TECHNOLOGY DEVELOPMENTS

MNRF-2001 proposal

In early 2001 the Government announced, as part of a new innovation statement, a new Major National Research Facilities program. Following a great deal of discussion at the ATNF and other astronomical institutions, the decision was made to combine the two highest priorities of the Australian astronomical community into one proposal for MNRF funding. These priorities, as identified by the Australian astronomical community in the report *Beyond 2000: The Way Ahead*, are additional access to the optical/infrared telescopes of the Gemini project and development of the SKA—the next generation radio telescope. This MNRF proposal was submitted to AusIndustry on 11 May 2001.

The specific aims of the program are to:

- **Increase Australia's share** in the International Gemini Telescopes (currently 5%). The MNRF funds will be used initially to purchase an additional share of Gemini. In addition it is hoped that future instrument construction contracts will enable further engagement in the Gemini program. This program will not only provide Australian astronomers with a bigger share of Gemini observing time, but will also improve the capabilities of the Gemini telescopes, and advertize Australia's expertise in instrument building, hopefully leading to more contracts to build instruments for other international telescopes.
- **Develop enabling technologies** for the SKA. The way in which we plan to do this not only develops the technologies which will be necessary for the construction of the SKA, but will also enhance our existing radio telescopes such as the Australia Telescope Compact Array, and reinforce Australia's bid as the prime location to host the SKA.

On 21 August 2001, Senator Nick Minchin, Minister for Industry, Science and Resources, announced the allocation of $155M under the MNRF-2001 program to fifteen successful proposals. Of these the ATNF-led proposal was granted the largest single allocation of $23.5M.

The combination of optical and radio astronomy priorities in the program mean that the activities of the Australian astronomical community as a whole are now closely aligned. The proposal also builds upon the strength and experience of the original MNRF-funded upgrade of the ATNF and University of Tasmania radio astronomy facilities, the high frequency upgrade of the Compact Array and the upgrade of Australian VLBI facilities.

The institutions that contributed to the successful proposal were CSIRO ATNF, the Anglo-Australian Observatory, the Australian National University Research School of Astronomy and Astrophysics, Swinburne University of Technology, the University of Sydney, the University of Melbourne, the University of New South Wales, the Government of Western Australia, CTIP, University of Melbourne, Advanced Powder Technologies Pty Ltd, CEA Technologies Pty Ltd and Dell Computer Pty Ltd.

Executive Special Project

In December 1997 CSIRO's Chief Executive Officer, Dr Malcolm McIntosh, announced a number of projects to be undertaken by large research teams within CSIRO in the 1997 – 2000 triennium. One of these projects was a joint proposal of the ATNF and CTIP to develop high frequency integrated circuits for radio astronomy and telecommunications. The circuit designs are developed within ATNF and CTIP and are fabricated in the USA by the US foundry TRW using their leading-edge indium phosphide foundry process. Devices produced under the program include monolithic microwave integrated circuits (MMICS) and high speed digitiser circuits.

Monolithic microwave integrated circuits

Wafers from the final foundry run of InP high electron mobility transistor (HEMT) devices were delivered in November 2001. These wafers contained production quantities of successful designs from the initial foundry run as well as several new circuits. On-wafer testing showed that the performance of existing designs was maintained over the two fabrication runs. A number of new designs were also shown to have excellent performance. In particular, two new low-noise wideband 3-mm amplifiers offer the prospect of extending the frequency coverage of ATNF receivers in the band to 115 GHz. Packaged circuits from this final run should be available in mid-2002.

High-speed digitiser circuits

Tests on the packaged InP heterojunction bipolar transistor (HBT) digitiser circuits were completed in March 2001. These confirmed the excellent results obtained in the on-wafer tests. Successful operation of the digitiser/demultiplexer circuit was demonstrated at 4 Giga-samples per second in conjunction with a 2-GHz bandwidth correlator. These circuits will be used in the new 2-GHz bandwidth correlator which will be installed at Parkes in March 2002.

Photo: Department of Industry, Science and Resources

Senator The Hon Nick Minchin, Minister for Industry, Science and Resources, announcing the successful MNRF-2001 proposals.

The Square Kilometre Array

The ATNF is one of a consortium of major radio astronomy institutions in 11 countries now planning the world's next-generation large radio telescope, the Square Kilometre Array (SKA). This instrument's one million square metres of collecting area will make it 100 times more sensitive than the best present-day instruments. This area will be distributed across many hundreds, perhaps thousands, of kilometres in a location yet to be decided. Using a combination of technologies, the SKA will cover frequency ranges from 150 MHz to above 10 GHz.

A main scientific driver for this enormous array is to study the early Universe at centimetre wavelengths and to complement next generation telescopes operating at other wavelengths. The ATNF is a very active player in the SKA consortium and, with input from universities and other Divisions across CSIRO, is making major contributions to the design of the array in several key areas including the antenna elements, the receivers, signal processing, the correlator, site investigations, array configurations and interference mitigation. Construction of the SKA is expected to start by 2012.

