

## Description of control file keywords of VLBI data processing software PIMA

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*L. Petrov*

### *Abstract:*

*This document provides detailed description of syntax of the language used for specification of control file for VLBI data processing package PIMA*

### *Table of contents:*

- 1 [General rules](#)
- 2 [General keyword](#)
  - 2.1 [SESS\\_CODE:](#)
  - 2.2 [BAND:](#)
  - 2.3 [UV\\_FITS:](#)
  - 2.4 [STAGING\\_DIR:](#)
  - 2.5 [SOU\\_NAMES:](#)
  - 2.6 [STA\\_NAMES:](#)
  - 2.7 [PCAL:](#)
  - 2.8 [TSYS:](#)
  - 2.9 [GAIN:](#)
  - 2.10 [SAMPLER\\_CAL:](#)
  - 2.11 [OBS:](#)
  - 2.12 [INCLUDE\\_OBS\\_FILE:](#)
  - 2.13 [EXCLUDE\\_OBS\\_FILE:](#)
  - 2.14 [WARNING:](#)
  - 2.15 [DEBUG\\_LEVEL:](#)
  - 2.16 [CHECK\\_SEVERITY:](#)

## PIMA keywords

- 2.17 [FRINGE\\_ERRORS:](#)
- 2.18 [FFT\\_METHOD:](#)
- 2.19 [FFT\\_CONFIG\\_FILE:](#)
- 2.20 [NUM\\_THREADS:](#)

### 3 [Observation processing keywords](#)

- 3.1 [AP\\_TOLERANCE:](#)
- 3.2 [MIN\\_SCAN\\_LEN:](#)
- 3.3 [MAX\\_SCAN\\_LEN:](#)
- 3.4 [MAX\\_SCAN\\_GAP:](#)
- 3.5 [SCAN\\_LEN\\_SKIP:](#)
- 3.6 [SCAN\\_LEN\\_USED:](#)
- 3.7 [FRT\\_OFFSET:](#)
- 3.8 [STA\\_REF:](#)
- 3.9 [VTD\\_CONFIG\\_FILE:](#)
- 3.10 [EXPER\\_DIR:](#)
- 3.11 [UV\\_EXCLUDE\\_FILE:](#)
- 3.12 [BANDPASS\\_USE:](#)
- 3.13 [BANDPASS\\_FILE:](#)
- 3.14 [POLARCAL\\_FILE:](#)
- 3.15 [BANDPASS\\_MASK\\_FILE:](#)
- 3.16 [PCAL\\_MASK\\_FILE:](#)
- 3.17 [INTMOD\\_FILE:](#)
- 3.18 [INTMOD\\_TYPE:](#)
- 3.19 [CORR\\_FLAG\\_MIN:](#)
- 3.20 [TIME\\_FLAG\\_FILE:](#)

## PIMA keywords

- 3.21 [TEC\\_FILE:](#)
  - 3.22 [FRINGE\\_FILE:](#)
  - 3.23 [FRIRES\\_FILE:](#)
  - 3.24 [BEG\\_FRQ:](#)
  - 3.25 [END\\_FRQ:](#)
  - 3.26 [FRQ\\_GRP:](#)
  - 3.27 [POLAR:](#)
  - 3.28 [WVR\\_FILE:](#)
  - 3.29 [WVR\\_USE](#)
  - 3.30 [WVR\\_SMOOTHING\\_INTERVAL](#)
  - 3.31 [WVR\\_SMOOTHING\\_SIGMA](#)
  - 3.32 [PHASE\\_ACCELERATION:](#)
  - 3.33 [PHASE\\_ACCEL\\_MIN:](#)
  - 3.34 [PHASE\\_ACCEL\\_MAX:](#)
  - 3.35 [EPHEMERIDES\\_FILE:](#)
  - 3.36 [EPHEMERIDES\\_USE:](#)
- 4 [Baseline fringe fitting keywords](#)
- 4.1 [FRIB.SEARCH\\_TYPE:](#)
  - 4.2 [FRIB.DELAY\\_WINDOW\\_CENTER:](#)
  - 4.3 [FRIB.RATE\\_WINDOW\\_CENTER:](#)
  - 4.4 [FRIB.DELAY\\_WINDOW\\_WIDTH:](#)
  - 4.5 [FRIB.RATE\\_WINDOW\\_WIDTH:](#)
  - 4.6 [FRIB.AUTOCORR\\_CALIB:](#)
  - 4.7 [FRIB.AMPL\\_FUDGE\\_TYPE:](#)
  - 4.8 [FRIB.AMPL\\_EDGE\\_WINDOW\\_COR:](#)

## PIMA keywords

- 4.9 [FRIB.AMPL\\_EDGE\\_BEAM\\_COR:](#)
  - 4.10 [FRIB.OVERSAMPLE\\_MD:](#)
  - 4.11 [FRIB.OVERSAMPLE\\_RT:](#)
  - 4.12 [FRIB.FINE\\_SEARCH:](#)
  - 4.13 [FRIB.AUTOCORR\\_THRESHOLD:](#)
  - 4.14 [FRIB.WEIGHTS\\_THRESHOLD:](#)
  - 4.15 [FRIB.NOISE\\_NSIGMA:](#)
  - 4.16 [FRIB.SNR\\_DETECTION](#)
  - 4.17 [FRIB.FRQ\\_TRANSFER\\_BAND:](#)
  - 4.18 [FRIB.FRQ\\_TRANSFER\\_METHOD:](#)
  - 4.19 [FRIB.FRQ\\_TRANSFER\\_DEG:](#)
  - 4.20 [FRIB.FRQ\\_TRANSFER\\_MSEG:](#)
  - 4.21 [FRIB.2D\\_FRINGE\\_PLOT:](#)
  - 4.22 [FRIB.PLOT\\_DELAY\\_WINDOW\\_WIDTH:](#)
  - 4.23 [FRIB.PLOT\\_RATE\\_WINDOW\\_WIDTH:](#)
  - 4.24 [FRIB.OVERSAMPLE\\_PLOT\\_MD:](#)
  - 4.25 [FRIB.OVERSAMPLE\\_PLOT\\_RT:](#)
  - 4.26 [FRIB.1D\\_RESFRQ\\_PLOT:](#)
  - 4.27 [FRIB.1D\\_FRQ\\_MSEG:](#)
  - 4.28 [FRIB.1D\\_RESTIM\\_PLOT:](#)
  - 4.29 [FRIB.1D\\_TIM\\_MSEG:](#)
  - 4.30 [FRIB.1D\\_DRF\\_PLOT:](#)
  - 4.31 [FRIB.1D\\_DRF\\_SPAN:](#)
- 5 [Bandpass processing keywords](#)
- 5.1 [BPS.MODE:](#)

## PIMA keywords

- 5.2 [BPS.MODE:](#)
  - 5.3 [BPS.NOBS\\_ACCUM:](#)
  - 5.4 [BPS.MSEG\\_ACCUM:](#)
  - 5.5 [BPS.NOBS\\_FINE:](#)
  - 5.6 [BPS.MINOBS\\_FINE:](#)
  - 5.7 [BPS.MSEG\\_FINE:](#)
  - 5.8 [BPS.SNR\\_MIN\\_ACCUM:](#)
  - 5.9 [BPS.SNR\\_MIN\\_FINE:](#)
  - 5.10 [BPS.DECOR\\_TIM\\_MIN:](#)
  - 5.11 [BPS.AMPL\\_REJECT:](#)
  - 5.12 [BPS.PHAS\\_REJECT:](#)
  - 5.13 [BPS.INTRP\\_METHOD:](#)
  - 5.14 [BPS.DEG\\_AMP:](#)
  - 5.15 [BPS.DEG\\_PHS:](#)
  - 5.16 [BPS.NORML:](#)
  - 5.17 [BPS.SEFD\\_USE:](#)
- 6 [Phase reference fringe fitting keywords](#)
- 6.1 [FRIP.SCAN\\_FILE:](#)
  - 6.2 [FRIP.STA\\_INC\\_FILE:](#)
  - 6.3 [FRIP.STA\\_EXC\\_FILE:](#)
  - 6.4 [FRIP.STA\\_REFS:](#)
  - 6.5 [FRIP.RESOLUTION:](#)
  - 6.6 [FRIP.OVERSAMPLE:](#)
  - 6.7 [FRIP.SCA:](#)
  - 6.8 [FRIP.MAP\\_DIR:](#)

## PIMA keywords

6.9 [FRIP.ATM\\_ZEN\\_FILE:](#)

6.10 [FRIP.CAL\\_PLOT:](#)

6.11 [FRIP.CAL\\_RES:](#)

6.12 [FRIP.TAG\\_PLOT:](#)

6.13 [FRIP.TAG\\_RES:](#)

6.14 [FRIP.BEAM\\_PLOT:](#)

6.15 [FRIP.FRQ\\_MSEG:](#)

6.16 [FRIP.TIM\\_MSEG:](#)

6.17 [FRIP.RA\\_CENTER:](#)

6.18 [FRIP.DEC\\_CENTER:](#)

6.19 [FRIP.RA\\_STEP:](#)

6.20 [FRIP.DEC\\_STEP:](#)

6.21 [FRIP.RA\\_RANGE:](#)

6.22 [FRIP.DEC\\_RANGE:](#)

## 7 [Splt keywords](#)

7.1 [SPLT.SOU\\_NAME:](#)

7.2 [SPLT.FRQ\\_MSEG:](#)

7.3 [SPLT.TIM\\_MSEG:](#)

7.4 [SPLT.WEIGHT\\_TYPE:](#)

7.5 [SPLT.POLAR:](#)

7.6 [SPLT.AUTOCORR\\_NRML\\_METHOD:](#)

7.7 [SPLT.BPASS\\_NRML\\_METHOD:](#)

7.8 [SPLT.BPASS\\_NRML\\_RANGE:](#)

7.9 [SPLT.SUBARRY\\_CONSOLIDATION:](#)

7.10 [SPLT.TOTAL\\_UV:](#)

## PIMA keywords

- 7.11 [SPLT.TOTAL\\_UV:](#)
- 7.12 [SPLT.GAIN\\_CORR\\_FILE:](#)
- 7.13 [SPLT.STA\\_BASED:](#)
- 8 [ONOF processing keywords](#)
  - 8.1 [ONOF.GEN\\_FLAGS\\_MODE:](#)
  - 8.2 [ONOF.KERNEL\\_START\\_SHARE:](#)
  - 8.3 [ONOF.KERNEL\\_END\\_SHARE:](#)
  - 8.4 [ONOF.COHERENT\\_INTERVAL:](#)
  - 8.5 [ONOF.COHERENT\\_INTERVAL:](#)
  - 8.6 [ONOF.NSIG\\_THRESHOLD:](#)
  - 8.7 [ONOF.MIN\\_LOW\\_AP:](#)
- 9 [Creation of the output database keywords](#)
  - 9.1 [MKDB.OUTPUT\\_TYPE:](#)
  - 9.2 [MKDB.SRT:](#)
  - 9.3 [MKDB.GD\\_MAX\\_ADD\\_ERROR:](#)
  - 9.4 [MKDB.GD\\_MAX\\_SCL\\_ERROR:](#)
  - 9.5 [MKDB.FILTER:](#)
  - 9.6 [MKDB.FRINGE\\_ALGORITHM:](#)
  - 9.7 [MKDB.2ND\\_BAND:](#)
  - 9.8 [MKDB.VCAT\\_CONFIG:](#)
  - 9.9 [MKDB.OUTPUT\\_NAME:](#)
  - 9.10 [MKDB.DESC\\_FILE:](#)

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## 1 General rules

Control file for PIMA consists of lines of variable length. Lines which

## PIMA keywords

starts from characters # or \* are considered as comments and ignored by parsing software. Each line consists of a keyword and the value. All keywords must be specified, no defaults are allowed. A value should be separated from the keyword by one or more blanks. The first line and the last of the control file should have the label of the format version. The current label version is

```
# PIMA_CONTROL file. Format Version of 2015.09.01
```

If the file does not have correct format label, PIMA will issue an errors message and stop. New keywords may be added in the future. PIMA control files may require an upgrade if the control file satisfies specifications of the old version of PIMA, but it misses some keywords added in the newer version. An upgrade of control file can be done automatically with task upgr. This task accept the name of the control file in the old, obsolete format and generate the output control file that conforms to the current format b adding lines with new keywords that are set to some defaults.

All keywords may be defined more than once. With exception of the keywords UV\_FITS and INTMOD\_FILE the latest definition supersedes the previous definition.

PIMA supports a number of kludge environment variables that tweak the normal operation. They are are either for printing debugging information or modifying existing code that are invoked on an exceptional basis. These environment variables have prefix PIMAVAR\_. They can be either defined outside PIMA or placed in the control file. In that case colon is appended to the end of the environment variable name.

## 2 General keyword

### 2.1 SESS\_CODE:

**SESS\_CODE:** value

Session code. It may be different from the experiment code embedded in FITS-IDI code. This session code is appended to names of



scratch files.

## 2.2 BAND:

**BAND:**            **value**

One character letter in upper case that describes the band of the experiment. For processing multifrequency data usually two or more control files are used. The band helps to distinguish different control files and, if necessary, to coming multi-frequency observations.

