The calibration of the 26m HartRAO telescope

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Abstract

This paper discusses the calibration of the HartROA 26m telescope against 3C218. This entails taking drift scans at 2.5,3.5,6,13 & 18 cm wavelengths, fitting gaussians to the data and calculating the telescopes point source sensitivity and half power beamwidth. This paper also covers correcting for pointing error and the use of Dicke radiometers.

1 Introduction

The signal received by a radio telescope is hardware dependent. Different designs, low level hardware variations introduced in construction and gradual variation in the hardware over time all require that the telescope be calibrated. This facilitates the sharing of information calibrated to the same standard, and is achieved by receiving information from a known source. We selected a calibration source from a list provided by Ott et al. (1994) based on its angular diameter, associated strength and its position in the sky. We decided to calibrate the telescope against 3C218.

2 Theory

$$A_e = \frac{1380(T_{Alcp} + T_{Arcp})K_s}{S_o} \quad (1)$$

$$\epsilon_{ap} = \frac{A_e}{A_p} \quad (2)$$

$$PSS = \frac{S}{2K_s T_{Alcp/rcp}} \quad (3)$$

$$\Omega_M = 1.133\theta^2_{HPBW} \quad (4)$$

$$\Omega_A = \frac{\lambda^2}{A_e} \quad (5)$$

$$\epsilon_M = \frac{\Omega_M}{\Omega_A} \quad (6)$$

A_e	effective aperture $[m^2]$
ϵ_{ap}	aperture efficiency
θ_{HPBW}	half power beamwidth [deg]
θ_{BWFN}	beamwidth to first nulls [deg]
Ω_A	beam solid angle[st]
Ω_M	main beam solid angle[st]
ϵ_M	main beam efficiency
T_sys	system temperature at zenith
$\Delta\ \nu$	noise bandwidth
$\Delta\ T_{rms}$	receiver noise fluctuation for $\tau = 1$ second [k]
$\Delta\ S_{rms}$	minimum detectable flux density
PSS	point source sensitivity $[\frac{Jy}{K}]$

Table 1: The values we seek to determine

The receivers for the varying wavelengths measured by the telescope are all independent hardware units, and must therefore be independently calibrated. The telescope has receivers for the following wavelengths : 2.5 cm, 3.5 cm, 6 cm, 13 cm and 18 cm. There are two distinct receivers for each wavelength, with a separate receiver for left and right-hand circularly polarised light.

There is a great deal of noise in the 2.5 cm bandwidth, and this necessitates that three separate runs are taken and averaged in order to reduce the noise in a dataset. The 3.5 and 6 wavelengths received from the source have very little penetrating power and a Dicke radiometer is used to circumvent this. This entails both the 2.5 and 3.5 cm receivers having two separate feed-horns. Instead of receiving a single beam of information, two beams are received at any moment of time, with the second feed-horn following the path of the first feed-horn. The second signal is subtracted from the first signal, removing environmental artifacts which are shared by both horns. At 13 cm and 18 cm receiving signals is comparatively straight forward.

3C218 has a small angular diameter that can therefore be treated as a point source. The radio telescopes sensitivity is described across the dish by a sinc function. The convolution of a sinc function with a point source produces another sinc function. We therefore know the form of the signal. We wish to mathematically model the signal since the characteristics we are interested in are encapsulated in the form of the received data. We therefore approximate the sinc function with a gaussian.

A gaussian has the form

$$y = Ae^{\frac{-(x-x_0)^2}{\sigma^2}} \tag{7}$$

The gaussian will lose accuracy if the sinc function has been rotated on its axis. It is therefore necessary to peg both sides of the sinc down, and thereby remove any transient information from the original sinc function. This is achieved for the 2.5, 13 and 18 cm wavelengths by plotting a line through the first nulls bordering the main gaussian, and subtracting this line from the sinc. For the 3.5 and 6 cm wavelengths a line is taken from the leftmost null to the rightmost null, and this is subtracted from the sinc. In both cases the line is found by sampling points from the specified points, and utilising the microsoft regression tool. A gaussian is then fitted to a subset of the corrected sinc function. For the 2.5, 3.5 and 6 cm wavelengths there are three components to each scan. These are north, on and south respectively, and corrected for the possibility of missing the centre of the object during a drift scan. This error is referred to as the pointing error, and requires the fitting of a gaussian to each of the component scans. The amplitude of the component gaussians reveal any deviation from the desired course and allows for its correction. The corrective equations, shown below, are taken from Gaylard (2005). The appropriate equation is selected based on the comparative amplitudes of the respective components. When the north and south gaussians are very similar equation 8 is used. If the south gaussian is disproportionately large then equation is used. If the north gaussian is disproportionately large then equation is used.

$$T_{cor} = T_{on} e^{\frac{(ln(T_s)-ln(T_n))^2}{16ln(2)}} \quad (8)$$

$$T_{cor} = T_{on} e^{\frac{(ln(T_s)-ln(T_{on})+ln(2))^2}{4ln(2)}} \quad (9)$$

$$T_{cor} = T_{on} e^{\frac{(ln(T_{on})-ln(T_n)-ln(2))^2}{4ln(2)}} \quad (10)$$

The point source nature of 3C218 simplifies calculations as we can take $K_s = 1$ and $S_o = S$ (Gaylard, 2005). Using information from Ott et al. (1994) a table of the expected flux densities can be calculated.

