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Title: **System Temperature Calibration of the Australia Telescope Receiver Systems**

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ABSTRACT
In the Australia Telescope, signals from antennas are combined in a correlator. The strength of a radio source is obtained by scaling the correlator output by a factor which depends on antenna efficiency and the system temperature. The system temperature depends on noise contributions from the receiver system, the cosmic background and from atmospheric attenuation. Typical antenna receiver system temperatures are given and the effects of atmospheric attenuation at low elevations and antenna focus are discussed.

* The Australia Telescope is operated in association with the Division of Radiophysics by CSIRO

1. INTRODUCTION

The Australia Telescope [1] is a synthesis radio telescope. Each of its seven antennas has been equipped with dual-polarization, low-noise radiometers for the four frequency bands listed in Table 1.

Band (cm)	Frequency (GHz)
20	1.25 - 1.78
13	2.2 - 2.5
6	4.4 - 6.1
3	8.0 - 9.2

Table 1

The antennas are used in pairs to form interferometers. [2] The noisy signals from each pair of antennas are combined in a correlator which measures the fraction of the signal from the antennas common to both signals. The more noise that comes from an antenna receiver system, the smaller that fraction will be. Noise in a receiver system is measured as a temperature in Kelvin: the system temperature. A load at this temperature radiates a power equivalent to the noise power in the receiver system.

The accuracy of the system temperature measurement depends on assumptions made about contributions from the antenna, from the cosmic background, and from atmospheric attenuation due to water vapour, oxygen and other atmospheric gases. As well as discussing this, we describe how the system temperature is made, and compare typical receiver system temperatures measured on the antenna with those measured off the antenna.

2. GAIN CALIBRATION DURING OBSERVATIONS

The correlator measures the degree of correlation, C, between the signals from two antennas, say antennas m and n. To obtain strength, S, of the radio source, we scale the correlation:

$$S = K \cdot C\sqrt{T_{SYS_m} \cdot T_{SYS_n}} \qquad (1)$$

where T_{SYS_m} and T_{SYS_n} are the system temperatures of antennas m and n respectively and K depends on a number of factors including dish efficiency.

Observations are made by tracking a radio source for up to 12 hours, during which time the elevation of the antenna may change substantially. Contributions to system temperature from both ground radiation and attenuation through the atmosphere are elevation dependent, and will change over the course of an observation. Rain clouds and water vapour also increase the system temperature. Because the system temperature varies over the course of an observation, it is important to monitor the system temperatures of the receivers accurately.

Fig. 1 shows a block diagram of the receiver system. The system temperature is measured by continuously comparing the receiver output power, P_{OUT}, with the change in the output power, ΔP, which occurs when a calibration noise diode in the receiver input is switched on and off.

$$T_{SYS} = T_{CAL} \frac{P_{OUT}}{\Delta P} \tag{2}$$

where T_{CAL} is the size of the calibration noise source. ΔP is also a measure of receiver gain, from the noise source coupler to the power detector in the output. P_{OUT}, ΔP, T_{SYS} and other array parameters are displayed by a monitoring program[3].

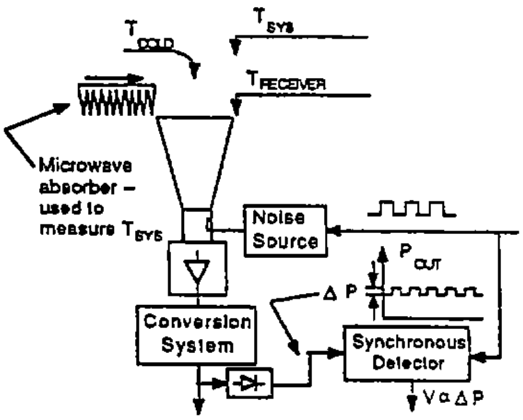

Fig. 1 Block diagram of receiver showing T_{SYS}, $T_{RECEIVER}$ and T_{COLD}

3. SYSTEM TEMPERATURE MEASUREMENT

The system temperature is initially measured using the Y-factor method, and the noise source step is then calibrated by comparing T_{CAL} with T_{SYS}. A microwave absorber at ambient temperature $T_{ABSORBER}$ and the cold sky are used to provide loads at two different temperatures, T_{HOT} and T_{COLD}. By measuring the corresponding receiver output powers, P_{HOT} and P_{COLD}, the receiver temperature is computed as

$$T_{RECEIVER} = \frac{T_{HOT} - YT_{COLD}}{Y - 1} \tag{3}$$

where

$$Y = \frac{P_{HOT}}{P_{COLD}} . \tag{4}$$

As illustrated in Fig. 1, the system temperature is the sum of $T_{RECEIVER}$, the receiver noise temperature, and T_{COLD}

$$T_{SYS} = T_{RECEIVER} + T_{COLD} = \frac{T_{HOT} - T_{COLD}}{Y - 1} . \tag{5}$$

