$\mathcal{AIPS}$ Memo 123 revised

New Pulse-cal Capabilities for VLBI in $\mathcal{AIPS}$

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Abstract

The DiFX correlator has acquired the capability of measuring and recording large numbers of pulse-cal tones, typically at intervals of 1 MHz through each spectral window. These pulse-cal tones have very high signal-to-noise, but show a roll-off at the edges of each spectral window and usually have one or more single channels which have amplitude and residual phase differing significantly from the average for the spectral window. $\mathcal{AIPS}$ has acquired the ability to deal with these data including new tasks to display and edit them and to derive calibration from them. This memo was revised in December 2024 to add additional descriptions of typical many-tone PC tables.

1 Introduction

Pulse cal tones have been measured and recorded for a long time in continuum VLBI observations. Typically, there have been only a few tones recorded. $\mathcal{AIPS}$ task PCCOR would use only two tones to measure a delay for the particular antenna. A simplified delay solution on the visibilities of a strong calibration scan is used to remove the lobe ambiguities from the pulse-cal values. The DiFX software correlator has changed this. DiFX can measure and record a great many pulse-cal tones, typically one each MHz across each spectral window. These data are not typically written in the FITS-IDI data set as yet, but are recorded in text files available to the user. This will probably change to have the new, large PC tables written in the FITS-IDI file normally. The pulse-cal data show a bandpass-like roll-off at the edges of each spectral window. They also, typically, have a single interior channel which has amplitude and phase systematically different from the average amplitude and residual phase of the spectral window. Furthermore, there are times where the pulse-cal amplitudes are abnormally low (and sometimes high) compared to the average over the observing run or when the rms of the amplitude in the spectral window is abnormally high or low. It has been found that editing the PC table for these defects is necessary before using the data for calibration.

$\mathcal{AIPS}$ has acquired a number of new and revised tasks to handle the large number of tones in the new PC tables. If the many-tone pulse-cal data did not appear in the FITS-IDI file, they may be found in text files recorded with the data. PCLOD can read in such text files to make a large PC table. Then PCPLT will plot such data, PCEDT and PCFLG will edit the pulse-cal data interactively, PCAVG will average them over time, PCFIT will write an SN table with changes in delay and phase found in the pulse-cal data, PCRMS will edit them automatically from the amplitude rms and discrepant channels found, PCHIS will plot histograms from text files written by PCRMS, and PCASS will write a bandpass table to be applied to the visibilities from the spectral shapes in the pulse-cal data.

This memo is intended to provide instruction in the use of these tasks. A "standard practice" for applying these tasks has yet to be determined, although one is suggested at the end. Note that the test data set used in all examples in this memo has four spectral windows each with 64 pulse-cal tones and two polarizations. The ten antennas of the VLBA were used. There are about 33000 times in the input data set (24 hours

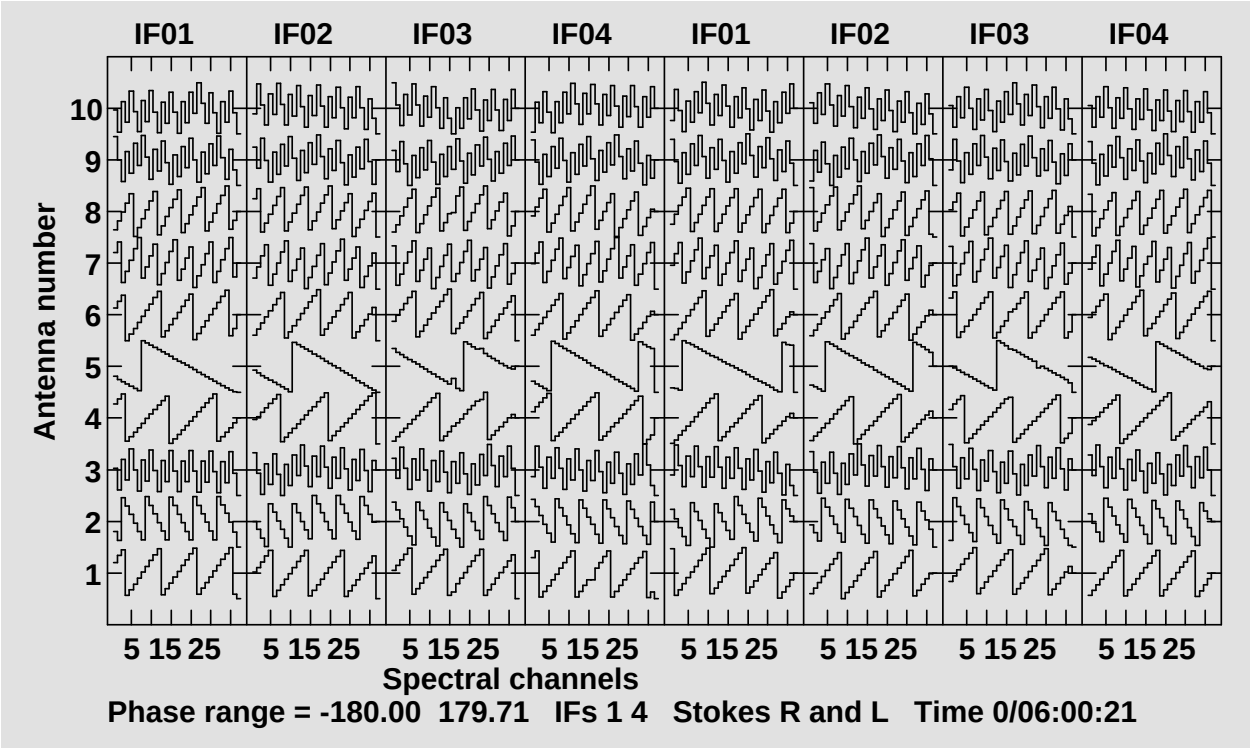

Figure 1: PCPLT of unedited PC table showing phases at one single 2-second time sample.

of 2-second samples observing about 75% of the total elapsed time). This is a large data set which poses some challenges and renders some of the tasks less than useful. But others rise to the challenge. The data set consisted primarily of observations of stronger sources. I was able therefore to compare the results of PCFIT to those, lower signal-to-noise, results from FRING to discover that the pulse-cal tables should be able to provide calibration of delay variations and jumps even for data sets where the sources are not strong enough for FRING. Be careful of the sort order. Resorting the table from antenna-time to time-antenna can be expensive. Each task has a required sort order and will sort the table if necessary. The text below will identify the required sort orders.

2 The data phases and delays

The initial version of this memo emphasized instructions on how to use the then-new tasks in *AIPS* and did not adequately describe the data themselves. The data set mentioned above is BM413Z3 observed 8–9 June, 2017. The last revision of this memo was in November 2018, at which time the full many-tone PC table was still present on disk. Unfortunately, since then, the copy of the data on disk was lost. While the visibility data and conventional 2-tone PC table are available from the archive, the many-tone text files used by PCLOD are no longer accessible.

