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Conversion of New Zealand's 30m 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 – New – Zealand – VLBI – IVS

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 approximatly 5km 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 2). Geographic coordinates for the 30-m antenna are Latitude: 36° 25' 59" S, Longitude: 174° 39' 46" E and Altitude: 90 m. Figure 1 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 30m at Ceduna in Australia (McCulloch et al. 2005) and the 32m Yamaguchi antenna in Japan (Fujisawa et al. 2002).

Figure 1. Shows a panorama of the WRAO: 12-m radio telescope is on the left, 30-m is on the right.

Figure 2. Geographic location of WRAO. The insert shown a map of New Zealands North Island with location of WRAO. (Google Earth)

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

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 30m in design and structure. There are also similar 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 manufacturers (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 6).

2 PLAN FOR CONVERSION

First bring the telescope up to a required mechanical performance by replacing motors, drive and control system etc. as necessary. Install a new C-Band receiver and feed system as necessary (including noise-diode switching calibration and phase-calibration systems), total-power back-end, VLBI recorder system and some form of auto-correlator. Determine if the frequency range can cover the whole 4.7 GHz to 6.7 GHz range with the waveguide, this would be a great advantage, otherwise might initially have to use the current range. Determine telescope pointing and sensitivity, and measure surface profile. The sufrace profile should also indicate the expected performance level at 22 GHz.

Then use the telescope for C-Band VLBI and single-dish programmes, preferably to include 6.7 GHz methanol and 6 GHz hydroxil maser observations (This may have to be delayed initially if the receiver + feed does not cover the 6 GHz frequency range). Continuum observations of a number of variable sources should also provide a number of publications and experience in using the telescope.

Finally assuming that the surface is good and that a 6 GHz receiver is already in use, equip the telescope with with other receivers such as L-Band, S/X Band (for geodetic VLBI as well as science with the Australian Long Baseline Array [LBA]), and K-Band receivers for VLBI observations and single-dish. These additional receivers will have to be mounted to avoide the use of the waveguide.

3 IMPLEMENATION OF THE CONVERSION PLAN

On a detailed inspection of the 30m antenna, it became clear that the following work had to be done towards its conversion to 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, 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 had to be changed to modern more economic and powerful motors. A change of motors was also dictated by safety issues due to the poor condition of their outside shell being very rusty.

Table 1 Specifications of the Earth Station according to the manufacturers (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 Speed	0.3 deg/sec or 18.0 deg/min
Elevation Maximum 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

Figure 4. The state of the old motors was very poor and where considered a safety issue.

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 8mm 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 with in 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 allow direct coupling to a single turn encoder through an 8 mm to 1 0mm 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 where reinstalled 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.

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

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

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, five screened power cables, four coaxial cables, one unscreened power cable 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.

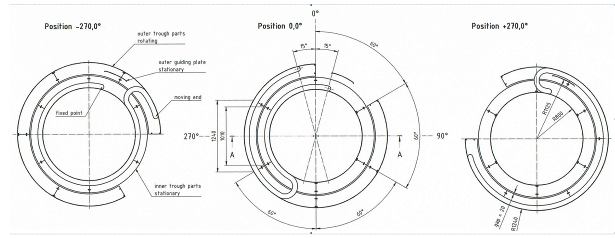

Figure 5. The IGUS Energy chain system. Drawing by L. Woodburn

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.

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 (11kW) 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 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,

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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 via 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 [reference]
- 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 was necessary. Figure 6 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 separation on the surface of the MR, with the accuracy of distance measurement of $\sigma = 1$ mm (Chow et al. 2012).

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Table 2 New parameters after control system replacement.

Description	Detail
Azimuth Maximum Speed	0.3700 deg/sec or 22.2 deg/min
Elevation Maximum 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 6. Photos of the 30-m antenna (after cleaning). Images courtesy of Stuart Weston

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 when it had Elevation $El = 6$ degrees.

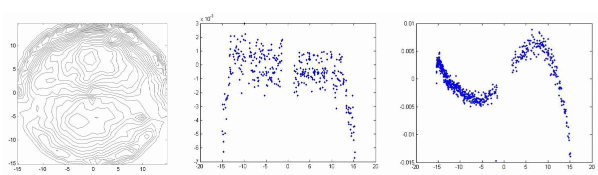

Figure 7. Measurements of the MR surface quality at the lowest elevation angle $El = 6$ degrees: (left) the contours for residuals; (center) the cross-section of residuals through the MR centre along the horizontal direction; rightc) same along the vertical direction. All axes are in meters

Figure 7 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 7. The total RMS (standard deviation) of the surface residuals at $El = 6$ degrees is 3.5 mm (Figure 7, left) TheRMS along the vertical cross-section through the MR centre is 5 mm (Figure 7 right) The horizontal cross-section (Figure 7 center) that is not effected by the gravitational deformation demonstrates RMS 1.5 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 preperation)

5 INSTRUMENTS

5.1 Field System

To maintain consitency 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 seperate 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, aventually the DBBC (see Section 5.3) will be used for automated pointing with the FS module "*aquire*" as now used on the 12m.

