What can go wrong with VLBI calibration

TOG Workshop Notes March 2006

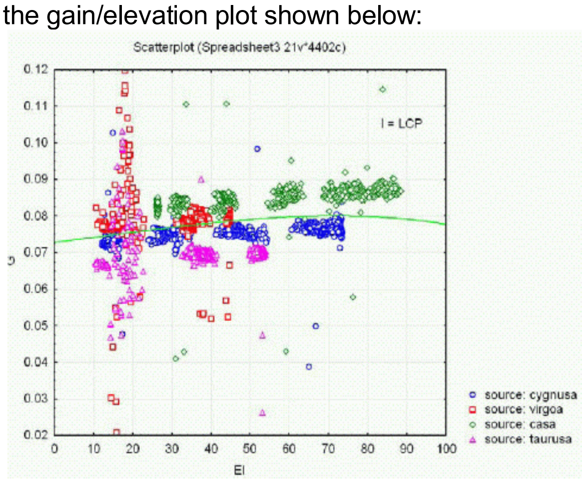
VLBI Calibration process

- Check pointing
- Run acquir / onoff to get gain/elevation curve and Tcal/frequency variations
- Run gnplt to get rxg files
- Using rxg files, run antabfs to produce calibrated gain curves and Tsys against time
- Carefully check if antab files are OK
- Put rxg and antabfs files on server within 2 weeks of observation.

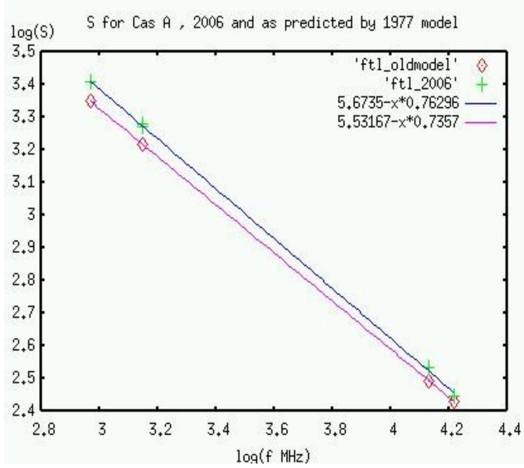
Most points are well covered in the Haystack TOW notes from May 2005 (references).
This text discusses some details, and problems which can arise. Many of the problems are apparent from visual inspection of antabfs files and plots made from them.

The Flux Density Scale

The calibrator sources in the flux.ctl list come from various sources (Baars 1977, Ott 1994). The sources Cas A , Cyg A and Tau A are primary calibrators, their fluxes have been measured accurately in the past and these values are transferred to secondary calibrators. Some antennas use primary calibrators for FS calibration, others secondary sources.
Cas A and Tau A are supernova remnants, their flux is variable. FS uses a fit from 1977 to predict Cas A flux. Recently Michael Lindqvist measured several of the primary sources at L-band, giving the gain/elevation plot shown below:



Apparently the assumed flux density of Cas A is too low, so the flux density drop against time calculated in 1977 is too rapid. Also the flux of Taurus A has dropped, the value in calibration tables is too high as no decay is taken into account. This conclusion is consistent with recent literature (O'Sullivan, Vinyajkin).
The following plot shows Cas A flux density against frequency for 2006 (blue curve) from recent literature, and the curve obtained by extrapolating to 2006 using the 1977 model. This curve is lower.



Note that for Onsala85, a HA/DEC instrument, the gain may also depend on hour angle and not only on elevation.

Strong sources needed

For 25m class antennas, particularly at K band, it is difficult to find strong calibration sources. One can take DR21 (20Jy) or a strong flat-spectrum source, putting up-to-date flux density value in flux.ctl. Planets are also possible, Venus can give 300Jy at 22GHz but is extended (see refs.) . FS works out beam dilution. If the source is too extended of course dilution calculation can be inaccurate, e.g. for Cygnus A, a 2' double.