Therefore, this section will be based on the data set TA035I observed on 27 April 2021 at a frequency of 5 GHz. The data are comprised of four scans on four different sources. There are 4 spectral windows each 32 MHz wide. Thus there are 32 tones in each spectral window and two polarizations. The phases before any calibration show quite a range of apparent delays; PCFIT reveals that these delays are slightly different in each IF and polarization but quite different between antennas. Figure 1 illustrates this. That the phases are quite constant over this rather short time is illustrated in Figure 2. The scan average delays found by PCFIT for this data set are listed in Table 1. The changes with scan are mostly well less than 0.1 ns.

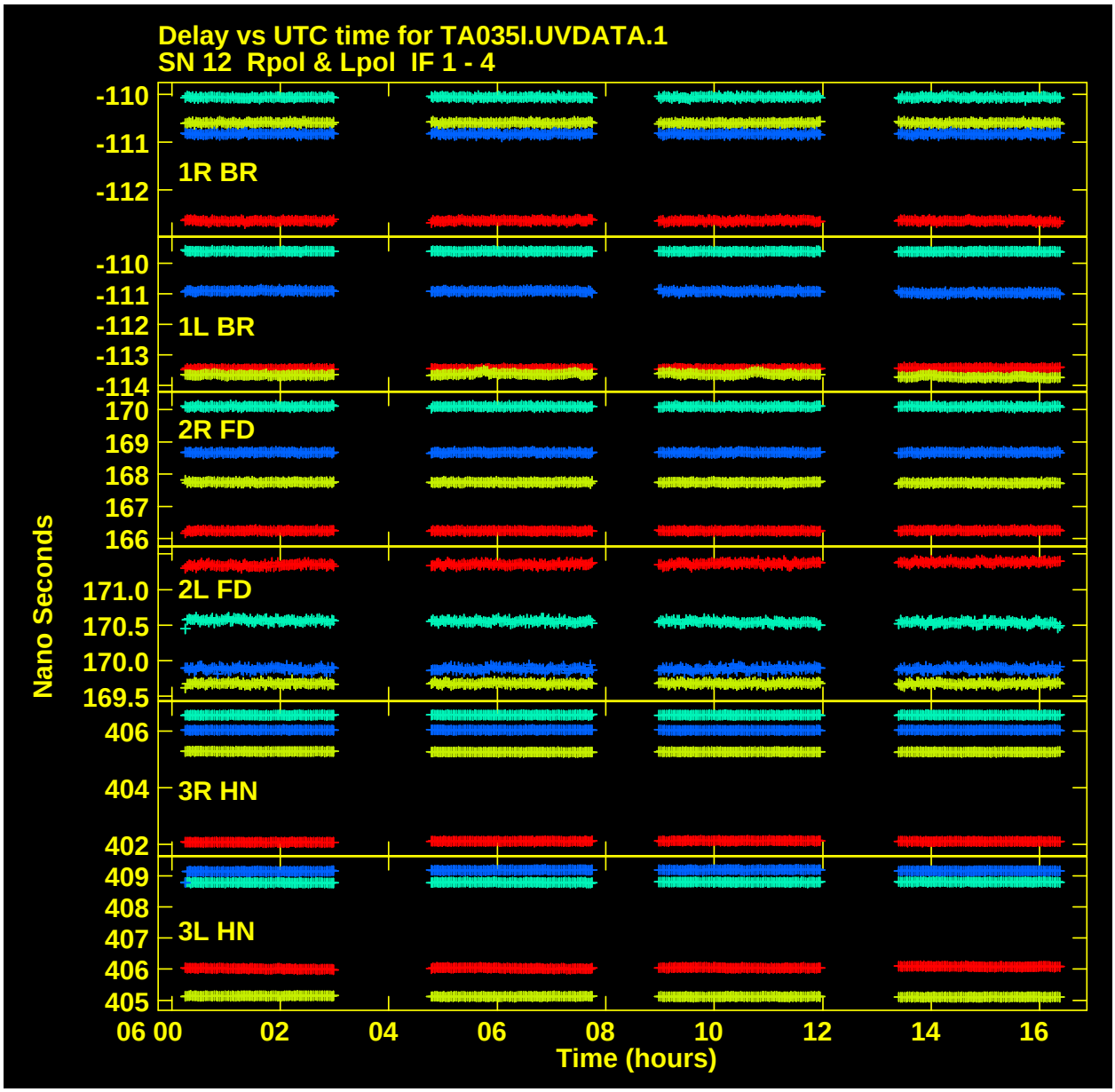

Figure 2: SNPLT of PCFIT fit delays from an unedited PC table showing delays from BR, FD, and HN. Spectral window one is red, 2 yellow, 3 cyan, and 4 blue.

Ant	Src	R 1	R 2	R 3	R 4	L 1	L 2	L 3	L 4
1	1	112.6	110.6	110.1	110.8	113.4	113.6	109.6	110.9
1	2	112.6	110.6	110.1	110.8	113.4	113.6	109.6	110.9
1	3	112.6	110.6	110.1	110.8	113.4	113.6	109.6	110.9
1	4	112.6	110.6	110.1	110.8	113.4	113.7	109.6	111.0
2	1	-166.2	-167.8	-170.1	-168.7	-171.3	-169.7	-170.6	–169.9
2	2	-166.2	-167.7	-170.1	-168.7	-171.4	-169.7	-170.6	–169.9
2	3	-166.2	-167.7	-170.1	-168.7	-171.4	-169.7	-170.5	–169.9
2	4	-166.2	-167.7	-170.1	-168.7	-171.4	-169.7	-170.6	–169.9
3	1	-402.1	-405.3	-406.6	-406.1	-406.1	-405.1	-408.7	-409.1
3	2	-402.1	-405.3	-406.6	-406.0	-406.0	-405.1	-408.8	-409.2
3	3	-402.1	-405.3	-406.6	-406.0	-406.0	-405.1	-408.8	-409.2
3	4	-402.1	-405.3	-406.6	-406.0	-406.1	-405.1	-408.8	-409.2
4	1	87.1	85.1	84.5	84.6	87.3	86.2	83.6	80.9
4	2	87.1	85.1	84.5	84.6	87.3	86.2	83.6	80.9
4	3	87.1	85.1	84.5	84.6	87.3	86.1	83.6	80.9
4	4	87.1	85.1	84.5	84.6	87.2	86.0	83.6	81.0
5	1	-43.0	-45.8	-46.5	-45.8	-40.9	-45.7	-44.1	-41.9
5	2	-43.0	-45.8	-46.5	-45.8	-40.9	-45.7	-44.1	-41.9
5	3	-43.0	-45.8	-46.5	-45.8	-40.9	-45.7	-44.1	-41.9
5	4	-43.0	-45.8	-46.5	-45.8	-40.9	-45.7	-44.1	-41.9
6	1	119.3	117.7	116.3	116.2	119.0	116.9	111.1	118.5
6	2	119.3	117.7	116.3	116.2	119.1	117.0	111.0	118.4
6	3	119.3	117.7	116.3	116.2	119.1	117.0	111.0	118.4
6	4	119.3	117.7	116.3	116.2	119.1	116.9	111.0	118.5
7	1	217.4	215.6	215.1	214.7	216.4	219.3	215.6	219.8
7	2	217.4	215.6	215.1	214.7	216.4	219.3	215.6	219.8
7	3	217.4	215.6	215.1	214.7	216.4	219.3	215.7	219.8
7	4	217.4	215.6	215.1	214.7	216.4	219.4	215.7	219.8
8	1	172.9	170.0	170.6	171.3	165.9	170.3	168.9	169.5
8	2	172.9	170.0	170.6	171.3	165.8	170.4	169.0	169.6
8	3	172.9	170.0	170.6	171.3	165.8	170.4	169.0	169.6
8	4	172.9	170.0	170.6	171.3	165.8	170.3	169.0	169.6
9	1	-421.5	-423.8	-424.4	-423.9	-414.5	-418.5	-417.2	-413.1
9	2	-421.5	-423.8	-424.4	-423.9	-414.5	-418.5	-417.2	-413.1
9	3	-421.5	-423.8	-424.4	-423.9	-414.5	-418.5	-417.2	-413.1
9	4	-421.5	-423.8	-424.4	-423.9	-414.5	-418.6	-417.1	-413.1
10	1	-401.1	-403.1	-404.3	-404.0	-409.6	-407.7	-409.4	-404.1
10	2	-401.1	-403.1	-404.3	-404.0	-409.6	-407.7	-409.3	-404.1
10	3	-401.1	-403.1	-404.3	-404.0	-409.5	-407.7	-409.3	-404.3
10	4	-401.1	-403.0	-404.3	-404.0	-409.5	-407.7	-409.3	-404.4

