Technology developments

Marsfield engineering developments

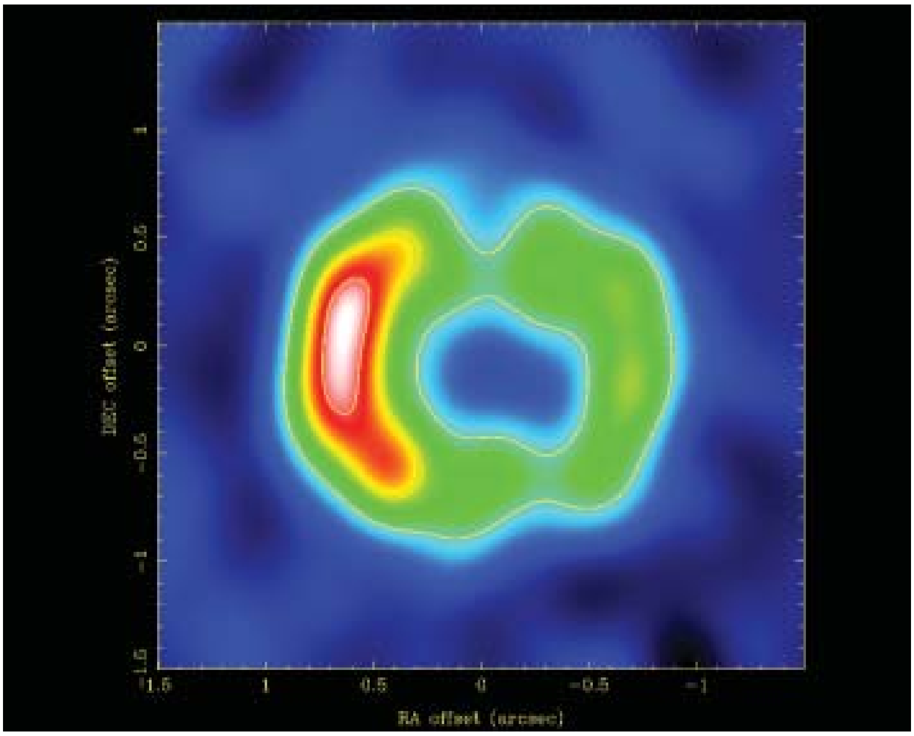
MNRF-1997

The ATNF, together with the University of Tasmania, is approaching completion on a set of substantial projects under the Commonwealth Government's Major National Research Facilities (MNRF) program, governed by a contract signed with the Government in February 1997. The major part of this contract was to upgrade the Australia Telescope Compact Array to work at high (millimetre-wave) frequencies in the 3- and 12-mm observing bands. Most of this work has now been completed with the full millimetre capabilities expected to be available from mid-2004.

12/3-mm receiving systems for the Compact Array and Mopra

A major milestone in the MNRF-1997 program was achieved in June 2003 with the installation of 12-mm receivers in all six Compact Array antennas, providing a frequency range from 16 – 25 GHz. The existing prototype 12/3-mm receivers on three of the antennas were supplemented by three production receiver packages on the remaining antennas. The new packages are designed to provide coverage of three wavelength bands, 12, 7 and 3 mm, but are currently fitted out for the 12-mm band only. The 3-mm systems are planned to be installed in mid-2004 when final production units will also replace the three prototype 12/3-mm receivers. The 7-mm system is not part of the MNRF1997 project and funding to provide a 7-mm system is being sought elsewhere.

The new mm-wave receiver package installed at Narrabri. The 12-mm feed is in the centre. The 3-mm feed will be enclosed inside the dewar extension on the left and behind. The position for an eventual 7-mm feed is on the right.
Photo: © CSIRO



The completion of the 12-mm system has provided an exciting new capability for the Compact Array. The increased resolution of the instrument was splendidly demonstrated by this image of SN 1987A from the first observations taken using all six antennas at 12 mm.

3-mm receiver developments

A major effort for the 3-mm systems has been the design of the final local oscillator (LO) chain. A significant difference between the prototype and production systems occurs in the first conversion stage, with the final system required to provide a considerably wider frequency coverage. This could be achieved only by replacing the largely commercial components in the prototypes with specially-developed custom components. Most of these components use purpose designed MMIC circuits. The longer-than-expected development time of these specialised components has resulted in the delayed completion of the 3-mm systems.

