Installation of a 70-115 GHz Receiver on the Mopra Antenna

J.M. Payne March 1992

Summary

This memorandum gives an initial design of a 3 mm receiver designed to use the inner portion (15.3m diameter) of the Mopra antenna. The receiver is a dual polarisation SIS receiver that may be very simply expanded to cover other frequency ranges. An alternative, that involves virtually no wasted effort, is to build the receiver around Schottky mixers and a 20K refrigerator and, later, fit SIS mixers together with a 4K refrigerator.

The receiver will be easily installable on the existing rotating receiver mount.

The use of the inner portion of the antenna gives a higher magnification at the Cassegrain focus and so leads to less stringent tolerances for the receiver installation.

A suggested course of action is given that should result in an excellent receiver on the antenna with a minimum (although still considerable) amount of work.

The Antenna Optics

James Lamb has very kindly acted as a consultant on the optical design and much of the work here stems from his suggestions and calculations.

The AT antenna uses a dual reflector axisymmetric system with the two reflectors shaped in such a way as to produce the maximum G/T performance (1, 2, 3). The antenna surface consists of solid panels out to the 7.67 m radius; the two outer panels consist of perforated sheet. The perforations are of circular holes 2.84 mm in diameter at 4.223 mm spacing (staggered) and may be shown to be virtually non reflective at frequencies above 70 GHz (4, 5).

Due to the shaping of both the main reflector and subreflector, there is not a linear relationship between the radius of an input ray on the main reflector and the radius of the same ray on the subreflector.

Fine resolution printouts of both the main reflector and subreflector profiles were available and simple ray tracing gave a value of 6.740 degrees for the half angle of a ray from the Cassegrain focus to the 7.67 m radius on the main reflector. For this particular ray, using conventional Cassegrain antenna terms, the magnification is 9.36 and the equivalent focal length is 65.1 m.

The relationship between a ray from the feed and its intersection with the main surface is described by the mapping function H_M.

$$\Theta_{FEED} = H_M(r) \qquad - \qquad 1$$

where r is the radial ordinate in the aperture normalised to D/2.

The mapping function for the AT is shown in Figure 1 and, at a radius of 7.67 m gives a feed angle of 6.747 degrees - in good agreement with the geometrical ray tracing.

An equivalent focal length can be defined as

$$F_e(r) = \frac{r}{2 \tan \frac{H_M(r)}{2}} \qquad 2$$

For $r = 7.67$ m $\quad F_e = 65.06$ m
$r = 5.5$ m $\quad F_e = 70.81$ m

Obviously there is not a single equivalent paraboloid. The mapping function can be calculated for a conventional Cassegrain:-

$$\Theta_{FEED} = 2 \tan^{-1} \frac{rD}{4F_e} \qquad 3$$

Plotting this on figure 1 indicates that an equivalent focal length of 71 m is probably a reasonable choice for deriving the approximate values needed for defining the receiver optics and the sensitivity of the system to various misalignments.

<u>Approximate constants for inner 15.34 m diameter</u>

Equivalent focal length	71 m
Magnification	10.10
Plate scale at Cass focus	2.90 arc sec/mm
Ratio of feed movement to subreflector movement $\frac{\Delta Z_f}{\Delta Z_s}$	78.7
Pointing change with lateral subreflector movement	29 arc sec/mm

The increase in magnification that results from using the inner portion of the antenna gives an increase in the depth of focus. In fact the Cassegrain feed may be displaced by up to a meter from the nominal focus and virtually all the gain may be recovered by moving the subreflector by around 12 mm.

The Receiver Optics

Gaussian beam optics may be used to derive the feed parameters and clearances through the various optical components. Goldsmith (6) gives a good review of the design procedures.

The antenna optics produces a beam waist at the Cassegrain focus in response to a point source. Away from the beam waist the beam expands:-

$$W_{(Z)} = W_{CASS} \left[1 + \left(\frac{\lambda Z}{\pi W^2_{CASS}} \right)^2 \right]^{1/2} \quad - \quad 4$$

where $W_{(Z)}$ is the distance away from the propagation axis at which the intensity drops to $\frac{1}{e}$ of the on axis value (-8.68 dB). Z is the distance along the propagation axis away from W_{CASS}.