## 2.3 UV\_FITS:

**UV\_FITS:**        **file**

Full path name of the data file with the correlator output that conforms to FITS-IDI standard. More than one UV\_FITS: keyword may be specified and, unlike to other keywords, the next definition does not supersede the previous one. Restrictions:

- 1) Files should follow in chronological order.
- 2) The number of spectral channels for all intermediate frequencies (IF) should be the same.
- 3) The source names and station names should be consistent between files, i.e. the same name should be used for the same source.

## 2.4 STAGING\_DIR:

**STAGING\_DIR:**    **directory**

directory -- This keyword specifies the name of staging directory.  
When the name of staging directory is specified, PIMA

## PIMA keywords

first checks whether the directory has all files with visibilities. If not, then PIMA removes all files from that directory and copies there files with visibilities. If drive where the staging directory is significantly faster than the directory with UV data specified UV\_FITS keyword(s), PIMA will run faster. It is recommended to have SSD RAD1-0 disk arrays for staging directory. NB: of a side effect: PIMA will remove from that directory all files which are not UV-files for this experiment.

NO -- no staging directory is specified

## 2.5 SOU\_NAMES:

**SOU\_NAMES:**     **file**

Name of the source definition file. The purpose of this file is to match the source names in FITS-IDI files with the source names used in data reduction. Correlator may use non-standard names. The source definition file has a separate column that associate non-standard names used by the correlator with standard names. In addition, the source definition file may have several entries for the same source in the column with source name alias and these entries may have a "splitting" flag. In that case PIMA will treat these same uv-data as belonging to two different sources with different a priori coordinates. Supported data format: SOURCE\_NAMES.

## 2.6 STA\_NAMES:

**STA\_NAMES:**     **file**

Name of the station definition file. The purpose of this file is to match station names in FITS-IDI files with the station names used in data analysis. Correlators often use 2-characters long names, while data analysis software uses 8-characters long names.

## 2.7 PCAL:

**PCAL:** [NO or USE\_ONE or USE\_ALL or tone\_index][:action:[station[:station]...]]

This keyword specified how information about measured phases and amplitudes of phase calibration information should be used for fringe fitting. Supported values:

NO -- no measured calibration is applied.

USE\_ONE -- to apply one tone per intermediate frequency (IF).  
If two tone are available, then the tone with the lowest frequency will be applied. If more than two phase calibration tones are available, then the tone with index equal to the ratio of the total number of phase cal tones per IF will be applied. The phase of phase-calibration signal will be subtracted with appropriate sign from cross-correlation phases in every spectral channels of a given IF.

USE\_ALL -- to apply all tones per intermediate frequency (IF).  
PIMA computes group delay and phase delay in phase calibration signal. Using these two values, it computes ph-cal phase for every spectral channel in the IF and then subtracts them with an appropriate sign from cross-correlation phases in every spectral channels of a given IF.

tone\_index -- to apply one tone per intermediate frequency (IF).  
The value of tone\_index sets the index of the phase calibration tone. If the index is out of range, then the tone with index equal to the ratio of the total number of phase cal tones per IF will be applied.

The value may has an optional qualifier for fine-grained station selection. The qualifier is separated from the value with a column. Sub-value action can be TO\_USE or NOT\_TO\_USE. A column separated list of stations follows the action sub-value. The action is case insensitive. Either column or comma can be used as a separation in the station list. If action is TO\_USE, then pcal only from the stations form the list will be considered for using. If action is NOT\_TO\_USE, then pcal from the stations on the list will not be used. If phase calibration for a given station is not available or was deselected with task gear pcal\_off,

then fine-grained phase calibration will have no effect. Task gear pcal\_off has a precedence over fine-grained selection.

## 2.8 TSYS:

**TSYS:**            **[NO or MEASURED or MODELED or CLEANED]**

This keyword specified how system temperature calibration should be used. Keywords MEASURED or CLEANED or MODELED instruct PIMA from which slot to take the Tsys. In order to use CLEANED or MODELED Tsys, the Tsys model has to be computed with task tsmo before.

NO -- System temperature is ignored

MEASURED -- System temperature measured when the antenna was on the specified source will be used. PIMA will find Tsys measurement of the same source to the epoch the nearest of the fringe reference time.

Value INTRP is equivalent to MEASURED and supported for compatibility with control files generated before 2017.08.30

MODELED -- System temperature from the "model" slot will be used.

It is assumed task tsmo ran before and populated

"modeled" Tsys slot. See documentation of task tsmo for

details. In short, task tsmo decompose Tsys into a product

of regular functions of IF, elevation and time assuming

a) Tsys ratio between IFs is constant during the experiment;

b) Tsys dependence on elevation is not changing with time;

c) Tsys is can be decomposed on somewhat smoothed functions

of time and elevation. Task tsmo flags outliers and computes

the decomposition using the dataset free from outliers"

CLEANED -- System temperature from the "clean" slot. Tsys from that

slot is a mixture of MEASURED and MODELED Tsys. Tsys

in the CLEANED slot is the same as in the MEASURED slot

for the points that has measured Tsys that is not flagged

out by tsmo task. System temperature is equal to the Tsys

from the MEASURED slot for the points without measured Tsys

or for the points that were flagged out.

## 2.9 GAIN:

**GAIN:** [NO or USE]

NO -- do not use antenna gains in the input file or internal PIMA data structures. This is equivalent to using gain 1 Jy/K

USE -- use antenna gains in the input file or internal PIMA data structures if during calibration new gain tables have been loaded in PIMA.

## 2.10 SAMPLER\_CAL:

**SAMPLER\_CAL:** [NO or USE]

NO -- do not apply calibration for amplitude distortion due to digitization in the samplers.

USE -- apply calibration for amplitude distortion due to digitization in the samplers.

## 2.11 OBS:

**OBS:** [ALL or index or index1:index2 or file]

This keyword specifies which observations are to be used for processing. It should be considered as the second filter that is applied after the first filter specified by the keyword INCLUDE\_OBS\_FILE. Keyword OBS restricts a set of processed observations among those that passed the first filter. The third filter specified by the keyword EXCLUDE\_OBS\_FILE impose further restrictions that are imposed on the set of observations that passed the second filter.

## PIMA keywords

- ALL -- all observations will be used.
- index -- Index of the observation that will be used.
- index1:index2 -- Range of indices that will be used.  
index2 should be greater or equal than index1.
- file: -- Name of the ascii file that contains indices of observations. The file has one observation index per line. Lines that start from # are considered as comments and bypassed.

### 2.12 INCLUDE\_OBS\_FILE:

**INCLUDE\_OBS\_FILE: [NO or file]**

This keyword specifies the first filter of observations that are to be used. Those observations that passed this filter are considered as eligible for checking for the second filter specified by the keyword OBS: and the third filter specified by the keyword EXCLUDE\_OBS\_FILE:

NO -- all the observations are to be used.

file -- Name of the file that specifies indices of observations that are put in the include list. The file has one observation index per line. Lines that start from # are considered as comments and bypassed.

### 2.13 EXCLUDE\_OBS\_FILE:

**EXCLUDE\_OBS\_FILE: [NO or file]**

This keyword specifies the third filter of observations that are to be used. Those observations that passed this filter form the final list of used observations.

## PIMA keywords

NO -- Exclude list is empty. That means that all observations that passed the first filter specified by the keyword INCLUDE\_OBS\_FILE: and the second filter specified by the keyword OBS: are considered as eligible.

file -- specifies indices of observations that form the exclude list. The observations indices specified in this files are excluded from the list that passed the first and the second filter.

### 2.14 WARNING:

**WARNING:**      **[NO, ON, OFF]**

NO -- No warning messages will be printed

OFF -- No warning messages will be printed

ON -- Warning messages will be printed.

### 2.15 DEBUG\_LEVEL:

**DEBUG\_LEVEL:**      **value**

Level of verbosity of information messages issued by PIMA

0 -- completely silent mode. Only errors or warnings (if WARNING: ON is specified) are printed.

1 -- terse mode. Only very important messages are printed.

2 -- normal mode.

3 -- talkative mode. More messages are displayed.

4 -- chat-box mode. A lot of messages are displayed that may be annoying.

5-99 -- debugging messages are printed. These messages are for facilitation of debugging.

## 2.16 CHECK\_SEVERITY:

**CHECK\_SEVERITY:** value

Level of severity of checks for internal data consistency. During loading the data, situations occur when a portion of data is corrupted. PIMA detects data corruption and issues warning, but then it should decide what to do further: to continue or to stop. The level of severity governs the algorithm.

0 -- permissive mode. Unless the error is fatal that prevents further data processing, PIMA discards corrupted data and continues.

1 -- normal mode. PIMA may or may stop after an error depending on its severity. It stops if corrupted data *\*may\** produce bogus results.

2 -- strict mode. PIMA stops if it finds corrupted data.

## 2.17 FRINGE\_ERRORS:

**FRINGE\_ERRORS:** [IGNORE, STOP]

This keywords set the action if fringe search ended with error

IGNORE -- the error is ignored and PIMA proceeds to the new observation. Code failure is written in the status field for the affected observation.

STOP -- pima stops on the error.



## 2.18 FFT\_METHOD:

**FFT\_METHOD:** [FFTW or MKL]

PIMA supports two software packages that implements fast Fourier transform: MKL (Math Kernel Library by Intel) and open source FFTW. MKL support is optional and depends on PIMA configuration in compile time. Keyword FFT\_METHOD defines which library to use. Both libraries produce correct answers, but depending on size of the problem have different speed. If in doubt, please use FFTW method.

MKL -- use the MKL library

FFTW -- use open source FFTW library

## 2.19 FFT\_CONFIG\_FILE:

**FFT\_CONFIG\_FILE:** [NO or file]

When FFTW is used, its configuration, so-called "wisdom" that keeps optimal setting should be loaded. Refer to PIMA INSTALL document, Post-Installation section with a detailed explanation how to create this configuration file. PIMA will run without FFTW configuration, but its performance will be significantly degraded.

NB: FFTW configuration depends on the number of threads. Single threaded configuration file will be rejected if FFTW is called in multi-thread mode and performance will be severely impacted. An M-threaded configuration file will be rejected if the number of threads for FFTW is not equal to M.

NO -- no FFTW configuration file is specified. FFTW configuration file is ignored if FFT\_METHOD MKL is used. You can use NO value even if FFTW methods is used, but PIMA performance will be worse by a factor of 2-20.

file -- name of the FFTW configuration file.

## 2.20 NUM\_THREADS:

**NUM\_THREADS:** value

The number of threads used by FFT. Usually, FFT\_NUM\_THREADS is set to the number of processors (cores) available. But you may want to reduce the number of threads for load balancing.

## 3 Observation processing keywords

### 3.1 AP\_TOLERANCE:

**AP\_TOLERANCE:** value

PIMA assumes the time epochs of all the uv data within each scan forms a rail of ticks with spacing equal to some constant, accumulation period length. Parameter AP\_TOLERANCE sets the tolerance in seconds for UV data to have time epochs with interval slightly greater or less than the accumulation period length. If PIMA finds UV data that have time epoch that differs from previous accumulation period by more than AP\_TOLERANCE, it will discard that data point. NB: the start time of a scan may be not commensurate to the accumulation period length counted from the previous scan, only time stamps within each scan are checked.

For geodesy and astrometry applications AP\_TOLERANCE should not exceed 1.D-6 seconds. For imaging application the tolerance may be relaxed.

### 3.2 MIN\_SCAN\_LEN:

**MIN\_SCAN\_LEN:** value

Parameter MIN\_SCAN\_LEN determines the minimum scan duration in seconds. It instructs the PIMA internal algorithm for splitting visibility data into scans that a scan should not be shorter than that value. If it finds a set of visibility data shorter than this value that cannot be attached to another scans in accordance with the constraints set by other parameters of PIMA, it will flag these visibilities.

### 3.3 MAX\_SCAN\_LEN:

**MAX\_SCAN\_LEN:** value

Parameter MAX\_SCAN\_LEN determines the maximum scan duration in seconds. It instructs the PIMA internal algorithm for splitting visibility data into scans that a scan should be not longer than not that value. Scan duration is set as an interval between the beginning of the first accumulation period and the end of the last accumulation period. A set of data of the same source may last longer than MAX\_SCAL\_LEN. In that case that set of data will be split into several scans. Splitting of data into scans occurs in chronological order. Thus, after putting the earliest visibility set into a given scan, the scan end is fixed, and the visibilities for the following epochs are put into the next scan.

### 3.4 MAX\_SCAN\_GAP:

**MAX\_SCAN\_GAP:** value

Parameter MAX\_SCAN\_GAP controls maximum duration of a gap in data within each scan for the algorithm that splits visibilities into scans. If a gap in visibility data of the same source long than this value occurred, it triggers setting the scan boundary at the beginning of the gap. The start time epoch of the new scan is set to the the first time epoch after the gap.

### 3.5 SCAN\_LEN\_SKIP:

**SCAN\_LEN\_SKIP:** value

This parameter instructs PIMA to discard the visibilities at the beginning of a scan from the nominal scan start for the interval of time equal to this value in seconds. The value of SCAN\_LEN\_SKIP cannot be negative.