Components developed for the LO chain and first conversion stage include:

- Frequency doubler MMICs, in both gallium arsenide (GaAs) and indium phosphide (InP), from 25 – 50 GHz and from 50 – 100 GHz.
- High power amplifier MMICs in GaAs in the frequency ranges 48 – 52 GHz and 96 – 104 GHz, designed by CSIRO CTIP.
- Wideband single sideband mixer MMICs in InP covering a radio frequency (RF) range of 84 – 116 GHz.

Initial results of tests on the performance of the 3-mm first conversion stage, using an LO produced with the prototype of the final LO chain, show good performance across the full frequency range from 84 – 116 GHz.

Another significant development for the 3-mm receivers is a new InP MMIC coplanar waveguide low noise amplifier (LNA). Extensive tests at cryogenic temperatures carried out late in the year show that these circuits perform well up to 115 GHz. There is still some uncertainty in the noise measurements above 107 GHz, due to limitations in the test setup, but the performance is very promising. Although it will not be possible to use these

A diffraction-limited 12-mm image of SNR 1987A obtained on 31 July 2003 using the Compact Array in the 6D configuration.
Image: Dick Manchester, ATNF

LNAs in the initial outfitting of the Compact Array, they could be installed in a later upgrade to extend the current upper frequency limit of 105 GHz to 116 GHz. Initially they will be installed in a new 3-mm receiver for the Mopra radio telescope, matching the frequency coverage of the current SIS system which will be replaced in late 2004.

Compact Array local oscillator upgrade

The final task in this project, the installation of the tuneable high frequency local oscillator reference system for the millimeter-wave receivers was completed in May 2003.

MNRF-2001

In early 2001 the government announced, as part of a new innovation statement, a Major National Research Facilities program. The Australian astronomical community decided to combine their two highest priorities for future growth 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 Square Kilometre Array (SKA) – the next generation radio telescope. The MNRF-2001 proposal was submitted to AusIndustry in May 2001. On 21 August 2001 the Minister for Industry, Science, and Resources, Senator Nick Minchin, announced the allocation of A$155M under the MNRF-2001 Program to fifteen successful proposals. Of these, the ATNF-led proposal was granted the largest single allocation, A$23.5M. The major goals of the MNRF-2001 program are to increase Australia's share in the International Gemini Telescopes, and to develop enabling technologies for the SKA.

Compact Array broadband upgrade

This project has the aim of developing new signal processing techniques for the SKA and applying them in a significant upgrade for the Compact Array. This will provide a significantly enhanced facility for National Facility users whilst also providing a test bed for SKA developments. The upgrade will increase the bandwidth of the Compact Array by a factor of 16 to a total bandwidth of 8 GHz.

At the heart of the new backend being developed for the Compact Array is a polyphase digital filterbank (DFB). This device is used to split the intermediate frequency (IF) signals from each antenna into many narrow

