Overview on data reduction, calibration and analysis: Continuum

Sergio Poppi

Osservatorio Astronomico di Cagliari - INAF

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What is calibration?

Calibrate */'kalıbreıt/*

- mark (a gauge or instrument) with a standard scale of readings.
- correlate the readings of (an instrument) with those of a standard in order to check the instrument's accuracy.
- adjust (experimental results) to take external factors into account or to allow comparison with other data.

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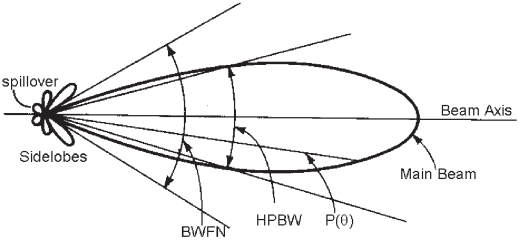
Power Pattern

The response of the antenna as a function of the direction is described by the power pattern $P(\theta, \phi)$ or the normalized power pattern P_n



Descriptive parameters

- Beam solid angle:

$$\Omega_A = \iint_{4\pi} P_n d\Omega$$

- Main beam solid angle:

$$\Omega_{mb} = \iint_{mainlobe} P_n d\Omega = 1.133(\theta_b^2)$$

$$\theta_b = HPBW = b\frac{\lambda}{D}$$

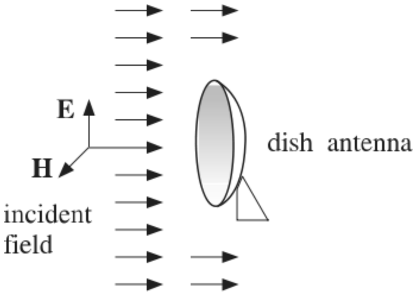
$b = 1 \div 1.3$ depending on the feed taper.

Effective Area

$$A_{eff} = \frac{P_e}{\langle S \rangle}$$

$\langle S \rangle$ = power density of the wave (W m^{-2})
P_e = Power extracted from the wave by the antenna(W)
The effective area is a sort of "cross section" of the antenna

$$A_{eff}\Omega_A = \lambda^2$$



Antenna Temperature

The *antenna temperature* is the temperature of a resistor matched at the output of the antenna:

$$P_\nu = \frac{1}{2} A_{eff} S_\nu$$

$$P_\nu = k_b T_a$$

$$T_a = \frac{A_{eff}}{2k_b} S\nu = \Gamma S_\nu$$

Γ is the flux gain of the radio telescope.

Measuring the Antenna Temperature

If we point the telescope towards a source, at the continuum detectors output we have:

- the signal from the source T_A (partially absorbed by the atmosphere);
- the noise from the receiver T_R
- the spillover T_{spill}
- contribution of the atmosphere T_{atm}

$$T_a + T_R + T_{spill} + T_{atm} = T_{sys}$$

T_{sys}= System Temperature

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System Temperature

- Measures the overall sensitivity of the receiving system

$$\Delta T_{rms} = \frac{\alpha T_{sys}}{\sqrt{\Delta t \Delta \nu}}$$

α depends on the receiver design
Δt = integration time
$\Delta \nu$ =bandwidth

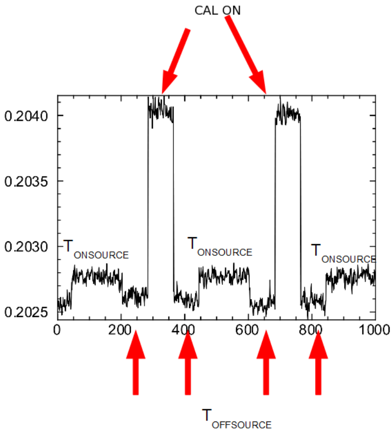
Measuring the Antenna Temperature(2)

The antenna temperature is, usually much lesser than the system temperature thus is mandatory to use an observing strategy aimed at revealing the T_a.

$$T_{onsource} = T_a + T_R + T_{spill} + T_{atm}(1 - e^{-\frac{\tau}{sin(el)}})$$
$$T_{offsource} = T_R + T_{spill} + T_{atm}(1 - e^{-\frac{\tau}{sin(el)}})$$
$$T_a = T_{onsource} - T_{offsource}$$

Position Switching

Switching between on source position and off source.