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*" module was not time efficient as much time was lost in moving and the sky coverage in a 24hr period would be very sparse. So we addopted an approach where the pointing catalogue was broken up into two, one containing northern sources and the other southern sources. Each was then run in sequence for one quarter of a 24hr period. Producing the sky coverage shown in Appendix A Figure A1.

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. Originaly this had a satellite C-Band send and receive system, this has been removed and a new feedhorn transition unit manufactured by BAe Systems Austrlia to match a uncooled C-Band receiver from Jodrell Bank (shown in Figure 8 formally on the Mk IV) to the existing waveguide.

The C-band is pre-mixed 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.

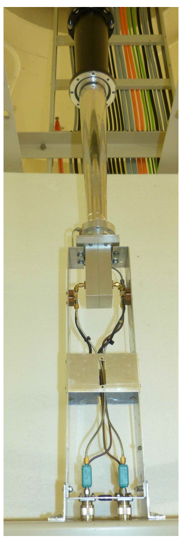

Figure 8. The C-Band receiver.

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 12m 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 originaly 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.

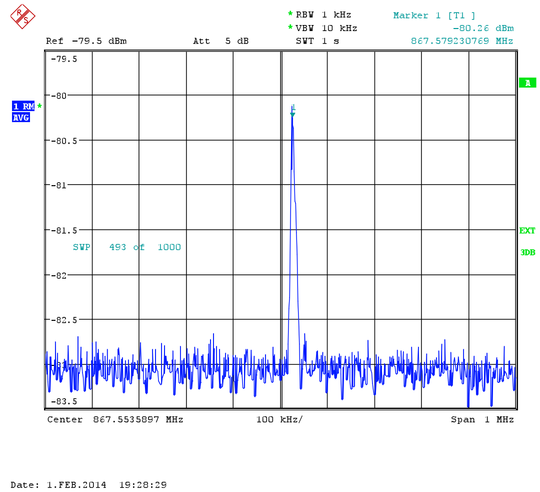

Figure 9. First spectra of Methanol Maser G188.95+0.89.

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 seperate standalone Mk5C has also been obtained for etransfers of the data to the end user or correlator, thus not tiying up the recording unit with data transfers preventing further observations.

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6 WARKWORTH OBSERVATORY

6.1 Site Survey and tie to the GNSS station

Figure 10. Collocated space geodesy facilities: the GNSS base station WARK and the IVS network station WARK12M (12m radio telescope)

An important part of the 30m antenna science case is space geodesy and participation in geodetic projects such as AuScope and IVS. A GNSS base station WARK is a part of IGS global network. It is a station that is collocated with the 12m geodetic antenna (Figure 6). The tie survey of 12m and GNSS station was conducted by the Land Information NZ (LINZ) in the end of 2012 [Sergei - reference]. A plan for geodetic survey of the 30m antenna is under discussion with LINZ.

6.2 Networking

It is envisaged that the 30m 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) provided a 1Gbps 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) latter in the year it is hoped that we can conduct eVLBI at 1Gbps or greater (16 channels each with16MHz bandwidth and 2bit).

7 SCIENCE WITH THE NZ 30m RADIO TELESCOPE

First-class radio astronomy research can be undertaken with the 30m antenna at Warkworth following appropriate telescope refurbishment and receiver installation. Frequencies of operation from 1.3 GHz to 22 GHz (possibly higher) can be used for various types of astrophysical, astronomical and geodetic observations.

7.1 VLBI

The NZ 30m Radio Telescope can be a valuable addition to the LBA, to Asia-Pacific (Chine, Korea, Japan, South and North America) VLBI, as well as to European VLBI network EVN and the global geodetic network (IVS) depending on frequencies of operation. for example, the geodetic (IVS) observations would require a dual S and X receiver, and possibly Ka capability in the future.

We envisage that, when equipped with additional receving systems, the NZ 30m radio telescope will contribute to both VLBI and single-dish observations.