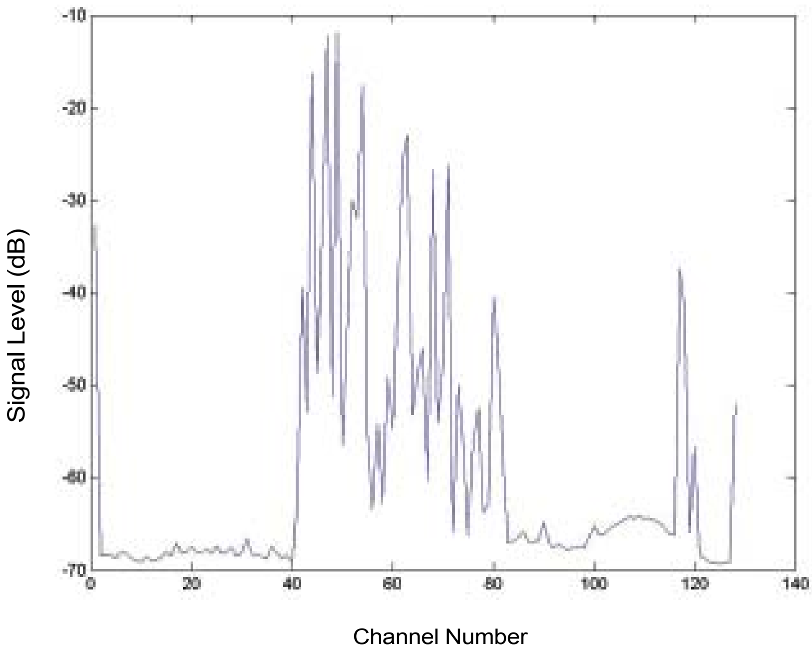


Figure 26 An early spectrum, showing radio frequeny interference, taken with the prototype polyphase digital filterbank. The channel width is 0.5 MHz, and the spectrum is centred on approximately 100 MHz. The spectrum has a large dynamic range of 60 dB.

frequency channels prior to the correlation processes which form the interferometer outputs. A great deal of effort has gone into developing tools to assist in the highly complex DFB design process. The DFBs are implemented in large reconfigurable logic circuits called field programmable gate arrays (FPGAs). An important milestone was reached at the end of 2003 when the first operational DFB was demonstrated. This initial design, having just 128 frequency channels over a 64-MHz bandwidth, falls well short of the 2048 channels over 2 GHz required for the final Compact Array system but is a significant first step towards that goal.

Already some excellent characteristics of the DFB have been demonstrated with this first design, in particular a large dynamic range and spectral purity. This can be seen in Figure 26, which is a measurement of the local radio frequency environment taken with a test antenna centred on approximately 100 MHz.

The next stage in the development of the DFB will be a 600-MHz bandwidth system which will be installed at Mopra as an interim spectrometer for the 2004 mm-wave observing season. This will provide a full functional test of the DFB in an operational observing environment, as well as a much enhanced spectral line performance compared to the existing Mopra correlator.

MMIC developments

A number of new designs were prepared for an InP HEMT fabrication run with Velocium in February 2003. ATNF obtained access to this run through its participation in the Faraday (FP5) collaboration with EU based partners. The wafers were returned in September and wafer tests will be completed in early 2004. Of particular interest are a number of wideband LNA designs aimed at a possible future upgrade of the Compact Array cm-wave systems. The goal is to replace the existing 20/13-cm LNAs by one device covering the range 1 – 3 GHz, and, similarly, the 6/3-cm LNAs by a single 4 – 12 GHz device. Not only will this extend the frequency coverage at cm wavelengths, but it is expected to give significantly lower noise performance as the lossy frequency diplexers will no longer be needed. On-wafer tests of these designs have shown very promising performance, although the full story will not be known until the MMICs are packaged and tested at cryogenic temperatures.

Also in the MMIC development area, a new project was started in mid-year aimed at developing a fully integrated receiver system on a chip. This work looks ahead to the requirements of large systems such as focal plane arrays and the SKA. Initially, radio-frequency CMOS technology will be used to integrate a complete receiver, including LNA, filtering, down conversion, analogue to digital conversion and parallel to serial processing onto a single MMIC. The design will cover the frequency range 500 – 1700 MHz, with an instantaneous bandwidth of 500 MHz. Fabrication is planned to begin in September 2004.

In December 2002 the ATNF/CTIP MMIC team, John Archer, Mal Sinclair, Russell Gough, Paul Roberts and Oya Sevimli, was awarded a Medal for Scientific Achievement for their role in designing advanced InP MMICS for radio astronomy and telecommunications. ATNF staff member Henry Kanoniuk contributed considerable expertise in the testing and initial applications of these MMIC designs.

Other developments

New pulsar instrumentation at Parkes

A significant step towards the completion of the new pulsar observing system at Parkes was taken in late October 2003 with the installation of the new dual-band 10/50-cm receiver. This receiver offers simultaneous operation at two frequency bands, with 1-GHz bandwidth at 10 cm (3.1 GHz) and 64-MHz bandwidth at 50 cm (680 MHz). When combined with existing backend systems it provides a powerful new facility for pulsar observing at Parkes.

Early tests show that the sensitivity of the system is meeting specifications, although the full 1-GHz bandwidth at 10 cm has not yet been achieved due to problems in both the receiver and wideband correlator.

Extension of wideband analogue correlator on the Compact Array

Following the success of the single baseline 4-GHz bandwidth analogue correlator system in a trial 20-GHz survey in 2002, a new enhanced system was developed and installed in October 2003.

