Publications of the Astronomical Society of Australia (PASA)

doi: 10.1017/pas.2014.xxx.

Conversion of New Zealand's 30 metre Telecommunication Antenna into a Radio Telescope

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Abstract
We describe our approach to the conversion of a former 100-foot (30-m) telecommunication antenna in New Zealand into a radio telescope. We provide the specifications of the Earth Station and identify the priorities for the conversion. We describe implementation of this plan with regards to mechanical and electrical components, as well as design of the telescope control system, telescope networking for VLBI, and telescope maintenance. Plans for RF, front-end and back-end developments based on radio astronomical priorities are outlined.

Keywords: Antenna – Conversion – Radio Telescope – VLBI – IVS – LBA – Methanol – Maser

1 INTRODUCTION

In 1984 the 100-foot (30-m) Earth Station was designed and built by NEC Corporation, Japan for the New Zealand Post Office approximately 5 km south of the Warkworth township in North Island New Zealand. From 1987 the operation of this facility was assumed by Telecom New Zealand (formed out of the telecommunications division of the New Zealand Post Office, a Government department) until 2010. Where upon it was transferred to the Institute for Radio Astronomy and Space Research (IRASR) of Auckland University of Technology (AUT) by Telecom New Zealand as reported in New Zealand media (Cellular News 2010) (Keall 2010) for conversion to a radio telecope. By this time IRASR already operated a 12-m radio telescope at the Warkworth Radio Astronomical Observatory (WRAO), which was launched in 2008.

The WRAO is located 60 km north of Auckland and 5 km south of township of Warkworth (Figure 1). Geographic coordinates for the 30-m antenna are Latitude: 36° 25' 59" S, Longitude: 174° 39' 46" E and Altitude: 90 m. Figure 2 shows a panorama of the WRAO; horizontal distance between 12-m (left) and 30-m (right) antennas is 188 m.

There are now several operational converted satellite communication antennas such as the 30-m dish at Ceduna in Australia (McCulloch et al. 2005) and the 32-m Yamaguchi antenna in Japan (Fujisawa et al. 2002). Recently there has been reporting of the conversion of former satellite communication antennas in Africa (Nordling 2012) (Perks 2012) (Gaylard et al. 2012) to produce an African VLBI network and also to extend the baselines with the European VLBI Network (EVN). Some of these former satellite antennas in Africa such as Kuntunse, Ghana are very similar to the Warkworth 30-m in design and structure. There are also similar

Figure 1. Geographic location of WRAO. The insert shows a map of New Zealand's North Island with location of WRAO. (Google Earth)

Figure 2. Shows a panorama of the WRAO: 12-m radio telescope is on the left, 30-m is on the right. (Image courtesy of Sergei Gulyaev)

Figure 3. Photos of the 30-m antenna (after cleaning). (Images courtesy of Stuart Weston)

projects in Great Britian with the former earth station at Goonhilly, UK (Heywood et al. 2011) and in the Republic of Ireland (Gabuzda et al. 2005) which also would enhance the resolution and *uv*-coverage for eMERLIN and EVN.

We first reported our activity in Physics World (Weston 2012) and a subsequent progress summary was reported in the International VLBI Service for Geodesy & Astrometry (IVS) 2012 annual report (Weston et al. 2013). It is now possible to provide a more detailed report about this antenna conversion, as the antenna is now fully stearable and able to operate in C-Band with an un-cooled receiver.

In Table 1 are presented the original specifications of the Earth Station according to the manufacturer‘s (NEC) handbook. Photos of the 30-m antenna (after cleaning) are provided in Figure 3 (these can be compared with the state of the dish before cleaning in Figure 9).

2 PLAN FOR CONVERSION

The plan for the antenna conversion was discussed, and, after a thorough inspection of the facility, it was decided the first step should be to bring the telescope up to the required mechanical performance by replacing motors, cables, drive and the control system.

It was decided further that the next step should be installation of a new C-band receiver using the existing feed system if possible. The receiving system would have to include a noise-diode switching calibration and phase-calibration systems, total-power back-end, VLBI recorder system and some form of auto-correlator.

After these steps are fulfilled, the telescope pointing and sensitivity measurements would have to be conducted.

In order to decide whether the telescope can operate outside C-band, measurements of the main reflector surface would have to be conducted. We hoped that the surface profile would indicate the opportunity to perform at higher frequencies, ideally up to 22 GHz (see Section 4).

It was planned that initially, the telescope would operate as a Methanol machine (6.7 GHz), both in VLBI and single-dish modes. In addition, we considered the possibility to operate in the 6 GHz Hydroxyl maser line and in the wider C-band continuum.

Assuming that the surface is good and that a 6 GHz receiver is already in use, it was suggested that the next steps would include equipping the telescope with other receivers such as L-Band, S/X Band (for geodetic VLBI as well as science with the Australian Long Baseline Array), and K-Band receivers for VLBI and single-dish observations. These additional receivers would probably have to be mounted above the primary surface at the secondary focus to avoid the use of the beam-waveguide.