The greatest uncertainty in the absolute measurement of system temperature is the linearity of the detector. A 0.1 dB uncertainty in the Y-factor will result in a 2.5% uncertainty in the system temperature. By comparison, a 1 Kelvin uncertainty in T_{HOT} or T_{COLD} will result in only a 0.4% error in the system temperature.

T_{HOT} is equal to the the absorber temperature, $T_{ABSORBER}$ in the 6 cm and 3 cm bands, but in the 20 cm and 13 cm bands the 600 mm square absorber does not completely fill the horn aperture, so we use

$$T_{HOT} = \alpha T_{ABSORBER} + (1 - \alpha) T_{COLD} \tag{6}$$

where α = 0.80 in the 20 cm band and α = 0.75 in the 13 cm band.

T_{COLD} is the sum of the noise contributions from sources external to the receiver system

$$T_{COLD} = T_{BACKGROUND} + T_{ANTENNA} + T_{SPILLOVER} + T_{ATMOSPHERE} \tag{7}$$

$T_{BACKGROUND}$ is the contribution to system temperature from the 2.7 Kelvin cosmic microwave background[3]. $T_{ANTENNA}$ is the contribution from ground radiation which is scattered off the antenna and quadrupod structure. $T_{SPILLOVER}$ is the contribution from ground radiation which is received directly by the horn as it slightly over-illuminates the subreflector. $T_{ATMOSPHERE}$ is the contribution from attenuation due to water vapour, oxygen and other atmospheric gases in the column above the antenna.

$$T_{ATMOSPHERE} = (1 - \tfrac{1}{L}) \cdot (T_m - T_{BACKGROUND}) \tag{8}$$

where L is the loss and T_m is the mean temperature of the attenuating medium. For example, if the ambient temperature is 25°C, and the relative humidity 0.6, T_m is 284 K, and at 8.6 GHz the atmospheric attenuation of 0.06 dB will contribute 4 Kelvin to the system temperature at the zenith. Fig. 2 shows the atmospheric contribution at the zenith in three of the observing bands. The atmospheric contribution in the 13 cm band was omitted as it is only slightly greater than that in the 20 cm band. As an antenna is tipped, the path length (and thus the attenuation) through the atmosphere varies as 1/sin (Elevation). Thus

$$T_{ATMOSPHERE} \approx \frac{T_{ATMOSPHERE}(Zenith)}{\sin(Elevation)} . \tag{9}$$

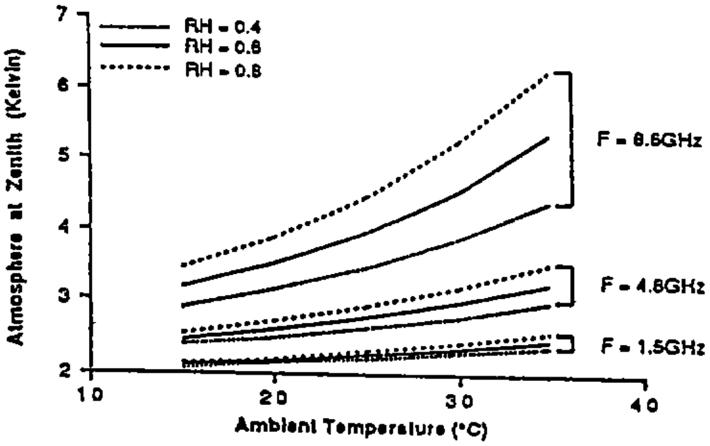

Fig. 2 Zenith atmospheric noise contribution for relative humidities (RH) of 0.4, 0.6, 0.8, and frequencies of 1.5, 4.8 and 8.6 GHz

4. RESULTS

The zenith system temperature contributions are summarized in Table 2. The atmospheric contributions correspond to typical site conditions: an ambient temperature of 25°C and a relative humidity of 0.6.

