Antenna Gain Calibration with gnplt

Carl Holmström

September 2003

To open a log file in gnplt:

- Use 'Open' on the 'File' menu, and select your log file.
- Give the log file as a command line argument.

Selecting the axes to plot:

- Y-axis can be Time, Elevation, Frequency, Azimuth or Airmass, and is selected from the 'Y-axis' menu-
- The 'X-axis' menu has more options, and also has two sub menus at the bottom, Assumed items and Gain:
  - Assumed items are the values in the .rxg file.
  - On the gain menu you can select how the gain is computed.
- Unless you start gnplt with the flag '-r' (or set it manually on the 'Edit' menu), you will have to replot after changing the axes for the selection changes to effect the plot.
- If you want to select "Gain vs. Elevation", "$T_{Cal}(K)$ vs. Frequency" or "$T_{rec} - T_{spill}$ vs. Airmass" as your axes, there are shortcut menus on the 'Edit' menu. This is a bit trickier, but much faster, so I encourage you to use it!

Selecting sources and frequencies:

- Sources (on the 'Edit' menu):
  - Select either "All", "All Calibrators" or "All Pointing and Calibrators".
  - If you wish to select a single source from a bunch of sources, select "None" and the go to the sub menu of that source and click on "All Times".
  - Possible to delete specific times for specific sources.

- Frequencies (also on the 'Edit' menu):
  - Frequencies are grouped by polarization.
  - Check buttons control if a frequency is shown or not.
  - On each polarization sub menu, you can easily select all or no frequencies for that polarization, or no frequencies for both polarization.
  - The LO values for the polarization are shown. Clicking on one of them, selects the frequencies associated with that LO, and deselects the rest.

Don't forget to replot after you are satisfied with your selection!

Editing out "bad" data points:

- Click on the point with the left mouse button. (It turns red.) To include the point again, click on it one more time.
- Draw a box with the right mouse button around the point(s) you wish to edit out. (The point(s) turn red.) To include the point(s) again, draw a box with the middle mouse button around the point(s).
- Holding down the 'Shift' key and clicking the left mouse button while over a point deletes all points with that specific time. To include the points again, repeat the procedure.

Three different types of fitting:

- Gain vs. Elevation
  - Fit a new DPFU
  - Fit a new Gain Curve and DPFU
  - Scale the $TCal$(K) table by a factor
- $T_{Cal}(K)$ vs. Frequency
  - Fit to average value at each frequency
  - Fit to median value at each frequency
- $T_{rec} - T_{spill}$ vs. Airmass
  - Select T_{atm}
  - Choose a time interval, and fit for T_{rec}

Remember to update your working file when you are satisfied with the fit!

To update the .rxg file(s):

- Gain vs. elevation fitting
  - Make polarization, source and frequency selections using the "Gain vs. Elev." shortcut.
  - Fit using the "Update Gain Curve and DPFU" option.
  - Update the working file.
  - Select the other polarization.
  - Fit using the "Update DPFU" option.
  - Update the working file.
- TCal vs. Frequency fitting
  - Make polarization, source and LO selection using the "TCal vs. Freq." shortcut menu.
  - Fit TCal using either average or median option.
  - Update the working file.
  - Select the other polarization.
  - Fit TCal again.
  - Update the working file.
- Done! (Make sure the changes are written to the original .rxg file before exiting)

Updating Trec value in working file.

- Make polarization, source and LO selection using the "Tsys-Tspill vs. Airmass" shortcut menu.
- Select "Fit for Trec" from the 'Tools' menu.
- Select Tatm, and a time interval for the fit. Click "Ok".
- A number of curves are drawn. For example, if you have selected a one hour interval, and there are five hours of data in the log file, five curves are drawn.
- If you are satisfied with the new Trec, update the working file. If not, you might want to deselect a few of the fitted points and recalculate the Trec on the 'Tools' menu.

Correction for opacities.

- Possible to correct the gain for opacities. Option is located on the 'Edit' menu, in the 'Gain' sub menu.
- Should only be used for frequencies $> 8GHz$.
- Fitting is done in the same way as usual for Gain vs. Elevation.

Miscellaneous.

- To edit out points based on Gain Compression, use the "Delete points with bad GC" option on the 'Edit' menu. You can define what "bad" GC means, the default is points with GC $< 95\%$ or $> 105\%$.
- You can print the current plot using the "Print" option on the 'File' menu. You can also print it to a postscript file.
- For easy access to information about keyboard and mouse shortcuts, please see the "Help" menu.
- Please report bugs and make suggestions for changes and enhancements to f99caho@dd.chalmers.se.