Problems running onoff

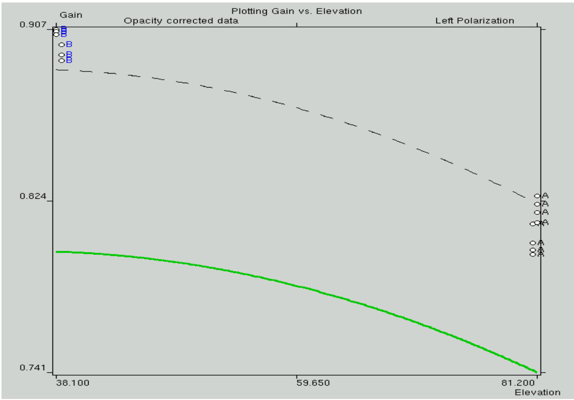
proper operation of the onoff process is dependent on proper reporting from the antenna. Data taking must wait until the antenna has settled. If integration starts before the antenna settles, or before levels have settled after switching cal signal on and off, the root-mean-square deviation on the data will be obviously too high:

```
OFFS 125.5 -0.0000 -0.7801 1u  6089.0     8.5
OFFS 125.5 -0.0000 -0.7801 3u  6386.5     9.2
OFFS 125.5 -0.0000 -0.7801 5u  7351.5     9.2
OFFS 125.5 -0.0000 -0.7801 7u  6069.5    10.6
#antcn#Commanding new offsets       0       0
ONSO 143.1  0.0000  0.0000 1u  9142.0  1955.9
ONSO 143.1  0.0000  0.0000 3u 10151.0  2436.7
ONSO 143.1  0.0000  0.0000 5u 11687.5  2840.4
ONSO 143.1  0.0000  0.0000 7u  9627.5  2320.0
                                          ^
                                    RMS-----|
```

In some cases data taking can start even before the antenna starts to move, since “TRACKING“ may be reported by the antenna for several seconds between commanding a move and before the move starts. (Possibly SH, TR, UR). RMS is useful to check this. (HH and MC do not report RMS since only 1 integration/point.) Points with high RMS and high “comp“ should be flagged and not used. A wait may also be necessary in 'caloffnf' and 'calonnf' to give time for cal to switch on or off (Effelsberg : 4 seconds).

Problems running gnplt

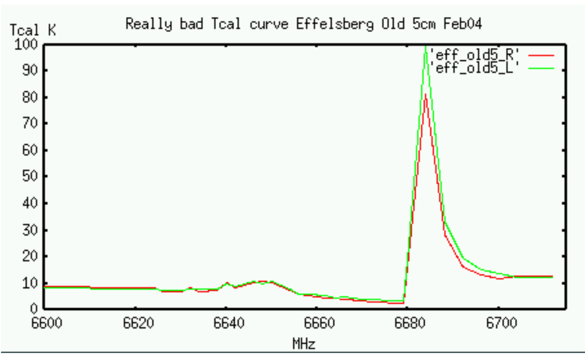
In its present version the gnplt program, when given good data, usually gives an excellent result. Calibration runs have two main purposes, gain/elevation and Tcal against temperature. Two runs are often needed to optimise these two aspects. The gain curve calculated and posted should be the one needed to calibrate data, this is gain including average atmospheric absorption. This is obtained by using gnplt *without* opacity correction. If the opacity correction is used to correct measured values, the gain curve will be that of antenna alone, without atmosphere. This difference is particularly important at K-band. The figure below shows part of the standard Effelsberg gain curve at K-band, the dotted line is opacity corrected.



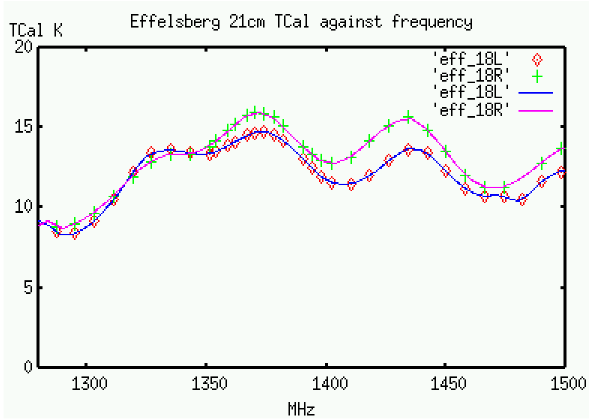
Note that to correct for opacity, values for Trec and spillover in the rxg files are needed (example in Appendix). An irritation is that the rxg files have two places for gain (LCP,RCP), but only one Trec. This should perhaps be changed since Trec is often different in two polarisation channels, but gain does not vary.