### 3.6 SCAN\_LEN\_USED:

**SCAN\_LEN\_USED:** value

This parameter instructs PIMA to discard the visibilities at the end of a scan. It control the duration of the interval in seconds with used visibilities. The beginning of the interval is counted from the nominal scan length if SCAN\_LEN\_SKIP is 0. If SCAN\_LEN\_SKIP > 0, the beginning of the interval is offset at SCAN\_LEN\_SKIP with respect to the nominal scan start. The visibility data beyond the interval specified by this keyword are discarded.

### 3.7 FRT\_OFFSET:

**FRT\_OFFSET:** [AUTO or value or file]

Keyword FRT\_OFFSET instructs PIMA how to determine to fringe reference time, i.e. the time to which residual phase related.

AUTO -- Instructs PIMA to determine the fringe reference time automatically. PIMA determines it as a mean weighted epoch within a scan for each observation separately.  
NB: In general, the fringe reference time for different observation of a given scan is not the same.

value -- sets the offset of the fringe reference time with respect to the nominal scan start.

## PIMA keywords

`file` -- Specifies the file with fringe reference time. The file is in ASCII format. Each line has two words separated by one or more blanks. The first word defines the observation index, the second words defines the fringe reference frame in seconds with respect the scan nominal start. Lines that start from `#` are considered as comments and ignored.

### 3.8 STA\_REF:

**STA\_REF:**      **Station name**

Specifies the name of the reference station. The reference station is used for computation of the complex bandpass.

### 3.9 VTD\_CONFIG\_FILE:

**VTD\_CONFIG\_FILE:**    **file**

Specifies the name of VTD (VLBI Time Delay) control file. The VTD control file specifies parameters of the VLBI model for path delay.

### 3.10 EXPER\_DIR:

**EXPER\_DIR:**      **directory**

Name of the directory where PIMA task load writes index files. Index files have names that start from the session name and end on specific extensions.

### 3.11 UV\_EXCLUDE\_FILE:

**UV\_EXCLUDE\_FILE:** [file or AUTO or NO]

file -- File name with indices of visibility dates that are excluded from processing. Lines that start from # are considered as comments and ignored.

AUTO -- invokes a special algorithm for automatic accounting for bad uv data points for PIMA task load. The algorithm first searches for a file in EXPER\_DIR directory with the name that has the first part session name and the last part \_uv.exc. If it finds that file, it reads it. The file contains the indexes of the visibility data that are excluded before further analysis. These are so-called a priori excluded visibilities. If PIMA finds bad visibilities, it generates a list of bad visibility names. These are so-called a posteriori bad visibilities. If there is at least one bad a posteriori visibility, PIMA combines the indexes of a priori and a posteriori bad visibilities, writes them down into a file with the same name: the first part session name and the last part \_uv.exc, and sets exit code 23.

If the control file has UV\_EXCLUDE\_FILE: AUTO and the first run of PIMA task load returned exit code 23, then the second run is recommended. Bad points identified in the first run, will be bypassed during the second run.

NO -- No visibility data are excluded.

### 3.12 BANDPASS\_USE:

**BANDPASS\_USE:** [AMP or PHS or AMP\_PHS or NO]

This keyword controls whether to apply complex bandpass and if to apply, then how. A bandpass is a complex function of frequency.

## PIMA keywords

For each station, each IF and each spectral channel, a complex value is defined. Applying the bandpass is an operation when raw visibilities are divided by this value.

AMP -- apply the amplitude part of the bandpass, i.e. to change only amplitudes, but do not change phases.

PHS -- apply phase part of the bandpass, i.e. to change only phases, but do not change amplitudes.

AMP\_PHS -- apply the complex bandpass, i.e. change both amplitudes and phases.

NO -- do not apply the complex bandpass.

### 3.13 BANDPASS\_FILE:

**BANDPASS\_FILE:** file or NO

This keyword controls the name of the bandpass file. Bandpass is a complex function of frequency. It defines a complex number for each station, each spectral channel of each IF. The visibility is divided by a product of bandpasses for the pair of stations of the baseline. Bandpass file name is an output parameter for task `bpas`. Therefore, it may not exist for this task. The bandpass file name is an input parameters for many other tasks, such as `frib`, `splt`, `mkdb`. PIMA checks whether the specified file exists and stops with an error message, if cannot find it and read.

file -- name of the bandpass file.

NO -- No bandpass file exists. You cannot specify NO with `bpas` task.

### 3.14 POLARCAL\_FILE:

**POLARCAL\_FILE:** file or NO

## PIMA keywords

This keyword controls the name of the polarization bandpass file. In a case of dual-polarization data PIMA supports two bandpasses. The first bandpass is for RR data. It is defined in the file specified by BANDPASS\_FILE name. The second bandpass determines the complex function of frequency that describes the ration of complex response of LL band with respect to RR. That second bandpass is specified by POLARCAL\_FILE. Therefore, the LL bandpass is the product of these two bandpasses. When PIMA calibrates RR data, it uses only the first bandpass. When PIMA calibrates LL data, it uses the product of two bandpasses. When PIMA calibrates data for polarization I, which it computes on the fly, it uses both bandpasses. POLARCAL\_FILE is not used for single-polarization data. Bandpass file name is an output parameter for task bpas. Therefore, it may not exist for this task. The bandpass file name is an input parameters for many other tasks, such as frib, splt, mkdb. PIMA checks whether the specified file exists and stops with an error message if it cannot find it and read.

file -- name of the second polarization bandpass file.

NO -- No polarization bandpass is to be used or to be created.  
Task bpas will not compute polarization bandpass  
if POLARCAL\_FILE: NO.

### 3.15 BANDPASS\_MASK\_FILE:

#### **BANDPASS\_MASK\_FILE: file or NO**

This keyword controls the name of the mask file. Mask file consists of 0 and 1 for each station, each IF, each frequency channel. PIMA defines 4 masks: 1) for autocorrelation; 2) for computation of bandpass; 3) for fringe fitting, and 4) for task splt. Normally mask 2-3-4 are the same. When PIMA processes autocorrelation, it multiplies autocorrelation data by the mask value 0 and 1. Then it interpolates the autocorrelation and puts on place those spectral channels that were masked out (i.e. had 0 in the mask file) the value computed by interpolation between neighboring channels that were not masked out. When PIMA processes cross correlation data, it multiplies visibilities on mask values. If a given channels is masked out, it is effectively excluded from further processing.



## PIMA keywords

Bandpass mask file must define mask values for all spectral channels, all IFs, all stations. PIMA supports task `bmge` (Bandpass Mask GEneration) that allows to describe in an ascii files only those spectral channels, IFs or their ranges that have to be masked out. Task `bmge` reads the input mask definition file and generates the output bandpass mask file.

`file` -- name of the the bandpass mask file. This file name is the output for task `bmge`. When task `bmge` is used, this file may not exist. For other tasks this file should exists. PIMA will stop with an error message if it will not find it.

`NO` -- No bandpass file exists. You cannot specify `NO` with `bmge` task.

### 3.16 PCAL\_MASK\_FILE:

#### **PCAL\_MASK\_FILE: file or NO**

This keyword controls the name of the mask file for phase calibration data. It is applied only when all phase calibration tones are used (`PCAL: USE_ALL`). Phase calibration signal is often affected by internal radio interference. The mask file allows to exclude (to mask out) the tones that are affected by the RFI. When the interpolation spline is computed to approximate the frequency dependence of phase calibration signal, these tones are excluded from computation of the spline.

Phase calibration mask file must define mask values for all spectral channels, all IFs, all stations. PIMA supports task `pmge` (Phase calibration Mask GEneration) that allows to describe in an ascii files only those spectral channels, IFs or their ranges that have to be masked out. Task `pmge` reads the input mask definition file and generates the output polarization mask file.

`file` -- name of the the phase calibration mask file. This file name is the output for task `pmge`. When task `bmge` is used, this file may not exist. For other tasks this file should exists. PIMA will stop with an error message if it will not find it.

`NO` -- No polarization make file exists. You cannot specify `NO` with `pmge` task.

### 3.17 INTMOD\_FILE:

**INTMOD\_FILE:** [directory or NO]

Normally, the a priori interferometric model is defined inside the FITS-IDI data. However, some correlators omit these sections in FITS-IDI files, which prevents astrometry and geodetic applications that require computation of the total phases, group delays, phase delay rates and group delay rates. As a workaround PIMA supports import of interferometric models in the form that were used by the correlator. Keyword INTMOD\_FILE specifies the directory tree(s) that contains files with the a priori model for path delay. Interpretation of files depends on the correlator. In a case of VERA hardware correlator in Mitaka, PIMA searches for files that has "ANT." pattern and ignores all others. In a case of SFXC correlator, PIMA searches for files with extension ".del" and ignores all others. This keyword is used by task moim (MOdel IMport).

More than one keyword INTMOD\_FILE can be specified.

directory -- directory name where PIMA will search for files with a priori model, including all sub-directories.

NO -- No directory name is specified. NO can be specified only when INTMOD\_TYPE is NO.

### 3.18 INTMOD\_TYPE:

**INTMOD\_TYPE:** [VERA1000 or VERA2000 or SFXC or NO]

This keywords defines the type of external path delay model. This value of this keyword controls how PIMA should interpret the files with a priori path delay used by the correlator specified by the keyword INTMOD\_FILE.

VERA1000 -- delay files are in CODA format for VERA1000 recording systems. The files are named ANT.x, where x is an

## PIMA keywords

integer number.

VERA2000 -- delay files are in CODA format for VERA2000 recording systems. The files are named ANT.x, where x is an integer number. NB: VERA1000 and VERA2000 have different format.

SFXC -- delay files are in ASCII format for SFXC correlator. The files have extension .del

NO -- format is undefined. Should be used when INTMOD\_TYPE: NO and cannot be specified otherwise.

### 3.19 CORR\_FLAG\_MIN:

**CORR\_FLAG\_MIN:** value

This keyword defines the threshold for discarding the data that are marked by the correlator as potentially corrupted. The data with CORR\_FLAG\_MIN equal or less are discarded. Usually, CORR\_FLAG\_MIN: 1 is a good choice. That means any data flagged by the correlator will be discarded. However, if you think that the correlator discards too many 'good' data, you can lower the threshold.

FITS-IDI specifications define the flag the following way:

- 1 No severity level assigned
- 0 Data are known to be useless
- 1 Data are probably useless
- 2 Data may be useless

The VLBA hardware correlator may assign flag -1 (i.e. undefined severity). In that case FITS-IDI keyword CORR\_FLAG\_REASON string that describes the problem that resulted in flagging must be defined. When PIMA finds a severity flag -1 it parses the string with the reason. Then it assigns the severity level, i.e the correlator flag, the following way:

- 2-16 ghz synthesizer #2 -- FLAG = 2
- 2-16 ghz synthesizer #2 -- FLAG = 2
- antenna not in point mod -- FLAG = 0

## PIMA keywords

Antenna not pointed -- FLAG = 0  
antenna position error t -- FLAG = 0  
Antenna off source -- FLAG = 0  
BBC Synth Unlocked -- FLAG = 2  
channel 1 bbc synthesizer -- FLAG = 2  
channel 2 bbc synthesizer -- FLAG = 2  
channel 3 bbc synthesizer -- FLAG = 2  
channel 4 bbc synthesizer -- FLAG = 2  
channel 5 bbc synthesizer -- FLAG = 2  
channel 6 bbc synthesizer -- FLAG = 2  
channel 7 bbc synthesizer -- FLAG = 2  
channel 8 bbc synthesizer -- FLAG = 2  
Ellipsoid posn error -- FLAG = 2  
ellipsoid position error -- FLAG = 2  
observing system idle -- FLAG = 2  
Recorder 1 head posn err -- FLAG = 2  
Recorder 1 not running -- FLAG = 2  
Recorder 2 head posn err -- FLAG = 2  
Recorder 2 not running -- FLAG = 2  
Source change in progres -- FLAG = 0  
source change in progres -- FLAG = 0  
Subreflector error -- FLAG = 2  
Synthesizer 1 unlocked -- FLAG = 2  
Synthesizer 2 unlocked -- FLAG = 2  
Synthesizer 3 unlocked -- FLAG = 2  
System idle -- FLAG = 0  
subreflector position er -- FLAG = 2  
2-16 ghz synthesizer #1 -- FLAG = 2  
2-16 ghz synthesizer #2 -- FLAG = 2  
2-16 ghz synthesizer #3 -- FLAG = 2

If it does not find CORR\_FLAG\_REASON string or finds a string that is not in the table above, it stops with an error message.

value -- the threshold of the correlator flag. If a UV point has the correlator flag equal or less than that code, PIMA flags that observation out, i.e. replaces the visibility data with zeroes.

### 3.20 TIME\_FLAG\_FILE:

**TIME\_FLAG\_FILE:** [file or NO]

## PIMA keywords

This keyword defines the name of the file that sets multiplicative reweighting factors for all visibilities at specified time epochs at specified observations. Observations weight will be multiplied by this factor. Usually, these reweighting factors are zero. In that case, TIME\_FLAG\_FILE sets the accumulation periods that PIMA must discard.