EVN Memo ???

NOTES ON USING GNPLT (Ver 9.6.4)

John Conway, Onsala Space Observatory

4th June 2003

1) Introduction

The Tcl/Tk program GNPLT is provided with the FS release as a tool to help examine the performance of your telescope, check the accuracy of the amplitude calibration parameters stored in the control .rxg file and to update this information if needed. GNPLT takes as its main input an ONOFF log (usually collected by the ACQUIRE programme). In addition the relevant current calibration parameter information for the observed band is read in from the appropriate .rxg file.

Many system parameters are collected by ONOFF such as SEFD, Gain compression etc; GNPLT can plot all these against versus frequency and elevation and many other variables as a way of checking telescope performance. In terms of checking the calibration the most important ONOFF measurement in the noise cal in Janskies. Tcal(Jy), which is found from comparing the change in output power when switching the noise cal on with the change in power going on and off a source of known flux density in Jansky. It can be shown that if the combination of dpfu, gain curve, and Tcal(K) versus frequency in the station .rxg files accurately predicts the measured Tcal(Jy) at all frequencies and elevations then the calibration produced for user experiments is ensured to be accurate. GNPLT allows us to adjust the dpfu, gain curve and Tcal(K) versus frequency so that the predicted and observed Tcal(Jy) are the same; when you are satisfied with the results and exit the program the .rxg files kept on disk can be updated with the new calibration parameters.

A more general description of the principals of FS calibration is described in a separate document, this present document instead is meant to be a brief 'how to use' guide to the GNPLT programme. More detailed documentation on every command may be also be produced in a separate document.

2) Nature of plotted Quantities

When GNPLT is started the CALIBRATION PARAMETERS (dpfu, gain curve polynomial, Tcal(K) versus freq) are loaded from the relevant .rxg file into an internal working file. If in the course of running GNPLT we fit new calibration parameters these values are changed in the working file. On exiting GNPLT we can choose to update the calibration parameters in the .rxg file with the current parameters in the working file.

On starting GNPLT and choosing an input ONOFF log files certain MEASUREMENT QUANTITIES are loaded from the ONOFF VAL lines. The most important are SEFD(Jy),

Tcal(Jy) and the gain compression value GC. The latter is the ratio of change in counts switching the cal on when on the source to the change when off the cal source; this ratio should be close to one. These pure measurement quantities never change during a GNPLT session.

Finally in GNPLT are internally calculated DERIVED QUANTITIES these are calculated when needed from a measurement quantity and calibration quantities. For instance the Gain (K/Jy) when plotted against some quantity is calculated by dividing the Tcal(K) (usually taken from the working file) with the measured Tcal(Jy) for that point in the ONOFF log. Likewise the Tcal(K) versus frequency is calculated from the Tcal(Jy) and the dpfu and gain curve polynomial in the working file. The 'Tcal ratio' which is the ratio of measured Tcal(Jy) in the ONOFF log file and that predicted from the calibration parameters in the working and so is also a combination of measurement and calibration parameters.

Note that some of the derived quantities such as Tcal(K) and Tcal ratio are also given on the ONOFF VAL line, these are the values derived from the .rxg file when ONOFF was run, when the log is read into GNPLT these quantities are recomputed by the GNPLT programme and are updated whenever new values of the calibration parameters are put into the internal working file.

The following sections indicate give step by step instructions on how calibration parameters can be checked and updated if needed.

3) Check Pointing

Calibration data will only worth plotting in GNPLT if the pointing performance of your telescope is good. If as part of your ACQUIRE FIVEPT data was collected the FS Tcl/Tk program PDPLT can be used to check pointing. If the pointing offsets are large but are consistent you can go ahead and analyse the ONOFF data, but in this case you will have to update the pointing model for your telescope to ensure good calibration in the VLBI runs.

4) Starting GNPLT and loading a Logfile

Start the program by typing 'gnplt'. The log file can be including on the command line or inside GNPLT you can click on FILE-NEW, select input file from menu and then click to load the log file containing ONOFF data.

5) Selecting data and plotting quantities.

There exists both a general method of plotting data and 'shortcuts' for plotting the most important calibration quantities (i.e. Gain versus elevation, and Tcal(K) versus frequency). We describe below the general method first and then the shortcuts.

5.1 General method In the General method the menus EDIT must be first be used to decide what is to be plotted, then the axes chosen using X-AXIS and Y-AXIS. Finally plot the data using Ctrl-r.