SKA meetings

An important milestone in Australian SKA work was reached in late 2000 with the formation of the Australian SKA Consortium, a 14-member steering committee constituted from CSIRO, other research organizations, industry, science policy bodies and professional organizations. The first meeting of the Consortium was held in February 2001 together with a one-day open symposium on SKA-related astronomy and engineering issues.

An international SKA meeting was held at Berkeley (USA) on 9 – 12 July 2001. Australia was well represented at this meeting with a strong contingent from both the ATNF and CTIP. Between the two Divisions five oral papers and 11 poster papers were presented. The topics covered included antenna issues, interference mitigation, correlator development, demonstrator requirements, radio-quiet reserves and site considerations. Ron Ekers, Peter Hall and Bruce Thomas were also active in strategic roles following election to senior positions within the SKA international project structure.

Antennas for the SKA

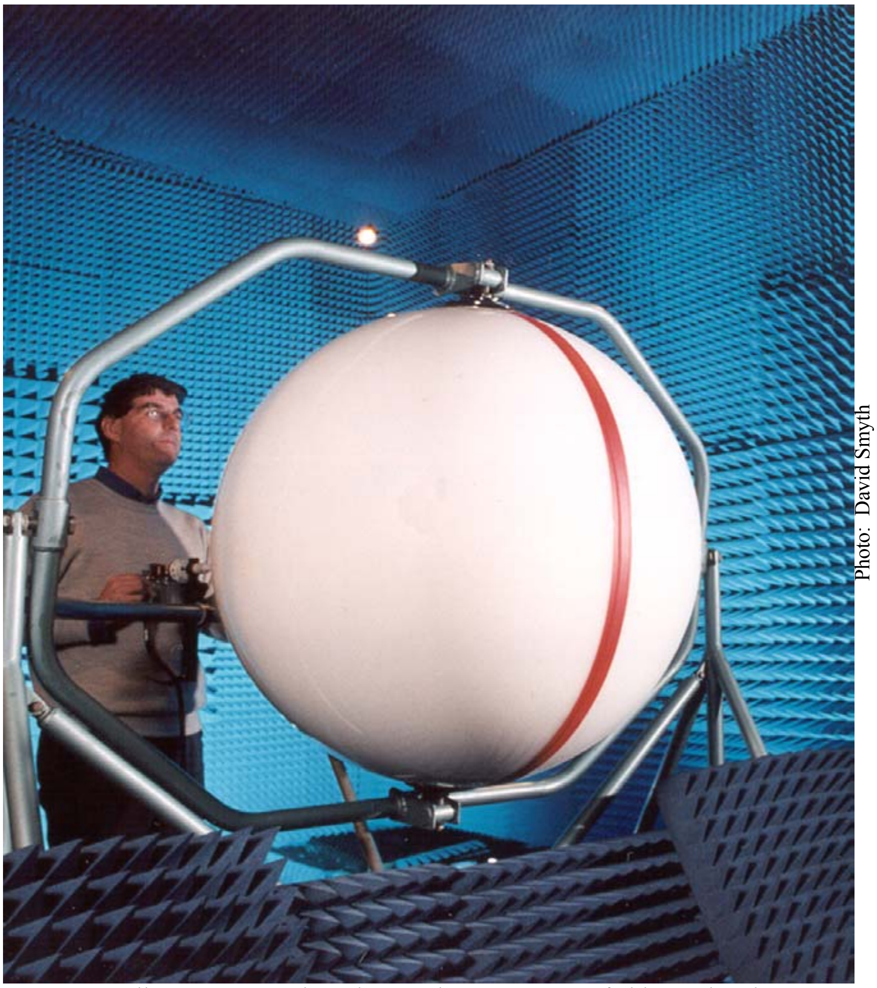
Antennas are the highest profile components in the various SKA concept designs. The SKA goal is to have many simultaneous, widely-separated beams.

Constructing antennas which are capable of efficient operation over a wide frequency range, and which yield many beams "placeable" over the whole sky, is a formidable challenge to designers. To build the SKA at an affordable price within the next 10 – 15 years, heavy reliance is being placed on new materials and manufacturing techniques, and on economies of scale.

The successful outcome of the MNRF-2001 proposal has given considerable impetus to SKA antenna prototype design. Three types of antenna are under active consideration in Australia. The first is the Luneburg lens—a spherical lens characterized by an inhomogeneous but spherically-symmetric refractive index profile. This antenna combines the advantages of optical beam forming with inherently wide bandwidth capability. Its main attraction for the SKA is the ease with which multibeaming and source tracking can be achieved.

While the Luneburg lens was first proposed in 1944, its use to date has been somewhat limited. Cost and loss issues make the lens viable only if new ways of producing artificial dielectrics can be found. In 2001 a joint project between four CSIRO Divisions* was instigated to investigate and develop suitable artificial dielectric materials. For these investigations low-density, low-loss foam is being doped with small ceramic inclusions to produce artificial dielectrics. As part of the MNRF-2001 proposal, a prototype lens will be constructed out of this material.

