

# Design of an X-Band Feed System for the Auckland University of Technology 30m Diameter Warkworth Radio Telescope

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**Abstract**—An innovative way to nest a new X-band feed system inside an existing C-band feed system is proposed.

**Index Terms**—antenna, horn, reflector, radio-astronomy, radio-telescope.

## I. INTRODUCTION

The conversion of a former 100-foot (30-m) telecommunications antenna (Earth Station) in New Zealand into a radio telescope is described in [1]. The antenna is a former C-band beam-waveguide Earth Station that was operating in the commercial C-band (3.7 – 4.2 GHz in receive and 5.925 – 6.425 GHz in transmit). The first stage of the conversion was to use the existing C-band horn and design a suitable transition and receiver system to enable the antenna to work in the radio astronomy band of 6.45 – 6.75 GHz. Auckland University of Technology (AUT) was interested in knowing if the antenna could be used at X-band (8 – 9 GHz) and contracted Lyrebird Antenna Research (LAR) to do a feasibility study.

The X-band capability of a large (30 m) antenna located in the South Pacific region would make it a valuable extension for VLBI networks, such as the Australian Long Baseline Array (LBA), the Asia-Pacific (APT) and European (EVN) VLBI networks. It will increase the number of baselines in these arrays, improve uv-coverage and therefore, improve the angular resolution and quality of synthesized images.

The International VLBI Service for Geodesy and Astrometry (IVS) currently uses S and X bands for definition of the International Celestial Reference Frame (ICRF), monitoring the Earth orientation parameters (EOP), and monitoring of the properties of the Earth's troposphere. Currently the 30-m antenna does not have an S-band receiving system, but the 12-m antenna of the AUT's Warkworth Observatory is equipped with both X and S band systems. Because of proximity of the 12-m and 30-m antennas (just 250 m apart), the S-band data from the 12-m antenna can be used to correct geodetic observations performed on the 30-m. In this case, both 12-m and 30-m antennas would have to observe simultaneously and form a "siblings pair" [2].

In single-dish mode, observations in X-band can be used for monitoring Pulsars, in particular, Magnetars, and for spectroscopic observations of Radio Recombination Lines

(RRLs) of Hydrogen, Helium and Carbon [3], as well as the high-order RRLs [4], and for observations of interstellar molecules (e.g. interstellar Methylamine  $\text{CH}_3\text{NH}_2$  [5])

Given the predominant use of X Band frequencies for Deep Space communication [6], this new capability would allow the 30-m antenna to significantly extend the scope of spacecraft tracking projects currently undertaken by the observatories 12-m antenna [7].

The radio telescope is shown in Fig. 1 and the beam waveguide is more clearly seen in Fig. 2.

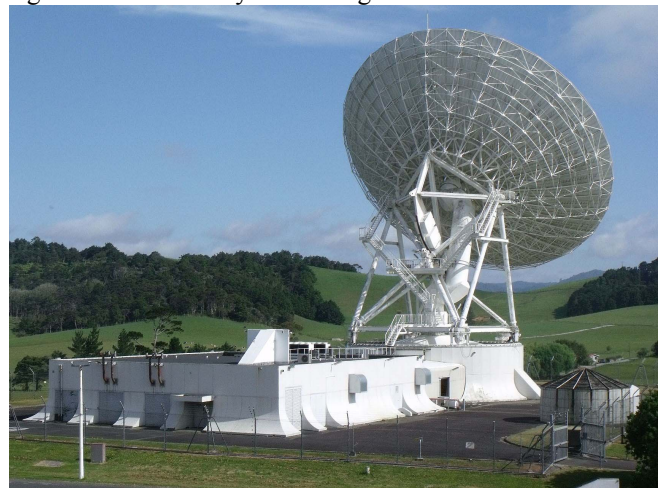


Figure 1: The 30-m diameter Warkworth radio telescope.

## II. FEASIBILITY STUDY

The first stage of the feasibility study was to visit the antenna and look at the physical and mechanical constraints.