In detail first click EDIT and under submenus LEFT and RIGHT for left and right polar-

isations decide which frequency channels to plot. Next choose a x-axis type from ITEMS(X-AXIS), e.g elevation. Finally choose a y-axis type from ITEMS(Y-AXIS). In this drop down menu are listed a set of data that can be plotted such as azimuth, elevation, gain compression, Tsys(K), SEFD(Jy=, Tcal(Jy) Tcal(K), Tcal(ratio) some of these are 'measurement quantities' other are 'derived quantities' (see Section 2). The Y-AXIS drop down menu also contains an 'assumed items' submenu where you can choose to plot the currently assumed 'calibration quantities' in the working file, including Tcal(K) and gain. The final button on the Y-AXIS menu is 'Gain', this is a derived quantity calculated from Tcal(Jy) in the log file and an assumed Tcal(K). A drop down submenu gives a choice on where to obtain this Tcal(K). The most common choice is to choose it from the working file. Alternatively an input value can be set manually. Finally we can choose to set Tcal(K) to a value such that the gain will have a certain mean value over a range of elevation. The last two options are provided to allow input to the calibration process of external calibration data from making hot-load/cold-load measurements or from calculating an antenna gain from its known area and efficiency.

5.2 Shortcut method Two shortcuts exist for plotting gain versus elevation and Tcal(K) versus frequency respectively. These are the two main plots required when re-fitting calibration parameters (see Sections 7,8). Under the EDIT menu you can choose the required shortcut, and a cascade of submenus will appear where which frequency, polarisation etc you wish to plot can be chosen. IMPORTANT *when selecting a option do not keep the mouse button down - if so you will get an error on older Tk versions.* Instead click and release the mouse button for each selection in the cascade you have. Note that what is plotted with the shortcuts is more restricted than in the general method. Only a single sense of polarisation can be plotted at a time, and for gain versus elevation a single frequency. Also for the Gain plot the assumed calibration parameter Tcal(K) which is needed to calculate the gain is taken from the value in the working file, if you wish to use a manual input or set it based on obtaining a fixed gain at an elevation range you should use the general method in section 5.1.

6) Editing and Display options.

Moving the cursor close to a point displays on the right hand side of the plot the data for that point including time, frequency, polarisation etc. Clicking on a point with the right mouse button connects associated points together. In the Gain versus elevation plot all points taken at the same frequency are connected. For the Tcal(K) versus frequency plot all points taken at the same time are connected. To remove these lines simply replot the display using ctrl-r.

Options for how data points are plotted are available under the SOURCES menu. In particular a point can have an associated letter plotted to indicate the radio source (the default) or just plotted as a circle.

Before fitting for new calibration parameters it is important to delete bad data. The main way to do this is using the cursor and mouse buttons. Clicking a point using the left mouse button toggles its delete status. Clicking the right button and dragging to make a

rectangle does an area delete. Using the middle mouse button and dragging does an area undelete. Points deleted in one plot (say Gain versus elev) stay deleted in another plot (such as Tcal(K) versus freq).

Using the left mouse button and dragging a rectangle does a zoom to display a region in more detail but does no deleting in itself. However under the EDIT menu there is the option to delete all points outside of the display window. Under the same menu one can undelete all currently deleted points, either in the whole log or just with the current selection of polarisation, frequency etc.

To change the scale of the display use the SCALE menu - there is the option of scaling to include all points or just all undeleted points. Points outside the current display window are shown at the edge of the window. Deleted points are shown red, undeleted points outside the current display window as blue.

Normally to replot after making a change you can type ctrl-r or under EDIT choose replot. You can set under EDIT to automatically replot - which causes a replot whenever the axes types are changed.

A useful way to edit out bad data in to use the 'Flag using Gain Compression' option under EDIT. The Gain compression is the ratio of change in counts firing the cal on-source compared to off source. This value should be close to 1. If it is not this could be due to gain compression, RFI or some timing problem with switching on and off source, in any case if the GC is not close to 1 the other measured parameters are likely not reliable.

7) Checking Gain Curve and overall cal scale.

The first step to check/update calibration parameters is to look at gain versus elevation at each polarisation and update if needed the gain curve and peak gain (dpfu). Note although left and right polarisation have different dpfu they share the same gain polynomial in the .rxg file. This means that if the gain curve polynomial is updated for one polarisation it effects what is plotted for the the other polarisation.