Table 1: `PCFIT` scan average delays in nanoseconds. The stated delay errors are less than or about 0.1 ns in most cases.

The two PC tables provided with these data are somewhat different in more ways than just the number of tones. The two-tone data are pre-averaged to 30 seconds centered on 15 and 45 seconds. They are at frequencies matching tones 5 and 27 in the many-tone data set. The many-tone data are averaged to 2 seconds centered on 1, 3, 5, and so forth. The values appear to be different, but applying PCAVG to the 2-second data produced pulse-cal values that matched the 2-tone data in phase but with amplitudes a factor of 2 larger.

3 PCLOD

Use FITLD to read the FITS-IDI file for your current observations. This will make a uv data set with an index (NX) table containing the scan structure of your data and, at present, a small PC table containing at most a few tones. It is possible that this will change and the PC table will already contain all available tones. If it does, then PCLOD is not needed. If it does not, then you will need to acquire a text file (or files) containing the pulse-cal data. The current situation is somewhat cumbersome and not directly available to the normal user. The data reside in numerous text files located in Socorro. These files can be made available by contacting the VLBA data analysts to those needing the information for testing. You may read each of these PCAL text files into *AIPS* with PCLOD, setting OUTVER to a constant value so that all data end up in the same table. Alternatively, you may concatenate many of these text files together into one, possibly large, text file and then read that file with PCLOD.

PCLOD offers the SUBARRAY option, but it is recommended that you read in the pulse-cal data before possibly separating the data into multiple subarrays (if that is needed). The DOKEEP option allows you to read in pulse-cal data that occur outside the scans currently shown in the index table. There may be reasons to invoke this option, such as a desire to look at pulse-cal data from multiple bands while having visibilities from only one band. However, for calibration purposes, loading data with DOKEEP false is to be preferred. Note that the uv data set also provides the start date used in computing times in the PC table. The PC table written by PCLOD will not have a sort order specified and may be seriously unsorted depending on the text files used.

4 PCPLT

PCPLT is a task similar to BPLOT to plot pulse-cal spectra graphically. Each page of output contains either all antennas at a single time (SORT = 'TA') or all selected times for a single antenna (any other value of SORT). For a small pulse-cal table, this might be quite useful and may be used on large tables with DOTV = 1 to get some sense of the contents of the table before editing. Note that this task will sort the input PC table to the specified SORT, either 'AT' or 'TA'. The two possible plot types are illustrated in Figure 3.

5 PCEDT

PCEDT is a graphical editor very similar to BPEDT and not unlike EDITA and EDITR. The principal difference is that it is designed to flag times and channels in a PC table, writing a new and improved table, rather than flagging the visibility data. In this way it is similar to SNEDT. Because PCEDT displays one antenna and time to be edited, it is more suitable for small pulse-cal tables or for a quick examination of a larger table. Nonetheless, for completeness, it will be described here.

PCEDT requires that the output PC table be in 'TA' sort order. Figure 4 shows a typical screen shot seen when running PCEDT. The larger area at the bottom in yellow is the area in which editing may be performed and currently shows pulse-cal amplitude. The smaller area above, also in yellow, shows a second physical parameter for the same antenna, in this case the residual phase after a large delay has been solved and