We discuss possible science with the New Zealands 30m radio telescope in Section 7.

3 IMPLEMENTATION OF THE CONVERSION PLAN

A line drawing of the antenna is shown in Figure 4. On a detailed inspection of the 30-m antenna, it became clear that the following work had to be done towards its conversion to a radio telescope:

- Change the Azimuth limits so that the antenna could move ±270 degrees instead of the original ±170 degrees
- Change cables and motors
- Change the control system
- Clean the surfaces for the antenna and supporting system
- Treat rusty surfaces and change rusty bolts
- Change the antenna RF system from the specified frequency range to radio astronomically important frequencies

3.1 Cableveyor, cables and motors

To change from the original Earth Station ±170 degrees motion in Azimuth to radio astronomical ±270 degrees,

PASA (2014)
doi:10.1017/pas.2014.xxx

Table 1 Specifications of the Earth Station according to the manufacturer's (NEC) handbook.

Description	Detail
System	Alt-azimuth, wheel-and-track, Cassegrain, beam-waveguide antenna
Drive system	Electric-servo, dual train for antibacklash
Transmission frequency band	C-Band
Reception frequency band	C-Band
Primary mirror diameter	30.48 m
Subreflector diameter	2.715 m
Azimuth Maximum Slew Speed	0.3 deg/sec or 18.0 deg/min
Elevation Maximum Slew Speed	0.3 deg/sec or 18.0 deg/min
Max Acceleration/deceleration in both axes	0.2 degree/second
Azimuth Working Range (as defined by soft limits)	-170 to 170 deg
Elevation Working Range (as defined by soft limits)	0 to 90 deg
Surface accuracy (rms)	0.4 mm
Track diameter	16.97 m
Total weight on track	268 tons
Wind speed in tracking operation	up to 40 m/s
Survive wind speed in stow position	up to 70 m/s

conversion of the cable wrap mechanism (cableveyor) was necessary. Increase in Azimuth motion meant that most of the cables had to be longer, in some cases significantly longer, which resulted in the necessity of changing all cables. It was also decided that the original old NEC motors (one of the original elevation motors is shown in Figure 5) should be changed to brushless permanent magnet servo motors to allow the bi-directional 0 to 3000 rpm drive systems required for astronomical operation. A change of motors was also dictated by safety issues due to the very rusty condition of their outside shell.

Figure 5. The state of the old motors was very poor and was considered a safety issue. (Image courtesy of Stuart Weston)

3.1.1 Position encoders

Azimuth. The azimuth position encoder is installed under the floor of the cable wrap room and is driven by a 600 tooth gear wheel attached to the outer wall of the RF feed housing. The 600 tooth gear engages a composite 30 tooth gear, two gears on the same shaft one fixed to the shaft and the other free on the shaft but attached to the other gear through a spring to eliminate backlash. This gives a 1 to 20 ratio increase to the primary shaft.

In the original NEC system the primary shaft drove two resolvers through a series of gears, one at the primary shaft speed and the other revolves at 45 times the primary shaft speed. The replacement system called for a single encoder directly driven at the primary shaft speed. The primary shaft is supported by two precision ball races, a 10 mm internal diameter at the gear end and an 8 mm internal diameter at the other end. The shaft terminated flush with the 8 mm ball race. A new shaft was machined from a M16 stainless steel bolt which allowed the 8 mm end to extend sufficiently through the ball race to attach a coupling. An 8 mm to 10 mm coupling was machined allowing the new encoder to be coupled directly to the primary shaft. An additional mounting plate, for the new encoder is added behind the original resolver mounting plate. All this fitted within the original housing.

Elevation. As in the Azimuth position encoder, NEC used a two resolver system again with one at primary shaft speed and the other at 45 times primary shaft speed. Also as in the Azimuth position encoder, a single encoder was called for requiring a new primary shaft to be machined again with an extension on the end to