Checking/re-fitting at each polarisation can be done either using the general plotting method or the shortcut as described in Section 5. The shortcut always takes the Tcal(K) needed to calculate gain from the current working file. If the general plotting method is being used then for *checking calibration* one should also choose this option by clicking on 'Tcal(K) from file'. If on the other hand you are starting the calibration process from scratch and have an external measurement of the correct Tcal(K) based on say a hot/cold load measurement at the plotted frequency you should use the general method of plotting and enter the measured Tcal(K) for this frequency manually. Likewise there is the option under general plotting to set Tcal(K) to a value which forces the gain to have a expected (externally measured or calculated) value over at a range of elevations.

After plotting the data, plot the current gain curve to compare. Click on TOOLS and then GAIN CURVE to plot as a solid green line the current gain curve stored in the working file and check to see whether it fits the measured points. If the shape of the gain curve is correct but not the height this suggests an overall scale error in the amplitude calibration (see section 7.1) and there are two options on what to update in this case. If the shape is incorrect this implies an inaccurate gain curve polynomial and you can choose to fit a new

polynomial and dpfu factor (see Section 7.2). Whenever re-fitting is done the re-fitted curve is shown as a dashed black line. If you are satisfied with the new fit you can under TOOLS choose to update the calibration parameters in the working file with the new values. An example Gain versus elevation plot is shown in Figure 2, with the final updated gain curve shown as a solid green line.

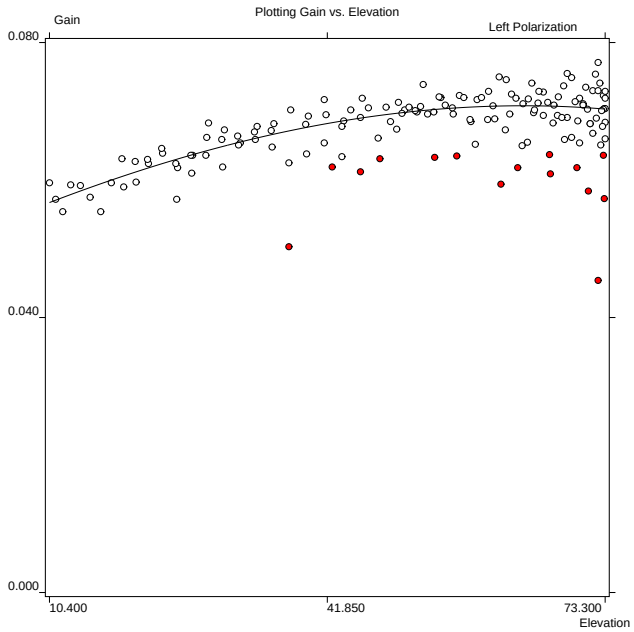

Fig 1. Plotted data of antenna gain versus elevation at a single LCP C-band frequency channel (4950MHz) made with the Onsala 25m telescope in December 2002. The filled symbols have been deleted and were not used in fitting. The line shown is the result of fitting to dpfu and gain curve polynomial (order 3), and then updating the gain curve and dpfu values in the working file.

7.1) Updating Amplitude cal scale.

If the amplitudes of the model gain curve and the measurements are inconsistent in amplitude this means that the Tcal(Jy) predicted from the .rxg file and that measured from sources of known flux density using ONOFF are not consistent. In order to get accurate calibration for VLBI you will need to change either the DPFU or scale the Tcal(K) vs freq table as stored in the current 'working file'. For the purposes of getting good VLBI amplitude calibration it does not matter which option you choose - but you should ideally choose the option which is closest to what really has changed in your system as described below. To choose one of these fitting options click on TOOLS - FIT-TO and then select 'DPFU' or 'scale the Tcal(K)'.

Updating DPFU You should select to update DPFU if you believe your Tcal(K) is correct but that your effective telescope gain stored in the .rxg file may be in error. You would choose this option if for instance the Tcal(K) has recently been measured absolutely

by hot/cold measurements. You might also prefer this option if the plotted points are close to what you expect for the antenna gain given the diameter and efficiency but the plotted curve is not. Using this option a better fit between data and model is obtained by rescaling the gain curve to better fit the measured points. After re-fitting for DPFU a new model gain curve is plotted as a dashed black line. If this is a good fit you can choose under TOOLS to update the DPFU in the working file, in which case the black curve changes to green to show that the working file has been updated.