The new system is a three-antenna, three-baseline instrument with a nominal bandwidth of 8 GHz. The original 4-GHz analogue lag correlator, made from commercial multiplier circuits, was replaced by a new design employing wideband InP multiplier MMICs designed at ATNF and fabricated under the CSIRO Executive Special Project program.

Although the wideband optical data transmission and correlator worked very well and were shown to be providing the full 8-GHz bandwidth, problems were encountered in compensating for the very steep slope across the band in the 12-mm receiver IFs. With the limited dynamic range of the data transmission, this resulted in an overall effective bandwidth of the system of only 2 GHz. Despite this disappointing result, the system was used in a successful pilot 20 GHz survey. A modification is planned to achieve the full 8-GHz bandwidth before the survey begins in earnest in 2004.

External contracts

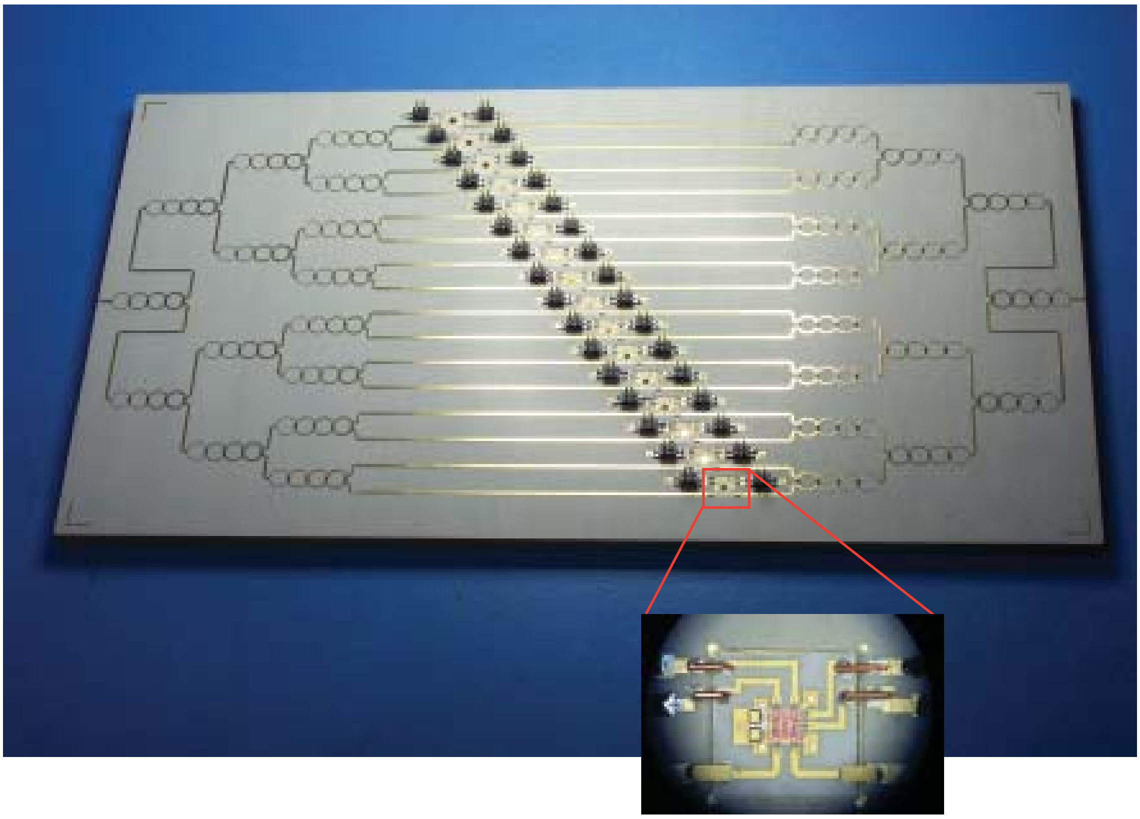
Arecibo 21-cm multibeam receiver

The seven-beam 21-cm multibeam receiver being built under contract to NAIC for the Arecibo radio telescope was nearing completion by the end of 2003. This receiver is an adaptation of the successful Parkes 13-beam 21-cm multibeam receiver. It is due for delivery to Arecibo in March 2004.