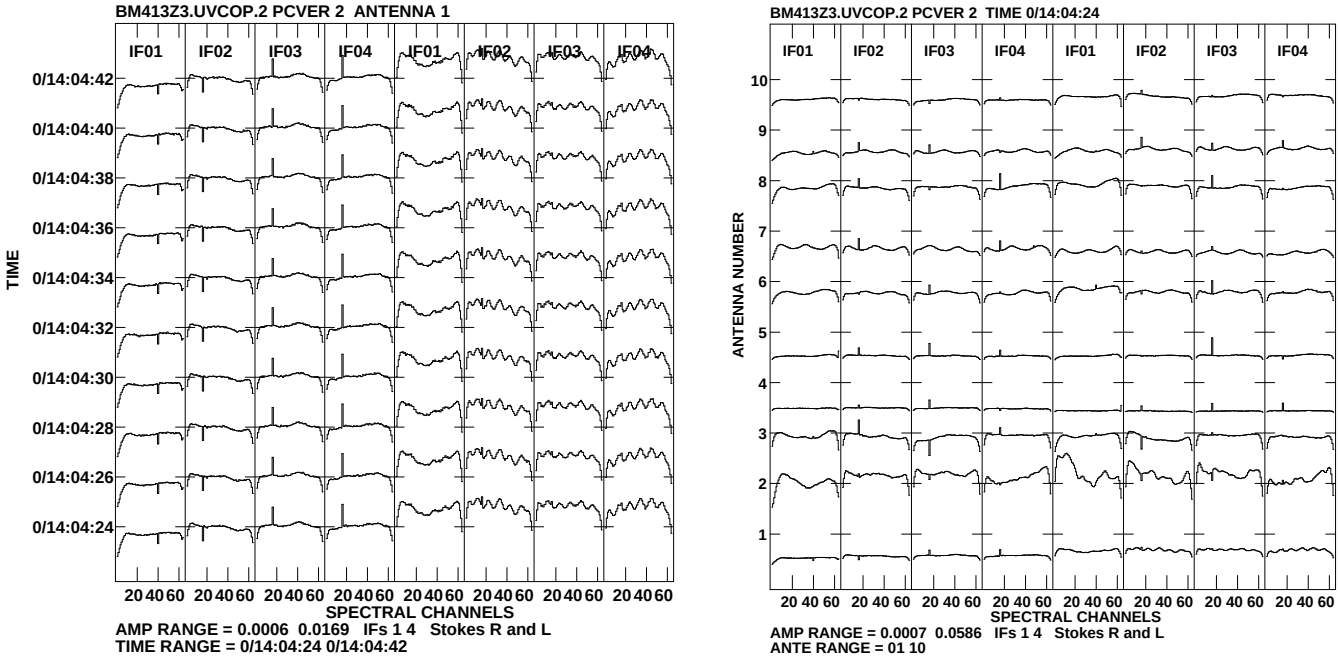

Figure 3: PCPLT of unedited PC table; left: a few times for antenna 1, (SORT='AT'), right: single time for all antennas (SORT='TA').

removed. The amplitude spectra for two other antennas are shown in the green colored panels above. The display is for a single time.

You select a particular option by moving the cursor to that menu option (it will change color) and hitting "buttons" A, B, or C. Button D causes a display in your terminal window of some helpful information about the option. When you are expected to enter numeric values, a prompt will appear in that terminal window and you type in the values there.

The left-hand menu begins with a choice of flagging methods. You can flag one channel at a time, a range of channels, all values below or above an interactive level, all points with rectangular areas, or one point at a time with or without a button push. You can enter the display range for all three types of display. You can list the current flag commands, undo some of the flag commands, and then redo the remaining ones. You can recompute the delays and residual phases taking into account the flagged samples. You can set a screen zoom for use during flagging and reset it. You can pause the automatic updating of the screen and then resume it and you can re-plot the current screen taking into account any new flags. You can exit PCEDT applying the flags and keeping the output PC table or you can "abort" deleting the flag information and the new output table.

The right hand menu allows you to switch between displayed polarizations. It allows you to change which data are flagged when a flag is generated, one or all polarizations, times, sources, and antennas. It allows you to enter the next antenna you wish to edit or simply select the next one. You can plot all PC tones or interactively select a smaller range of these channels or select a single IF (spectral window) or the next IF or previous IF. You can move to the next or previous time for the current antenna. And you can choose what parameter appears in the edit window (amplitude, input phase, or residual phase) and what parameter appears in the second, comparison window.

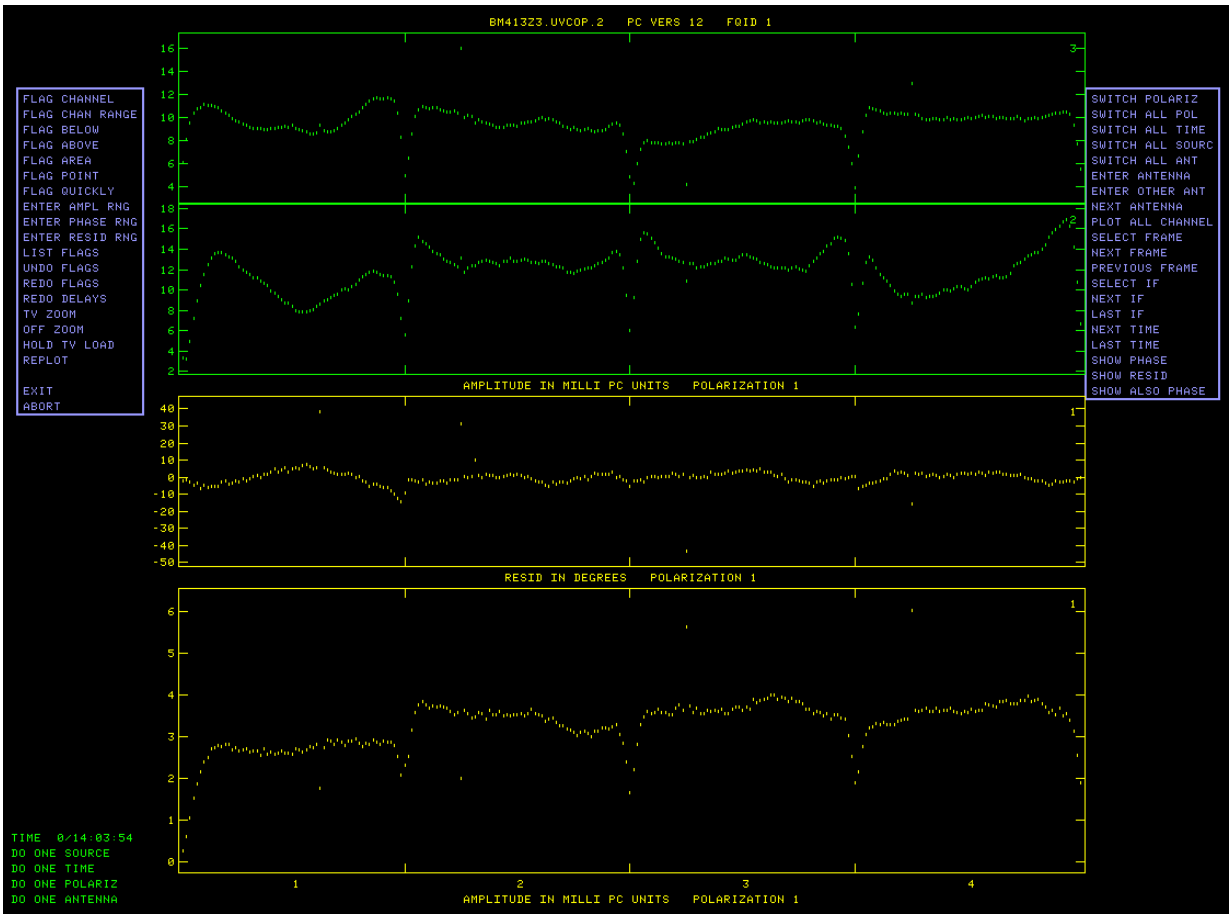

Figure 4: PCEDT of unedited PC table; antenna 1 is being edited in amplitude with residual phase also shown. Amplitude spectra for antennas 2 and 3 are shown for comparison. Any flags generated will apply only to one time, one polarization, and one antenna.

6 PCFLG

Unless you wish to trust an automatic editor (see PCRMS below), the task you will use on any good-sized PC table is PCFLG. It is a task much like SPFLG in that it displays pulse-cal amplitude, input phase, or residual phase as a grey-scale image with time on the vertical axis and pulse-cal tone (channel) on the horizontal axis. If there are more times or channels than will fit on the TV display, the data are averaged over time and every $n^{\rm th}$ channel is displayed. One may then select windows in time and in channel and have every time and channel be displayed. The example data set fits well on the screen in channels, but grossly overruns the time axis. One can then display one "piece" of the time axis at a time and step through the pieces. Note that PCFLG will copy the input table to a new output table, sorting if the input is not in 'TA' order.