One of the unknowns is the exact geometry of all the reflectors (main reflector, subreflector and four reflectors of the beam-waveguide). The antenna was designed, manufactured and installed in 1984 by the NEC Corporation (Japan) but unfortunately they have been unable to furnish complete geometry information. A number of small photogrammetry surveys have been done on the main reflector and subreflector but unfortunately not tied together and no information on the beam waveguide is formally known. A few sketches and information on similar (but not identical)

antennas around the world give us a few clues but a photogrammetry survey is needed to give definitive information.



Figure 2: Beam waveguide.

Nevertheless, the visit by LAR to the antenna highlighted a number of points:

- The reflector surface of the main-reflector is in good condition and seems suitable for X-band.
- The subreflector would need to be checked as there is some flaking apparent on the surface but hopefully it is just paint flakes.
- The existing C-band horn is enormous, over 4.5 m long with an aperture diameter of 0.976 m. It is manufactured in six sections of increasing diameter and weight and the last couple of sections cannot be removed without significant modifications to the structure of the antenna itself and this seemed too big a task. So we had to assume that the last two sections of the existing C-band horn, at least, could not be removed. The access to the C-band receiver is through the control room (Fig. 3), where some of the C-band horn sections can be seen (Fig. 4) but the access to the aperture of the existing C-band horn is through a small hatch as seen in Fig. 5.
- AUT wants to be able to continue observing at C-band as well as observing at X-band (but not simultaneously for now), so a way to effectively swap

from one band to the other in a minimum of time and effort is required.

This challenge required some novel thinking “outside the square”.

The first thing investigated was to see if the existing corrugated C-band horn could give reasonable performance at X-band if a suitable transition could be designed. A number of transition designs were tried, but it was not possible to obtain satisfactory performance using the existing feed.

The second approach was to design a dedicated X-band horn. Based on our experience with high-performance spline-profile smooth-walled horns [8], LAR designed a suitable X-band horn that has an equivalent radiation pattern as the C-band horn. This was done to ensure that the X-band horn would work well in the beam-waveguide system.

The geometry of the X-band horn is shown in Fig. 6 while the circular polarized radiation pattern over the 8 – 9 GHz band is shown in Fig. 7.

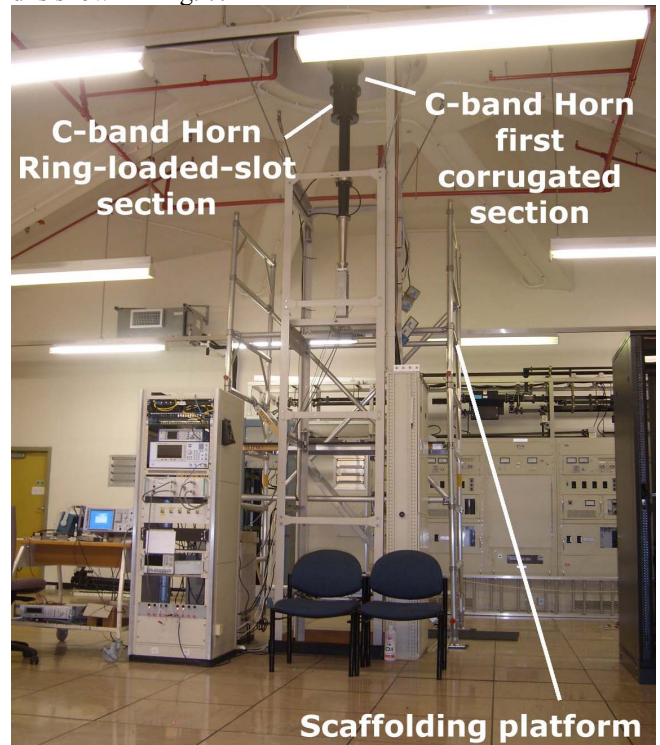


Figure 3: Control room at Warkworth.

With a working feed design, a practical way was needed to switch from C-band observations to X-band observations that did not require an excessive amount of time and effort.

As the last couple of sections of the C-band horn cannot be removed without significant modification to the antenna, the possible solution was to locate the new X-band horn within the existing C-band horn. There were two options: Nesting from the top or nesting from the bottom. These two concepts, as presented by LAR to AUT, are shown in Figs. 8 and 9.





Figure 4: Some of the visible C-band horn sections.



Figure 5: Access hatch and C-band horn aperture.