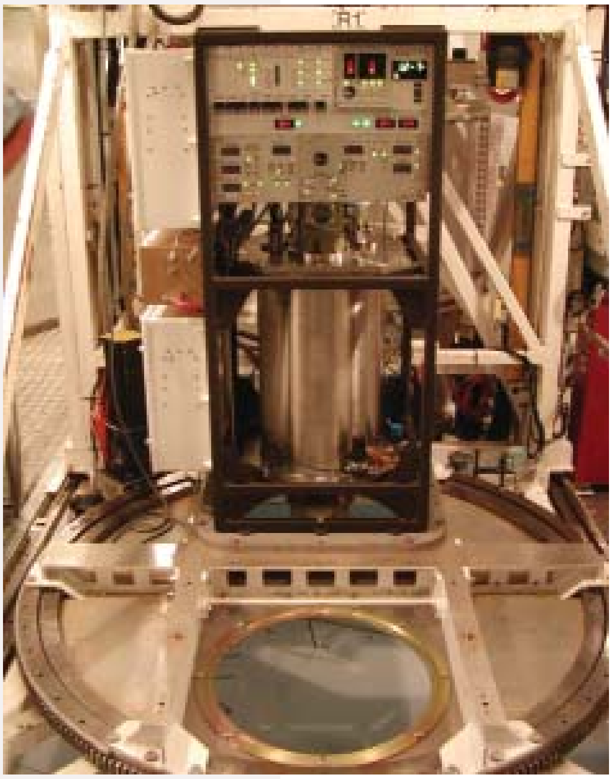
The LNAs in this receiver are an ATNF development based on the Jodrell Bank units used in the Parkes 21-cm multibeam receiver. After seven years operation the Parkes receiver was removed from the telescope in October 2003. Part of the refurbishment which will occur over the coming months will be a replacement of all LNAs with the new design.

NASA Mars tracking

The upgrade of the surface of the Parkes antenna, providing new panels in the 44 – 54 m diameter region was completed in March 2003. The new purpose-built 8.4-GHz receiver was installed at Parkes in August 2003. Overall system acceptance testing showed that the NASA gain/temperature specification was exceeded by almost a factor of two. The measured antenna gain was very close to the expected value for the upgraded surface, but the receiver noise was well below specification. Regular tracking of the Mars spacecraft began as planned in September 2003.



A wideband 0 – 12 GHz analogue correlator using indium phosphide MMIC multipliers.
Photo: © CSIRO



The Square Kilometre Array and next-generation radio telescopes

Overview

The ATNF is committed to the SKA as its primary strategic development project. The SKA is a next-generation radio telescope which will have a collecting area of one square kilometre, making it one hundred times more sensitive than any existing radio telescope. It will operate at centimetre wavelengths. Construction is expected to start about 2012, with full operation in 2020. The SKA is so ambitious that international collaboration is mandatory in its design, construction and operation.

The International SKA Consortium is headed by an International SKA Steering Committee (ISSC), and managed by the International SKA Director. Within Australia, SKA activities are coordinated by the Australian SKA Consortium Committee (ASKACC), and the ATNF is one of several institutions who contribute to ASKACC activities.

ATNF is contributing to the international SKA project in a number of ways, including the development of technology and the evaluation of potential locations within Australia. The selection of the location of SKA will take place in 2006, and a great deal of testing is taking place in Australia leading up to that date.

The ATNF is also exploring the possibility of building a low-frequency SKA pathfinder facility. The drivers for this include:

- Cutting-edge science drivers which could be successfully addressed by such an instrument;
- A demonstration of the credibility of Australia as a potential host country for SKA;

The 8.4-GHz NASA Mars receiver in the aerial cabin of the Parkes dish.
Image: © CSIRO

- Development of technology (e.g. signal transmission, correlator, software, and infrastructure) for the pathfinder telescope which is well-aligned to that needed for SKA;
- A shorter-term goal to focus and maintain the momentum and enthusiasm of those working on SKA.

SKA technology

ATNF SKA technology developments (in collaboration with other CSIRO divisions) include the goal of a wideband, multibeam technology demonstrator, incorporating the core technologies of:

- wide field-of-view microwave lenses ("Luneburg lenses") or phased-array antennas;
- optical fibre signal transport;
- sustainable energy provision to stations in remote locations.