With the 24-hour example PC table, PCFLG finds 36503 separate times to grid from 325 scans. It chooses an averaging interval of 53, but, because of scan breaks, this results in an image with 1828 rows which is much too big for my display. It is necessary to first enter a much larger smooth time (*e.g.*, 250) and re-load the image. Then set a small vertical window and load it, select a smooth time of one, and re-load. Turning on axis labeling, we have the image shown in Figure 5. Note the low amplitudes at the edges of each spectral window and in the initial 5 times. Note also the discrepant amplitudes in channel 40 of IF 1 and channel 16 of the remaining IFs. We should flag the edge and discrepant channels and also the times of low amplitude.

The first column of the menu may contain

OFFZOOM	turn off any zoom magnification
OFFTRANS	turn of any black & white enhancement
OFFCOLOR	turn of any pseudo-coloring
TVFIDDLE	allows zoom, pseudo-color contours or black & white enhancement
TVTRANSF	black and white enhancement as in AIPS
TVPSEUDO	many pseudo-colorings as in AIPS
DO WEDGE ?	switches choice of displaying a step wedge
LOAD $xxxx$	switch TV load transfer function to $xxxx$
LIST FLAGS	list selected range of flag commands
UNDO FLAGS	remove flags by number from FC table and from the master grid
REDO FLAGS	reapply all current flags to master grid
REDO DELAY	recompute the fits for delays and center phases and recompute the corrected (residual) PC values
VIEW RESID	to switch from viewing the input data to viewing the residual data (only phase differs)
VIEW INPUT	to switch from viewing the residual data to viewing the input data (only phase differs)
DO LABEL ?	turns on/off axis labeling

Note: when a flag is undone, all cells in the master grid which were first flagged by that command are restored to use. Flag commands done after the one that was undone may also, however, have applied to some of those cells. To check this and correct any improperly unflagged pixels, use the REDO FLAGS option. This option even redoes CLIP operations! After an UNDO or REDO FLAGS operation, the TV is automatically reloaded if needed. Note that the UNDO operation is one that reads and writes the full master grid.

The load to the TV for all non-phase displays may be done with all standard transfer functions: LINear, LOG, SQRT, and LOG2 (more extreme log). The menu shows the next one in the list through which you may cycle. The TV is reloaded immediately when a new transfer function is selected. Only one of the VIEW *yyyyy* options will appear, depending on which form you are currently viewing. Note that the two forms differ only in phase, but that that affects vector RMS and amplitude of the vector difference as well as the phase display types.

Column 2 offers type-in controls of the TV display and controls of which data are to be flagged. In general, the master grid may be too large to display on the TV screen in its entirety. The program begins by loading every n^{th} channel and time smoothing by m time intervals in order to fit the full image on the screen. However, you may select a sub-window in order to see the data in more detail. You may also control the range of intensities displayed (like the adverb PIXRANGE in TVLOD inside AIPS). The averaging time to smooth the data for the TV display may be chosen, as may the averaging time for the "scan average" used in some of the displays. Which correlators are to be flagged by the next flagging command may be typed in. All of the standard STOKES values, plus any 4-bit mask may be entered (see HELP file above). The antenna number may be typed in. Flagging may be done only for the current antenna and IF and source, or it may be done for all antennas and/or IFs and/or sources. Note that these controls affect the next LOADs to the TV or the flagging commands prepared after the parameter is changed. When the menu of options is displayed at the top of the TV, the current selections are shown along the bottom. If some will change on the next load, they are shown with an asterisk following.

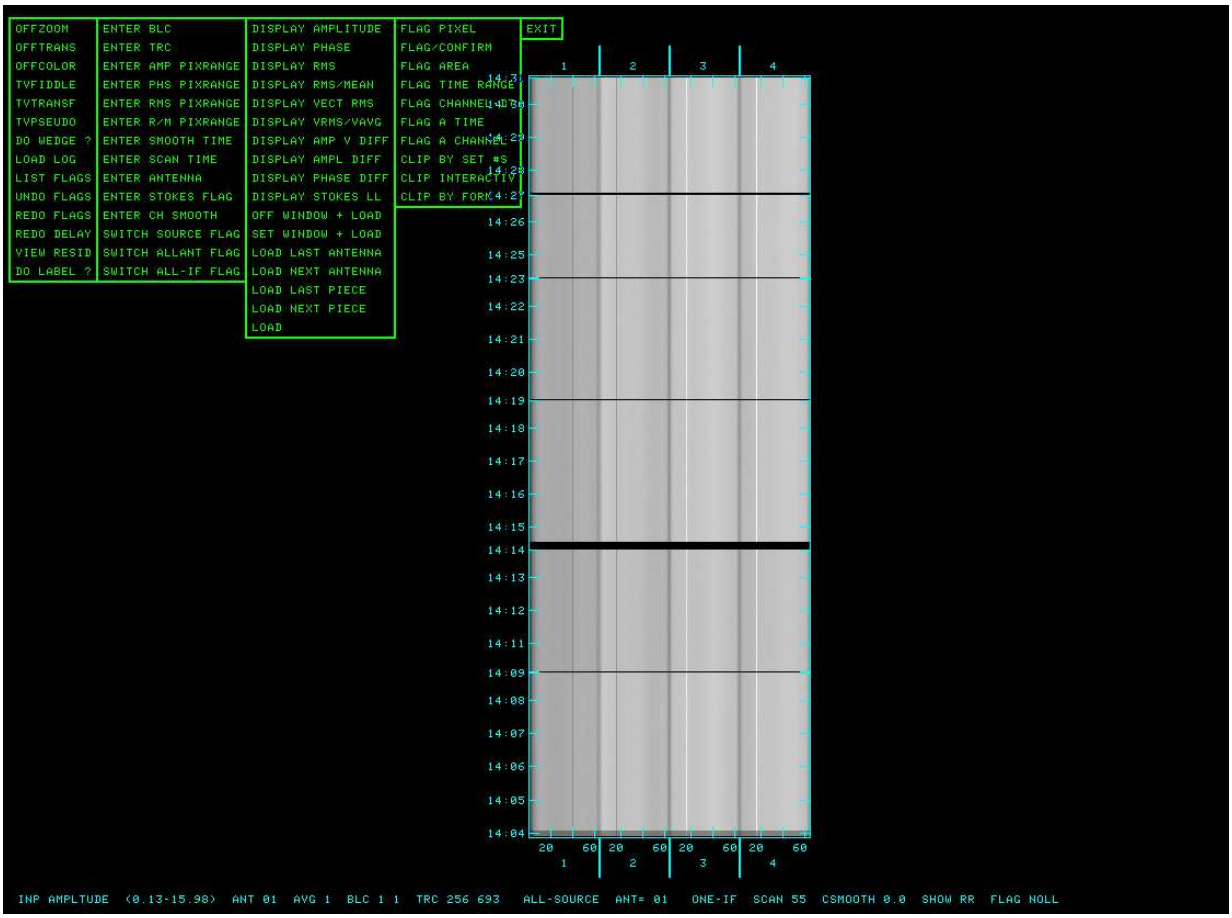

Figure 5: PCFLG of unedited PC table; antenna 1 is being edited in amplitude. The averaging over time has been turned off and only a small piece of the total time range is displayed.