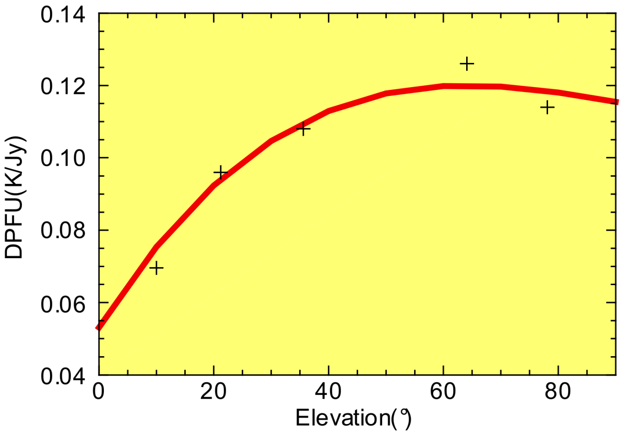
Calibration Curves

- Curves obtained following sources of flux well known over a wide range of elevations.

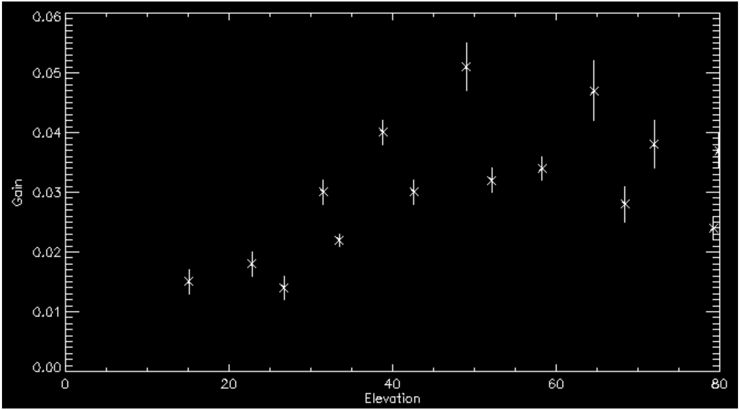
$$\Gamma = \frac{T_a}{S\nu} = \frac{A_{eff}}{2k_b} = \quad (1)$$

$$= DPFU \times G(el) \quad (2)$$

Calibration Curves



Calibration Curves(2)