The Luneburg Lens prototyping work is progressing well, and a new feed translator system for the Lens has been designed and manufactured. A new artificial dielectric material has been developed, and the manufacturing process for this has been patented.

A trial assembly of the Luneburg lens components.
Photo: © CSIRO

November 2003 saw the completion of the "proof-of-concept" prototype spherical lens at CSIRO MIT in Clayton, Victoria, and delivery of the lens to the Radiophysics Laboratory in Sydney. The lens comprises four spherical shells, each one made from moulded foam spherical diamonds, with a fibreglass protective shell. The lens was attached to its mounting successfully, and we have now started testing its performance in the antenna test range.

Remote area power provision has been identified as a crucial design factor for SKA and LOFAR, particularly for the proposed Australian sites and also for remote areas in the other proposed SKA sites. Australia is a world leader in remote area power provision and it is expected that this project will demonstrate advanced remote area power provision compatible with the extreme radio requirements of the next generation radio telescopes. A workshop was held in early September 2003 which brought together Australian research and industry experts to address this topic, resulting in several continuing collaborations.

LOFAR

In 2003 the ATNF was actively engaged in discussion with the international LOFAR consortium about the possibility of building LOFAR (Low Frequency Array) in Australia. In May, at the invitation of the international LOFAR consortium (consisting then of ASTRON (NL), MIT (US), and NRL (US)), ATNF, in collaboration with the Government of Western Australia (WA), submitted a detailed siting proposal for LOFAR in Australia. The ATNF and the WA Government decided to explore full participation rather than merely locating LOFAR in Australia, and engaged in fruitful and positive discussions with the LOFAR consortium. In early 2003 representatives from the LOFAR consortium visited the proposed site at Mileura in outback Western Australia, and in September 2003 an international site evaluation process chose Mileura as being the optimum site for LOFAR, based on scientific and technical considerations. Discussions then commenced between Australia and the international LOFAR consortium to develop plans for implementation of LOFAR in Western Australia.

At the same time a consultation process was started within the Australian astronomical community, to gauge the level of interest for LOFAR science within the community. In December 2003 the National Committee for Astronomy endorsed the recommendations of the Australian LOFAR working group that Australia should seek to become full members of the LOFAR consortium, on the basis that the telescope was sited in WA and that LOFAR helped to facilitate Australian astronomy's longer term goals, including the SKA.

In November 2003 ASTRON received funding of €52m for development of LOFAR, with the funding linked to infrastructure development in The Netherlands. In early 2004 it became clear that ASTRON funds would not be available for an international project on a site in WA. The ATNF therefore decided not to proceed with the LOFAR project, while remaining committed to the development of the SKA.

Industry collaborations and other activities

The ATNF has several formal industry collaborators in the SKA and LOFAR projects, including Connell Wagner, CEA, and Australia Powder Technologies, each of whom has kindly agreed to contribute resources towards the projects. We are also in discussion with a larger number of other industry partners who are contributing in various other ways to the projects.

After the IAU General Assembly held in July 2003, an international SKA Meeting was held in Geraldton, Western Australia. This included an SKA conference, a meeting of the ISSC, and several meetings of specialist SKA groups. It also included visits by the ISSC to the Mileura station site, which, as well as being the optimum LOFAR site, is also one of the candidate sites for SKA. The meetings were initiated by a collaboration between CSIRO ATNF and the Government of Western Australia, and also received assistance from the Mid West Development Commission. They were also supported by several industry sponsors, including Cray Australia, Stott and Hoare, Connell Wagner, SGI Australia, Telstra Countrywide and the WA branch of the Institute of Engineers.

SKA siting

Australia offers some of the most radio-quiet locations on Earth. Australian site studies for SKA began in 1997, and have been strongly supported by several State Governments. In 2003 ASKACC submitted an Initial Site Analysis Document to the International SKA Steering Committee on behalf of Australia. The document was jointly prepared by ATNF and Connell Wagner, and analysed and highlighted many of the features of an Australian siting for the SKA.

A meeting was held on 30 October 2003, to which officials of all State and Territory Governments were invited. Representatives of WA, SA, NSW and NT attended. Mileura station in WA has been adopted as a reference site for international testing, and other Australian sites will be compared with this.

The Luneburg lens installed in the CSIRO ICT Centre's antenna test range at the Radiophysics Laboratory in Sydney.
Photo: © CSIRO