At large distances from the beam waist the asymptopic growth of the beam waist radius $W_{(Z)}$ is given by:-

$$\Theta_{W_{CASS}} = \frac{\lambda}{\pi W_{CASS}} \quad \text{RADS} \quad - \quad 5$$

If we require the illumination to be -12dB at the half angle of 6.76° then $\Theta_{W_{CASS}}$ = 5.743° from the Gaussian distribution. This is shown in Figure 2.

From 5 $W_{CASS} = 3.16\ \lambda$.

Using 4, we can now plot the beam dimensions from the Cassegrain focus towards the subreflector. A conservative rule is to use apertures with diameter of 4 times the W_Z value (6) and this forms the basis of the receiver optics as shown in Figure 3.

A practical feed system is to use a long corrugated horn illuminating a dielectric lens (7). In our system the lens will be cooled to 4K and significant corrections must be made for changes in both density and dimensions. Suitable dielectric materials are PTFE or HDPE (High Density Polyethylene) and James Lamb has run profiles of two suitable lenses to be used with the horn described in (7). These are shown in Figure 4.

As can be seen from Figure 2, the outer, mesh portion of the reflector is underilluminated and over this part of the surface the receiver will "see" the ground. This will add approximately 20K to the system temperature.

The Receiver

General Description

A preliminary outline drawing of the receiver is shown in Figure 5.

The receiver consists of two basic assemblies; the optical assembly, at room temperature, and the dewar containing the cooled components.

The dewar contains four receiver channels which may be selected in pairs (diagonally across the dewar) by rotating the optical assembly on top of the dewar. The two channels selected will then receive orthogonal polarisations and each of the channels may be equipped to receive either the 70-90 GHz or the 90-115 GHz band.

The final configuration of the receiver is expected to be two channels to cover 70-90 GHz and two to cover 90-115 GHz.

The polariser and the optical components will work well up through the 2mm band and, if the site and telescope permit, operation at 2mm would be merely a matter of changing the mixers and LO system.

The receiver is easily mountable on the AT receiver turntable using a standard receiver frame and, perhaps, a standard dewar.

Space has been left in the proposed installation for a fast beam switcher, should this prove to be desirable in the future.

With the NRAO mixers, a receiver with noise temperatures of below 80K SSB across the entire 70-115 GHz band with dual channel operation, will be easily achievable.

CRITICAL RECEIVER COMPONENTS

Component	Acquisition
Cross Grid Polarizer	Fabricate at CSIRO
Rotating Optical Assembly	Fabricate at CSIRO
Vacuum Windows	Fabricate at CSIRO
Infrared Filters	Fabricate at CSIRO - NRAO design
Dewar and Radiation Shields	Fabricate at CSIRO
Mixers and Backshort Drives	Purchase from NRAO
Circulators	Commercially available
IF Amplifiers	Fabricate at CSIRO
4K Circuit	Long term loan from NRAO
20K Refrigerator	Commercially available
Feed/Lens	Scaled NRAO design - fabricated at CSIRO
LO Components	Already purchased

References

1. James, G.L., Analysis of Radiation Pattern and G/T_A for Shaped Dual Reflector Antennas. IEE Proc., Vol. 127, Pt H, No 1, Feb 1980

2. James, G.L., The Australia Telescope Antennas: Reflector Optics and the Feed System. IREE

3. Kennedy, R.A., Parametric Study of Shaped Cassegrain Antennas, IEE Proc., Vol. 134, Pt H, No 3, June 1987, pp 297-302

4. Yabsley, D.E., Antennas and Feeds, AT/21.2.1/009. 17 October, 1983

5. Chen, C.C., Trans M.T.T. 21(1) 1973, pp 1-6

6. Goldsmith, P.F., Quasi-Optical Techniques at mm and Sub-millimeter wavelengths, Infrared and Millimeter Waves, Vol. 6, Ed K.S. Button, Academic Press, 1982

7. Ulich, B.L., Optimum Cassegrain Feed System. Tucson Operations, Internal Report #6, March 1980

5th March, 1992

JMP:gam
6/92