ENTER BLC	Type in a BLC on the terminal
ENTER TRC	Type in a TRC on the terminal
ENTER AMP PIXRANGE	Type in the intensity range to be used for loading amplitude images to the TV
ENTER PHS PIXRANGE	Type in the phase range to be used for loading phase images to the TV
ENTER RMS PIXRANGE	Type in the intensity range to be used for loading images of the rms to the TV
ENTER R/M PIXRANGE	Type in the value range to be used for loading rms/mean images to the TV
ENTER SMOOTH TIME	To enter the time smoothing length in units of the master grid cell size
ENTER SCAN TIME	To enter the time averaging length for the "scan average" in units of the master grid cell size
ENTER ANTENNA	To enter a desired antenna using the terminal
ENTER STOKES FLAG	To type in the 4-character string which will control which correlators (polarizations) are flagged. Note: this will apply only to subsequent flagging commands. It will change whenever a different Stokes is displayed.
ENTER CH SMOOTH	To type in the FWHM of a Gaussian smoothing in spectral channels in the data type being loaded.
SWITCH SOURCE FLAG	To switch between having all sources flagged by the current flag commands and having only those sources included in this execution of PCFLG flagged.
SWITCH ALLANT FLAG	To switch between flagging only the current antenna and flagging all antennas.
SWITCH ALL-IF FLAG	To rotate the flag all IFs status from one IF to a range of IFs, to all IFs. Applies to subsequent flag commands.

The third column of options is used to control which data are displayed and to cause the TV display to be updated. The master grid must be converted from complex to amplitude or phase for display. Using either scalar or vector averaging, it may be converted to the rms of the amplitude or the rms divided by the mean of the amplitude. It may also be converted to the amplitude of the vector difference between the current observation and the "scan average" as defined by the selected "scan" time, or the absolute value of the difference in amplitude with the scalar-average amplitude or the absolute value of the difference in phase with the vector scan average. This column has the options:

DISPLAY AMPLITUDE	To display amplitudes on the TV
DISPLAY PHASE	To display phases on the TV
DISPLAY RMS	To display scalar amplitude rms on the TV
DISPLAY RMS/MEAN	To display scalar amplitude rms/mean on the TV
DISPLAY VECT RMS	To display vector amplitude rms on the TV
DISPLAY VRMS/VAVG	To display vector amplitude rms/mean on the TV
DISPLAY AMP V DIFF	To display the amplitude of the difference between the data and a running (vector) "scan average"
DISPLAY AMPL DIFF	To display the abs(difference) of the amplitude of the data and a running scalar average of the amplitudes in the "scan"
DISPLAY PHASE DIFF	To display the abs(difference) of the phase of the data and the phase of a running (vector) "scan average"
DISPLAY STOKES xx	To switch to Stokes type xx (where xx can be RR, LL).
OFF WINDOW + LOAD	Reset the window to the full image and reload the TV
SET WINDOW + LOAD	Interactive window setting (like TVWINDOW) followed by reloading the TV.
LOAD LAST ANTENNA	Reload TV with the current parameters and the previous antenna in sequence.
LOAD NEXT ANTENNA	Reload TV with the current parameters and the next antenna in sequence.
LOAD LAST PIECE	Load the previous overlapping piece of the data
LOAD NEXT PIECE	Load the next overlapping piece of the data
LOAD	Reload TV with the current parameters.

SET WINDOW + LOAD is "smarter" than TVWINDOW and will not let you set a window larger than the basic image. Therefore, if you wish to include all pixels on some axis, move the TV cursor outside the image in that direction. The selected window will be shown. LOAD LAST PIECE and LOAD NEXT PIECE appear only when there are too many times to fit on the TV screen at the current smoothing parameter. It lets you load one piece at a time in sequence. The pieces will overlap somewhat.

The fourth column is used to select the type of flagging to be done. During flagging, a TV graphics plane is used to display the current pixel much like CURVALUE in AIPS. Buttons A and B do the flagging (except A switches corners for the area and time range modes). Button C also does the flagging, but the program then returns to the main menu rather than prompting for more flagging selections. Button D exits back to the menu without doing any additional flagging. Another graphics plane is used to show the current area/time/antenna being flagged. All flagging commands can create zero, one, two, or more entries in the flagging list; hit button D at any time. There are also two clipping modes, an interactive one and one in which the user enters the clip limits from the terminal. In both, the current image computed for the TV (with user-set windows and data type, but not any other windows or alternate pixels etc. required to fit the image on the TV) is examined for pixels which fall outside the allowed intensity range. Flagging commands are prepared and the master file blanked for all such pixels. In the interactive mode, buttons A and B switch between setting the lower and upper clip limits, button C causes the clipping to occur followed by a return to the main menu, and button D exits to the menu with no flagging. The options are

FLAG PIXEL	To flag single pixels
FLAG/CONFIRM	To flag single pixels, but request a yes or no on the terminal before proceeding
FLAG AREA	To flag a rectangular area in Channel-T
FLAG TIME RANGE	To flag all channels for a range of times
FLAG CHANNEL-DT	To flag a channel for a range of times
FLAG TIME	To flag all channels for a specific time
FLAG A CHANNEL	To flag all times for a specific channel
CLIP BY SET #S	To enter from the terminal a clipping range for the current mode and then clip
CLIP INTERACTIV	To enter with the cursor and LUTs a clipping range for the current mode and then clip the data.
CLIP BY FORM	To clip selected antennas using the "method" and clipping range of some previous clip operation.

The last operation allows you to apply a clipping method already used on one antenna to other antennas and/or Stokes. CLIP BY FORM asks for a command number (use LIST FLAGS) and applies its display type (amp, phase, rms, rms/mean), averaging interval and clip levels to a range of antennas and Stokes (as entered from the terminal). To terminate the operation, doing nothing, enter a letter instead of one of the requested antenna numbers. To omit a Stokes, reply, if requested for a flag pattern, with a blank line. You may watch the operation being carried out on the TV as it proceeds.

The final column selects an exit from the task. If flag commands were prepared, the task will ask if you wish to apply them. Answer "no" twice to cause all editing to be abandoned and the grid file deleted (unless you selected DOCAT true when starting PCFLG). In that case, you may restart PCFLG specifying the cataloged work file to resume editing where you left off.

7 PCAVG

PCAVG sorts the input data set into antenna-time order if needed and then writes out a new PC table averaging over time while honoring scan breaks. You may choose to do this to improve the already very good signal-to-noise of the pulse-cal data and to reduce the size of the pulse-cal table. It is probably best if you do the flagging on the input table, since you do not want to average times of bad data with times of good data.