Problems with rxg files

These contain tables of Tcal against frequency, which are ideally flat. However often the files have a considerable structure in frequency. If there are resonances in the cal coupler the results can be extreme (Effelsberg 5cm February 2004):

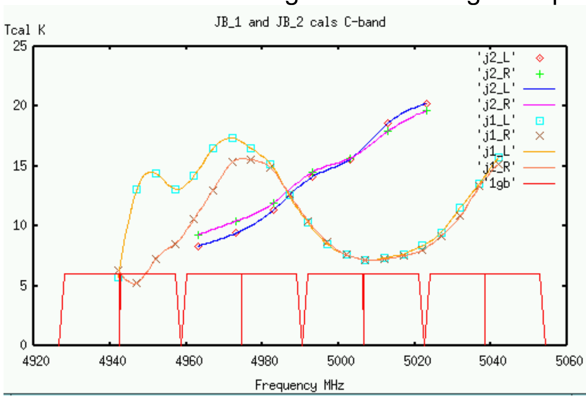


A more moderate, more typical example is shown next:



Points are measured every 8MHz. One sees a sinusoidal variation with a period of about 50MHz. The usual cause of ripples is mismatch in directional couplers used for putting in the cal. Also 18cm couplers are often not directional, but merely a probe in the waveguide. Then power is also sent out of the horn and returns as frequency - dependent reflection.

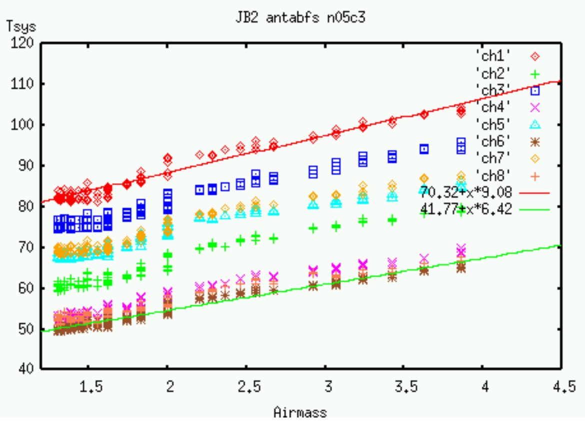
The FS interpolates the given rxg values to get a cal value for the middle of each channel, antabfs does the same. If Tcal varies strongly with frequency it is very difficult to find the correct Tcal. This has become worse recently with 1Gb/s observations, which use double-sideband operation with 16MHz filter bandwidths. We therefore have to find an average cal value for a 32MHz channel. Looking at the following example



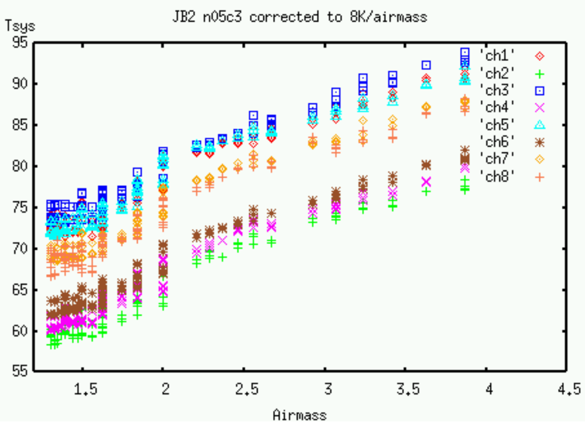
we can see that a 32MHz channel will include a large range of Tcal values. The resulting values of Tcal which antabfs interpolates then look like this:

```
L1: bbc01 4942.49  BW=16.000  LSB Tcal= 6.5 K
L2: bbc01 4942.49  BW=16.000  USB Tcal= 6.5 K
L3: bbc03 4974.49  BW=16.000  LSB Tcal=16.9 K
L4: bbc03 4974.49  BW=16.000  USB Tcal=16.9 K
L5: bbc05 5006.49  BW=16.000  LSB Tcal= 7.2 K
L6: bbc05 5006.49  BW=16.000  USB Tcal= 7.2 K
L7: bbc07 5038.49  BW=16.000  LSB Tcal=14.2 K
L8: bbc07 5038.49  BW=16.000  USB Tcal=14.2 K
```