The ascii TIME\_FLAG\_FILE consists of lines that contains three words: observation index, ap index from the nominal observation start, weight. Usually this file is generated automatically either by a user application or by PIMA task onof.

file -- name of the time flag. When PIMA uses onof task in the mode of time flag file generation, the file name must be specified. PIMA will stop if the file name is not specified. For all other tasks, keyword TIME\_FLAG\_FILE with the file name specified means that PIMA should read this file and update weights for the specified observations, specified accumulation periods.

NO -- means no multiplicative reweighting factors will be applied.

### 3.21 TEC\_FILE:

**TEC\_FILE: file or NO**

TEC file name. At the moment is not supported. Reserved for future use. TEC\_FILE: NO should be specified.

### 3.22 FRINGE\_FILE:

**FRINGE\_FILE: file**

Name of the ascii output file where results of fringe fitting are written. If the file exists, PIMA will append records to its end. PIMA first writes the header that starts with # character and writes a terse footer at the end.

### 3.23 FRIRES\_FILE:

**FRIRES\_FILE:**    **file**

Name of the ascii output file where residuals of fringe fitting are written. If the file exists, PIMA will append records to its end. PIMA first writes the header that starts with # character and writes a terse footer at the end.

### 3.24 BEG\_FRQ:

**BEG\_FRQ:**        **value**

The start intermediate frequency (IF) index that is used by PIMA. Cannot be less than 1.

### 3.25 END\_FRQ:

**END\_FRQ:**        **value**

The end intermediate frequency (IF) that is used by PIMA. Cannot be less than BEG\_FRQ and cannot be greater than the last IF.

### 3.26 FRQ\_GRP:

**FRQ\_GRP:**    **[value or value\_min:value\_max or value\_min-value\_max]**

Frequency group. In a case if the input FITS-IDI data have more than one intermediate frequency (IF), the IFs can form one or more groups. This keywords specifies which frequency groups will be used. A valid FITS-IDI file contains at least one frequency group with index 1.

## PIMA keywords

NB: PIMA can perform fringe fitting only within one frequency group.

value -- the index of the used frequency group.  
Cannot be less than 1 and cannot be greater than  
the total number of frequency groups.

value\_min:value\_max -- merge several frequency groups together for  
overlapping data. It is assumed that there are  
visibility data for the same time epochs  
within groups that are being merged.  
value\_min and value\_max are the indexes of  
the first and the last frequency group  
to merge. They form a virtual frequency group.  
The number of IFs in the merged frequency  
group is the sum of the number of IFs in  
participating groups.

value\_min-value\_max -- combine several frequency groups together for  
non overlapping data. It is assumed that there  
are no visibility data for the same time epochs  
within the groups that are being combined.  
A new virtual group is created with the index  
that is by one greater than the number of  
non-virtual groups. The new combined group  
has all IFs of its constituents.

NB: keep in mind the distinction between merged and combined frequency  
groups.

### 3.27 POLAR:

**POLAR:** [RR or LL or RL or LR or I]

Polarization code. In the case if one polarization was correlated,  
it must be either RR or LL depending on used polarization. If two  
polarization were correlated, it can be RR or LL or I. In a latter  
case PIMA apply the bandpass to RR and both bandpass and polarization  
bandpass to LL polarizations, rotates RR fringe phase at the  
parallactic angle and LL fringe phases at the same angle but with the  
opposite sign and forms a calibrated linear combination  $I = (RR + LL)/2$ .  
The SNR of this combination is at 40% better than the SNR of RR or LL  
data. NB: polarization I should be used only after both bandpass

and polarization bandpasses were computed. Otherwise, the results will be totally unsatisfactory.

### 3.28 WVR\_FILE:

**WVR\_FILE:** file name

file\_name: Full path name of the WVR data. At the moment, only form "\*" WVR\_EFL data. Format version 2014.07.24" is supported. If no WVR data are available, NO should be used. More than one file can be specified, one file per station.

### 3.29 WVR\_USE

**WVR\_USE:** usage

usage: WVR usage. Specifies the algorithm for interpolation and smoothing of original WVR data and the contribution of WVR path delay phases should be subtracted from the visibility phases. Supported values:

NO -- do not apply visibility phases

WVR\_3SPL -- Expand original data into smoothing spline of the 3rd degree.

WVR\_LIN -- Expand original data into smoothing spline of the 1st degree.

WVR\_AVR -- Expand original data into smoothing spline of the 3rd degree.

### 3.30 WVR\_SMOOTHING\_INTERVAL



**WVR\_SMOOTHING\_INTERVAL: value**

value: interval of the smoothing spline in seconds.  
10-40 seconds is usually adequate

### **3.31 WVR\_SMOOTHING\_SIGMA**

**WVR\_SMOOTHING\_SIGMA: value**

value: Reciprocal weight of the constraint imposed on WVR smoothing spline in seconds. The smaller parameter, the closer smoothing spline to the averaged path delay. The bigger parameter, the greater fluctuations in WVR phases are allowed. 2.0D-11 is usually adequate.

### **3.32 PHASE\_ACCELERATION:**

**PHASE\_ACCELERATION: value**

Ad hoc phase acceleration that will be applied to visibilities. Units: rad/s<sup>2</sup>. Normally 0.0 value used. Values different from zero are used for radio interferometer with a station at the space.

### **3.33 PHASE\_ACCEL\_MIN:**

**PHASE\_ACCEL\_MIN: value**

Minimal phase acceleration in rad/s<sup>2</sup> that will be used for iterations. PIMA supports the mode when it tries a range of phase accelerations with a step that it determines automatically. The step

## PIMA keywords

is found in such a way that the maximum contribution of the phase acceleration term be less than 0.33 rad. PIMA runs N times fringe fitting with different phase accelerations for each observation. PHASE\_ACCEL\_MIN: 0.0 and PHASE\_ACCEL\_MAX: 0.0 tells PIMA that no tries with a range of phase acceleration should be done

### 3.34 PHASE\_ACCEL\_MAX:

**PHASE\_ACCEL\_MAX:** value

Maximal phase acceleration in rad/s<sup>2</sup> that will be used for iterations. PIMA supports the mode when it tries a range of phase accelerations with a step that it determines automatically. The step is found in such a way that the maximum contribution of the phase acceleration term be less than 0.33 rad. PIMA runs N times fringe fitting with different phase accelerations for each observation. PHASE\_ACCEL\_MIN: 0.0 and PHASE\_ACCEL\_MAX: 0.0 tells PIMA that no tries with a range of phase acceleration should be done

### 3.35 EPHEMERIDES\_FILE:

**EPHEMERIDES\_FILE:** [file or NO]

Name of the ephemeride file for space interferometer. The file should conform CCSDS\_OEM\_VERS specifications. This ephemerides file is used for computation of the position of the station that is in space. If one of the stations is marked in antenna description file used by VTD as space station, ephemerides file must be specified.

NO -- no ephemerides file is specified. If you analyze an experiment only with ground station, use NO.

### 3.36 EPHEMERIDES\_USE:

**EPHEMERIDES\_USE: [NO or RA\_PUSCH or RA\_GBT or RA\_GB140 or EARTH\_OR or STA\_ORB or INTERPLA]**

This keyword specifies the type of space interferometer. It instructs the algorithm for computation of path delay.

RA\_PUSCH -- Radioastron type of interferometer. The space station has its H-maser that does not keep time between scans and is synchronized with the ground H-maser at PUSCHINO radiotelescope.

RA\_GBT -- Radioastron type of interferometer. The space station has its H-maser that does not keep time between scans and is synchronized with the ground H-maser at GB-VLBA radiotelescope.

RA\_GB140 -- Radioastron type of interferometer. The space station has its H-maser that does not keep time between scans and is synchronized with the ground H-maser at NRAO140 radiotelescope.

EARTH\_OR -- the space radio telescope is Earth orbiting. Its clock are synchronized before the experiment.

INTERPLA -- the space radio telescope is an interplanetary station.

NO -- there are no space radio telescopes in this experiment.

## **4 Baseline fringe fitting keywords**

The baseline fringe fitting procedure is the main task of PIMA. The goal of the fringe fitting procedure is to find group delay, group delay rate, phase delay rate and possibly phase delay acceleration in such a way that would minimize the loss of coherency during averaging over time and frequency.

Baseline fringe fitting is done for each observation independently. It consists of two steps: coarse fringe search and refinement. In general, optimal determination of group delay, group delay rate, phase delay rate and phase delay acceleration is a non-linear procedure. The goal of the mandatory coarse fringe search is to find

## PIMA keywords

an approximate value of group delay and phase delay rate in order to shrink the search area and make possible linear estimator.

PIMA supports several algorithms of fine search that improves result of the coarse fringe search. Results of fringe search and statistics of residuals are written in the ascii output files defined by keywords FRINGE\_FILE and FRIRES\_FILE.

### 4.1 FRIB.SEARCH\_TYPE:

**FRIB.SEARCH\_TYPE: 2FFT**

At the moment the only supported fringe search type is 2FFT. It is based in the procedure that uses 2D FFT in order to find the maximum of the visibility for the observation averaged with respect to time and frequency with trial group delay and phase delay rate.

### 4.2 FRIB.DELAY\_WINDOW\_CENTER:

**FRIB.DELAY\_WINDOW\_CENTER: value**

PIMA allows to restrict the area in group delay, phase delay rate space where the maximum of visibilities averaged over frequency and time is sought. This rectangular area is determined by four parameters: FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER, FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH.

Keyword FRIB.DELAY\_WINDOW\_CENTER sets the center of the window over group delay in seconds.

If you want to set the maximum search window, i.e. you do not see a reason to restrict it, please set all four parameters FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER, FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH to zero.

### 4.3 FRIB.RATE\_WINDOW\_CENTER:

**FRIB.RATE\_WINDOW\_CENTER: value**

PIMA allows to restrict the area in group delay, phase delay rate space where the maximum of visibilities averaged over frequency and time is sought. This rectangular area is determined by four parameters: FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER, FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH.

Keyword FRIB.RATE\_WINDOW\_CENTER sets the center of the window over phase delay rate. This quantity is dimensionless.

If you want to set the maximum search window, i.e. you do not see a reason to restrict it, please set all four parameters FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER, FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH to zero.

#### **4.4 FRIB.DELAY\_WINDOW\_WIDTH:**

**FRIB.DELAY\_WINDOW\_WIDTH: value**

PIMA allows to restrict the area in group delay, phase delay rate space where the maximum of visibilities averaged over frequency and time is sought. This rectangular area is determined by four parameters: FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER, FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH.

Keyword FRIB.DELAY\_WINDOW\_WIDTH sets the half-width of the delay in seconds. That means the search window is [FRIB.DELAY\_WINDOW\_CENTER - FRIB.DELAY\_WINDOW\_WIDTH, FRIB.DELAY\_WINDOW\_CENTER + FRIB.DELAY\_WINDOW\_WIDTH].

If the value is zero, then the maximum search window is set up:  $1.0/\text{Chan\_width}$  where Chan\_width is the spectral resolution of visibility data in Hz. NB: setting FRIB.DELAY\_WINDOW\_WIDTH greater than the maximum search window has no effect. Parameter FRIB.DELAY\_WINDOW\_WIDTH used for restricting the search window, not for its increase.

If you want to set the maximum search window, i.e. you do not see

a reason to restrict it, please set all four parameters  
FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER,  
FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH to zero.

#### 4.5 FRIB.RATE\_WINDOW\_WIDTH:

**FRIB.RATE\_WINDOW\_WIDTH: value**

PIMA allows to restrict the area in group delay, phase delay rate space where the maximum of visibilities averaged over frequency and time is sought. This rectangular area is determined by four parameters: FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER, FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH.

Keyword FRIB.DELAY\_WINDOW\_WIDTH sets the half-width of the delay in seconds. That means the search window is  
[FRIB.DELAY\_WINDOW\_CENTER - FRIB.DELAY\_WINDOW\_WIDTH,  
FRIB.DELAY\_WINDOW\_CENTER + FRIB.DELAY\_WINDOW\_WIDTH].

If the value is zero, then the maximum search window is set up:  
 $1.0/\text{Chan\_width}$  where Chan\_width is the spectral resolution of visibility data in Hz. NB: setting FRIB.DELAY\_WINDOW\_WIDTH greater than the maximum search window has no effect. Parameter FRIB.DELAY\_WINDOW\_WIDTH used for restricting the search window, not for its increase.

If you want to set the maximum search window, i.e. you do not see a reason to restrict it, please set all four parameters  
FRIB.DELAY\_WINDOW\_CENTER, FRIB.RATE\_WINDOW\_CENTER,  
FRIB.DELAY\_WINDOW\_WIDTH, FRIB.RATE\_WINDOW\_WIDTH to zero.

#### 4.6 FRIB.AUTOCORR\_CALIB:

**FRIB.AUTOCORR\_CALIB: [NO or CNST1 or CNST2 or SQRT\_MEA or SQRT\_KOG]**

Correlators apply arbitrary normalization factors that affect both autocorrelation and cross-correlation PIMA allows to re-normalize

## PIMA keywords

cross-correlation visibilities.