Flux Calibrators

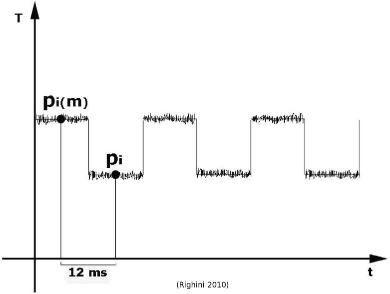
source	ν [MHz]	JD 244..	S [Jy]	ΔS [Jy]	N	C_g or C_d	diff. [%]
	1408	7933[1)]	16.27	0.08	25	1.000	+2.5
3C48	2695	8171	9.49	0.05	18	1.000	+3.0
	4750	7965	5.72	0.03	2	1.000	+4.0
0134+329	10550	7894[2)]	2.65	0.01	4	1.001	+6.3
	23780	7752	1.11	0.02	3	1.001	+7.8
W3(OH)	23780	7752	3.17	0.03	5	1.010	—
0223+617	43200	8352[3)]	3.72	0.06	15	1.03	—
	1408	7933[1)]	47.47	0.24	7	1.001	−2.0
3C123	2695	8171	27.62	0.14	6	1.003	−3.0
	4750	7965	16.56	0.08	3	1.009	−4.1
0433+296	10550	7894[2)]	7.27	0.04	5	1.042	−9.7
	23780	7752	3.12	0.09	1	1.111	−9.5
	1408	7933[1)]	21.86	0.11	4	1.000	−2.2
3C147	2695	8171	13.04	0.07	9	1.000	−4.2
	4750	7965	7.92	0.04	12	1.000	−5.3
0538+498	10550	7894[2)]	3.68	0.02	5	1.000	−4.5
	23780	7752	1.70	0.02	2	1.001	+7.7
3C161	1408	7933[1)]	18.58	0.09	7	1.000	−2.0
	2695	8171	11.13	0.06	5	1.000	−2.7
0624−058	4750	7965	6.75	0.03	3	1.000	−2.8
	10550	7894[2)]	2.94	0.02	4	1.002	−6.3
3C218	1408	7933[1)]	42.65	0.11	7	1.004	−0.4
	2695	8171	23.19	0.12	6	1.017	−2.2
0915−119	4750	7965	13.65	0.07	3	1.053	−3.6
	10550	7894[2)]	6.53	0.04	4	1.245	−4.7
3C227	1408	7933[1)]	7.61	0.04	7	1.048	+6.0
0945+077	2695	8171	4.39	0.02	8	1.208	+4.6
	4750	7965	2.96	0.10	1	M	+12.7
3C249.1	1408	7933[1)]	2.28	0.01	6	1.001	−7.5
1100+772	2695	8171	1.33	0.01	4	1.003	−5.1
	4750	7965	0.82	0.01	2	1.010	+1.0
	1408	7933	203.0	6.0	1	M	−4.6
3C274	2695	7917[4)]	121.7	2.1	2	M	−0.3
1228+127	4750	7965	77.3	2.0	1	M	+2.9
	10550	7898	40.2	1.6	1	M	+6.0

(Ott et al. of radio flux density calibrators, 1994)

Internal Calibration

- The outputs of the digital backends are measured in *counts*.
- The conversion from *counts* and T_a is made using a reference mark, i.e. the calibration mark.

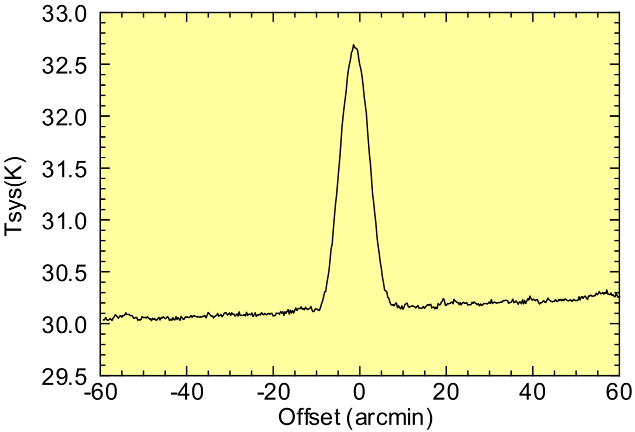
Let $p_i(m)$ and p_i the measured counts respectively with mark on and off ;



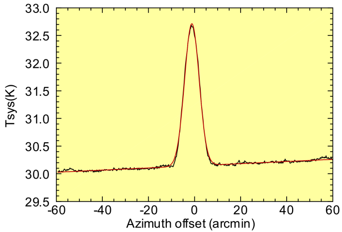
$$T_a = p_i \frac{T_{cal}}{p_i(m) - p_i}$$

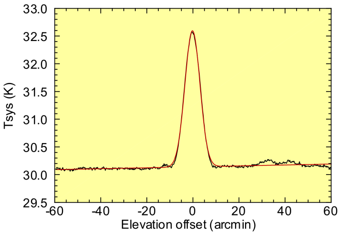
Cross-Scanning

- The antenna moves following a cross shaped path centered on the source;
- Data are acquired while the antenna is moving.