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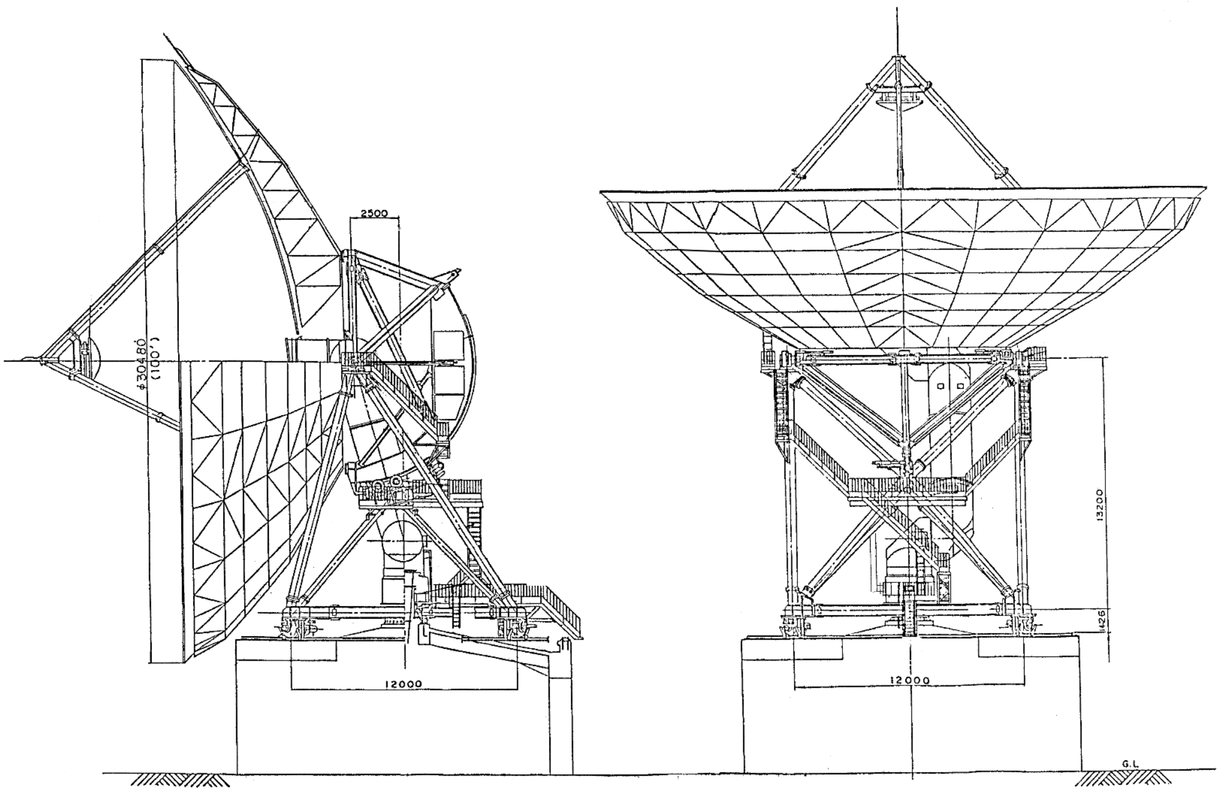

Figure 4. Line drawing of the Warkworth 30-m radio telescope - based on a modified NEC drawing,1984

allow direct coupling to a single turn encoder through an 8 mm to 10 mm coupling. Again all within the original housing.

3.1.2 Limit Switches

Azimuth. In the original installation the Azimuth limit switches were mounted under the floor of the cable wrap room requiring wiring to be passed through the cable wrap. The original switches, after servicing were re-installed in a position under the cable wrap room ceiling and are fixed to the central RF Feed Housing eliminating the need for the cable to pass through the cable wrap and allowing easy access for adjustment (as can be seen in the right hand image of Figure 6).

Elevation. The original Elevation limit switches were serviced and re-installed in the same position as previously installed by NEC.

Figure 6. Photos of the Azimuth Emergency limit switch arrangement.The left photo shows the pully arrangement, and the right photo is the cord playout around the inside of the cable wrap room ceiling. Also in the second image on the left hand side can be seen the new mounting position of the Azimith limit switch. (Images courtesy of Stuart Weston)

3.1.3 Emergency limit switches

These switches are fitted into the "Emergency Stop" circuits and open the main power contactor to the Drive Control Cabinet in the event that the antenna travels outside the mechanical limit switches on either axis.

Azimuth. Due to the requirement that the antenna should operate through ±270 degrees in this axis it is not possible to use switches positioned after the mechanical limit switches. By using a number of pulleys and nylon sail cord a system is created that operates a switch that is mounted on the non-moving central RF Feed Housing with the nylon sail cord attached to the moving antenna structure. As the antenna moves

doi:10.1017/pas.2014.xxx

around, the cord raises a weight which in turn activates the azimuth EMERGENCY LIMIT SWITCH should the antenna travel beyond the mechanical limit switch (see Figure 6).

Elevation. As the Elevation movement is limited to 90 degrees the two original NEC elevation "Emergency Limit Switches" were serviced and restored to their original NEC mounting position.

3.1.4 Azimuth direction of travel switches

These two switches operate a latching relay that provides an indication of direction as the antenna passes through 0 degrees. These switches and the azimuth mechanical limit switches are all activated by the same striker plate mounted on the moving structure of the antenna.

3.1.5 Azimuth cable wrap mechanism

The original cable wrap mechanism allowed the antenna to travel through ±170 degrees, a total of 340 degrees. As the requirement for Radio Telescope operation is ±270 degrees, a total of 540 degrees, a completely new cable wrap mechanism had to be installed. All the original NEC cables were discarded along with the original metal chain.

Twelve screened control cables, six screened power cables, four coaxial cables and one lightning earth cable, a total of 23 cables of varying sizes and weights, had to be routed through a cable chain system.

IGUS, a German company that specialises in plastic energy chains, was approached to provide a suitable design for a replacement to the original NEC chain. Their design was accepted and they then manufactured the chain and the chain carrier system.