* CTIP (CSIRO Telecommunications and Industrial Physics), ATNF, CMS (CSIRO Molecular Science) and CMST (CSIRO Manufacturing Science and Technology).



Dr Peter Hall testing a Luneburg lens in the CSIRO near-field test chamber at Marsfield, Sydney.

In collaboration with the Pushchino Radio Astronomy Observatory in Russia, the ATNF has acquired a commercial 0.9-m diameter Luneburg lens from the Russian company KONKUR. This lens has been used in tests of the near-field and far-field antenna performance. The results indicate good beam-forming properties and the knowledge gained from the tests will be used in upgrading antenna metrology techniques for future CSIRO-produced lenses.

The second proposal for an SKA antenna element is based around a cylindrical reflector. The advantage of the cylindrical reflector is simplicity, since the reflector has only one direction of curvature.

This provides for an economical structure, where a rotation of the reflector provides azimuthal coverage while a line feed provides the elevation coverage of the sky. In principle, a phased array line feed can provide multiple beams within an elevation fan beam. The main challenge for this proposal is in the design of the broadband, dual polarization line feed; this aspect is included in the MNRF-2001 proposal where, in conjunction with Sydney University, part of the Molonglo Observatory Synthesis Telescope is being used to examine the feasibility of cylindrical reflectors as antenna elements for the SKA.

Finally, ATNF and CTIP are expanding their SKA activities in the area of phased array antennas, either in aperture or focal surface roles. It is now clear that phased arrays will be central to many SKA design concepts. A milestone in 2001 was the establishment of collaboration with ASTRON, emphasizing wide bandwidth performance and low-cost integration of electronics. Part of this work is being undertaken within the FARADAY project, a consortium of European Union radio astronomy groups working on focal plane arrays. By the end of 2003 the ATNF will have decided, on the basis of first-round prototyping, which antennas, or combination of antennas, offer the most promising direction for Australian SKA demonstrators.

Interference mitigation

In addition to antenna design, engineers are all too aware of the importance of other systems, such as signal transmission and interference mitigation. To meet its scientific objectives, the SKA will need to observe outside the narrow bands reserved for radio astronomy. As part of the SKA research program, the ATNF is actively involved in the development of both pre-correlation (coherent) and post-correlation (incoherent) interference mitigation techniques.

The ATNF has made extensive use of its "software radio telescope" concept to develop and test interference mitigation algorithms on real data. Using the S2 VLBI system, signals (astronomical and interference) have been recorded coherently from the Parkes radio telescope and individual elements of the Compact Array. These recordings have been distributed internationally to several groups interested in new signal processing techniques and, using workstation and super-computer facilities in Australia, it has been possible to experiment with, and evaluate, a number of different approaches. In common with most other groups, initial ATNF work involved coherent adaptive processing. However, new techniques have been developed which invoke post-correlation analogues of the adaptive process, vastly reducing the computational load and making interference mitigation testable on real telescopes.

In 2001 research into radio frequency interference mitigation techniques has continued at ATNF and the University of Sydney, and algorithms have been tested in software on baseband data from the ATCA, Parkes radio telescope and the Rapid Prototyping Array at the University of California, Berkeley.

An artist's impression showing one station of the Square Kilometre Array, composed of a number of Luneberg Lens antennas.

The Mileura station in Western Australia is one of several sites being tested as a possible location for the SKA. In 2001, radio data were taken to survey the area and determine whether it is a radio-quiet site.

SKA site investigations

Four states (Western Australia, South Australia, New South Wales and Queensland) are carrying out studies to determine candidate locations (of about 50-kilometre diameter) for the central section of the SKA. In addition, Western Australia is being considered as one of three possible sites for locating the Low Frequency Array (LOFAR), the low-frequency counterpart of SKA. A decision relating to a site for LOFAR is expected in early 2003, with preliminary proposals for an SKA site due in October 2004.

One of the major steps in the SKA and LOFAR site evaluation process is the completion of high-sensitivity radio-quietness tests. A preliminary testing program was carried out on Mileura Station in the Murchison region of Western Australia in March – April 2001. This was supported by industry in Western Australia following awards of field-testing contracts by the Western Australian Government. The ATNF also participated, and was responsible for the data processing. Initial results indicate that the radio spectrum at this representative site is indeed extremely "quiet" over a broad frequency range.

Integrated RF systems

This year a working group on integrated radio-frequency systems has been formed to develop highly-integrated receiver solutions for the SKA and its demonstrator antennas. The ATNF will complete an uncooled GaAs MMIC low-noise amplifier design in the first half of 2002 and, with international collaborators, will then examine silicon germanium (SiGe) MMIC options. These prototypes will be used to select the most appropriate semiconductor technology for Australian SKA demonstrators. Following the preliminary work, integrated receiver solutions for the SKA will be investigated; these may include the use of micro-electronic mechanical systems for switches and tunable inductors, and on-chip fibre optic interfaces.