This is probably not a good approximation. If we use a Tcal table like this to calibrate, the resulting plot of Tsys for 8 channels against airmass gives us:



There must be something wrong here because the gradient of Tsys against airmass varies between 9.1 and 6.4. If we adjust Tcal values to give a gradient of 8K/airmass for all channels the following picture results:

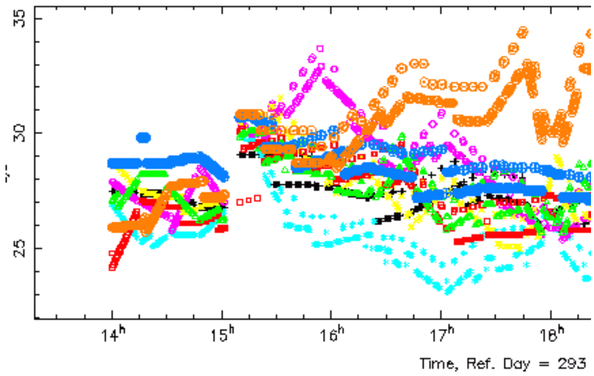


This looks more realistic. There are two families of curves corresponding to odd and even channels, L and R pol with different TRec, (only channel 8 is in the wrong group). So except for a scale factor, calibration according to airmass can give a useful method of checking calibration in individual channels.

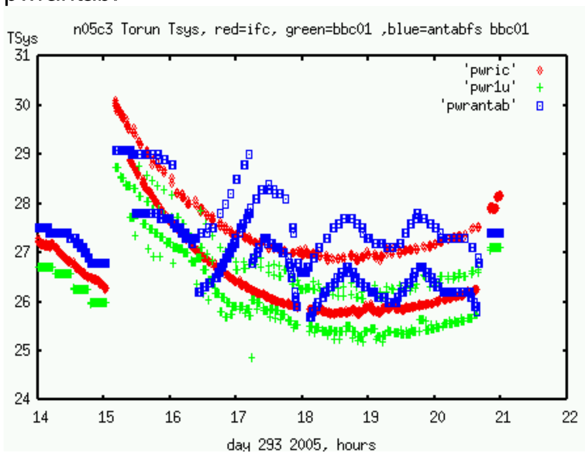
Particularly for wideband experiments a better method than simple interpolation of tabulated values is needed to find an appropriate Tcal for a particular channel, taking account of single- or double – sideband operation. What must then follow is careful inspection of antabfs files before they are sent out, for instance using the antabfs plot facility provided by Cormac.

Tsys data from VLBA4 terminals

Noto, Torun Shanghai and Cambridge use VLBA4 terminals. Here the “tpicd“ output is not the level, but the gain steps applied to keep the BBC output levelled. These gain steps are about 0.14dB at mid-range. Cambridge does not do calibration at all, but the others show strange antabfs plots. Here Torun is taken as an example since it has an excellent stable, low-noise receiver and high gain at 6cm. Problems are extreme for the “N“ series of experiments with strong sources, for instance N05L2, and N03C3 illustrated below:



The individual channels on the antabfs plot show a seemingly random off-source noise level, increases of 1.5K in antenna temperature caused by 3C454.3 can be seen on top of this. To check this a simple script was used to plot power in IF channel “c“ , and in bbc01 which is connected to it, scaled according to the variable attenuator setting. The traces are pwric and pwr1u in the plot. The '1u' channel taken from the antabfs file is pwrantab.