The "Energy Chain" system works by using an inner fixed wall and an outer moving wall; both walls are concentric with each other like two metal cans of different diameters with one inside the other. The plastic chain is looped from one wall to the other and unloops / loops depending on the direction of travel, as shown in the drawing Figure 7.

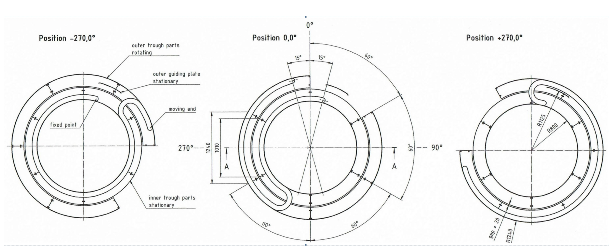

Figure 7. The IGUS Energy chain system. (Drawing by IGUS)

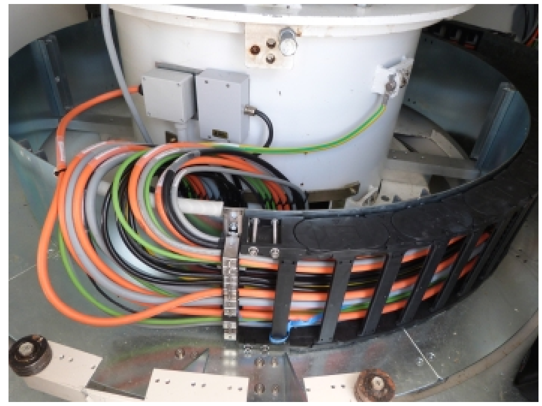

Figure 8. The IGUS Energy chain system in situ. (Images courtesy of Stuart Weston)

Some difficulty was experienced with the chain tending to travel away from the walls when being pushed in the case of the inner wall or being pulled in the case of the outer wall. This is mainly due to the stiffness of the cables going through the tight corner of the loop. The problem was relieved when the chain is wrapping about the inner wall by magnetic strips glued to the chain vertical struts. These have the effect of magnetically holding the chain against the inner wall while being pushed. Unfortunately the same does not hold true with the outer wall as the magnetic strips are not strong enough to work through the thick coat of paint on the outer wall. Some relief is given to the problem when the chain is being pulled with the replacement of the outer guiding plate with a wheeled gantry that has no drag on the chain. The new IGUS chain in situ is shown in Figure 8.

3.2 Control system

The control system that supported the work of the Earth Station was designed to serve the tasks of the telecommunication antenna, which included pointing at geostationary telecommunication satellites with very limited motion/tracking. The new control system had to support radio astronomical tasks with tracking astronomical objects across the sky, quickly changing from one object to another, finding the optimal path from one radio source to another, etc. It had to have a modern interface, work with modern computers and respond to all requirements of modern observational radio astronomy. New parameters of the RT are provided in Table 2 (old parameters in Table 1).

Originally the antenna was fitted with two sets of motors; large (11 kW) induction motors for slewing and small DC servomotors with extra gearing for tracking the small daily motions of geostationary satellites. Two pairs of motors of each type were used on each axis

doi:10.1017/pas.2014.xxx

to apply anti-backlash torque and a system of clutches selected between the slew and track motors.

For tracking over the full speed range of the antenna the large induction motors were replaced with brushless, 55 Nm, AC servomotors with optical shaft encoders. (The old DC servomotors are still present but are permanently disengaged from the drive chain.) There are no longer separate modes for slewing and tracking, and the antenna is always under closed loop position control.

A new optical elevation encoder provides 26 bit resolution with a specified accuracy of better than 5 arc seconds. Careful alignment of the mechanical coupling to the elevation axis should contribute an additional error, small compared to that of the encoder itself.

The original dual resolver arrangement was also replaced by an optical encoder, driven from the azimuth axis via the original 1:20 gears (the encoder rotates twenty times faster than the antenna). This means that the new encoder must be a multi-turn device and the one chosen provides 25 bit resolution with a specified accuracy of better than 20 arc seconds. However, the dominant source of azimuth axis angle measurement error is expected to be the precision and alignment of the gearing which reduces the impact of encoder error by one twentieth. The error contribution from these precision gears is not known but no pointing issues have been reported to date.

The new Integrated Antenna Controller (IAC) is a single enclosure located in the equipment room beneath the antenna that provides all the functionality of motor inverter drives and a high level antenna control unit. The IAC uses only COTS process control hardware and follows a design that has been successfully used on antennas from 1-m diameter and bigger for LEO, GEO, and astronomical tracking applications.

The IAC has an inverter drive for each of the four servo motors and inbuilt drive firmware handles the motor current and speed control loops. However the drives provide extensive capability for user programability and this allows the IAC to run custom software for different antenna control applications. The position control loop algorithms are implemented in these areas, as well as motion controller algorithms specially designed for careful control of the accelerating forces and jerk applied to the antenna structure. With this configuration, all elements of the position control algorithm are synchronous and timing jitter is therefore not a problem. Synchronous communication between drives is another important feature for sending the control demands to the pairs of motors that drive each axis to limit mechanical backlash.