PCAVG suffers from the same issues that affect all time averaging tasks. If SOLINT>0 each interval begins with a data sample for the current antenna and lasts until the first time more than SOLINT later (or the scan ends, the source changes, etc.). This means that the different antennas will end up with different averaged times if there has been any editing or drop outs. PCFLG on such a data set will be (way) less than desirable. Thus PCAVG offers a second averaging scheme, indicated by setting SOLINT negative, in which each scan is broken into intervals of approximate length ABS (SOLINT). Each interval is labeled with its central time and any data falling in the interval is averaged. This means that all antennas will have records at the same times, but those records may contain differing amounts of data. Of course, the other averaging scheme also has the same issue. PCFLG will be very much happier with the fixed interval method.

8 PCFIT

PCFIT uses the same fitting routine found in PCPLT, PCEDT, and PCFLG to fit each spectral window for a delay and phase. It remembers the initial delay and phase for each antenna and IF and polarization and writes a solution (SN) table usually containing the differences between the currently fit values and the initial ones. If the delay changes by too much (defined by CUTOFF), then the change is ignored by resetting the "initial" value to the new value after the change. PCFIT writes a new PC table containing the pulse-cal spectra after the fit delays and phases are removed. It does this on the cadence of the input table, even if time averaging is used in finding the delays and phases.

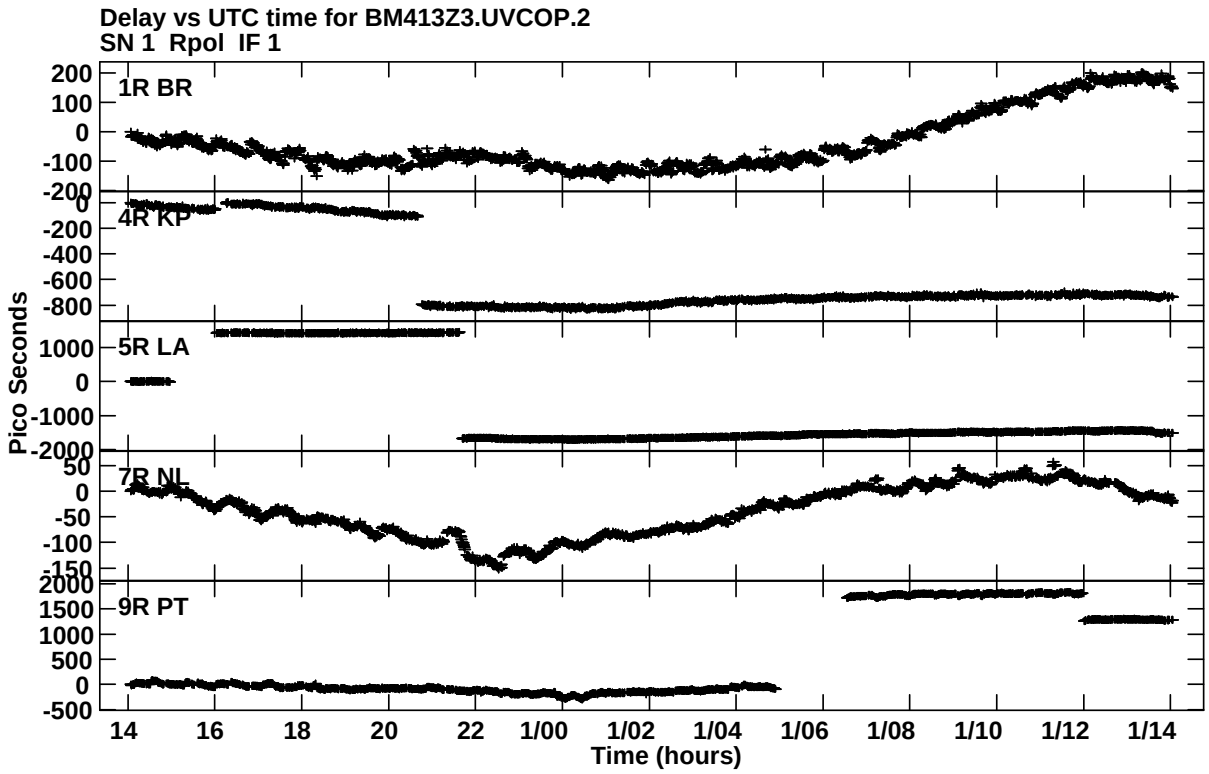

Figure 6: PCFIT of edited PC table delay solutions for 5 of the antennas. BR and NL (as well as FD and SC) had no jumps but delays still wander around smoothly with time. All other antennas had jumps in delay associated with periods of time in which the antenna was not observing. KP actually also had a jump of about 600 ns which was "ignored" by PCFIT.

PCFIT offers the option of time averaging using the irregular grid method, since the SN table plus CLCAL handle that well. It has an option to combine spectral windows before solving, but it is best to leave NPIECE at 0 (solves each spectral window separately). If you like looking at lots of numbers, you may set PRTLEV greater than zero to view solutions with error bars and even to view the initial guesses. The sort order used by PCFIT is antenna-time is SOLINT is > 0 and time-antenna otherwise.

The delays written by PCFIT in the SN table are shown for four representative antennas in Figure 6.

9 PCRMS

PCRMS is a task designed to spare the user from the interactive editing in PCFLG. It sorts the input PC table into antenna-time order. Then, in the first pass through the input PC table, the task computes the amplitude and phase statistics of the pulse-cal values in each IF and polarization for each antenna, after the fit delays and phases have been removed. It then looks for channels that deviate from the mean and channels that stick out compared to their immediate neighbors. If a channel sticks out from its neighbors often enough, it is scheduled for deletion. In the second pass through the data, the channel in each IF, polarization, and antenna that sticks out is flagged along with the edge channels. The delays may be recomputed (APARM(5) > 0) which will allow phase statistics to be reported along with amplitude ones. The phase statistics are not currently used for flagging, so the expense of a second round of delay fitting is only for information purposes. The average amplitude and rms over time are stored along with the rmses of these parameters