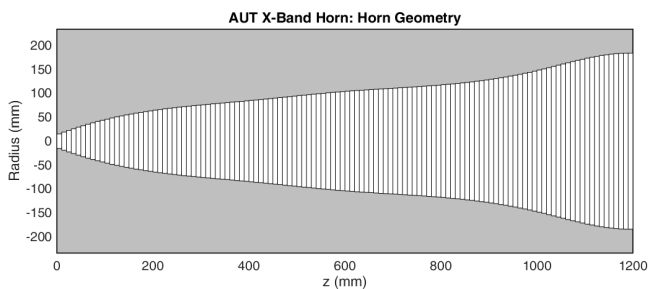


Figure 6: X-band horn geometry.

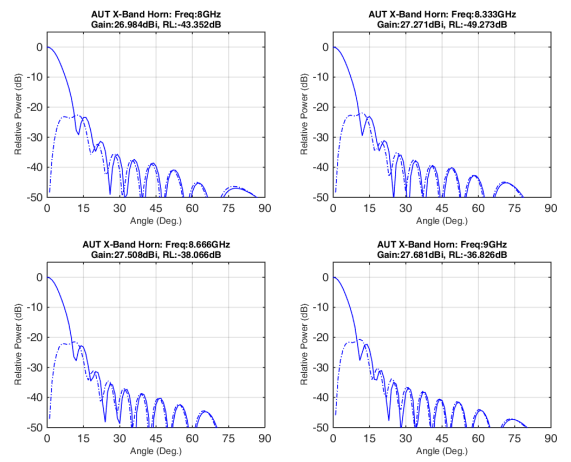


Figure 7: Radiation pattern of the horn (CP).

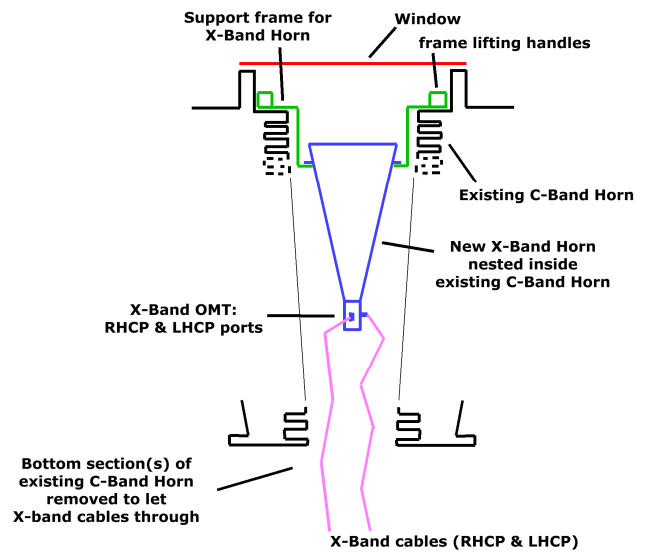


Figure 8: Option 1: X-band horn nested from the top.

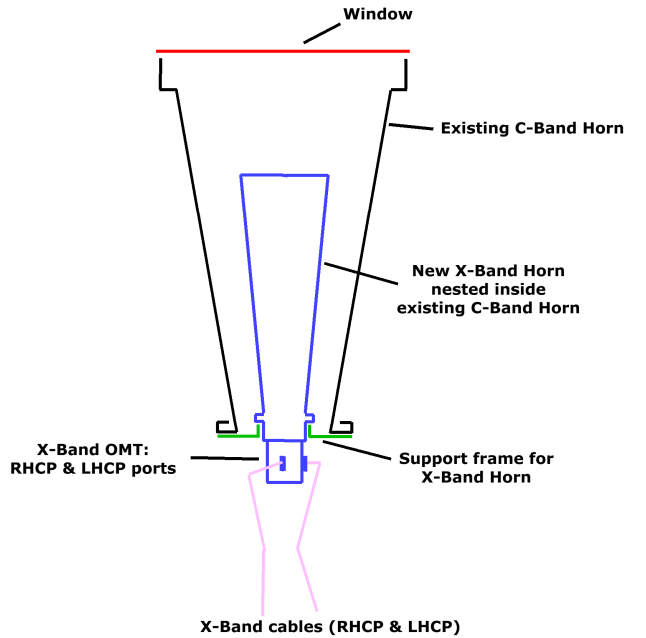


Figure 9: Option 2: X-band horn nested from the bottom.