A range of functions specific to use of the antenna as a radio telescope are incorporated in the IAC's application software, including the following:

- Internal clock (set and regulated from network time)
- Pointing Error Correction using a standard nine term error model (?)
- Correction for atmospheric refraction
- Accepts position commands in both the Horizontal (El, Az) and Equatorial (RA, Dec) coordinate system
- Interpolator for tracking from time tagged data (2 x 2000 point arrays)
- Command Scheduler
- Monitoring and diagnostics

The application software and the position control algorithms cycle every 4 ms. Remote communication with the IAC is via a 10/100 Mbps Ethernet interface in optical fibre. Control and monitoring uses the well proved Modbus TCP/IP (Industrial Ethernet) master slave protocol and multiple clients are supported. The antenna can also be driven locally from the IAC for maintenance purposes.

One of the challenges in designing a new control system for this antenna was very limited knowledge of its mechanical characteristics, for example, stiffness, inertias, drive train efficiencies, wind loads, etc. However recommissioning tests showed the system to be stable with a servo accuracy of better than one millidegree under light wind conditions. Further operational experience is awaited regarding wind gust performance but sufficient margin is available to tighten the sytem response further if required.

3.3 Cleaning and maintenance

The structure is only 5 km from the sea on the east, thus salt and corrosion are an issue. NZ Telecom had stopped maintenance some time before passing the dish to AUT as they anticipated demolition. We thus had several years of maintenance to catch up on. Cleaning surfaces and changing rusty bolts were necessary. Figure 9 shows the initial state of the main reflector surface, some panels and the state of some bolts. Since 2012, with a local rigging contractor we have initiated a bolt replacement program and general maintenance/repair of the dish structure. We are now back on top of the maintenance after two summers.

4 SURVEY OF THE MAIN REFLECTOR SURFACES

The quality of the main reflector (MR) surface was investigated with the help of the FARO Laser Scanner provided to us by Synergy Positioning Systems Ltd. The initial scanning was conducted from the ground when the dish was positioned at the Elevation $El = 6$ degrees. Measurement points were generated with 1 mm separa-

Table 2 New parameters after control system replacement.

Description	Detail
Azimuth Maximum Tracking Speed	0.3700 deg/sec or 22.2 deg/min
Elevation Maximum Tracking Speed	0.3600 deg/sec or 21.6 deg/min
Max Acceleration/deceleration in both axes	0.2 degree/second
Azimuth Working Range (as defined by soft limits)	-179 to 354 deg
Elevation Working Range (as defined by soft limits)	6.0 to 90.1 deg

Figure 9. Photos of the 30-m antenna (before cleaning).(Images courtesy of Stuart Weston)

tion on the surface of the MR, with the accuracy of distance measurement of $\sigma = 1$ mm (Chow et al. 2012).

We processed the data and compared the measured surface with a theoretical surface, which was provided to us by Dr Granet of BAE Systems Australia Ltd (Granet 2013). The residuals between the measured surface and the theoretical one were computed, and the result of data processing revealed a noticeable gravitational deformation of the antenna along the vertical direction at the Elevation angle $El = 6$ degrees.

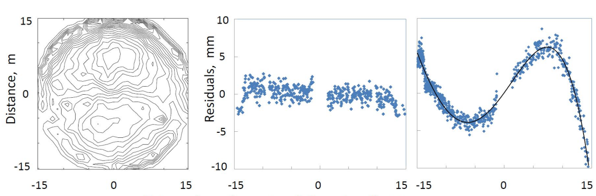

Figure 10. Measurements of the MR surface quality at the lowest elevation angle $El = 6$ degrees: (left) the contours for residuals; (center) the cross-section of residuals through the MR centre along the horizontal direction; (right) same along the vertical direction.

Figure 10 shows measurements of the MR surface quality at the lowest elevation angle $El = 6$ degrees:(left) the contours for residuals; (center) the cross-section of residuals through the MR centre along the horizontal direction; (right) same along the vertical direction.

We found the RMS for all three figures provided in Figure 10. The total RMS (standard deviation) of the surface residuals at $El = 6$ degrees is 3.5 mm (Figure 10, left). The RMS along the vertical cross-section through the MR centre is 5 mm (Figure 10 right). The horizontal cross-section (Figure 10 center) that is not affected by the gravitational deformation demonstrates RMS≈1.0 mm, which corresponds to the antenna specifications (1.5 mm) and the accuracy of the laser scanner (1 mm). A more detailed investigation of the gravitational deformation and its dependence on the antenna Elevation will be provided in a separate paper (in preparation).