Zenith Noise Temperature (Kelvin)

	20 cm	13 cm	6 cm	3 cm
Background	2.7	2.7	2.7	2.7
Antenna	5.6	5.4	5.5	6.3
Spillover	0.0	0.0	0.0	0.0
Atmosphere	2.2	2.4	2.75	4.0
Receiver	17.5	20.5	39.0	53.0
Total System	28.00	31.00	50.00	66.00

Table 2

Fig. 3 shows the elevation dependence of the system temperatures in the 6 cm and 3 cm bands. Also plotted in Fig. 3 is $T_{RECEIVER} + T_{BACKGROUND} + T_{ANTENNA} + T_{ATMOSPHERE}$. The difference,

$$T_{SPILLOVER} = T_{SYS} - T_{RECEIVER} - T_{BACKGROUND} - T_{ANTENNA} - T_{ATMOSPHERE} \tag{10}$$

is shown more clearly in Fig. 4. The contribution due to spillover is negligible at the zenith, increases rapidly at elevations below 40°, and is greater in the 6 cm band than in the 3 cm band.

When the antenna was pointed at the strong radio source Virgo A, which has a flux of 68×10^{-26} $W.m^{-2}.Hz^{-1}$ (68 Jy) at 4.8 GHz, the output power of the receiver increased by 12%, indicating that the power received from the

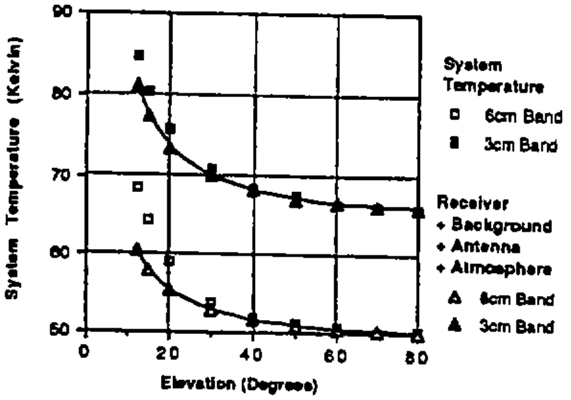

Fig. 3 T_{SYS} and $T_{RECEIVER} + T_{BACKGROUND} + T_{ANTENNA} + T_{ATMOSPHERE}$

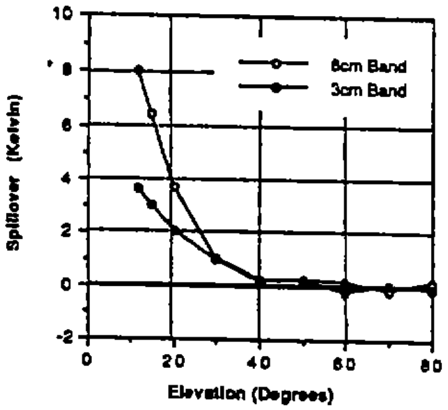

Fig. 4 Contribution to system temperature due to spillover, $T_{SPILLOVER} = T_{SYS} - T_{RECEIVER} - T_{BACKGROUND} - T_{ANTENNA} - T_{ATMOSPHERE}$

radio source was equivalent to 6.04 Kelvin. For a 22 metre diameter antenna, the power incident on the surface from Virgo A is 2.6×10^{-22} W.Hz^{-1}, which is equivalent to 9.37 Kelvin. Thus the antenna has an efficiency of 0.646, which is very close to the theoretical value of 0.64 [5].

Displacement of the subreflector from the optimum position will reduce the observed efficiency. Fig. 5 shows how the relative strength of a radio source changes as the subreflector is moved. Note that the optimum subreflector position is different for the 6 cm and 3 cm bands.

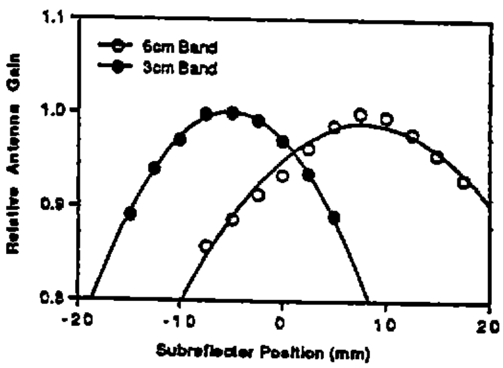

Fig. 5 Effect of axial subreflector movement on antenna gain.

5. CONCLUSION

We have described how system temperature measurements are made, have given typical antenna receiver system temperatures and have discussed the noise contributions from the antenna, from cosmic background, from spillover, and from atmospheric attenuation. Measurements of antenna efficiency and the strength of a calibration radio source compare well with theoretical antenna efficiency and the accepted flux for the source.

6. REFERENCES

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