After consideration, AUT decided to go for Option 1 and use an X-band feed nested from the top.

### III. X-BAND FEED NETWORK

The two possible approaches for a dual polarization receive only network for this 8 – 9 GHz band are a septum polarizer, and a waveguide polarizer followed by an orthomode junction (OMJ). The septum polarizer has advantages due to its compactness, but in our experience, the manufacture at these frequencies is relatively complex, due to the thin septum, and so it is less suited to a one off design that can be machined simply. For that reason we have concentrated on the waveguide polarizer plus OMJ approach.

The initial design of the polarizer plus OMJ is shown in Fig. 10, in the form of a “vacuum” model, where the interior shape of the waveguide network is shown. The OMJ is designed without an interior vane, for ease of manufacture, and machining rads have been included in the model to allow machining of the components in a relatively simple “split-block” form. The network has a circular waveguide port to connect to the feed horn, and a pair of WR112 rectangular waveguide ports for the left and right hand circular polarizations (LHCP and RHCP).

The reflection coefficient across the band is approximately -24 dB. While the axial ratio due to the polarizer plus OMJ is around 0.2 dB over the band.

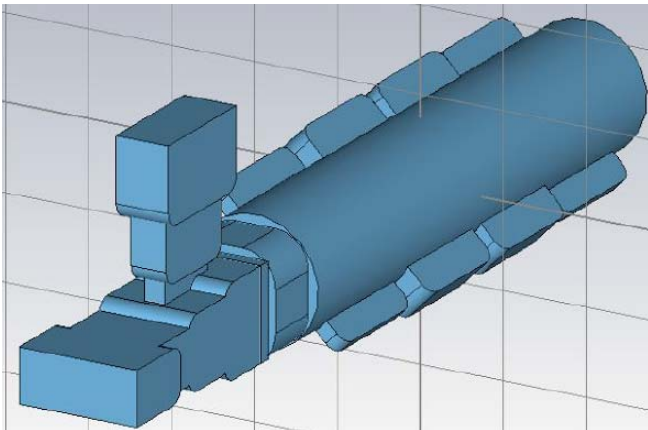


Figure 10: X-band waveguide polarizer and OMJ.

### IV. MECHANICAL DESIGN

LAR was then contracted by AUT to perform the mechanical design of the X-band feed system and the necessary mounting mechanism to be able to nest the X-band feed system inside the existing C-band horn.

The following mechanical constraints and design goals were provided to scope the mounting component:

- Able to locate the aperture of the X-Band horn, centrally, squarely and safely between 500mm and 1000mm below the aperture of the existing C-band Horn.
- All components to fit via 495mm x 495mm Access Hatch (700mm diagonal) (See Fig. 5).
- Two-man team assembly and installation.
- Able to refit Feed Window after installation (See Fig. 5).
- X band Feed Mass, approximately 20 to 30kg.

- Goal of 600mm frame opening at C-Band Horn Aperture.

The mechanical design of the horn, polarizer and OMJ was straight forward and can be seen in Fig. 11.



Figure 11: X-band horn, polarizer and OMJ.

The X-band feed system will be suspended below the existing C-band horn aperture on linear bearings between a steel support frame and an aluminium feed mounting plate. There are two safety pins for locking the feed mounting plate to the support frame during installation. The feed is firstly lowered into the mounting plate. Then a twin rope and pulley system can be used to lower and raise the feed. This is illustrated in Figs 12 and 13.

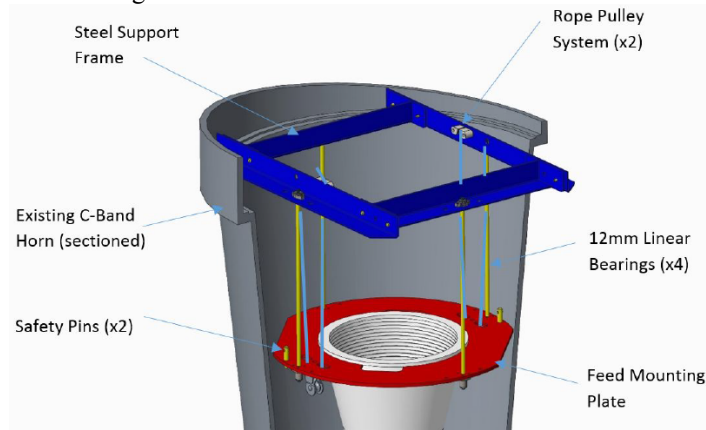


Figure 12: X-band feed system installation.