	18 cm	13 cm	6 cm	3.5 cm	2.5 cm
S [Jy]	36.45	26.84	13.04	7.92	5.81

Table 2: 3C218 flux densities (Ott et al., 1994)

Gaussians can be conveniently fitted under Microsoft excel. Following the baseline correction, there are two columns of corrected data for each gaussian pair, left circularly polarised and right circularly polarised. Three cells are created for each gaussian, to store the variables shown in equation 7. Two rows are adjoined to the existing data, containing equation 7 and referencing the appropriate cells. Two more columns are adjoined onto the gaussian fit, containing the squared error between the corrected data and the fitted data. These columns are summed at the bottom, and square rooted. Solver is pointed at the three cells containing the variables and told to minimise the sum of the errors, by varying the parameters. Solver can experience difficulties, and the rough shape of the fitted gaussian must sometimes be formed before excel can meaningfully minimise the errors. The A term directly relates to the amplitude of the gaussian. x_0 is the x axis offset for the gaussian, and is therefore used to shift it across the x-axis. σ corresponds to the width of the gaussian. By plotting the initial values and adjusting the variables intelligently alongside the plotted gaussian, it is a fairly straight forward procedure to discover rough values.

The σ term corresponds directly to θ_{HPBW}. θ_{BWFN} can be observed off the plot of the original data. The amplitude of the fitted gaussian, A, is taken as the antenna temperature.

3 Procedure

Drift scans of 3C218 were taken at all of the wavelengths, and the data was then processed as discussed in the theory. The steps involved in the data processing are shown for the 18cm wavelength in figures 1, 2 & 3.

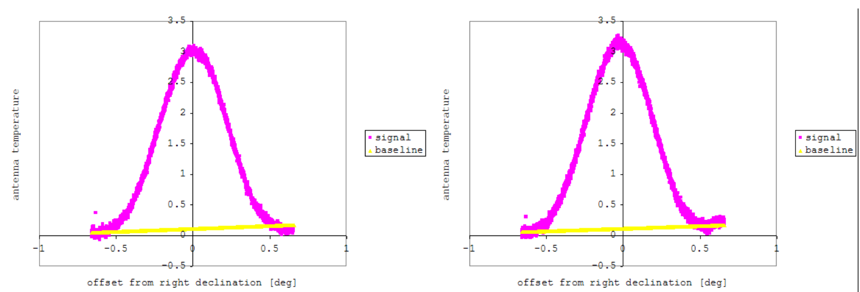

Figure 1: Fitting of baseline

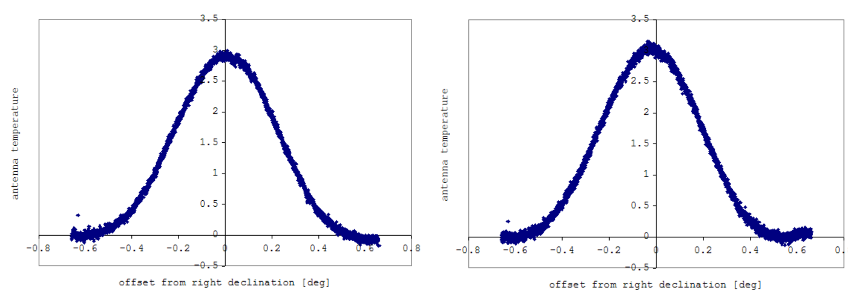

Figure 2: Baseline corrected signal

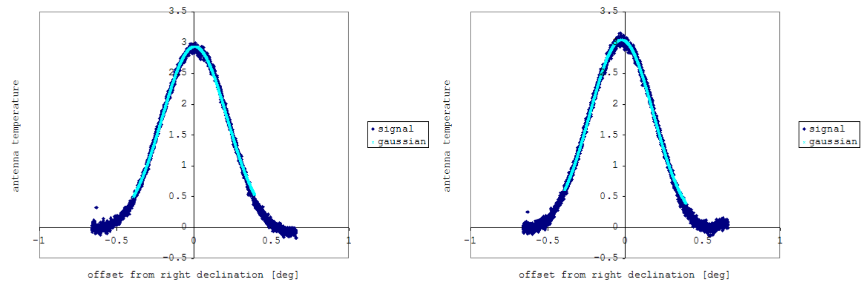

Figure 3: Fitted gaussian

The desired quantities were calculated using the equations supplied in the theory.