5 INSTRUMENTS

5.1 Field System

To maintain consistency and to reduce support effort we have decided on one control and scheduling system for both antennas, this is the Field System (Himwich 2014), although a separate instance is maintained for each. There are differences in such modules as "*antcn*" (The Antenna Control interface program) due to the differences between the antennas in number of motors etc. In addition although the antenna controller has a built in 9 point coefficient pointing model as described in section 3.2 we have selected to use the Field System pointing routines and pointing model (Himwich 1993) due to the automation provided within the Field System for its support and maintenance. In addition it has been well proven with the NASA deep space network. Pointing was initialy performed using a Agilent U2000A RF power meter and the first pointing model was produced. Eventually the DBBC (see Section 5.3) will be used for automated pointing with the FS module "*acquire*" as now used on the 12-m.

As the antenna can take 10-15 minutes to move between northern sources and southern sources, using one pointing catalogue for the field system "*acquire*" mod-

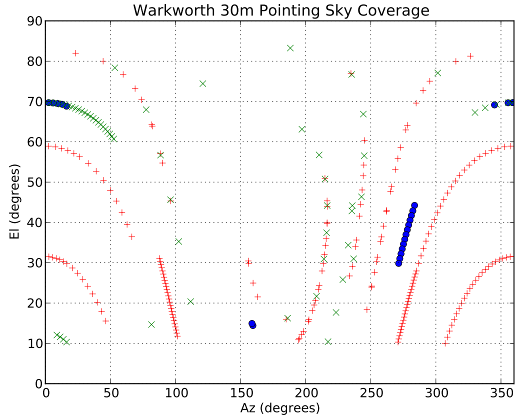

Figure 11. First pointing sky coverage, the symbols are the same from Figure 12. The blue filled circles are before any model; red + for first model; green x current model.

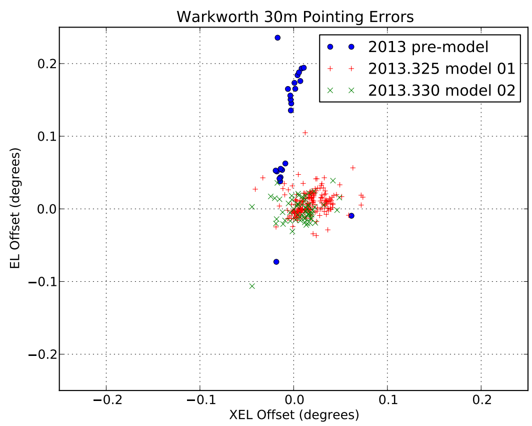

Figure 12. Comparison of the first pointing, over several days in 2013 building new models using the Field System "acquire" and "fivpt". This is a plot of the EL and XEL offsets in degrees: blue filled circles are before any model; red + for first model; green x current model.

ule was not time efficient as much time would be lost in moving and the sky coverage in a 24hr period would be very sparse. So we adopted an approach where the pointing catalogue was broken up into two, one containing northern sources and the other southern sources. A short northern pointing was run to determine some of the basic offsets and coefficients, then northern and southern pointing catalogues where run in sequence for one quarter of a 24hr period producing the sky coverage shown in Figure 11 with the red +'s. A third run was conducted to verify the offsets and coefficients produced from the second pointing sequence. The results from each pointing run are shown in Figure 12 and demonstrates the iterative refinement of the model, the final model produced RMS values in Elevation of 0.020 degrees and Cross Elevation of 0.0186 degrees.

Once the DBBC is ready and configured to be used by the Field System for pointing this will be repeated to refine the model yet further in an iterative sequence, also to monitor and see if we have any drift in either elevation or azimuth offsets.

5.2 Receiver

The radio telescope is equipped with a beam waveguide bringing the signal down into a feed horn system within the building underneath the telescope. Originally this had a satellite C-Band send and receive system. This has been removed and a new feedhorn transition unit manufactured by BAE Systems Australia has been installed to match an uncooled C-Band receiver from Jodrell Bank (shown in Figure 13 formerly on the Mk IV) to the existing waveguide.

Figure 13. The C-Band receiver with the new feedhorn transition unit manufactured by BAE Systems Australia. (Image courtesy of Stuart Weston)

The C-band is premixed to down convert the RF into a range that meets the input specification of the DBBC analogue to digital modules as described in Section 5.3.

5.3 Digital Base Band Converter

We already had a Digital BaseBand Converter (DBBC) (Gino et al. 2010) which has been developed for IVS VLBI2010 (Petrachenko et al. 2010) for use on the 12-m antenna primarily used for geodetic VLBI. The DBBC replaces the VLBI terminal used elsewhere with a complete and compact system that can be used with any VSI compliant recorder or data transport. It consists of four modules each with four RF inputs, these can receive input in the ranges 0.01-512, 512-1024, 1024-1536, 1536-2048 MHz and 2048-2100 MHz. Upon each IF input one is RCP the default used by IVS and input two to receive LCP leaving two additional inputs currently unused and terminated. Support for the DBBC from the Field System was originally developed locally to allow control and programming within a schedule prepared via SCHED, but is now supported in the later releases of the Field System 9.11.5.

