivers are dual polarization types, with 12 mm linear polarization splitting being done using quad-ridge orthomode transducers. At 3 mm, waveguide components are used to separate orthogonal linear modes. Each production receiver will use indium phosphide MMIC low-noise amplifiers cooled to 20 K and, in the case of the 3 mm receiver, the feed horn itself is also cooled. Figure 2b shows a prototype four-stage 100 GHz MMIC amplifier packaged in a waveguide assembly. Scroll-action, air-cooled, cryogenic helium compressors with a 5 kW capacity have been developed, allowing high performance and reliability to be maintained throughout the year at Narrabri.



(a) (b)

Figure 2 - (a) ATNF multi-band mm-wave receiver being assembled (b) detail of four-stage 100 GHz InP MMIC amplifier mounted in a waveguide assembly

Local Oscillator

The existing series-connected ("daisy chain") LO distributor limits ATCA reliability and, as part of the mm-wave upgrade, a new "star" topology (one line to each antenna) distributor is being developed. Low-cost, single-mode, optical fibre will replace coaxial cable as the transport medium, and a high-frequency reference of ~13 GHz will be distributed. A two-fibre, round-trip, phase measurement system will be used to correct for path length variations in the distribution medium. A test link has shown that fibre-to-fibre tracking is good enough to allow compensation, even during 3 mm observations. No mechanical tuning will be used in the LO chain, allowing the excellent frequency agility of the ATCA to be retained during mm-wave observations. The ATCA is re-configured quite frequently (typically fortnightly) and finding a robust optical fibre connection arrangement has proved challenging. However, a scheme based on E-2000 connectors is now under test, and results are promising.

Atmospheric Phase Correction

Phase correction will be done using a four-channel 22 GHz water vapour sensing system. The ATCA implementation will most likely use a separate 22 GHz ambient-temperature feed and front-end, followed by a tuned radio frequency receiver design. For both 12 and 3 mm observing the sensing feed will be used off-axis, giving an insignificant beam shift of ~6 arcmin, corresponding to a few metres linear shift at water vapour sounding altitudes. A design currently being tested in the laboratory uses printed, suspended-substrate, filters (BW ~1 GHz) and a digital backend based on existing ATCA data acquisition systems. With system temperatures of ~160 K at 22 GHz and stabilities of the order of 1 part in 10^4, it is expected that path corrections of ~ 70 µm rms can be achieved, corresponding to phase fluctuations of <10° at 100 GHz.

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