4 Results

wavelength [cm]	18	13	6	3.5	2.5
K_s	1	1	1	1	1
S	36.45126421	26.84016633	13.04447707	7.919837259	5.809725031
R	12.95	12.95	12.95	12.95	12.95
c	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08
f	1.67E+09	2.31E+09	5.00E+09	8.57E+09	1.20E+10
λ	0.180072029	0.13	0.06	0.035	0.025
A_p	526.852942	526.852942	526.852942	526.852942	526.852942
A_e	226.5112733	276.0081652	237.4585519	212.3814318	210.4931918
ϵ_{ap}	0.429932634	0.523880847	0.450711257	0.403113307	0.399529309
Ω_A	0.000143154	6.12301E-05	1.51605E-05	5.76792E-06	2.96922E-06

Table 3: Values utilised in calculations

The results are summarised in table 4 and 5.

λ [cm]	polarisation	T [K]	PSS $[\frac{Jy}{Kpol}]$	θ_{HPBW} [$\circ$]	θ_{BWFN} [$\circ$]	Ω_M	ϵ_M
18	LCP	2.94	6.21	0.483	1.215	0.000081	0.563
	RCP	3.05	5.98	0.472	1.153	0.0000770	0.538
13	LCP	2.72	4.93	0.319	0.800	0.0000350	0.572
	RCP	2.65	5.07	0.318	0.800	0.0000349	0.570
6	LCP	1.218	5.35	0.1550	0.320	0.0000083	0.547
	RCP	1.026	6.36	0.1541	0.320	0.0000082	0.541
3.5	LCP	0.648	6.11	0.0878	0.320	0.00000266	0.461
	RCP	0.570	6.94	0.0945	0.320	0.00000308	0.534
2.5	LCP	0.433	6.71	0.0640	0.1	0.00000141	0.476
	RCP	0.453	6.41	0.0621	0.1	0.00000133	0.449

Table 4: calibration results

λ [cm]	polarisation	T [K]	PSS $[\frac{Jy}{Kpol}]$	θ_{HPBW} [$\circ$]	θ_{BWFN} [$\circ$]	Ω_M	ϵ_M
18	LCP	0.15	0.31	0.024	0.061	0.000010	0.094
	RCP	0.15	0.30	0.024	0.058	0.0000096	0.090
13	LCP	0.14	0.25	0.016	0.040	0.0000044	0.095
	RCP	0.13	0.25	0.016	0.040	0.0000044	0.095
6	LCP	0.061	0.27	0.0078	0.016	0.0000010	0.091
	RCP	0.051	0.32	0.0077	0.016	0.0000010	0.090
3.5	LCP	0.032	0.31	0.0044	0.016	0.00000033	0.077
	RCP	0.029	0.35	0.0047	0.016	0.00000039	0.089
2.5	LCP	0.022	0.34	0.0032	0.005	0.00000018	0.079
	RCP	0.023	0.32	0.0031	0.005	0.00000017	0.075

Table 5: uncertainties of calibration results

5 Discussion

wavelengths [cm]	18	13	6	3.5	2.5
Point Source Sensitivity per polarisation (Jy/K)	5.15	4.8	5.8	5.7	5.1
Beamwidth: full width at half max. (degrees)	0.494	0.332	0.160	0.092	0.059
Beamwidth: between first nulls (degrees)	1.19	0.80	0.36	0.23	0.16

Table 6: HartRAO telescope parameters as given by HartRAO (2005)

Comparing table 4 with table 6, our results confirm those supplied by the HartRAO fact page. The given values for θ_{HPBW} and θ_{BWFN} are included within the error margins of our our calculated values. Our PSS error margins do not encompass the given PSS values for each wavelength, although the discrepancy between our values and the given values is within 20 %. The close proximity to the given value tends to argue that the error is not experimental, but might be due to variations in the telescope since the values given on the page were last updated.

6 Conclusion

The HartRAO telescope was successfully calibrated by numerically analysing data gathered from drift scans of 3C218 at each of the receiver wavelengths. The pointing error was corrected for, and values consistent with the documented values were calculated for θ_{HPBW}, θ_{BWFN} and the point source sensitivity of the telescope at each of the wavelengths.

References

Gaylard, M. J. (2005), *Practical Radio Astronomy a hi-math introduction*, Hartebeesthoek Radio Astronomy Observatory.

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Ott, M., Witzel, A., Quirrenbach, A., Kirchbaum, T. P., Standke, K. J., Schalinski, C. J., and Hummel, C. A. (1994), *Astronomy and Astrophysics*, volume 284.