5.4 Recorder

The recording system is a Mark5B (Whitney 2006) connected to the DBBC via the VSI interface. These units are purpose built for VLBI but we have also used these for recording single dish experiments. A separate standalone Mk5C has also been obtained for etransfers of the data to the end user or correlator, thus not tying up the recording unit with data transfers preventing further observations.

6 WARKWORTH OBSERVATORY

6.1 Site Survey and tie to the GNSS station

Figure 14. Collocated space geodesy facilities: the GNSS base station WARK and the IVS network station WARK12M (12m radio telescope). (Image courtesy of Sergei Gulyaev)

An important part of the 30-m antenna science case is space geodesy and participation in geodetic projects such as AuScope and IVS. A GNSS base station WARK is part of IGS global network and is collocated with the 12-m geodetic antenna as shown in Figure 14. The tie survey of 12-m and GNSS station was conducted by the Land Information NZ (LINZ) in the end of 2012 (Gentle et al. 2013). A plan for geodetic survey of the 30-m antenna is under discussion with LINZ.

The WRAO has a Symmetricom Hydrogen maser clock as the primary time and frequency standard (Natusch & Gulyaev 2009), housed in a temprature controlled environment near the 12m antenna. The time and frequency standard are transferred from the maser using a Symmetricon fibre-optic distribution amplifier across to the 30-m using the fibre link between the two antenna, in the 30-m is a fibre-optic receiver to regenerate these standard signals for use by equipment in the 30-m building.

6.2 Networking

It is envisaged that the 30-m radio telescope will actively participate in VLBI and eVLBI observations. It means that the issue of data transfer becomes high priority. To provide a high speed data transfer REANNZ (Research and Education Advanced Network NZ) originally installed a 1 Gbps point of presence (Giga-PoP) at the WRAO.

From the 28th April 2014 the network to the observatory was upgraded from 1 Gbps to 10 Gbps, with the upgrade of the REANNZ international links to 40 Gbps (Sargeant 2014) later in the year it is hoped that we can conduct eVLBI at 1 Gbps or greater (16 channels each with 16 MHz bandwidth and 2 bit resolution).

7 SCIENCE WITH THE NZ 30-m RADIO TELESCOPE

First-class radio astronomy research both in single-dish and VLBI modes can be undertaken with the 30-m antenna in Warkworth following appropriate telescope refurbishment and receiver installation. Frequencies of operation from 1.3 GHz to 22 GHz (and possibly higher) can be used for various types of astronomical and geodetic research. The telescope will be a valuable addition to the LBA, to Asia-Pacific and European VLBI networks, as well as to IVS depending on available frequencies of operation. For example, the geodetic IVS observations would require simultaneous S and X band, and possibly Ka-band capabilities.

7.1 VLBI Observations

In the VLBI mode, the 30-m radio telescope can be used both in continuum and spectral line observations.

In continuum observations, it can be involved in study of AGNs and their jets, ultra-luminous IR galaxies, starburst galaxies and gravitational lenses. In extra-galactic astronomy, objects of particular interest are compact steep-spectrum sources, jets, superluminal expansions, individual supernovae and their expansions, HII regions in starburst galaxies, and supernovae in AGNs such as ARP220 type of objects. For galactic sources, areas of special interest include light-curves and images of expansions of recurrent novae, micro-quasars and transients.

VLBI spectral line observations will mainly include 21-cm hydrogen line, OH maser lines at 1.6 GHz, methanol maser line at 6.7 GHz and the 22 GHz water maser line.

For the 21 cm HI line, areas of interest are study of hydrogen in absorption in galaxies at intermediate/low

doi:10.1017/pas.2014.xxx

redshifts, study of small-scale structures of neutral hydrogen in our Galaxy through observation of HI absorption in continuum spectra of extra-galactic sources.

Observations in four OH maser lines at 1.6-1.7 GHz (1612, 1665, 1667 and 1720 MHz) will encompass both extra-galactic sources (OH megamasers and their variability) and Galactic objects, such as star-forming regions, AGB stars and Mira variables, including measurements of magnetic fields in these objects based on Zeeman effect.

Observations of the 6.7 GHz methanol maser line will be used to study star formation regions in the Galaxy, expanding methanol shells, time variability of methanol sources and magnetic field measurements, follow-up observations of maser sources discovered in Parkes multibeam survey.

In addition 22 GHz water maser observations will be important for study of extra-galactic sources, in particular, Doppler measurements of water masers to estimate masses of supermassive black holes in other galaxies. Observations of Galactic water masers in star-forming regions, semi-regular variable stars and AGB stars will provide information on their kinematics (expansion velocities either bipolar or circular) and molecular abundances.

7.2 Single-Dish Observations

In addition to the contribution this instrument can make with VLBI, it is a valuable instrument in its own right for single-dish observing with a six fold increase in collecting area over the existing 12-m Warkworth antenna. Subject to suitable receivers being available it can be used for the following.