NO -- no re-normalization is performed. NB: it is a bad idea to use the data without renormalization for imaging.

CNST1 -- cross-correlation is divided by a constant  
PIMA\_\_ACCR\_CNST1 defined in pima.i

CNST2 -- cross-correlation is divided by a constant  
PIMA\_\_ACCR\_CNST2 defined in pima.i

SQRT\_MEA -- PIMA computed re-normalization factors under assumptions that 1) the correlator applied the same normalization factor to both autocorrelation and cross-correlation; 2) the mean of the autocorrelation spectrum is 1.

The autocorrelation spectrum is corrected for sampling distortion. This is done by transforming the spectrum to the time domain, applying the digital sampler correction that may differ from the digital sampler correction of cross-correlator data since the autocorrelation data have much larger amplitude, normalizing the autocorrelation function to 1 at the zero lag and transforming the corrected autocorrelation data back to the spectral domain. Then the mean autocorrelation spectrum over an IF is computed for each station, and the cross-correlation visibilities are divided by the square root of the product of the mean autocorrelation spectrum for both stations of the baseline.

SQRT\_KOG -- Similar to SQRT\_MEA, but the original algorithm of Leonid Kogan used. The author of PIMA considers Kogans's algorithm erroneous, although the error affects the fringe amplitude at the amount of 0.5-3%.

### **4.7 FRIB.AMPL\_FUDGE\_TYPE:**

**FRIB.AMPL\_FUDGE\_TYPE: [VLBA or DIFX or KOGAN or NO]**

Fudge factor that accounts for disparity of amplitude distortion of the autocorrelation and cross-correlation. This factor is correlator

dependent.

VLBA -- the factor that is due to register saturation in VLBA \*hardware correlator\*. It depends on polarization and on data weights. NB: if you process the data processed with the software correlator located at Socorro you should NOT apply this correction.

KOGAN -- the factor that is due to register saturation in VLBA \*hardware correlator\*. The difference with respect to a case VLBA (see above) is that all weights are considered 1.0

DIFX -- For DiFX correlator: the fudge factor is 1.0

NO -- No fudge factor is applied.

## 4.8 FRIB.AMPL\_EDGE\_WINDOW\_COR:

### FRIB.AMPL\_EDGE\_WINDOW\_COR: [USE or NO]

There are three factors that reduces fringe amplitude when we observe a source that is off the main beam. The first factor is due to data loss at the edge of a frame with raw voltage record due to shifting of data streams. If the frame has N points, we can cross-multiply all N points of both streams when no shift is applied. If one of the streams is shifted at K points, we can cross-multiply only N-K points and the amplitude of the average will become less by the (N-K)/N factor. This factor is linear with respect to the group delay delay and the amplitude is reduced by the factor of 0.5 at the edge of the natural search window determined as a quantity reciprocal to the spectral resolution. The second factor is the power pattern of the primary beam. The third factor is appearance of the phase acceleration due to the third derivative of path delay over time, two times, and over source coordinates.

This keyword determines whether to apply the amplitude correction due to the amplitude loss for

USE -- to apply the amplitude correction for the amplitude loss in cross-multiplication of the data streams when due to



data stream shift. If in doubt, set USE.

NO -- do not apply the amplitude correction due to non data stream shifts. You should well understand what you are doing when you use this option.

#### **4.9 FRIB.AMPL\_EDGE\_BEAM\_COR:**

**FRIB.AMPL\_EDGE\_BEAM\_COR: [YES or NO]**

This keyword specifies whether to apply the amplitude correction for the antenna beam. Antenna beam is here the ratio of the power of the signal from a uniformly emitting sphere at angle theta from the beam direction to the power at  $\theta=0$ .

YES -- to apply the correction for the primary beams of both antennas of a baseline. If in doubt, set YES.

NO -- not to apply the correction for the primary beams of both antennas of a baseline. You should well understand what you are doing when you use this option.

#### **4.10 FRIB.OVERSAMPLE\_MD:**

**FRIB.OVERSAMPLE\_MD: value**

Oversampling factor over group delay axis. When PIMA grids the data for fringe search, it can reduce the step of the grid and pad the samples between grid points. When no oversampling is used, the amplitude of the coarse fringe may be less by a factor of 2.5 when the maximum happens just between grid points. The weak sources may be overlooked. When the oversampling factors are 4 for both group delay and phase delay rate, the amplitude drop of the coarse fringe search is only 5%. It should be noted that the amplitude is affected by the coarse fringe search only. If the sources is detected by the coarse fringe search, the fine fringe fitting corrects the amplitude underestimation.

value -- oversampling factor. General recommendation: 4, unless you can tolerate the detection limit drop up to the factor of 2.5. If you can tolerate it, set the oversampling factor to 1. The factor cannot be less than 1.

#### **4.11 FRIB.OVERSAMPLE\_RT:**

**FRIB.OVERSAMPLE\_RT:**      **value**

Oversampling factor over phase delay rate axis. See description of FRIB.OVERSAMPLE\_MD. Usually the oversampling over both axes is applied.

value -- oversampling factor. General recommendation: 4, unless you can tolerate the detection limit drop up to the factor of 2.5. If you can tolerate it, set the oversampling factor to 1. The factor cannot be less than 1.

#### **4.12 FRIB.FINE\_SEARCH:**

**FRIB.FINE\_SEARCH:**      **[LSQ or ACC or PAR or BIN or TEC or NO]**

This keyword specifies the algorithm for fine fringe fitting that follows the coarse fringe fitting.

LSQ -- the parameters following parameters are determined with least square: group delay, group delay rate, phase delay rate, and fringe phase at the fringe reference time and the reference frequency. The reference frequency is the lowest frequency of the data that are processed. Fringe phase for each visibility point is assigned according the the a priori SNR. The algorithm seeks the variance factor that corrects the a priori weights in such a way that the ratio of the weighted sum of the postfit residuals to its mathematical expectation be close to unity. The algorithm computes these reweighting parameters for two cases: multiplicative reweighting and additive

## PIMA keywords

reweighting, i.e. in the the first case the a posteriori weight is the a priori weight multiplied by the reweighting parameter, and in the second case the a posteriori weight is the a priori weight with the reweighted parameter added in quadrature. The algorithm returns three estimates of group delay, group delay rate, phase delay rate, phase and amplitude of observation-averaged visibilities: without reweighting, with multiplicative reweighting and with additive reweighting.

ACC -- the same as LSQ, but phase delay acceleration is evaluated instead of group delay rate.

PAR -- the fine fringe fitting is done by the parabolic fit through three points of the delay resolution function around the maxima. The search of the maxima is performed separately for delay and delay rate. The Lagrange interpolating polynomial is computed, and the linear equation which equalizes the derivative to zero is solved. The algorithm returns the estimates of group delay, phase delay rate, phase and amplitude of observation-averaged visibilities.

BIN -- the fine fringe fitting is done by binary division method. The algorithm returns the estimates of group delay, group delay rate, phase delay rate, phase and amplitude of observation-averaged visibilities.

TEC -- not implemented

NO -- no fine fringe fitting is performed.

### 4.13 FRIB.AUTOCORR\_THRESHOLD:

**FRIB.AUTOCORR\_THRESHOLD:** value

The threshold for autocorrelation. The autocorrelations that are less than this threshold are discarded. This results in discarding related cross-correlations if AUTOCORR\_CALIB is SQRTE\_MEA or SQRTE\_KOG. Value 0.05 for DiFX correlator is usually adequate.

#### 4.14 FRIB.WEIGHTS\_THRESHOLD:

**FRIB.WEIGHTS\_THRESHOLD:**     **value**

The threshold for visibility weights. The visibility points with weights less than this threshold are discarded. Value 0.2 is usually adequate.

#### 4.15 FRIB.NOISE\_NSIGMA:

**FRIB.NOISE\_NSIGMA:**       **value**

This parameter controls computation of the mean amplitude of noise. The 2d Fourier transform of visibility data over time and over frequency is analyzed for a search of the signal from the radio source. The result is analyzed also for determination of the mean amplitude of the noise. Among the results of the 2D Fourier transform the minimum among 32768 or 1/2 of the number of elements are randomly selected. The amplitudes of these random points of the spectrum are sorted in the ascending order. Then the iterative procedure for outlier elimination is launched. If the amplitude of the top point of the list is greater than FRIB.NOISE\_NSIGMA times the root mean square over amplitudes in the list, the point is discarded, the root mean squares is recomputed, and the procedure is repeated. Outlier elimination is made mainly to eliminate from statistics computation those points that are associated with signal rather than this signal.  
value 4.0 is usually adequate.

#### 4.16 FRIB.SNR\_DETECTION

**FRIB.SNR\_DETECTION:**       **value**

Sets the threshold for detection. Observations with the SNR

less than this threshold are considered as non-detections. Task splt discards observations with the SNR less than this threshold. Task mkdb set flag "non-detection" for observations with the SNR below this threshold. The detection limit depends on the number of visibility data used for fringe fitting. PIMA cannot determine the a priori threshold. It is set by a user. It is possible to determine the SNR detection limit by analyzing statistics of residuals from observations of the same type. The SNR is defined as the ratio of the fringe amplitude to the mean value of amplitude of noise. If to consider that real and image part of noise are independent and have Gaussian distribution with variance  $\sigma$ , the mean amplitude is  $\sqrt{\pi/2} \approx 1.253 \sigma$ . The variance of the amplitude noise is  $\sqrt{2 - \pi/2} \approx 0.655 \sigma$ .

#### 4.17 FRIB.FRQ\_TRANSFER\_BAND:

**FRIB.FRQ\_TRANSFER\_BAND:**    **value**

Controls how phase transfer from one frequency of simultaneous observations to another should be performed by tasks frtr.

NO            -- no phase transfer is made

control\_file -- name of the secondary control file for the lower band of this VLBI experiment. That control file determines the frequency band whether fringe phases should be taken for the phase transfer to the frequencies of the band specified in the main control file.

#### 4.18 FRIB.FRQ\_TRANSFER\_METHOD:

**FRIB.FRQ\_TRANSFER\_METHOD:**    **method**

Defines the smoothing method applied to phase before frequency

transfer.

SPLINE -- phase at the lower band is expanded in B-spline basis  
with the number of knots specified by keyword  
FRIB.FRQ\_TRANSFER\_DEG

LEGENDRE -- phase at the lower band is expanded in Legendre basis  
with the degree specified by keyword  
FRIB.FRQ\_TRANSFER\_DEG

ASIS -- phase at lower band is not expanded and transferred  
as is.

#### **4.19 FRIB.FRQ\_TRANSFER\_DEG:**

**FRIB.FRQ\_TRANSFER\_DEG: degree**

Defines the degree of the polynomial or the number of knots of B-spline for smoothing phase before frequency transfer.

degree -- The meaning of this keyword depends on FRIB.FRQ\_TRANSFER\_METHOD. If the expansion basis is LEGENDRE, then FRIB.FRQ\_TRANSFER\_DEG is the degree of the Legendre polynomial for expansion of the phase at the low band. If the expansion basis is SPLINE, then FRIB.FRQ\_TRANSFER\_DEG is the number of spline knots in each intermediate frequency for expansion of the amplitude of the phase at the low band. It is ignored if method is ASIS.

#### **4.20 FRIB.FRQ\_TRANSFER\_MSEG:**

**FRIB.FRQ\_TRANSFER\_MSEG: segment\_length**

Defines the length of the segment that will be coherently averaged before frequency transfer.

## PIMA keywords

`segment_length` -- The averaging factor for the phase at low band to be used for interpolation before transfer. An integer number in a range [1, NCHN], where NCHN is the number of spectral channels in an IF, or AUTO. Value AUTO forces PIMA to determine segment length in order to have the SNR within a segment no less than 1.5

### 4.21 FRIB.2D\_FRINGE\_PLOT:

**FRIB.2D\_FRINGE\_PLOT:**      **[XW or GIF or PS or TXT or NO]**

This keyword specifies the format of the 2D fringe plot. The 2D fringe plots shows the amplitude of the visibility averaged over frequency and time within the observation as a function of group delay and phase delay rate. The name of the output file is `fr2d_{scan_name}_{band_name}_{station1}_{station2}`. All components are in lower case. The plot is placed in subdirectory `{EXPER_DIR}/{SESS_CODE}_fpl/` where `EXPER_DIR` is the experiment scratch directory and `{SESS_CODE}` is the session code.

`XW` -- to display the plot of the 2D function on the screen using the PGPLOT library.

`GIF` -- to generate the plot in GIF format. Extension of the output file is `.gif`

`PS` -- to generate the plot in Postscript format. Extension of the output file is `.ps`

`TXT` -- to write the table with the averaged amplitude as a function of group delay and phase delay rate. Extension of the output file is `.txt`

`NO` -- do not generate the 2D fringe file output.

### 4.22 FRIB.PLOT\_DELAY\_WINDOW\_WIDTH:

**FRIB.PLOT\_DELAY\_WINDOW\_WIDTH: value**

This parameter sets the width of the 2d fringe plot along group delay axis. Units are sec.

