New Zealand 12-m VLBI Station for Geodesy and Astronomy

Sergei Gulyaev, Tim Natusch

Abstract

This report summarizes the radio astronomical and VLBI activities recently started in New Zealand. It provides geographical and technical details of a new 12-m geodetic VLBI antenna being operated by Auckland University of Technology. Details of the VLBI system to be installed in the station are outlined. A co-located GNSS station and specialized surveying equipment are also described.

1. Introduction

The IVS report [1] proposes a number of strategies to improve the long-term accuracy of geodetic VLBI with an eye to achieving 1 mm long-term accuracy on baselines. Among these strategies are: “to increase the number of antennas and improve their geographic distribution” and “to increase the number of observations per unit of time”. These IVS strategies can best be addressed through construction of new small (10-12 m), fast moving antennas in areas that are under-represented (Australia) or lack geodetic VLBI stations (New Zealand).

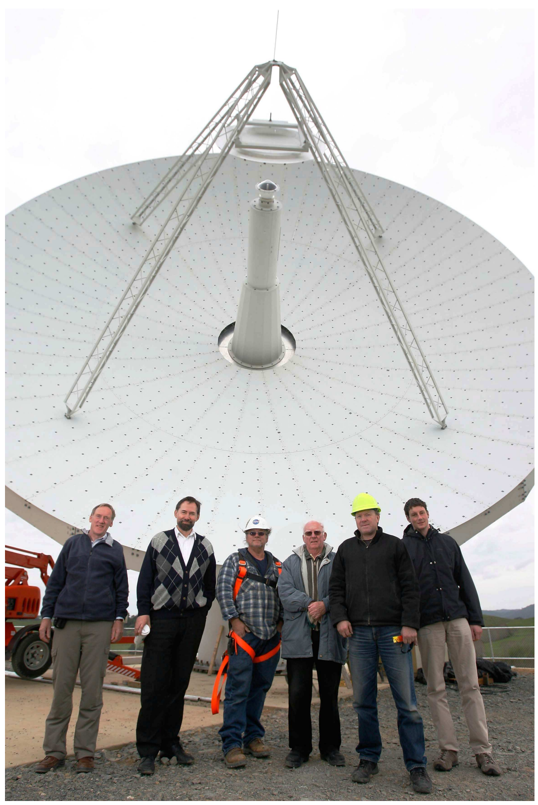

Figure 1. New Zealand 12-m VLBI antenna and the installation crew (Godwin, Gulyaev, Cato, Woodburn, Natusch, and Steinbach). September 2008. (Photo: Greg Bowker)

Developing this approach, Auckland University of Technology (AUT) has invested US $1m in a geodetic VLBI system, consisting of a new 12-m antenna, a hydrogen maser clock, digital receiving and backend equipment, and 10 Gbps network connectivity.

As a preliminary step towards establishing a full geodetic capability for New Zealand, the first Trans-Tasman (Australia — New Zealand) VLBI test was conducted as early as 2005 between an AUT system installed on a 6-m dish located near Auckland and six 22-m antennas of the Australia Telescope Compact Array (ATCA) in Narrabri, New South Wales. This work was successful, with fringes located from the recorded data and a high-resolution image of quasar PKS1921-231 obtained for the first time [2, 3]. In 2006 the New Zealand 6-m antenna took part in a three-way VLBI experiment with participation of the ATCA and the 34-m antenna in Kashima, Japan. Though New Zealand has demonstrated the capacity to contribute to modern radio astronomical and VLBI research, the principal problem for further development was the lack of an appropriate modern radio telescope suitable for geodetic VLBI.

The new 12-m antenna installed in August—September 2008, and officially launched on 8 October 2008 (Figure 1), is intended to comprehensively address this problem.

2. Geographical Information

The New Zealand VLBI Station is located at Satellite Station Valley some 5 km south of the township of Warkworth, which is about 60 km north of the city of Auckland (Figure 2).