In the VLBI mode, this instrument can be used in the following important research areas:

<u>L-Band continuum</u>: There is so much to look at here that it would take several pages to describe even very briefly. For example, study of Extra-galactic continuum sources (AGNs, Quasars, Ultra-luminous Infrared galaxies, Starburst Galaxies, Gravitational Lenses). E.g. Compact Steep-Spectrum sources, jets, superluminal expansions, individual supernovae and their expansions in starbursts, supernovae in AGNs such as ARP220 type of objects, distance scale from variable gravitational lenses (Ho) etc. Galactic sources (Light curves and images of expansions of Recurrent novae, micro-quasars, transients etc.)

<u>L-Band radio lines</u>: The 21cm neutrol hydrogen (HI) spectral line in external galaxies at intermediate/low redshifts; Small-scale structure of hydrogen in the Galaxy from Hl absorption of the continuum from extragalactic sources. Observations of 1.6 GHz hydroxyl (OH) maser can be conducted in four spectral lines (1612 MHz, 1665 MHz, 1667 MHz and 1720 MHz). Both galactic and extra-galactic sources of OH can be studied. Here we just mention OH megamasers and their variability (in other galaxies), star-forming regions in our galaxy, ABG stars, Mira variables, magnetic fields from Zeeman effect in all of above etc.

<u>C-Band continuum</u>: Observations can include all L-Band continuum topics if interest, but also ~ 55 GHz As for 1.4 GHz continuum observations, but also Hll regions in starburst galaxies, gamma-ray bursters.

<u>C-Band spectral lines</u>: Include first of all, 6.7 GHz Methanol masers in star-forming regions in the Galaxy; expanding methanol shells; time variability; magnetic fields; follow-up of masers discovered in the Parkes multi-beam survey.

7.2 Single-Dish

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

L-Band: 1.4 GHz Continuum and Pulsar timing and polarisation; solar wind (IPS) measurements from total power observations in conjunction with other individual telescopes; Hll region temperatures and densities; 1.6 GHz OH lines; outbursts and monitoring of light curves of OH masers from semi-regular and other variable stars; measurement of magnetic fields from Zeeman effect; H and C Recombination Lines at ~ 51.6 GHz; physical parameters of Hll regions (densities, temperatures and abundances)

C-Band: 5 GHz continuum as for 1.6 GHz continuum, but not pulsar observations; also light curves of recurrent novae, symbiotic variables, micro-quasars and transients etc; H and C Recombination lines at $\sim$ 5GHz; as for 1.6 GHz lines; ~ 6 GHz OH6030, OH6035 and methanol masers important for the identification and study of star-forming regions (Existence of methanol masers often indicates the presence of a star-forming region, when it might otherwise not be visible); monitoring of variability of methanol maser sources found by the Parkes multi-beam survey.

K-Band: 22 GHz water maser; monitoring of (and discovery of outbursts in) star-forming regions, AGB star envelopes, semi-regular variable stars etc; 23 GHz ammonia lines of which little work done to date as requires long integration times.

Radio recombination lines: With a dish of this capability it should be able to undertake the study of RRL's across all of the above bands.

8 CONCLUSION

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

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A INITIAL POINTING SOLUTION

Have two plots - Sky Coverage, and El vs XEL offsets before and after

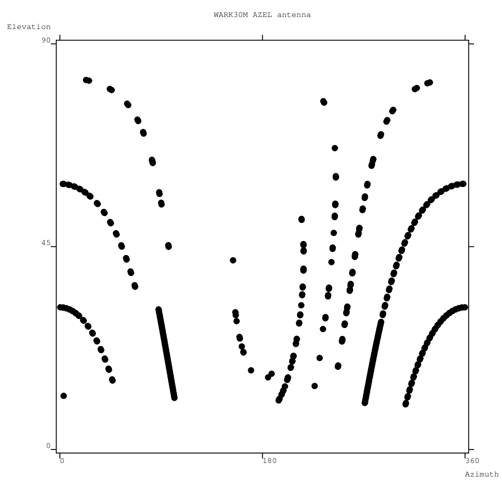

Figure A1. First pointing sky coverage.

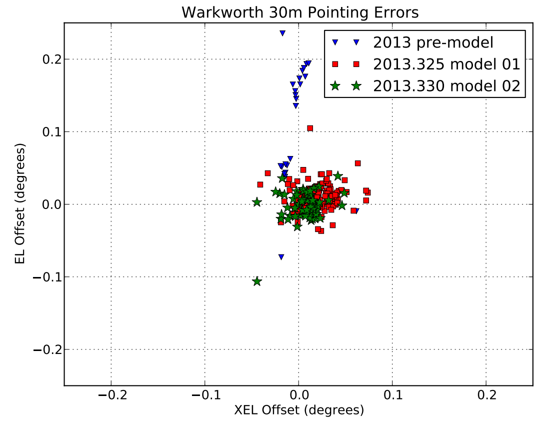

Figure A2. Comparison of the first pointing, over several days in 2013 building new models using the Field Sytem "acquire" and "fivpt". This is a plot of the EL and XEL offsets in degrees, before any model the blue filled triangles; the first model red rectangles and the current model in green stars.