**4.23 FRIB.PLOT\_RATE\_WINDOW\_WIDTH:**

**FRIB.PLOT\_RATE\_WINDOW\_WIDTH: value**

This parameter sets the width of the 2d fringe plot along phase delay rate axis. Units are sec.

**4.24 FRIB.OVERSAMPLE\_PLOT\_MD:**

**FRIB.OVERSAMPLE\_PLOT\_MD: value**

This parameter sets the oversampling factor along the group delay axis for generation of the 2D fringe plot. Natural choice is 'FRIB.OVERSAMPLE\_PLOT\_MD: 1. If to increase the value, the lines will become thicker.

**4.25 FRIB.OVERSAMPLE\_PLOT\_RT:**

**FRIB.OVERSAMPLE\_PLOT\_RT: value**

This parameter sets the oversampling factor along the phase delay rate axis for generation of the 2D fringe plot. Natural choice is 'FRIB.OVERSAMPLE\_PLOT\_RT: 1. If to increase the value, the lines will become thicker.



## 4.26 FRIB.1D\_RESFRQ\_PLOT:

**FRIB.1D\_RESFRQ\_PLOT:** [XW or GIF or PS or SAV or TXT or NO]

This keyword specifies the format of the 1D fringe plot that shows amplitude and phase of the visibilities averaged over time as a function frequency. The name of the output file is `fr1d_frq_{scan_name}_{band_name}_{station1}_{station2}_all`. All components are in lower case. The plot is placed in subdirectory `{EXPER_DIR}/{SESS_CODE}_fpl/` where `EXPER_DIR` is the experiment scratch directory and `{SESS_CODE}` is the session code.

XW -- to display the 1D plot of the fringe phase and fringe amplitude on the screen using the PGPLOT library.

SAV -- to write the plot in the internal format of graphic library DiaGI. Extension of the output file is `.sav`  
The plot can be displayed with program `diagi_rst` that accepts the name of the plot file in SAV format as its argument.

GIF -- to generate the plot in GIF format. Extension of the output file is `.gif`

PS -- to generate the plot in Postscript format. Extension of the output file is `.ps`

TXT -- to write the table with fringe phase and fringe amplitude as a function of frequency. Extension of the output file is `.txt`

NO -- do not generate the 1D fringe plot versus frequency output.

## 4.27 FRIB.1D\_FRQ\_MSEG:

**FRIB.1D\_FRQ\_MSEG:** value

## PIMA keywords

The averaging factor for 1D fringe plot over frequency.  
An integer number in a range [1, NCHN], where NCHN is the number of spectral channels in an IF. If FRIB.1D\_FRQ\_MSEG > 1, then the complex visibility is averaged over FRIB.1D\_FRQ\_MSEG consecutive spectral channels, and the number of points in the plot will be reduced by the same factor. Frequency averaging is used for displaying fringe plot of a weak source.

### 4.28 FRIB.1D\_RESTIM\_PLOT:

**FRIB.1D\_RESTIM\_PLOT:**      **value**

This keyword specifies the format of the 1D fringe plot that shows amplitude and phase of the visibilities averaged over frequency as a function time. The name of the output file is `fr1d_tim_{scan_name}_{band_name}_{station1}_{station2}_all`. All components are in lower case. The plot is placed in subdirectory `{EXPER_DIR}/{SESS_CODE}_fpl/` where `EXPER_DIR` is the experiment scratch directory and `{SESS_CODE}` is the session code.

`XW` -- to display the 1D plot of the fringe phase and fringe amplitude on the screen using the PGPLOT library.

`SAV` -- to write the plot in the internal format of graphic library DiaGI. Extension of the output file is `.sav`  
The plot can be displayed with program `diagi_rst` that accepts the name of the plot file in SAV format as its argument.

`GIF` -- to generate the plot in GIF format. Extension of the output file is `.gif`

`PS` -- to generate the plot in Postscript format. Extension of the output file is `.ps`

`TXT` -- to write the table with fringe phase and fringe amplitude as a function of frequency. Extension of the output file is `.txt`

`NO` -- do not generate the 1D fringe plot versus time.

## 4.29 FRIB.1D\_TIM\_MSEG:

**FRIB.1D\_TIM\_MSEG:**        **value**

The averaging factor for 1D fringe plot over time.  
An integer number in a range [1, NAP], where NAP is the number of accumulation periods. If FRIB.1D\_TIM\_MSEG > 1, then the complex visibility is averaged over FRIB.1D\_TIM\_MSEG consecutive accumulation periods, and the number of points in the plot will be reduced by the same factor. Frequency averaging is used for displaying fringe plot of a weak source.

## 4.30 FRIB.1D\_DRF\_PLOT:

**FRIB.1D\_DRF\_PLOT:**        **value**

This keyword specifies the format of the 1D plot of the delay resolution function -- dependence of the fringe amplitude averaged over frequency and time on group delay. The argument of the DRF is group delay with respect to the value found by the fringe fitting procedure. The name of the output file is `fr1d_drf_{scan_name}_{band_name}_{station1}_{station2}_all`. All components are in lower case. The plot is placed in subdirectory `{EXPER_DIR}/{SESS_CODE}_fpl/` where `EXPER_DIR` is the experiment scratch directory and `{SESS_CODE}` is the session code.

XW -- to display the 1D plot of the fringe phase and fringe amplitude on the screen using the PGPLOT library.

SAV -- to write the plot in the internal format of graphic library DiaGI. Extension of the output file is `.sav`  
The plot can be displayed with program `diagi_rst` that accepts the name of the plot file in SAV format as its argument.

GIF -- to generate the plot in GIF format. Extension of the output

## PIMA keywords

file is .gif

PS -- to generate the plot in Postscript format. Extension of the output file is .ps

TXT -- to write the table with fringe phase and fringe amplitude as a function of frequency. Extension of the output file is .txt

NO -- do not generate the 1D delay resolution function plot.

### 4.31 FRIB.1D\_DRF\_SPAN:

**FRIB.1D\_DRF\_SPAN:**      **value**

This parameter sets the half-width of the interval of the argument for a delay resolution plot. Units are sec.

## 5 Bandpass processing keywords

### 5.1 BPS.MODE:

**BPS.MODE:**      **value**

### 5.2 BPS.MODE:

**BPS.MODE:**      **[INIT or ACCUM or FINE]**

The mode of the complex bandpass computation procedure. This keyword specifies the stage where bandpass computation should stop. There are three stages for bandpass calculation.

## PIMA keywords

**INIT** -- to run the bandpass in the init mode. PIMA analyzes the input file with the fringe fitting results and finds the observations with the maximum SNR for each baseline with the reference station. NB: PIMA obeys **INCLUDE\_OBS:** and **EXCLUDE\_OBS:** keywords and checks only those observations that satisfies the filter. PIMA computes the visibilities averaged over time with parameters of fringe fitting applies. These time-averaged visibilities are a function of frequency. The phase of the complex bandpass is the residual phase of the visibilities after subtraction the time and frequency averaged phase over the observation. The amplitude of the bandpass is the amplitude of time-averaged visibility after dividing it over the amplitude averaged over time and frequency within the IF to which the individual point of the bandpass belongs. The bandpass can be considered as the averaged visibility. The normalization for phase is computed by averaging over all IFs, and normalization for amplitude is computed by averaging over individual IFs. In the case of dual-polarization data when **POLAR: I** is specified, the procedure is repeated twice: first for the RR polarization bandpass second for the LL polarization with respect to the RR polarization data.

**ACCUM** -- to run bandpass in the accumulation mode. After computation the bandpass in the init mode, the bandpass is applied to K observations at every baseline with the reference station. PIMA selects these observations as the ones that have the greatest SNR.

**FINE** -- to run bandpass in the fine mode. After computation the bandpass in the accumulation mode, the bandpass is re-computed using least squares. Accumulation bandpass is applied. Correction to the accumulation bandpass is computed by estimating parameters of the phase and amplitude bandpass using M observations with the highest SNR among all baselines with the references station. Estimated parameters for the phase part are coefficients of expansion over Legendre polynomials of B-spline basis. Estimated parameters for the amplitude part are coefficients of expansion of the logarithm of the residual amplitude ratios into either Legendre polynomials or the B-spline basis. After computing a solution, observations are checked for outliers. If the residual phases or amplitudes exceed a certain threshold, the observation is marked as outlier and the bandpass is recomputed. The procedure is repeated till either no outlier is found.

If at a given baseline the number of remaining observations fell to the specified threshold Q, no more outliers at that baseline is eliminated.

### **5.3 BPS.NOBS\_ACCUM:**

**BPS.NOBS\_ACCUM:** value

This keyword specified how many observations with the highest SNR at each baseline are taken for computation of the accumulation bandpass.

### **5.4 BPS.MSEG\_ACCUM:**

**BPS.MSEG\_ACCUM:** value

This keyword specifies how many adjacent spectral channels are coherently averaged during phases of the initial and accumulation bandpass calculation. Cannot be less than 1 or exceed the number of spectral channels in the IF.

### **5.5 BPS.NOBS\_FINE:**

**BPS.NOBS\_FINE:** value

This keyword specified how many observations with the highest SNR at each baseline are taken for computation of the accumulation bandpass.

### **5.6 BPS.MINOBS\_FINE:**

**BPS.MINOBS\_FINE:** value

The keyword specified the minimum number of observation at each baseline that should remain during bandpass computation in the fine mode. This parameter limits the number of outliers rejected.

### **5.7 BPS.MSEG\_FINE:**

**BPS.MSEG\_FINE:** value

This keyword specifies how many adjacent spectral channels are coherently averaged during phases of the fine bandpass calculation. Cannot be less than 1 or exceed the number of spectral channels in the IF.

### **5.8 BPS.SNR\_MIN\_ACCUM:**

**BPS.SNR\_MIN\_ACCUM:** value

This keyword specifies the minimum SNR for an observation to be eligible for being used for bandpass computation in accumulation mode. Observations with the SNR less than this limit are not considered. If the SNR is too small, there is a chance that the bandpass computation procedure will derail. If there are no high SNR observations in the experiment, parameter BPS.ACCUM\_MSEG should be raised.

### **5.9 BPS.SNR\_MIN\_FINE:**

**BPS.SNR\_MIN\_FINE:** value

This keyword specifies the minimum SNR for an observation to be eligible for being used for bandpass computation in fine mode. Observations with the SNR less than this limit are not considered.

### **5.10 BPS.DECOR\_TIM\_MIN:**

**BPS.DECOR\_TIM\_MIN: value**

This keyword specifies the minimum time decorrelation value computed by the fringe fitting for the observation to be eligible for being used for bandpass computation in any mode. It can be in a range of 0 to 1. DECOR\_TIM is the ration of the correlated amplitude coherently averaged over the scan to the arithmetic average (i.e. the incoherent average) of the correlated amplitude computed over elementary segments used by the procedure of fine fringe fitting. DECOR\_TIM is close to 1 for a perfect observation. Phase variations due to atmosphere of frequency standard degrades DECOR\_TIM. This degradation is harmless for bandpass calculation. However, DECOR\_TIM may be reduced due to catching artificial signal, either internal or external RFI. The purpose of this filter is to prevent using observations affected by RFI. Recommended value: 0.8 at frequencies below 15 GHz and 0.5 at frequencies above 15 GHz. Value 0.0 disables this filter entirely.

**5.11 BPS.AMPL\_REJECT:**

**BPS.AMPL\_REJECT: value**

The threshold for the residual amplitude after applying bandpass in the fine mode for being marked as the outlier. The observation is marked as the outlier if the the rms of the deviation of the normalized amplitude from 1.0 in any intermediate frequency exceeds BSP.AMPL\_REJECT.

**5.12 BPS.PHAS\_REJECT:**

**BPS.PHAS\_REJECT: value**

The threshold for the residual phase after applying bandpass in the fine mode for being marked as an outlier. Unit: radian. The observation is marked as an outlier if the the rms of the



residual phase in any intermediate frequency is greater than BSP.PHAS\_REJECT. Typical value is 0.4 rad.

### 5.13 BPS.INTRP\_METHOD:

**BPS.INTRP\_METHOD:** [LEGENDRE or SPLINE]

The keyword specifies the basis for expansion the bandpass.

LEGENDRE --Legendre polynomial

SPLINE -- B-spline of the 3rd degree.

### 5.14 BPS.DEG\_AMP:

**BPS.DEG\_AMP:** value

The meaning of this keyword depends on BPS.INTRP\_METHOD. If the expansion basis is LEGENDRE, then BPS.DEG\_AMP is the degree of the Legendre polynomial for expansion of the amplitude of the bandpass. If the expansion basis is SPLINE, then BPS.DEG\_AMP is the number of spline knots in each intermediate frequency for expansion of the amplitude of the bandpass.

### 5.15 BPS.DEG\_PHS:

**BPS.DEG\_PHS:** value

The meaning of this keyword depends on BPS.INTRP\_METHOD. If the expansion basis is LEGENDRE, then BPS.DEG\_PHS is the degree of the Legendre polynomial for expansion the phase of the bandpass. If the expansion basis is SPLINE, then BPS.DEG\_AMP is the number of spline knots in each intermediate frequency

for expansion of the phase of the bandpass.