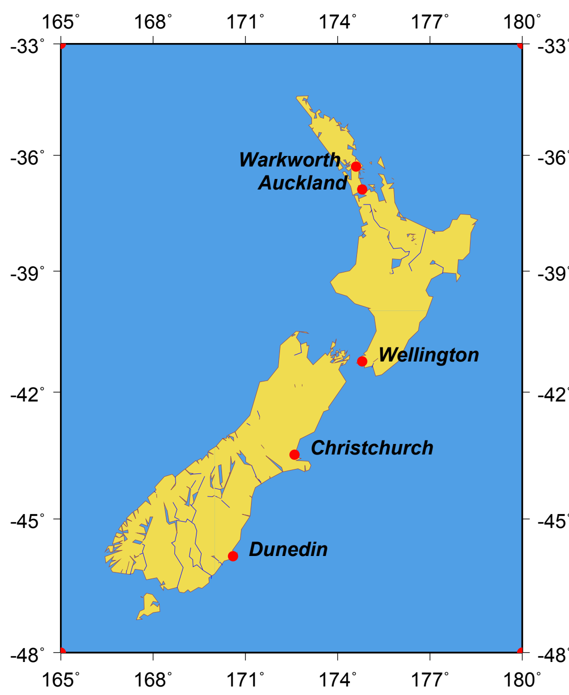

Figure 2. Map of New Zealand. Position of Warkworth is indicated. (Projection: Mercator)

The valley is owned by Telecom New Zealand with several satellite dishes installed (34-m is the biggest one) and operated to provide communication between New Zealand and Pacific Islands (Fiji, Cook Islands, Samoa). The dishes are directed towards geostationary satellites to the north of the site and operate in C-band (4 and 6 GHz). The location is reasonably radio quiet (see Figure 3 for RFI measurements at the site) and protected by local by-law from potential RFI sources.

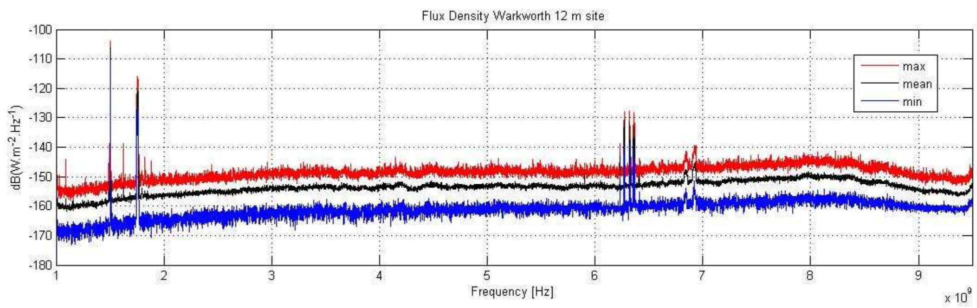

Figure 3. Result of RFI measurement at the Warkworth (New Zealand) site — flux density versus frequency (from 1 to 9 GHz). Three curves show maximal, minimal, and average (mean) levels of the radio noise floor (credit: Paul Banks, 2008).

The approximate (GPS) location of the antenna is
Latitude: $-36°26'05.3''$
Longitude: $174°39'47.7''E$

3. Technical Information

The 12m Radio Telescope (RT) was manufactured by Patriot Antennas Inc. in Albion, Michigan, USA. The list below provides technical specifications for the high-frequency RTNF antenna:

- Diameter: 12.1 m
- Surface Accuracy: 0.3 mm (0.012 inches) rms.
- Frequency range: 2.1 - 32 GHz.
- Dual shaped Cassegrain, F/D = 0.375 (primary surface)
- Directive efficiency: 85%
- Pointing Accuracy: 0.005 degree
- Operational temperature range: -15 to +55 deg C
- Specs apply in winds of 30 mph (50 km/h)
- 100 mph (160 km/h) survival in stow
- + 4.5 to 88 deg elevation travel
- +/- 270 degree azimuth travel
- Slew and scan rates
  - Up to 5 deg/s in Azimuth
  - Up to 1 deg/s in Elevation

The table below presents the major elements of the AUT e-VLBI receiving system and their current status.