In L-Band continuum observations can include pulsar timing and polarisation, solar wind and interplanetary scintillations (IPS) measurements from total power observations in conjunction with other individual telescopes, as well as contribution to physics of interstellar matter (ISM), e.g. Hll region temperature and density measurements.

The same objects as for L-Band can also be studied in C-Band continuum, but, in addition, light curves of recurrent novae, symbiotic variables, micro-quasars and transients.

Using almost unlimited integration time opportunities, important studies of radio recombination lines of hydrogen, helium and carbon can be conducted in all available wavelengths. They can be used to study parameters of Hll regions (including planetary nebulae and ultracompact HII regions), their densities, temperatures, dynamics and abundances, in particular, objects not accessible with the northern hemisphere radio telescopes.

Maser spectral line observations in a single-dish mode will include 1.6 GHz OH lines in outbursts and monitoring of light curves of OH masers from semi-regular and other variable stars, as well as measurement of magnetic fields from Zeeman effect.

In C-band, spectral line observations of OH maser lines at 6030 and 6035 MHz and methanol masers at 6.7 GHz are important for the identification and study of star-forming regions. For example, existence of methanol masers often indicates the presence of a star-forming region, when it might otherwise not be visible. The 30-m radio telescope in New Zealand can be effectively used for monitoring of variability of methanol maser sources found by the Parkes multi-beam survey.

The single-dish spectral observations of the 22 GHz water maser will include monitoring of (and discovery of outbursts in) star-forming regions, AGB star envelopes and semi-regular variable stars. Another important study can be conducted in 23 GHz ammonia lines of which little work has been done to date as it requires long integration times.

8 CONCLUSION

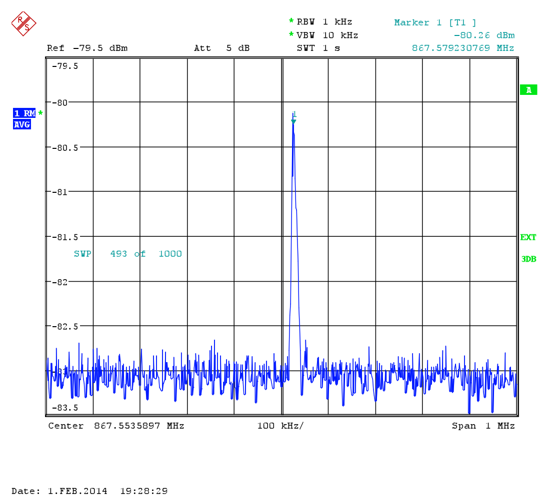

Figure 15. The "First Light": the spectrum of the galactic Methanol Maser source G188.95+0.89 near 6.7 GHz.

The First Light of the Warkworth 30-m radio telescope took place on the 4th July 2014, Figure 15 shows the first spectrum of a galactic methanol maser source.

This 30-m antenna with a large surface area adds significantly to New Zealand‘s capability in radio astronomy and is a highly sensitive instrument capable of significant single dish work. In addition, the inclusion of the Warkworth 30-m antenna will greatly enhance the LBA with its improved sensitivity on the end of its longest baselines, as well as partnering with other Asia-Pacific antennas.

Significant amount of work has been done during the last few years in order to convert the telecommunication antenna into the radio telescope capable of conducting important research in astronomy and astrophysics. Significant changes had to be introduced into mechanical, electrical and electronic systems of the facility which will allow professional radio astronomical operations both in single-dish and VLBI modes.

Further investigation of gravitational deformation of the main reflector surface quality is required in order to clarify the capability of the telescope at the cm and mm wavelengths.

Next step on the improvement of radio telescope sensitivity and enhancing its capabilities and usage will include installation of a cryogenically cooled C-band receiver. Solutions for the S and X bands capabilities, and possibly lower (L-band) and higher frequency (K-band) solutions will be sought. The S and X receivers if implemented, will allow using the 30-m radio telescope for geodetic research in cooperation with the International VLBI Service for Geodesy and Astrometry (IVS), AuScope, Geoscience Australia and Land Information New Zealand.

The Warkworth Radio Astronomical Observatory is operated by the AUT University where the Astronomy Major was introduced at the School of Computer and Mathematical Sciences in 2010. The Observatory plays an important role in preparation of both undergraduate and post graduate students being used as a polygon and facility for laboratories and students research projects.

The staff and postgraduate students of the Institute for Radio Astronomy and Space Research are involved in the design work of the Square Kilometre Array, mainly in its Central Signal Processor and Science Data Processor work packages. Potentially, the observatory and its facilities, including it supercomputing centre can be used as the testbed for some of the SKA design work conducted in New Zealand.

9 ACKNOWLEDGEMENTS

We would like to thank the many parties that have made this conversion possible undertaking many vital tasks. This is not an exhaustive list but includes NZ Telecom; BAE Systems, Australia; Australia Telescope National Facility which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

Stuart Weston is a recipient of a CSIRO Astronomy & Space Science, Australia Telescope National Facility Graduate Research Scholarship.

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