## 5.16 BPS.NORML:

**BPS.NORML:**     **[NO or IF or BAND]**

This keywords specifies the way how the bandpass normalization is made.

NO -- No normalization is applied.

IF -- The bandpass is normalize to have the mean amplitude 1.0 over each individual intermediate frequency.  
This is a typical choice.

BAND -- The bandpass is normalized to have the mean amplitude 1.0 over the band, i.e. over all intermediate frequencies.

## 5.17 BPS.SEFD\_USE:

**BPS.SEFD\_USE:**     **value**

Not used. Should be NO

# 6 Phase reference fringe fitting keywords

## 6.1 FRIP.SCAN\_FILE:

**FRIP.SCAN\_FILE:**     **file or NO**

Not implemented. Should be NO.

## 6.2 FRIP.STA\_INC\_FILE:

**FRIP.STA\_INC\_FILE:** file or NO

Name of the file that with station names. Should be NO.

## 6.3 FRIP.STA\_EXC\_FILE:

**FRIP.STA\_EXC\_FILE:** file or NO

Not implemented. Should be NO.

## 6.4 FRIP.STA\_REFS:

**FRIP.STA\_REFS:** value

Not implemented. Should be SAME.

## 6.5 FRIP.RESOLUTION:

**FRIP.RESOLUTION:** value

Not implemented. Should be 4096.

## 6.6 FRIP.OVERSAMPLE:

**FRIP.OVERSAMPLE:** value

Not implemented. Should be 1.

## 6.7 FRIP.SCA:

**FRIP.SCA:** value

Not implemented. Should be ALL.

## 6.8 FRIP.MAP\_DIR:

**FRIP.MAP\_DIR:** directory or NO

Not implemented. Should be SAME.

## 6.9 FRIP.ATM\_ZEN\_FILE:

**FRIP.ATM\_ZEN\_FILE:** file or NO

Not implemented. Should be NO.

## 6.10 FRIP.CAL\_PLOT:

**FRIP.CAL\_PLOT:** value

Not implemented. Should be GIF.

## 6.11 FRIP.CAL\_RES:

**FRIP.CAL\_RES:** value

Not implemented. Should be 400.

### **6.12 FRIP.TAG\_PLOT:**

**FRIP.TAG\_PLOT:** value

Not implemented. Should be GIF.

### **6.13 FRIP.TAG\_RES:**

**FRIP.TAG\_RES:** value

Not implemented. Should be 400.

### **6.14 FRIP.BEAM\_PLOT:**

**FRIP.BEAM\_PLOT:** value

Not implemented. Should be GIF.

### **6.15 FRIP.FRQ\_MSEG:**

**FRIP.FRQ\_MSEG:** value

Not implemented. Should be 128.

### **6.16 FRIP.TIM\_MSEG:**

**FRIP.TIM\_MSEG:** value

Not implemented. Should be 1.

### **6.17 FRIP.RA\_CENTER:**

**FRIP.RA\_CENTER:** value

Not implemented. Should be APRIORI.

### **6.18 FRIP.DEC\_CENTER:**

**FRIP.DEC\_CENTER:** value

Not implemented. Should be APRIORI.

### **6.19 FRIP.RA\_STEP:**

**FRIP.RA\_STEP:** value

Not implemented. Should be 0.1.

### **6.20 FRIP.DEC\_STEP:**

**FRIP.DEC\_STEP:** value

Not implemented. Should be 0.1

## 6.21 FRIP.RA\_RANGE:

**FRIP.RA\_RANGE:** value

Not implemented. Should be 1.0.

## 6.22 FRIP.DEC\_RANGE:

**FRIP.DEC\_RANGE:** value

Not implemented. Should be 1.0.

# 7 Splt keywords

Operation splt gathers all visibilities for the specified source(s), applies all calibrations, transforms baseline dependent group delays, phase delay rates, and group delay rates from baseline dependent quantities to station based quantities, rotates visibility phases for results of fringe fitting, averages visibilities over time and frequency, applies specified re-normalizations, and writes averaged visibilities in output FITS files, one file per sources, in a form suitable for imaging using software DIFMAP.

## 7.1 SPLT.SOU\_NAME:

**SPLT.SOU\_NAME:** [Bname or Jname or ALL]

Name of the source that is to be processed. All visibilities

## PIMA keywords

related to that sources subject of constraint in INCLUDE\_OBS\_FILE, EXCLUDE\_OBS\_FILE, OBS, and SNR\_DETECTION\_LIMIT keywords are considered.

Bname -- B1950 8-character long source name.

Jname -- J2000 10-character long source name.

ALL -- operation splt is performed in a cycle over all source names.

### 7.2 SPLT.FRQ\_MSEG:

**SPLT.FRQ\_MSEG:**            **value**

The keyword specifies the number of spectral adjacent channels that will be averaged. It should be no less than 1. Value 1 means no frequency averaging. The value should be exceeded the number of channels in the intermediate frequency. Typical choice: the total number of spectral channels in the IF. In that case the number of IFs in the output FITS file is the same as the number of used IFs in the input data. If SPLT.FRQ\_MSEG is less than the number of spectral channels in the intermediate frequency, the number of IFs in the output file will be greater than the number of IFs in the input data. PIMA does not support hierarchy spectral channel+IF in the output FITS files. The number of spectral channels is always 1 in the output file.

### 7.3 SPLT.TIM\_MSEG:

**SPLT.TIM\_MSEG:**            **value**

The keyword specifies the number of adjacent accumulation periods for time averaging. Value 1 means no time averaging. IF SPLT.TIM\_MSEG exceeds the number of accumulation periods in the scan, all accumulation periods are averaged.

### 7.4 SPLT.WEIGHT\_TYPE:



**SPLT.WEIGHT\_TYPE: [ONE, OBS\_SNR, OBS\_MS, SEG\_RMS, AUTO]**

This keywords specifies the method for computing visibility weights in the output FITS file.

ONE -- all weights are unity.

OBS\_SNR -- Calibrated amplitude is computed over the observation. The SNR for a given IF is computed based on the SNR over the observation. Rms of noise is computed as a ratio of calibrated amplitude to the SNR over the IF. Weight is reciprocal to the square of noise rms. Thus, the weight is computed for a given IF using all accumulation periods of the observation.

OBS\_RMS -- Weighted variance of calibrated visibilities is computed for a given IF using all accumulation periods of a given observation. Weight is reciprocal to the variance.

SEG\_RMS -- Weighted variance of calibrated visibilities is computed for a given IF using all accumulation periods over a given segment. Weight is reciprocal to the variance.

AUTO -- If the number of accumulation periods per segment is greater or equal than the threshold (currently 8), WEIGHT\_TYPE AUTO is equivalent to WEIGHT\_TYPE: SEG\_RMS. If the number of accumulation periods per segment is less than the threshold (currently 8), weighted variance of calibrated visibilities is computed over so-called "weights segments". These weight segments are longer than the output visibility segments. Weight for a given IF, given segment is reciprocal to the variance of the weight segment with the middle epoch nearest to the to the epoch of the given segment.

## 7.5 SPLT.POLAR:

**SPLT.POLAR: [RR or LL or RL or LR or I or PAR or ALL]**

## PIMA keywords

This keyword specifies for which polarizations the visibilities should be in the output FITS file. If the input data had single polarization then SPLT.POLAR value should be that polarization code. In a case of dual polarization the choice is

RR -- RR-polarization only.

LL -- LL-polarization only.

RL -- RL-polarization only.

LR -- LR-polarization only.

I -- I-polarization only. The I-polarization data are computed on the fly.

PAR -- RR-polarization and LL-polarization data. This is a usual choice when no cross-polarization analysis is intended.

ALL -- all polarization data present in the input FITS files are exported to the output FITS file.

## 7.6 SPLT.AUTOCORR\_NRML\_METHOD:

### SPLT.AUTOCORR\_NRML\_METHOD: [AVERAGED or NO]

This keyword specifies whether to apply the renormalization factor for system temperature due to discarding some spectral channels. The system temperature is measured over entire intermediate frequency. However, in general, the spectrum of noise is not constant over the band. PIMA uses autocorrelation function to compute the factor of  $T_{\text{sys}}(\text{used})/T_{\text{sys}}(\text{tot})$ , where  $T_{\text{sys}}(\text{used})$  is the system temperature over the used portion of the bandwidth, and  $T_{\text{sys}}(\text{tot})$  is the  $T_{\text{sys}}$  over the entire IF, i.e. measured  $T_{\text{sys}}$ . The portion of the bandwidth for renormalization is defined by [ICHN\_1ST, ICHN\_LAST] range \*and\* the band mask.

AVERAGED -- to apply the system temperature to renormalization due to discarded spectral channels.

NO -- do not apply the system temperature to renormalization

## 7.7 SPLT.BPASS\_NRML\_METHOD:

**SPLT.BPASS\_NRML\_METHOD:**    **[WEIGHTED or NO]**

This keywords specifies whether to apply the bandpass renormalization factors for given intermediate frequencies using only a part of the bandwidth. Initially, the bandpass is normalized to unity over the \*entire\* bandwidth of the IF. However, often decorrelation occurs at the edges of the band. PIMA allows to specify the portion of the band that is considered "representative". It is expressed in parameters Bl, Bh that stands for bandwidth low range and bandwidth high range that are specified in SPLT.BPASS\_NRML\_RANGE. The representative bandwidth is  $[F_{low} + Bl * F_w, F_{low} * Bh * f_w]$ . Renormalization factor  $R = (\sum B_r / N_r) / \sum B_t / N_t$ , where  $B_r$  -- bandpass in the bandwidth is  $[F_{low} + Bl * F_w, F_{low} * Bh * f_w]$ ,  $N_r$  -- the number of points in that bandwidth;  $B_t$  bandpass in the total bandwidth,  $N_t$  the total number of points in the entire IF. The IF-dependent factors scale the bandpass to make makes its normalized over the representative bandwidth within a given IF  $[F_{low} + Bl * F_w, F_{low} * Bh * f_w]$ . Usually, the factor is less than 1.0. If unsure, use WEIGHTED.

WEIGHTED -- to apply the bandpass renormalization.

NO    -- not to apply the bandpass renormalization.

## 7.8 SPLT.BPASS\_NRML\_RANGE:

**SPLT.BPASS\_NRML\_RANGE:**    **low:high**

These keyword specifies the range of the bandwidth as a share of the nominal bandwidth that are considered representative for bandpass renormalization. The parameters of the range are between [0,1]. The parameter is discarded when SPLT.BPASS\_NRML\_METHOD: NO. If unsure, specify 0.2:0.8

low -- the low frequency of the IF that belongs to the

## PIMA keywords

representative range. Should be in a range [0, 1).

high -- the high frequency of the IF that belongs to the representative range. Should be in a range (0,1]. High should be greater than low.

Example: let the IF frequency range 32 MHz, the number of spectral channels is 256. If SPLT.BPASS\_NRML\_RANGE: 0.2:0.75, then the low frequency of the representative range is  $0.2 \times 32 = 6.4$  MHz, the first spectral channel within the range is 52. The high frequency of the representative range is  $0.75 \times 32 = 24$  MHz, the last spectral channel within the range is 192. Thus the bandpass renormalization will be done in such a way that the mean bandpass over spectral channels with indices 52-192 be unity.

## 7.9 SPLT.SUBARRAY\_CONSOLIDATION:

### SPLT.SUBARRAY\_CONSOLIDATION: [NO or MIN or MAX]

Since PIMA performs fringe fitting in the baseline mode, an individual scan may not have detections less than  $N(N+1)/2$  baselines of a N-station network. PIMA designate a subnetwork with detections at a given scan as an subarray. Normally PIMA unites observations of different scans with the same subnetwork in a subarray. PIMA computes station-based visibility phases for each subarray individually. Keyword SPLT.SUBARRAY\_CONSOLIDATION controls how subarrays are consolidated after initial process for converting baseline-depended fringe phases into station-based fringe phases.

NO -- means to disable subarray consolidation.

MIN -- instructs PIMA to preform minimal subarray consolidation: if all stations of subarray A are present in the subarray B, then the subarray B is consolidated with subarray A.

MAX -- instructs to preform maximum subarray consolidation: if a subarray has at least one common station with subarray B, both subarrays are consolidated.

## 7.10 SPLT.TOTAL\_UV:

**SPLT.TOTAL\_UV: [NO or YES]**

Specifies whether or not to generate output files with the total visibilities averaged over frequency and over all accumulation period over the scan after applying phase rotation for the results of fringe fittings. The total visibilities are referred to the band reference frequency. If YES is specified, the files with total visibilities are written in the same output directories averaged visibilities, in addition to them.

## 7.11 SPLT.TOTAL\_UV:

**SPLT.SNR\_MIN: [value]**

Specifies the minimum SNR over the entire scan for the data to be used by splt to export to the output fits-file. The data from the observation with the SNR less than that limit are not exported.

The SNR is defined as the ratio of the fringe amplitude to the mean value of amplitude of noise. If to consider that real and image part of noise are independent and have Gaussian distribution with variance  $\sigma$ , the mean amplitude is  $\sqrt{\pi/2} \approx 1.253 \sigma$ . The variance of the amplitude noise is  $\sqrt{2 - \pi/2} \approx 0.655 \sigma$ .