Cross-Scan example





$$f(x) = A_0 e^{\frac{(-z^2)}{2}} + A_3 + A_4 x$$

$$z = \frac{x - A_1}{A_2}$$

A_0	2.57
A_1	-1.18
A_2	3.17
A_3	30.14
A_4	0.002
Residuals(RMS)	0.02

$$\text{FWHM} = 2\sqrt{2ln(2A_2)}$$

Obtaining antenna parameters (A_{eff} and flux gain)

- A_0 is the antenna temperature;
- the flux of the radio source 3C123 at 5 GHz is 16 Jy (1 $Jy = 10^{-26}\frac{W}{Hz \cdot m^2}$)

$$\Gamma = \frac{2.57}{16.0} = 0.160(K/jy)$$

- $A_{eff} = 2k_b\Gamma = 2 \times 1.38 \cdot 10^{-23} \times 10^{26} = 441.6\ m^2$

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Antenna efficiency :

$$\eta_a = \frac{A_{eff}}{A_g} = 0.54$$

Obtaining antenna parameters (main beam efficiency)

$$\Omega_{mb} = 1.133\theta_B^2$$

$$\Omega_A = \frac{\lambda^2}{A_{eff}}$$

With $A_{eff} = 440m^2$, $\theta_B = 7.4$ arcmin:

$$\Omega_{mb} = 5.39 \times 10^{-6} sr$$

$$\Omega_A = 8.18 \times 10^{-6} sr$$

Thus:

$$\eta_{mb} = \frac{\Omega_{mb}}{\Omega_A} = 0.64;$$

From antenna to brightness temperature

The brightness temperature is the Rayleigh-Jeans temperature of an equivalent black body with the same power per unit area per unit frequency per solid angle as the celestial source. For pointlike sources:

$$B = \frac{S_\nu}{\Omega_{mb}} = \frac{2k_b T_{mb}}{\lambda^2} \tag{3}$$

$$T_A^* = \frac{A_{eff}}{2K_b} B\Omega_{mb} = \frac{A_{eff}}{\lambda^2}\Omega_{mb}; \tag{4}$$

Thus:

$$T_{mb} = \frac{T_A}{\eta_{mb}}$$

And the brightness temperature of the source is:

$$T_s = T_{mb}\frac{(\theta_s^2 + \theta_b^2)}{\theta_s^2}$$

Expected SRT Calibration Parameters

- D = 64 m, A_g = 3200 m^2;

ν (GHz)	T_R (K)	T_{atm} (K)	T_{spill} (K)	T_{sys} (K)	η_a (%)	Γ (K/Jy)	SEFD (Jy)	$\Delta\nu$ (MHz)	Sens. (mJy $\sqrt{(s)}$)
0.3	30	16	6	52	58.7	0.684	76	2x110	5.1
1.5	5	5	10	20	59.4	0.693	29	2x500	0.9
5	15	5	-	20	57.7	0.673	30	2x1500	0.5
23	21	60	-	81	56.1	0.654	124	2x2000	2.0
43	40	20	-	60	52.5	0.612	98	2x2000	1.5
100	100	80	-	180	34.7	0.405	444	2x2000	7.0

Summarizing

- With internal calibration counts are converted to antenna temperatures;
- Calibration curves give the flux gains as function of the elevation;
- From gains, A_{eff} are obtained and thus also η_a is known;
- With A_{eff}, beam solid angles can be calculated and also beam efficency can be as well.

Conclusions

With calibration we can:

- convert data from internal scale (counts) to standard scale (antenna temperature);
- check the performances of the receving system (system temperature);
- measure the actual antenna parameters and efficiencies;
- get intrinsic properties of the radio sources.

Some good readings

General radio astronomy:

- Thomas L. Wilson,Kristen Rohlfs, Susanne H´uttemeister,**Tools of Radio Astronomy**,Springer;
- J.D.Kraus, Radio Astronomy, Cygnus Quasar Books;
- J.W.M. Baars, The Paraboloidal Reflector Antenna In Radio Astronomy And Communication, Springer

Something about SRT:

- E.Cenacchi, The SRT Project Book,2006
- S.Righini,The Enhanced Single-dish Control System and wide surveys of compact sources,PhD Thesis, Bologna University,2010