- **Radio telescope.** Installation of the 12-m radio telescope was finished in October 2008. Preparation of the radio telescope for VLBI observations is in progress.
- **Feed.** The coaxial dual band (S and X) dual polarization (circular left/right) feed horn was specifically developed by Patriot Antennas and installed in the AUT 12-m radio telescope.
- **Low noise amplifiers.** Four MITEQ high-gain low-noise amplifiers (LNAs) are installed (for both S and X bands and both polarizations).
- **Receivers.** See details on the S-band and X-band receivers below.
- **Frequency Standard.** Symmetricom Active Hydrogen Maser MHM-2010 (75001-114) has three outputs @ 5 MHz, one output @ 10 MHz, one output @ 100 MHz, two outputs @ 1 pps (pulse per second) and a 1 pps sync. The above selection is the most comprehensive available and contains at least one of all available outputs. A separate distribution amplifier unit allows up to 15 outputs of the 10 MHz signal to be obtained.
- **Digitizer.** The AUT VLBI receiving system will use the digital base band converter (DBBC) developed at the Italian Institute of Radio Astronomy.
- **Recorder.** The AUT VLBI receiving system uses the Mark 5B+ data recorder developed at Haystack Observatory, MIT.

The S/X receiver developed for the AUT radio telescope is of a superheterodyne design; signals from the antenna feed being mixed with LO signals to produce an IF signal at lowered frequency before propagation along coax cable to the digitizing and recording instruments. The receiver is designed to be mounted directly at the feed of the antenna and provide sufficient gain to overcome losses in the approximately 65 meter cable run back to the Observatory Control Room and provide a signal of suitable level for the data recorder.

The receiver may be viewed as consisting of 4 separate signal chains that provide the necessary gain and selectivity for both left and right circular polarizations of the two frequency bands (S and X) output by the antenna feed. The design of the feed is provided in Figure 4.

A Phase Locked Oscillator (PLO) referenced to the Observatory Maser provides the necessary LO signals, 7.6 GHz for X band and 1.9 GHz for S band to mix the signals down to the chosen intermediate frequencies (IF).

In each signal chain a set of three LNAs provide a total gain of approximately 110 dB. It is anticipated that some additional gain may be necessary to adjust signal levels immediately prior to input to the digital recorder equipment once that has been received.

Injection of a phase calibration tone and noise calibration signal is provided via a directional coupler located at the front end of the receiver chain. These two systems will respectively allow phase response and sensitivity (gain) of the receiver to be periodically checked during the course of a VLBI experiment.

The receiver is of an uncooled design, and as such its temperature will vary with the natural temperature of the environment. Both the receiver components and the coaxial cable used to pipe signal off the antenna have some sensitivity to temperature that will introduce phase and gain variations to the receiver output. By switching in phase and noise calibration signals at regular intervals the variations of these quantities during an experiment may be logged and then modelled and compensated for during the VLBI correlation process.

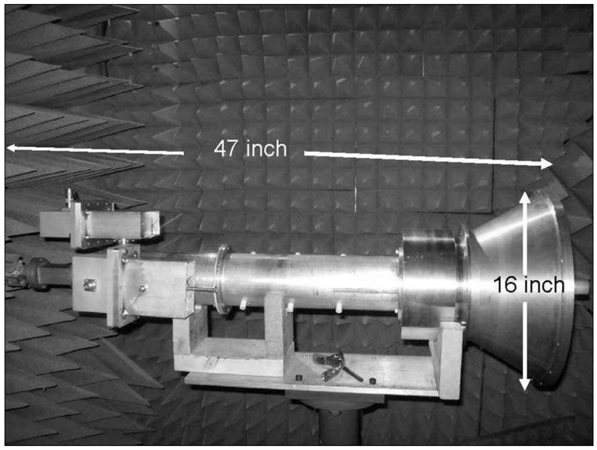

Figure 4. Dual band (S/X) dual polarization feed horn. Designed by Patriot Antennas.