## 7.12 SPLT.GAIN\_CORR\_FILE:

**SPLT.GAIN\_CORR\_FILE: [NO or file]**

Specifies the name of the gain correction file. The gain correction file contains empirical gain corrections. This keyword is used by tasks splt and gaco.

NO -- no gain correction will be applied

file -- name of the gain correction file. It consists of records of fixed lengths in plain ascii. Each record defines gain correction, its formal errors and the number of observations used to derived for a specific station and specific IF. Task splt checks whether keyword SPLT.GAIN\_CORR\_FILE defines a file. If it does it multiplies visibility by the product of two gain corrections for each station of a baseline.

### 7.13 SPLT.STA\_BASED:

**SPLT.STA\_BASED:**      [YES or ALL or NO]

This keyword specifies whether the station based or baseline based algorithm for computation of averaged visibilities will be used. Usually, station-based algorithm is required for imaging since baseline based algorithm does not preserve phase misclosure. However, station based algorithm prevents putting observations with less than three baselines in the output FITS-IDI file. Therefore, sometimes it is desirable to have a possibility to write the averaged visibilities split into sources even of they belong to a subarray with only two stations.

YES -- to use a station-based algorithm for computing averaged visibilities. All observations that passed input filter controlled by keywords INCLUDE\_OBS\_FILE, EXCLUDE\_OBS\_FILE, OBS, and SNR\_DETECTION\_LIMIT are process for computation of station-based quantities. The same observations are used for generating the output.

ALL -- to use a station-based algorithm for computing averaged visibilities. All observations that passed input filter controlled by keywords INCLUDE\_OBS\_FILE, EXCLUDE\_OBS\_FILE, OBS, and SNR\_DETECTION\_LIMIT are process for computation of station-based quantities. All observations between the station for which station-based group delays, phase delay rates, and group delays are used for generating the output **regardless** whether they passed the input filter or not. If unsure, specify ALL.

NO -- to use a baseline-based algorithm. Suitable mainly for processing single-baseline data.

## 8 ONOF processing keywords

PIMA task onof computes good start and stop time for every scan. This routine is used for mitigation of incorrect on/off time written by the field system in logs. The task finds the time interval at the beginning and the end of the scan with the fringe amplitude below the threshold and the flags accumulation periods that fits criteria of "not on source" interval.

### 8.1 ONOF.GEN\_FLAGS\_MODE:

**ONOF.GEN\_FLAGS\_MODE: [NO, CREATE, UPDATE]**

NO -- onof procedure is not running

CREATE -- original flagging status for a given observation is set to 1.0, i.e. unflag.

UPDATE -- original flagging status for a given observation is honored. Onof does not see flagged scans and preserves their flag value.

### 8.2 ONOF.KERNEL\_START\_SHARE:

**ONOF.KERNEL\_START\_SHARE: value**

value -- The start epoch of the kernel interval defined as an offset with respect to the nominal start time as a share of the scan length. Should be in a range [0, 1]. For instance if the scan

length is 100s, and ONOF.KERNEL\_START\_SHARE: 0.2, then the start epoch of the kernel is 20s.

### **8.3 ONOF.KERNEL\_END\_SHARE:**

#### **ONOF.KERNEL\_END\_SHARE: value**

value -- The end epoch of the kernel interval defined as an offset with respect to the nominal start time as a share of the scan length. Should be in a range [0, 1]. For instance if the scan length is 200s, and ONOF.KERNEL\_END\_SHARE: 0.9, then the end epoch of the kernel is 180s.

### **8.4 ONOF.COHERENT\_INTERVAL:**

#### **ONOF.COHERENT\_INTERVAL: value**

value -- Interval of coherency in seconds used for computation of mean amplitude. In a case if the kernel interval is longer than the coherency interval, the mean and wrms of visibilities is computed over the shorter coherency interval. If unsure, set it to 1200.

### **8.5 ONOF.COHERENT\_INTERVAL:**

#### **ONOF.AMPL\_THRESHOLD: value**

value -- Threshold criterion. An AP with amplitude times ONOF.AMPL\_THRESHOLD of the mean amplitude over the scan kernel is considered as a candidate for flagging.  
ONOF.AMPL\_THRESHOLD: 0.0 means no amplitude



threshold criterion is checked.

## 8.6 ONOF.NSIG\_THRESHOLD:

### ONOF.NSIG\_THRESHOLD: value

value -- N-sigma criterion. An AP with amplitude ONOF.AMPL\_THRESHOLD times wrms of the visibility over the scan kernel is considered as a candidate for flagging. ONOF.NSIG\_THRESHOLD: 0.0 means no amplitude n-sigma criterion is checked.

## 8.7 ONOF.MIN\_LOW\_AP:

### ONOF.MIN\_LOW\_AP: value

value: 0 means that the AP that satisfied flagging criteria ONOF.AMPL\_THRESHOLD or ONOF.NSIG\_THRESHOLD is flagged out. If ONOF.MIN\_LOW\_AP > 0, then onof checks how many consecutive APs have low amplitude. If ONOF.MIN\_LOW\_AP APs has low amplitude, then the rest of the scan portion (before the kernel interval or after kernel interval) is flagged out. If after k APs with low amplitude (  $k < \text{ONOF.MIN\_LOW\_AP}$  ) follows an AP with high amplitude, these k APs are not flagged.

## 9 Creation of the output database keywords

The fringe fitting procedure writes results in an ascii file. Task mkdb computes total group delay, phase delay rate, group delay rates and a number of auxiliary quantities using the results of the fringe fitting. The results of task are written in either plain ascii format or in GVF format that is native for geodesy/astrometry VLBI processing software VTD/post-Solve.

## 9.1 MKDB.OUTPUT\_TYPE:

**MKDB.OUTPUT\_TYPE:** [TEXT or GVF or AMPL]

Format of the output file generated by task mkdb.

TEXT -- total group path delays, phase delay rates and other quantities are written in a table in plain ascii format, one line per used observation.

GVF -- total group path delays, phase delay rates and other quantities are written in a binary GVF format suitable for processing with geodesy/astrometry software VTD/post-Solve.

AMPL -- fringe amplitude, fringe phase, Tsys, gain, uv baseline projections and other parameters are written in a plain ascii table, one line per used observation.

## 9.2 MKDB.SRT:

**MKDB.SRT:** [MID\_SCAN or SRT\_FRT or file]

This keyword controls the logic for computation of scan reference time (SRT). Since PIMA processes all observations independently, in general, fringe reference time of observations of the same scan is not the same. Group delays, phase delay rates, and fringe phases of the same scan, the same subarray are referred to a common epoch that is called scan reference time. PIMA computes this scan reference time in such a way that the errors of group delays is minimized. If unsure, use MID\_SCAN.

MID\_SCAN -- PIMA finds the scan reference time near in the middle of a scan that. In a simplest case when all stations started and ended a scan at the same time and there were no data losses, the scan reference time is the middle scan epoch rounded to 1 sec. Computation of scan

## PIMA keywords

reference time is not trivial if good data started and ended at different stations at different epochs. First PIMA finds the interval of time of valid accumulation periods (AP) over all used observations of a scan. If it finds observations that are not in common range, it splits the scan into subarrays that are treated as separate scans. Then within each subarray it finds for each observation the range of time for which the formal uncertainty of group delay increases by no more than either an additive parameter MKDB.GD\_MAX\_ADD\_ERROR and by no more than scaling factor MKDB.GD\_MAX\_SCL\_ERROR. If it finds observations that are not in common range, it splits the scan into subarrays that are treated as separate scans. Finally, for each remaining subarray PIMA assigns the scan reference time that is in the middle of the common range, subject of constraints imposed on allowed increase of group delay formal uncertainty. The scan reference time is rounded to the nearest second.

SRT\_FRT -- scan reference time is the same as fringe reference time. If this value is specified, the scan reference time may be different for each observation.

file -- name of the file with scan reference time. PIMA allows to compute the best fringe reference time externally and import it using MKDB.SRT keyword.

### 9.3 MKDB.GD\_MAX\_ADD\_ERROR:

#### **MKDB.GD\_MAX\_ADD\_ERROR: value**

Parameter MKDB.GD\_MAX\_ADD\_ERROR controls MID\_SCAN algorithm for setting the scan reference time. When the reference time epoch is changed, the uncertainty of group delay is increased. MKDB.GD\_MAX\_ADD\_ERROR controls the tolerance to this increase as an addition to the group delay uncertainty at fringe reference time. Units: sec. If unsure, use 5.D-15

## 9.4 MKDB.GD\_MAX\_SCL\_ERROR:

### MKDB.GD\_MAX\_SCL\_ERROR: value

Parameter GD\_MAX\_SCL\_ERROR controls MID\_SCAN algorithm for setting the scan reference time. When the reference time epoch is changed, the uncertainty of group delay is increased. GD\_MAX\_SCL\_ERROR controls the tolerance to this increase as a fraction of the group delay uncertainty at fringe reference time. Units: dimensionless. If unsure, use 0.2. Value 0.2 means that 20% increase of formal uncertainty due to a change of the scan reference time with respect to the fringe reference time is allowed.

## 9.5 MKDB.FILTER:

### MKDB.FILTER: [NO or ONLY\_DET]

ONLY\_DET -- only detected observations are put into the database, i.e. the observations with the SNR exceeding SNR\_DETECTION\_LIMIT. NB: if an observation has the SNR greater than the limit, this does not necessarily mean the observation is a detection.

NO -- no filter is applied. All observations regardless their SNR are put into the output database.

## 9.6 MKDB.FRINGE\_ALGORITHM:

### MKDB.FRINGE\_ALGORITHM: [DRF or LSQ or MUL or ADD or NO]

This keyword specifies what estimate of group delay, phase delay rate, group delay rate and their formal uncertainties to put in the output database. PIMA computes

## PIMA keywords

four estimates of group delays then fine fringe search algorithm, but only one estimate can be put in the output database. This keyword determines which estimate is to be put in the output file. If unsure, specify LSQ.

DRF -- estimates of group delay, phase delay rate, fringe phase, and fringe amplitude from the coarse fringe fitting will be put into the output database. Group delay rate is zero.

LSQ -- estimates of group delay, phase delay rate, group delay rate, fringe phase, and fringe amplitude from the LSQ fine fringe fitting algorithm without applying re-weighting will be put into the output database.

MUL -- estimates of group delay, phase delay rate, group delay rate, fringe phase, and fringe amplitude from the LSQ fine fringe fitting algorithm with applying multiplicative re-weighting will be put into the output database. The formal uncertainties are scaled by a certain factor in order to make the ratio of the weighted sum of squares of residuals to their mathematical expectation close to unity.

ADD -- estimates of group delay, phase delay rate, group delay rate, fringe phase, and fringe amplitude from the LSQ fine fringe fitting algorithm without applying re-weighting will be put into the output database. An additive parameter is found in such a way that after being added in quadrature to the a priori weights the ratio of the weighted sum of squares of residuals to their mathematical expectation close to unity.

NO -- estimates of group delay and phase delay rate from coarse fringe fitting will be put into the output database.

## 9.7 MKDB.2ND\_BAND:

**MKDB.2ND\_BAND:**     **[NO or file]**

This keyword specifies whether to chain results from two bands into one database.

## PIMA keywords

**NO** -- results from fringe fitting from one band specified in the current control file will be put in the output database.

**file** -- name of the second control file. Fringe fitting results from two bands, two control files, will be put in the output database. The first band is the band specified in the current database. The second band is the band specified in **MKDB.2ND\_BAND** keyword.

**NB:** Although PIMA does not require bands be in a certain order an order, VTD/Post-Solve does. VTD/Post-Solve requires the first band to have a higher frequency and the second band to have a lower frequency.

### 9.8 MKDB.VCAT\_CONFIG:

**MKDB.VCAT\_CONFIG:** [NO or file]

Name of the VCAT configuration file. Required if **MKDB.OUTPUT\_TYPE** is **GVF** and ignored otherwise. See VTD/Post-Solve documentation for format of VCAT configuration file.

### 9.9 MKDB.OUTPUT\_NAME:

**MKDB.OUTPUT\_NAME:** value

Meaning of this value depends on the value of **MKDB.OUTPUT\_TYPE** keyword. If **MKDB.OUTPUT\_TYPE** is **AMPL** or **TEXT**, then **MKDB.OUTPUT\_NAME** specifies the name of the output file for task **mkdb**. If **MKDB.OUTPUT\_TYPE** is **GVF**, then **MKDB.OUTPUT\_TYPE** specifies a suffix of the database name. The **GVF** compliant database name is **yyyymmddS\_vNNN.env**, where **S** is a one-letter long lower case suffix and **NNN** is the version number.

### 9.10 MKDB.DESC\_FILE:

**MKDB.DESC\_FILE:** [file or NO]

The name of the file with additional information about the experiment that propagates to the GVF database. If no information is available, NO can be specified. This parameter is used only by task mkdb when the output data type is GVF.

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Questions and comments about this guide should be directed to:

Leonid Petrov ( <http://astrogeo.org/petrov> )

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