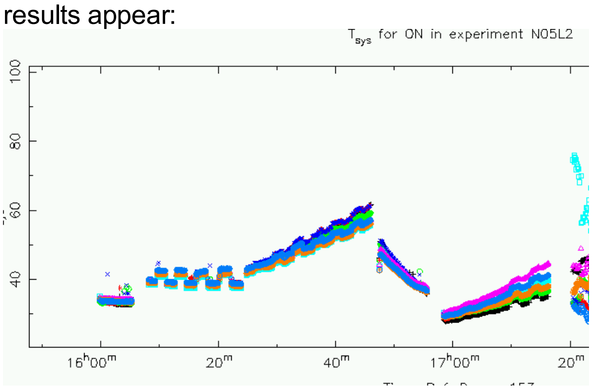
The high quality of the system is shown by the stability of the red curve from IF total power. The green curve shows reasonable accuracy, but the accuracy of the “tpdiffgain“ method is obviously limited. However the 'pwrantab' curve is obviously incorrect, showing breaks in the curve where the BBC attenuator changes by 1 step, which suggests an interaction of straight-line fitting with the attenuator switching steps.

One feature of the Torun logs can confuse analysis scripts: the selection of bbc units to use for tsys is not done according to the observation, using statements like `tpical=formvc,formif` but instead all units are used for calibration :
`tpical=1u,1l,2u,2l,....,7u,7l,8u,8l,ifa,ifc`
This means that the selection of channels is different for tsys than for tpicd, which could lead to problems.

Problems in logfiles

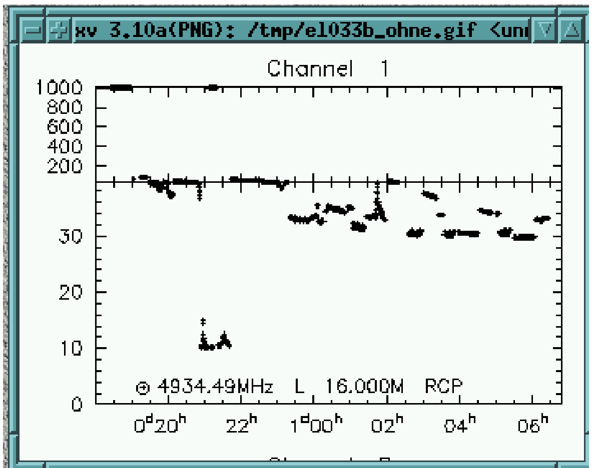
Often Tsys measurements are taken while the antenna is moving, because the PI has left too little time for the measurement. If Tantenna is large and Tcal small then this is a big problem.

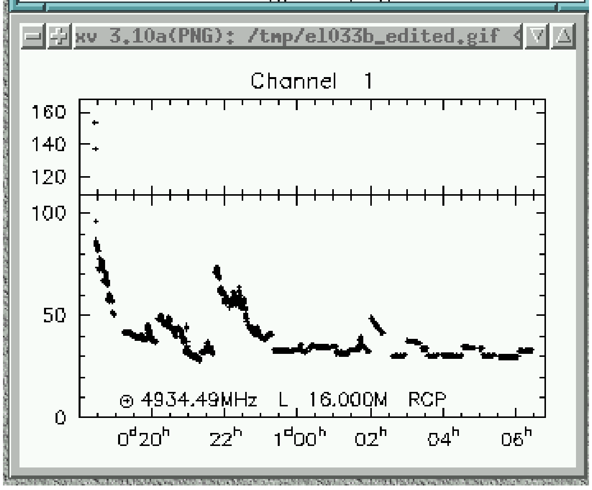
The 'caltsys' procedure should be made so that 'tpi' and 'tpical' are not separated by other tests. Before and after caltsys, an onsource check should be made. Failure of either of the onsource checks should lead to rejecting the Tsys measurement. If these are not rejected, strange results appear:



(n05L2 Onsala) Here large gradients appear because a straight-line fit is used between faulty Tsys points. So it is necessary to inspect all antabfs files at the stations, and hand-edit the logs if results like this appear.

The figure below shows Effelsberg Tsys plot for el033b, which needed considerable editing at the beginning. The top figure is shown without editing, the lower is with edit.





In this example editing consisted in flagging bad Tsys measurements although they passed the 'onsource' check, and in reinstating some good ones which were nominally off-source.