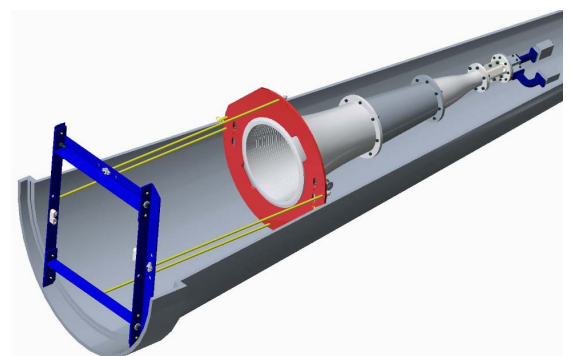


Figure 13: Mechanism to lower the X-band feed system.

The X-band feed system and support assemblies have been designed to fit through the square access hatch.

The feed and the bearing rods will fit through the hatch without any modification, even with the LNAs (as specified by AUT) fitted to the feed. Care should be taken with any LNA cabling that is pre-fitted by AUT.

The feed support plate assembly can be maneuvered through the opening with its shortest side perpendicular to the diagonal of the opening. The support frame assembly is designed to be disassembled into two parts using M12 bolts. The two sections can then fit through the hatch to be reassembled inside.

It is estimated that, with experience, a switch from C-band observation to X-band observation, and vice versa, can be done by a two-man team in a day.

## V. PERFORMANCE AT X-BAND

The performance that can be expected from the installation of this new X-band feed system is difficult to evaluate as there are so many unknowns.

As mentioned before, AUT has little information about the real shape of the antenna, but we know it is a shaped Cassegrain antenna with a beam-waveguide system that worked very well over the original C-band frequencies when it was used as an earth station antenna.

We have designed the X-band horn to have roughly the same radiation pattern as the existing C-band horn and that should ensure that it is a good way to illuminate the beam-waveguide and the shaped Cassegrain antenna.

As we do not know exactly where the focus of the antenna is and the effect at X-band of the nesting of the X-band horn inside the existing C-band horn, the X-band feed system has been designed to be lowered up to 1000 mm.

Upon installation, the procedure will be to make a number of observations with the X-band feed system at different positions within the 1000 mm positional range, find the "sweet spot", i.e., the best overall position in terms of  $G/T_{sys}$  of the X-band feed system for observation in the 8–9 GHz band and record that position.

That position can be used later on for other X-band observations.

## VI. LNAs

Based on prior experience on the AUT Observatories 12m antenna, uncooled MITEQ/Narda model no: AMFW-5S-08100910-50 waveguide coupled LNAs have been selected for installation.

Specifications (at 23 °C) from the manufacturer are:

- Frequency: 8.1 to 9.1 GHz
- Gain: 40 dB Min
- Gain Flatness:  $\pm 1$  dB
- Max Noise Temperature: 50 K
- Max VSWR In: 1.5:1 Max
- VSWR Out: 1.5:1 Max
- P1dB Out: 10 dBm Min
- Operating Temp: -15 to 60 °C

These have provided trouble free service on the observatory 12m antenna from installation in 2008, yielded good system noise temperatures and been found to provide

"head room" to cope with the RFI environment of the observatory without compression/non linearity issues.

## VII. CONCLUSIONS

The addition of an X-band capability will greatly enhance the ability of the AUT Warkworth Radio Observatory to participate in Astrophysical/Geodetic science programs and open up new possibilities for participation in spacecraft tracking programs. The novel "nested" feed design chosen greatly reduces the costs of this to the observatory with the added benefit of reduction of the time required to swap between C-band and X-band operation.

The authors would like to thank Karl Verran for the mechanical design of the X-band feed system.

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