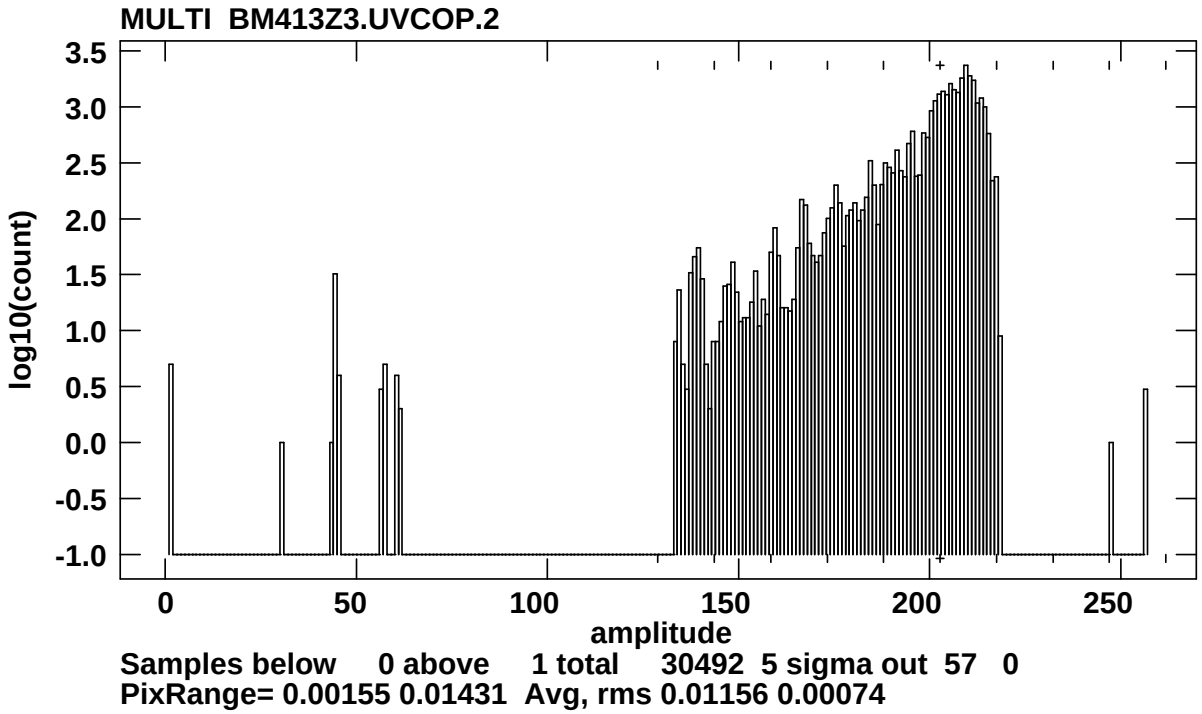

Figure 7: PCHIS plot from antenna 9 (PT) spectral window 2, L polarization. The plus sign identifies the mean, the interior ticks show n times the rms from the mean (up to 5) and the labeling indicates that 57 times had excessively low average amplitude while no times had excessively large amplitude. Note that the vertical axis is the log base 10 of the counts in each histogram cell. The logarithm of zero is taken as -1.

for each antenna, polarization, and IF.

If APARM(4) ≤ 0, a third pass through the input PC table is performed with a new PC table being written containing a flagged version of the input. The average amplitude and amplitude rms after flagging the channels that stuck out and ignoring the edge channels and is compared to the overall average and rms for that IF, polarization, and antenna. Values that deviate too much (APARM(1) and APARM(2)) are flagged, edge channels are flagged when APARM(6) ≤ 0, and the new, edited PC table is written. At the end of the third pass, summaries of the number of samples flagged for bad channels and the number of spectral windows flagged for bad amplitude and rms are reported. Adverb PRTLEV controls the amount of displayed information in each pass. Leaving the edge channels unflagged in the output is useful for the bandpass shape task PCASS; set APARM(6) > 0.

If you would like to examine the spectral-window average amplitude and rms for every time, PCRMS will write a text file when APARM(3) > 0 and OUTFILE is specified. The file contains 16 columns, 2 polarizations for 4 spectral windows of average amplitude followed by the same for rms of the average. One row is written for every time for the specified antenna. This file is really too large for much human examination. A task, described next, was written to plot the histogram and statistics of any one of the columns. Such plots may help in deciding what the best values for APARM(1) and APARM(2) might be in PCRMS. If you are using this option, you may wish to avoid writing a new PC table by setting APARM(4) > 0.

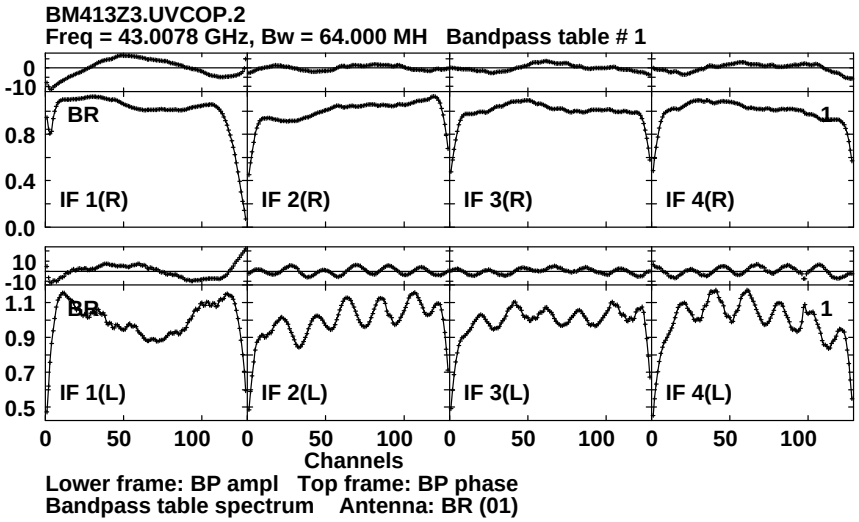

Figure 8: PCASS output bandpass function for antenna 1 (BR).

10 PCHIS

PCHIS will plot a histogram of the values found in one column of a many-column numerical text file identified by adverb INTEXT. APARM(5) identifies which column will be used for the histogram and the number of samples deviating from the mean by more than APARM(6) will be reported. Figure 7 shows a sample plot.

11 PCASS

Finally, PCASS is a task which averages pulse-cal data and writes a bandpass calibration table. It can use scalar or vector averaging for the amplitude, it can compute phases or set the bandpass phase to zero, and it can average all calibration scans together, writing one BP record for each antenna, or it can write separate records for each antenna and each scan. Calibration scans are signified by giving the source names in the usual way, with CALSOUR = ' ' signifying all sources. The output of PCRMS with APARM(6) > 0 is recommended since bad interior channels and bad times will be flagged but the edge channels remain to allow fitting of the edges of the bandpass. Note that PCASS interpolates the bandpass function from the frequencies of the pulse cals to the frequencies of the visibility spectral channels. The signal-to-noise is excellent, as illustrated in Figure 8, but it is not clear that this bandpass shape actually applies to the visibility data.

12 Suggestion

A "standard practice" for applying these tasks needs to be devised and vetted by VLBI scientists. This has yet to be done. The author's suggestion is first to have the large pulse-cal tables written in the FITS-IDI data files. Executing PCRMS twice, first on the input PC table and then on the output table from PCRMS, should remove up to two bad channels per spectral window and all times when the pulse-cal amplitudes are either low, high, or erratic. Then PCFIT, perhaps with some time averaging, will determine the relative delays and phases and write them into an SN table. Task CLCAL can then be used to apply the SN table values to the current CL table, writing a new CL table.