A frequent problem is that the first Tsys in a program fails, usually because the antenna started late. This means up to an hour of data could then be uncalibrated and therefore lost. The only cure is hand-editing of the log files, putting in values for tpi and tpical which ' look good'. Visual inspection of the antabfs files using the 'plot_tsys.pl' tool is therefore very important.

RFI Problems

Particularly at 18cm RFI messes up both onoff and Tsys measurements. Geo stations have problems at S-band because of UMTS. Some stations like Medicina have problems all over L-band , for some the main problem is the Iridium satellite system covering 1610-1626 Mhz (http://www.astron.nl/craf/iridium.htm) . The recent trend to 1Gbps at 18cm means that calibration measurements in the two lowest channels centered at 1602.49 and 1618.49MHz are severely disturbed.

Checking Amplitude corrections from pipeline

The final check is to look at amplitude corrections derived by the pipeline, for example http://archive.jive.nl/scripts/arch.php?exp=N05L2_050602 , files like n05l2_3C273B_CALIB_AMP2.PS.gz give amplitude corrections, here it is no surprise that the faulty antabfs data for VLBA4 stations lead to rapid variations in amplitude correction, different from channel to channel.

Conclusions so far

- Do not use Cas A and Tau A because of variability.
- Calibration sources of sufficient strength, particularly at K-band: DR21, flat-spectrum sources, planets.
- In good weather conditions, use several integrations per data point in onoff to allow RMS calculation
- Tcal not too big (causes nonlinearity), value should be reasonably constant against frequency
- Visual examination of rxg values and antabfs at stations before posting
- If there are problems, edit log files to fix, or edit rxg values used
- Visual examination at JIVE

Alternatives to present calibration methods

For the VLBA antennas a small (1-5K) calibration signal is used, switched at 80Hz and decoded in each VLBA BBC. This provides continuous, stable calibration at the expense of a slightly increased Tsys. This method would be a solution for Cambridge. An experimental FS based on 9.6.9 has been made which implements this.

References

Haystack TOW notes:
ftp://ivscc.gsfc.nasa.gov/pub/TOW/tow2005/notebook
particularly files Himwich.MW.pdf, Gunn-OrlatiMW.pdf and Gunn-Sem.pdf

Flux density of primary sources:
Ott,M., et al., 1994, Astron&Astrophys.,**284**, 331-339
Baars, J.W.M., et al., 1977, Astron.&Astrophys, **61**, 99
O'Sullivan and Green, 1999, MNRAS **303**,575
Reichart and Stephens, 2000, http://xxx.lanl.gov/pdf/astro-ph/0002032
Vinyajkin and Razin,2004, http://xxx.lanl.gov/pdf/astro-ph/0412593
Vinyajkin, 2005, http://xxx.lanl.gov/pdf/astro-ph/0502033

Planet flux density:
http://www.sao.ru/hq/lran/ratan_manual.html
http://wiki.gb.nrao.edu/bin/view/Knowledge/GBTMemos/XBand.pdf and references therein
www.vlbi.de/vlbi/planets.html

Behaviour of HA/DEC-mounted antennas:
von Hoerner , IEEE Trans Antennas & Propagation AP-26, P315 (1978) and AP-28, P652 (1980)

Appendix : Appearance of a typical rxg file

```
* 1.3cm.rxg
range 21000 25400
2006 01 26
frequency 0.95
rcp lcp
0.80 0.80
ELEV POLY 0.959 0.00235 -3.3887e-05
rcp 22188.0 4.7040
rcp 22196.0 4.7785
rcp 22204.0 4.7775
rcp 22212.0 4.6830
rcp 22220.0 4.6760
rcp 22228.0 4.6680
rcp 22236.0 4.5845
rcp 22244.0 4.4535
lcp 22188.0 4.8595
lcp 22196.0 4.9920
lcp 22204.0 5.1375
lcp 22212.0 5.1890
lcp 22220.0 5.2995
lcp 22228.0 5.3145
lcp 22236.0 5.2220
lcp 22244.0 5.1475
end_tcal_table
* Trec--------
64.1
* Spillover against elevation (fiction)
90 0
19 1
16 2
14 4
12 10
8  20
end_spillover_table
```