Updating Tcal(K) You should choose this option if you suspect the effective noise cal has changed (for instance the noise tube has been re-installed with a new cross coupler or attenuation in the path). You might consider choosing this option if you think the gain given by the model is closer to what you expect for your telescope than are the plotted gain points. This option produces a better fit between data and model by rescaling the data to fit the model gain curve. After fitting for 'scale Tcal(K)' the Tcal(K) versus frequency table stored in the 'working file' version of the cal parameters are rescaled at every frequency. Note that even though the scale correction might have been found using data from a single frequency channel the same rescaling is applied to the Tcal(K) values at all frequencies. New values of the antenna gain for each measurement are calculated using the updated Tcal versus frequency table and are re-plotted. The recalculated points should fit the plotted model gain curve - if they do you can choose to update the working file in TOOLS.

7.2) Updating Gain Polynomial and DPFU.

If the shape of model gaincurve versus elevation does not fit the data, then under TOOLS-FIT TO you should select option 'GAIN CURVE and DPFU'. After fitting a black line representing the new model gain is plotted, this should now fit the data. If it is a good fit you can choose to update the gain curve in the current working file under TOOLS, and the black dashed curve is changed to a green solid one to show that the working files has been updated.

8) Check and update Tcal(K) versus frequency.

This can also be done using the general method of setting the x and y axes or using the shortcut method (see Section 5). Again one polarisation should be checked/updated at a time. After plotting the data you can use an option under TOOLS to display the current Tcal(K) versus frequency table curve as a green line versus the data. If it does not fit then under TOOLS one can choose to refit, choosing to use either the average or median at each frequency bin. The re-fitted curve is shown as a black line. If you are satisfied with it then you can under TOOLS select to update the current working file. In this case the dashed black line becomes solid green to represent that the newly fitted curve is entered into the working file. An example Tcal(K) versus frequency plot is shown in Figure 2, with the final Tcal(K) versus frequency table after median fitting and updating the working file.

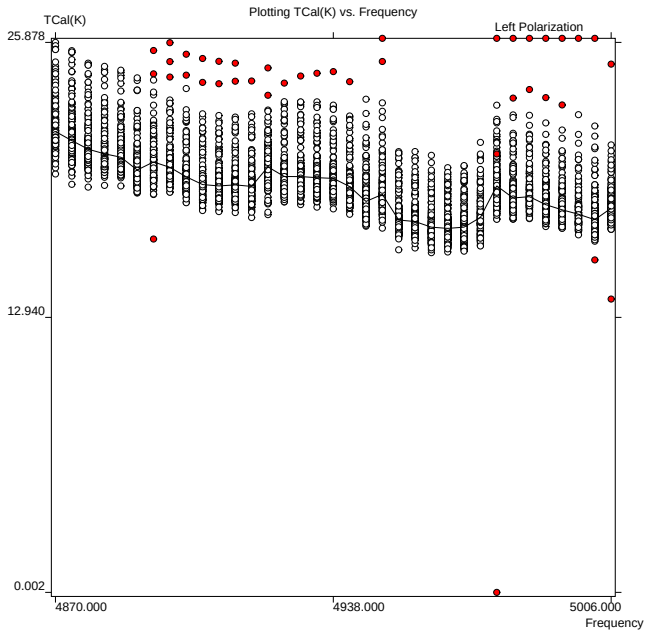

Fig 2. Plotted LCP data of Tcal(K) versus frequency from C-band measurements on the Onsala 25m. The line shown is the result of making a median fit, and then updating the Tcal(K) versus frequency table in the current working file.

9) Final checks and Exiting.

After fitting gain versus elevation for both polarisations (see Section 7) and then fitting Tcal(K) versus frequency for both polarisations (see Section 8) the model calibrations parameters in the working file should be such that the predicted values Tcal(Jy) match the observed values at each elevation/frequency. Under this condition the calibration parameters when used to create the Tsys in user experiments should give the correct calibration.

To check that consistent calibration parameters have been obtained you can choose the plot the 'Tcal ratio' both versus elevation and against frequency for all points. The Tcal ratio is the ratio of observed Tcal(Jy) to observed Tcal(Jy) and if the calibration is consistent this should be close to 1 for all measured points. An alternative way to check is again for each polarisation to plot the 'Gain versus elevation' and show that the model gain curve fits the data. Then plot the 'Tcal(K) versus frequency' and show it fits the model Tcal(K) versus frequency table fits the data points.

If you are finally satisfied that a good fit has been obtained for all data points you can choose under EXIT to update the .rxg file on disk. The old calibration information is kept in the .rxg files but is edited out.