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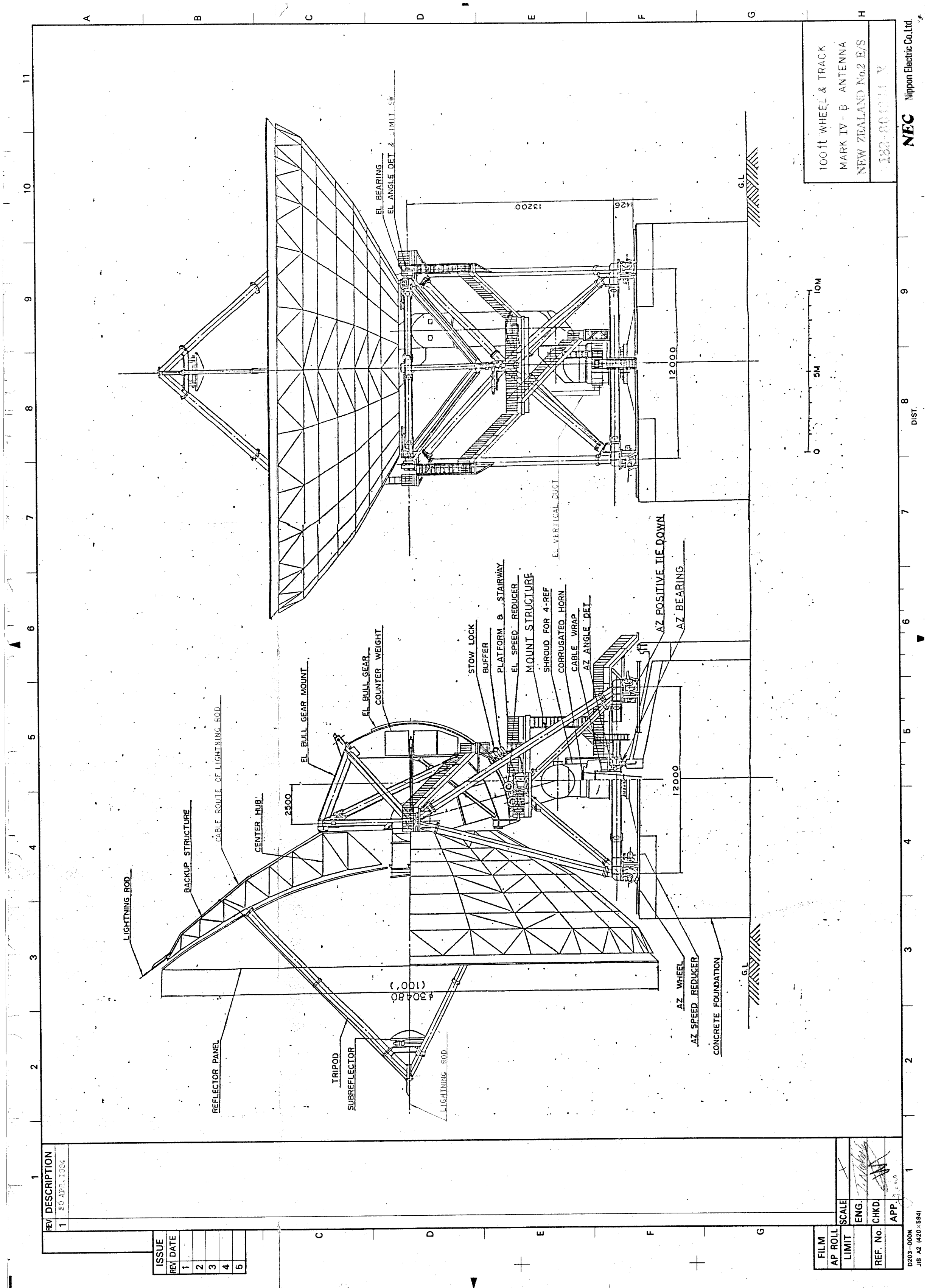

Figure 3. Line drawing of the Warkworth 30m radio telescope - a copy of an original NEC drawing og 1984

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