4. Co-located Facilities

New Zealand's traditional role in contributing to global reference frame determination is through its GNSS PositioNZ network operated by Land Information New Zealand in a partnership with the Geological and Nuclear Sciences Research Institute (GNS Science) . The PositioNZ network consists of 33 GNSS continuously operating reference stations (CORS) in mainland New Zealand, one on the Chatham Island (400 km east of Christchurch) and three in Antarctica [4]. Data from several of these sites are forwarded to the International GPS Service (IGS) where they are incorporated into solutions used to determine GNSS satellite orbit and global reference frame determinations.

In November 2008 a new PositioNZ station was built at the AUT radio telescope site, and an accurate tie will be made between the radio telescope antenna and the GNSS antenna. Data from this site will also be forwarded to the IGS, where it will be used to enhance global reference frames, along with the data from the VLBI station. The data will also contribute to an International Association of Geodesy (IAG) initiative to establish a Global Geodetic Observing System (GGOS).

In order to determine and survey an accurate position for the invariant point of the antenna (the intersection of the azimuth and elevation axes), four geodetic monuments have been built in the vicinity of the antenna (15-20 m from its pedestal). They will also be used to accurately determine the space vector (and its covariance matrix) between the reference center of the radio telescope and the GNSS antenna's phase center. The expected linear accuracy of the invariant point position is 1 mm.

5. Network Connectivity

With wide spread development of e-VLBI, the issue of broadband network connectivity becomes essential for both existing and emerging radio astronomical facilities.

Internationally, New Zealand's major broadband supplier is Southern Cross Cables Ltd—a commercial organization, which owns and operates the cable connecting New Zealand with Australia in the west and with the U.S. in the south-north direction. This is a multi-wavelength cable with the capacity of several hundreds of Gbps.

Another networking company, Kordia, is planning to lay a 2 Tbps fiber between New Zealand and Australia in 2010.

Locally, the regional advanced network operating in New Zealand is KAREN (Kiwi Advanced Research and Education Network), which provides 10 Gbps connectivity between New Zealand's educational and research institutions. Currently KAREN is planning to establish a GigaPoP in Warkworth, which will provide the connection for the radio telescope. The last mile connection between the radio telescope and Warkworth (5 km) will be provided by Telecom via the cable that already exists between the Satellite Station and the township of Warkworth.

6. Education

The radio telescope will be operated by the AUT Institute for Radiophysics and Space Research (IRSR). Being a research tool for astronomy and geodesy, the antenna will also be used in a new educational program in astronomy just started at AUT's School of Computing and Mathematical Sciences—an Astronomy Major in the framework of the Bachelor of Mathematical Sciences degree. It is envisaged that both undergraduate and post-graduate students will use the radio telescope in their research projects and as a teaching resource in the courses taught at AUT, such as Astrophysics, Radio Astronomy, Practical Astrophysics, Space Geodesy, and others.

References

[1] Niell, A. et al., VLBI2010: Current and Future Requirements for Geodetic VLBI Systems. Report of Working Group 3 to the IVS Directing Board. 2005.

[2] Gulyaev, S., Natusch, T., Tingay, S. and Deller A. Development of New Zealand radio astronomy and Trans-Tasman long-baseline array. Southern Stars, Vol. 44, No. 4, pp. 12–18, 2005.

[3] Gulyaev, S., Natusch, T., Tingay, S., Deller, A., West, C., Ellingsen, S., McCulloch, P., Reid, B., Baynes, E. and Tzioumis, T. First steps towards radio astronomy in New Zealand. ATNF News, Issue 58, 2006.

[4] www.linz.govt.nz/positioNZ